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METEOROLOGICAL OFFICE

# THE METEOROLOGICAL GLOSSARY

THIRD EDITION

In continuation of the Weather Map



*Published by the Authority of the Meteorological Committee*



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HER MAJESTY'S STATIONERY OFFICE

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# METEOROLOGICAL GLOSSARY

## CONTAINING INFORMATION IN EXPLANATION OF TECHNICAL METEOROLOGICAL TERMS

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The first edition of the Meteorological Glossary was issued in 1916, and was reprinted with additions in 1917 and again in 1918. Since 1918 there have been many advances in meteorology, for example in connexion with the study of weather maps, and the second edition issued in 1930 was almost completely re-written, the task being apportioned among the Professional Staff of the Office. In this second edition the opportunity was taken, by increasing the size of the page, to bring the Glossary into conformity with the other handbooks published by the Meteorological Office.

In accordance with the practice of the Oxford Dictionary the initial word of each article is in black type. Words in small capitals in the body of the text are the subjects of articles in another part of the Glossary. International definitions of cloud forms are distinguished by the use of italic type.

The International Meteorological Committee at the meeting in London in 1921 passed a resolution requesting the inclusion, in a future edition of the Meteorological Glossary, of the equivalents in various languages of the words defined. In the second edition effect was given to this resolution by the inclusion at the end of the work of equivalents in Danish, Dutch, French, German, Italian, Norwegian, Portuguese, Spanish and Swedish.

The progress of meteorological knowledge since 1930 has again made a number of revisions necessary, and the publication of a third edition has given an opportunity of incorporating these. Thanks are due to all those, both the staff of the Meteorological Office and others, who have given help in the revision.

*Meteorological Office, Air Ministry.*

November, 1938.





# METEOROLOGICAL GLOSSARY

**Absolute Extremes.**—See EXTREMES.

**Absolute Humidity**, also called vapour density\*, is the mass of aqueous vapour per unit volume of air, and is usually expressed in grammes per cubic metre of air. The term is sometimes incorrectly applied to the pressure of the aqueous vapour in the air. In accordance with Dalton's Law the water vapour in the atmosphere exerts the same pressure as it would if the air were not present. Knowing the vapour pressure  $e$ , we therefore obtain  $\delta$ , the mass of vapour in a cubic metre of moist air, from the formula—

$$\delta = \delta_0 \frac{e}{P_0} \times \frac{T_0}{T}$$

where  $\delta_0$  is the density of aqueous vapour under standard pressure and temperature  $P_0$  and  $T_0$

whence  $\delta = 216.7 \frac{e}{T}$  grams per cubic metre.

$e$  being measured in millibars and  $T$  in absolute degrees on the tercentesimal scale. See AQUEOUS VAPOUR.

**Absolute Temperature.**—The absolute scale of temperature is formulated by reasoning about the production of mechanical work at the expense of heat (which is the special province of thermodynamics, see ENTROPY). The absolute temperatures corresponding with  $0^\circ \text{C.}$  and  $100^\circ \text{C.}$  are  $273.16$  and  $373.16$  respectively. For practical purposes the scale may be taken as identical with that based on the change of volume and pressure of one of the permanent gases with heat. It is moreover sufficiently accurate to replace it by a scale (to which the name TERCENTESIMAL has been given) obtained by adding 273 to the Centigrade temperature. It is usual in meteorology to use temperatures on this scale in formulae which are strictly true only for absolute temperatures, such temperatures being frequently indicated by  $^\circ\text{A.}$  (thus  $10^\circ \text{C.} = 283^\circ \text{A.}$ ), a convention that has been adopted in the present edition of the Glossary. For thermometric purposes aiming at the highest degree of accuracy the hydrogen scale is used, but for the purposes of meteorological reckoning the differences of behaviour of the permanent gases, hydrogen, oxygen, nitrogen are unimportant. In physical calculations for meteorological purposes the absolute is the natural scale; the densities of air at any two temperatures on the absolute scale are inversely proportional to the temperatures. Thus the common formula for a gas,

$$\frac{p}{\rho(273 + t)} = \frac{p_0}{\rho_0(273 + t_0)}$$

where  $p$  is the pressure,  $\rho$  the density and  $t$  the temperature Centigrade of the gas at one time,  $p_0$ ,  $\rho_0$ ,  $t_0$  the corresponding values at another, becomes

$$\frac{p}{\rho T} = \frac{p_0}{\rho_0 T_0},$$

where  $T$  and  $T_0$  are the temperatures on the absolute Centigrade scale. Its most important feature for practical meteorology is that from its definition there can be no negative temperatures. The zero of the absolute scale is the temperature at which all that we call heat would have been spent. In the Centigrade scale all temperatures below the freezing point of water have to be prefixed by the negative sign  $-$ . This is very inconvenient, especially for recording observations in the upper air, which never gives temperatures above the freezing point in our latitudes at much above 4 kilometres (13,000 ft.), and often gives temperatures below the freezing point nearer the surface.

The absolute temperature comes into meteorology in other ways; for example, the rate at which heat goes out into space from the earth depends, according to Stefan's Law, upon the fourth power of the absolute temperature of the radiant substance. See RADIATION.

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\* Recently the World Meteorological Organization has adopted "vapour concentration"

Absolute temperature on the Fahrenheit scale is degrees Fahrenheit plus 459·4. The Absolute Fahrenheit scale is sometimes referred to as the Rankin Scale.

**Absorption (Atmospheric).**—See RADIATION (*Radiation and the atmosphere*).

**Acceleration**—the rate at which velocity changes with time. Any convenient unit such as the mile per hour per hour or the centimetre per second per second may be used, its dimensions being length/square of time. Acceleration, like velocity, is a vector having both magnitude and direction. Thus in uniform circular motion, although the speed does not change the direction does, and the motion has an acceleration directed towards the centre of rotation—the so-called centripetal acceleration.

In meteorology we are mainly concerned with the acceleration of the moving atmosphere and, in accordance with the fundamental principle of dynamics, we may write down an expression for the acceleration by equating it to the vector sum of all the forces acting upon unit mass of air. The only real forces concerned are the force of gravity and the gradient of pressure both of which are theoretically determinable by observation; but, in small scale motions, such as convection currents and squalls, where vertical accelerations are significant, the difficulties are such that no attempt has yet been made to solve the equations of motion even approximately. Large scale motions are more amenable to mathematical analysis because then the vertical acceleration is entirely negligible compared with the acceleration of gravity; the force of gravity may be cancelled against the vertical gradient of pressure. The only acceleration of significance is in that case the horizontal component and the only remaining force is the horizontal gradient of pressure. There are however two decisive reasons why we cannot determine the acceleration from the force in the atmospheric problem. First there is the effect of turbulence. The motion at any level is affected, through the process of mixing, by the motion both above and below. The result is in a sense analogous to that of viscosity in a non-turbulent fluid and may be allowed for by introducing a "frictional term" into the equation of motion. Near the earth's surface this term is important and gives a large contribution to the acceleration, but within the free atmosphere it may justifiably be ignored except perhaps in regions of rapid shear. The second factor is the effect of the rotation of the earth. The observed acceleration is referred to axes rotating in space, and this must be allowed for by including the "geostrophic acceleration" which is proportional to the velocity and acts at right angles to the direction of motion.

Ignoring turbulence the apparent acceleration of the air may be equated to the acceleration due to the pressure gradient plus that due to the earth's rotation. We may write

$$\frac{dV}{dt} = \frac{G}{\rho} - iV \quad \dots \dots \dots (1)$$

where  $V$  is the vector wind,  $G$  is the horizontal gradient of pressure taken positive towards the low pressure,  $\rho$  is air density,  $l$  the geostrophic factor  $2\omega \sin \phi$  (see GRADIENT WIND) and  $i$  signifies rotation of the vector  $lV$  through one right angle in the cyclonic direction. The vector equation may be expressed by the triangle of accelerations shown in Fig. 1 where  $V$  is the velocity,  $lV$  is at right angles to  $V$ ,  $G/\rho$  is directed towards the low pressure and  $\frac{dV}{dt}$  is the acceleration.

This equation, it should be noted, does not provide a method of determining acceleration from the pressure gradient, but merely gives a relationship between acceleration and velocity; theoretically, for a given gradient, the acceleration may have any arbitrary value if the velocity is suitably adjusted. To make any progress it is therefore necessary first to make some assumption as to the nature of the motion. For example we might assume zero acceleration when,

$$iV = G/\rho \quad \dots \dots \dots (2)$$

which is the familiar geostrophic wind equation. This gives a useful first approximation to the true wind, but of course gives no clue to the general problem since the essential factor, acceleration, has been ignored. Alternatively we might assume uniform circular motion, when equation (1) immediately reduces to the so-called gradient wind equation. This also is of some value but as it implies that only the direction and not the speed of the wind is changing, or in other words the kinetic energy is constant, it has no application to the fundamental problems. The most fruitful results have been obtained by developing equation (1) and ignoring certain derivatives of higher order. Brunt and Douglas\* in this way arrived at what is known as the isallobaric acceleration, proportional to the isallobaric gradient and directed along the isallobars. More recently Sutcliffe† has re-examined the problem and, removing certain restrictions made by Brunt and Douglas, has shown that the isallobaric acceleration is only one of four terms. Further work is however required to decide finally which of these is dynamically significant.

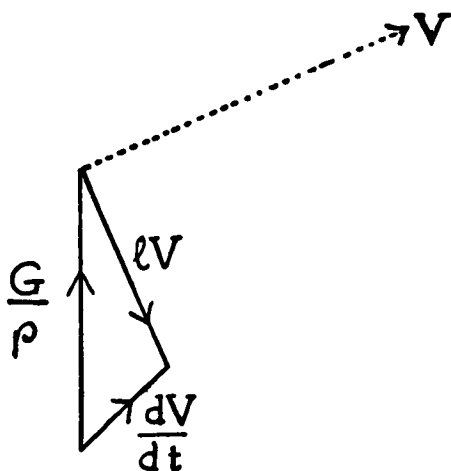


FIG. 1.

The determination of the field of acceleration is important not only directly but because it has certain interesting properties. Equation (1) might be written, by using equation (2),

$$\frac{dV}{dt} = -ilV'$$

where  $V'$  is the departure of the wind from the geostrophic value. Now geostrophic winds are rigorously non-divergent so that the field of convergence and divergence is given by the field of  $V'$ , that is of acceleration. Since convergence and divergence alone give rise to vertical currents with the accompanying cloud and rain and also alone are the cause of the development of cyclonic or anticyclonic circulation, a study of the field of acceleration should go a long way towards a final solution of the general problem of depressions and anticyclones.

**Accumulated Temperature.**—The integrated excess or deficiency of temperature measured with reference to a fixed datum over an extended period of time. If on a given day the temperature is above the datum value for  $n$  hours and the mean temperature during that period exceeds the datum value by  $m$  degrees the accumulated temperature for the day above the datum is  $nm$  hour-degrees or  $nm/24$  day-degrees. By summing the daily entries arrived at in this way, the accumulated temperature, above or below the datum value, may be evaluated for periods such as a week, a month, a season or a year. In practice,

\* *London, Mem. R. met. Soc.*, 3, 1929, No. 22.

† *London, Quart. J. R. met. Soc.*, 64, 1938, pp 495-504.

hourly values are not employed, and the daily entries are deduced from formulae based on readings of the maximum temperature,  $X$ , and the minimum temperature,  $N$ . It is sufficiently accurate to assume that the mean temperature for the day is equal to  $\frac{1}{2}(X + N)$ . If during a whole day the temperature remains continuously above the datum temperature  $D$  (i.e. if both  $X$  and  $N$  are greater than  $D$ ) then clearly the accumulated temperature above  $D$  is equal to  $\frac{1}{2}(X + N) - D$ , and the accumulated temperature below  $D$  is zero. Similarly if both  $X$  and  $N$  are less than  $D$ , the accumulated temperature above  $D$  is zero and the accumulated temperature below  $D$  is equal to  $D - \frac{1}{2}(X + N)$ . When  $D$  is intermediate between  $X$  and  $N$  empirical formulae of greater complexity must be used. For the purposes of the *Weekly Weather Report* the value of  $D$  is taken to be  $42^{\circ}$  F. and the following formulae are used :—

Cases	Accumulated temperature for the day expressed in day-degrees (Fahrenheit)	
	Above $42^{\circ}$ F.	Below $42^{\circ}$ F.
$(X - 42) > (42 - N)$	$\frac{1}{2}(X - 42) - \frac{1}{2}(42 - N)$	$\frac{1}{2}(42 - N)$
$(X - 42) < (42 - N)$	$\frac{1}{2}(X - 42)$	$\frac{1}{2}(42 - N) - \frac{1}{2}(X - 42)$

The practice of arriving at weekly accumulations by summing daily values obtained in this manner dates from the year 1928. Prior to that time weekly values were deduced directly from weekly means of daily maximum and minimum temperatures by the use of formulae due to Lt.-Gen. Sir Richard Strachey. For further information reference may be made to the Introduction to the *Weekly Weather Report*, Vol. XLV (New Series), 1928-9 and to Form 3300 which contains tables, based on the above formulae, to eliminate computation.

The adoption of  $42^{\circ}$  F. ( $6^{\circ}$  C.) as the basic temperature follows the practice of Angot and others who have considered that value to be the critical temperature above which the growth of vegetation in a European climate is initiated and maintained. For the study of heating problems a basic temperature of  $60^{\circ}$  F. has been adopted by American and British engineers.

**Accuracy.**—Strictly defined, the term accuracy signifies exactitude. No physical quantity, however, can be measured with exact precision. If a number of measurements are made of the quantity, every care being taken to eliminate all known sources of error, the final results will still differ amongst themselves. The deviation of these values from the true value is due to the accumulated sum of numerous small errors of unknown origin which cannot be allowed for. Hence in physical work the word accuracy is used in a comparative rather than in an absolute sense. It indicates the closeness with which an observation of a quantity is considered to approach the unknown true value of that quantity. A considerable body of mathematical doctrine has been built up dealing with this subject: it is usually called the Theory of Errors.

See also ERROR.

**Actinic Rays.**—Radiation which is effective in bringing about chemical changes, as in photography.

**Actinometer.**—An early name for an instrument measuring the rate at which radiation is received from the sun (see PYRHELIOMETER). More recently the same name has been given to instruments for measuring the intensity of actinic rays.

**Action Centre.**—See CENTRE OF ACTION.

**Adiabatic.**—The word which is applied in the science of thermodynamics to the corresponding changes which may take place in the pressure and density of a substance when no heat can be communicated to it or withdrawn from it.

In ordinary life we are accustomed to consider that when the temperature of a body rises it is because it takes in *heat* from a fire, from the sun or from some other source, but in the science of thermodynamics it is found to be best to consider the changes which occur when a substance is compressed or expanded without any possibility of heat getting to it or away from it. In the atmosphere such a state of things is practically realised in the interior of a mass of air which is rising to a position of lower pressure, or sinking to one of higher pressure. There is, in consequence, a change of temperature which is called mechanical or dynamical, and which must be regarded as one of the most vital of meteorological phenomena because it accounts largely for the formation and disappearance of cloud, and probably for the whole of our rainfall.

Tyndall illustrated the change of temperature due to sudden compression by pushing in the piston of a closed glass syringe and thus igniting a piece of tinder in the syringe. The heating of a bicycle pump is a common experience due to the same cause.\* On the other hand the refrigeration of air is often obtained simply by expansion, particularly in the free atmosphere.

To plan out the changes of temperature of a substance under compression and rarefaction alone, we have to suppose the substance enclosed in a case impermeable to heat—the word *adiabatic* has been coined to denote impermeable to heat in that sense. The changes of temperature thereby produced are very great, for example :—

For adiabatic change of pressure decreasing from 1,000 mb. by			The fall of temperature from 290° A., 62·6° F., is	
mb.	or	in.	° C.	° F.
10	or	0·30	0·9	1·6
100	„	2·95	8·7	15·7
200	„	5·91	18·2	32·8
300	„	8·86	28·4	51·1
400	„	11·81	39·9	71·8
500	„	14·77	52·8	95·0
600	„	17·72	67·6	121·7
700	„	20·67	85·5	153·9
800	„	23·62	108·1	194·6
900	„	26·58	141·3	254·3

The adiabatic lapse rate of dry air is given by the expression  $\frac{\gamma - 1}{\gamma} \cdot \frac{g}{R}$

where  $R$  = gas constant =  $2 \cdot 8703 \times 10^6$

$g$  = acceleration of gravity =  $980 \cdot 616$  cm./sec.<sup>2</sup> in latitude 45° at mean sea level

$\gamma$  = the ratio of the specific heats of dry air at constant pressure and constant volume respectively =  $1 \cdot 402$

from which the lapse rate in latitude 45° at M.S.L. is  $0 \cdot 98^\circ$  C. per hundred metres.

In the case of moist air matters are greatly complicated by the fact that when rising air cools to such an extent that condensation of water vapour takes place, the fall of temperature is checked by the latent heat liberated. In saturated ascending air there is in consequence a lower lapse rate, and one which varies greatly with the temperature. Two kinds of moist adiabatics are distinguished, one (reversible) in which the condensed water, whether in

\* Dangerous heating may result on firing a gun from sudden compression of gas within the bursting charge of the shell if there are cavities in the explosive therein.

the form of rain, hail or snow, is retained, and the other (irreversible) in which it falls out of the air. In the latter case the air on descending would follow the dry adiabatic relationship. In the diagram below the dotted lines are reversible adiabatics\*.

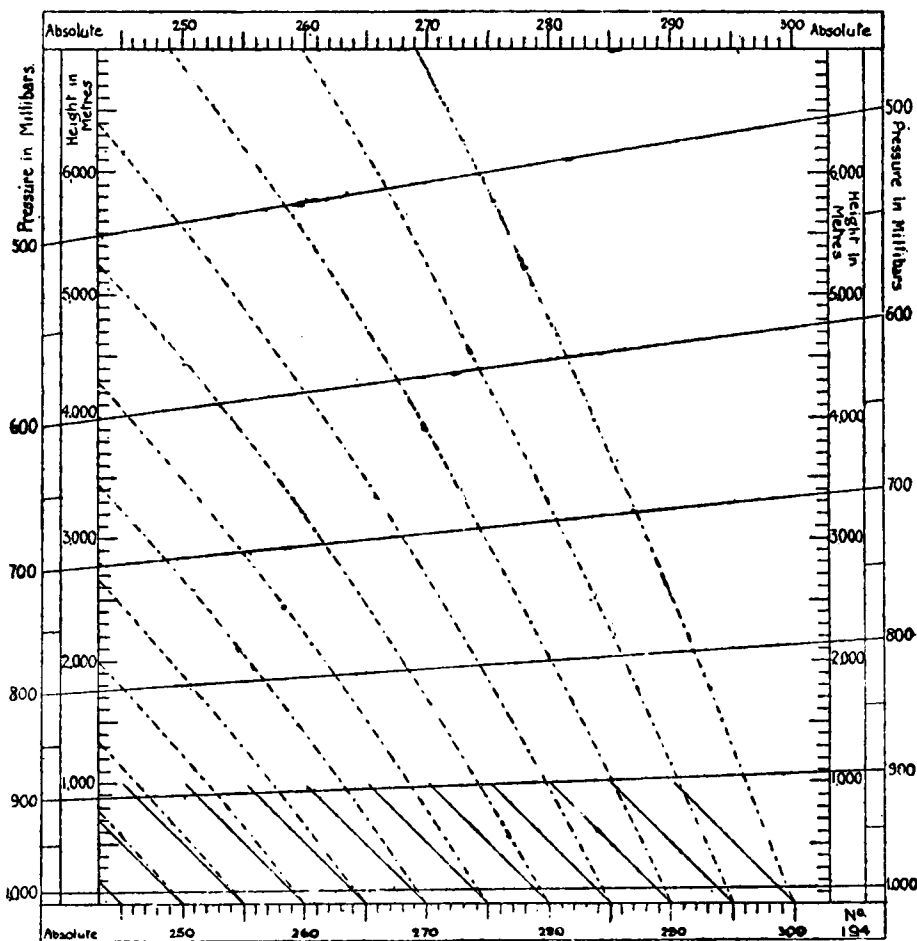


FIG. 2.—Diagram showing the pressure in the upper air corresponding with the standard pressure (1013.2 mb.) at the surface and adiabatic lines for saturated air referred to height and temperature. (From Neuhoff, *Smithsonian Miscellaneous Collections*, Vol. 51, No. 4, 1910.)

The pressure is shown by full lines crossing the diagram, and the adiabatic lines for saturated air by dotted lines. Temperatures are given in the absolute scale.

The short full lines between the ground and the level of 1,000 metres show the direction of the adiabatic lines for dry air.

**Advection.**—The process of transfer by horizontal motion. The term is more particularly applied to the transfer of heat by horizontal motion of the air. The transfer of heat from low to high latitudes is the most obvious example of advection.

**Aerodynamics.**—The study of the forces and reactions arising from the motion of bodies, more particularly the parts of an aeroplane, through the air. It is from such forces or reactions that the upward pressure beneath the wings of an aeroplane, which provides the lifting power, is obtained.

**Aerology.**—A word denoting the study of the atmosphere, and including the upper air as well as the more general studies understood by the word METEOROLOGY. It is frequently used as limiting the study to the upper air.

**After Glow.**—See ALPINE GLOW.

\* A table giving the saturated adiabatic lapse rate for different layers of the atmosphere is on p. 224.

**Air.**—The mixture of gases which form the atmosphere. Air from which the dust and water vapour have been removed shows no measurable changes in composition from place to place, within the limits of height accessible to direct observation. The dust is regarded as an impurity and the water, whether in the form of vapour or cloud, as an addition to the air. For meteorological purposes we may therefore treat dry air as a uniform mixture. Its composition is shown in the following table the figures in the penultimate column being those given by Paneth\* :—

	Specific gravity (0 = 16)	Proportional composition	
		By volume	By weight
		%	%
Dry air .. .. .	14.48	100.0	100.0
Nitrogen .. .. .	14.01	78.09	75.54
Oxygen .. .. .	16.00	20.95	23.14
Argon .. .. .	19.94	0.93	1.27
Carbon dioxide .. .. .	22.15	0.03	0.05
Neon .. .. .	10.1	0.0018	0.0012
Helium .. .. .	1.99	0.0005	0.00007
Krypton .. .. .	41.5	0.0001	0.0003
Hydrogen .. .. .	1.008	0.00005	0.000004
Xenon .. .. .	65	$8 \times 10^{-4}$	$3.6 \times 10^{-5}$
Ozone .. .. .	24	$1 \times 10^{-4}$	$1.7 \times 10^{-5}$

According to Paneth these percentages are practically the same throughout the troposphere and even for some distance into the stratosphere except in the case of ozone, the amount of which is variable and normally increases with height, while another gas of variable amount—radon—the percentage by volume of which is only about  $6 \times 10^{-18}$  decreases with height.

Dry atmospheric air at  $0^{\circ}\text{C}$ . and 1,000 mb. has a density of  $1.27617 \times 10^{-3}$  grams per cubic centimetre. The ratio of the density of water vapour to that of dry air at the same pressure and temperature is 0.6221, or very nearly  $\frac{1}{8}$ . If  $v$  is the volume in cubic centimetres of one gram of air,  $p$  the pressure in millibars, and  $T$  the temperature on the absolute scale, these quantities are related by the equation  $pv = RT$ , where  $R = 2.8703 \times 10^6$ . The number of molecules in one cubic centimetre of dry air at  $0^{\circ}\text{C}$ . and 760 mm., or 1013.2 mb. is  $2.75 \times 10^{19}$ . The specific heat of dry air at constant volume ( $c_v$ ) is 0.1715, and the specific heat at constant pressure ( $c_p$ ) is 0.2417. The ratio of the specific heats is 1.402. The thermal conductivity of air is very low, being  $5.6 \times 10^{-5}$  in C.G.S. units. See ADIABATIC.

Air is slightly viscous, the coefficient of viscosity,  $\nu$ , being  $1.7 \times 10^{-4}$  at  $0^{\circ}\text{C}$ . and  $2.2 \times 10^{-4}$  at  $100^{\circ}\text{C}$ .

**Air Mass.**—Broadly this term is used in synoptic meteorology to denote the mass of air which is bounded by frontal surfaces (often smoothed out into transitional zones), and often extending in well marked examples from the ground to the stratosphere. The horizontal dimensions are normally hundreds or even thousands of miles. The term may, however, legitimately be used in describing phenomena on a much smaller scale. The conception of large scale air masses was introduced in connexion with TRAJECTORIES and has been greatly developed in connexion with FRONTS and related questions. Its practical utility depends on two observed characteristics of the atmosphere. In the first place, although the temperature and humidity of the air in contact with a land or sea surface are much influenced by that surface, the upper air characteristics are relatively conservative throughout a motion of many hundreds of miles. When there is vertical motion the air is affected by ADIABATIC processes, but if the air is followed in three dimensions the

\* *London, Quart. J. R. met. Soc.*, 63, 1937, p. 436.

POTENTIAL TEMPERATURE and the water content per unit mass are independent of adiabatic processes in the absence of condensation or evaporation, and the WET-BULB POTENTIAL TEMPERATURE remains constant even when these are included. This function is therefore especially useful in identifying air masses. The non-adiabatic processes, turbulence and radiation, are slow in their operation in the upper air.

The other important feature is that the air is often nearly homogeneous over a large area, the horizontal differences being concentrated in the frontal zones. It is well known that a steep horizontal gradient of temperature involves a large change of wind with height. Such a shearing action distorts an air mass out of recognition, and readily leads to mixing between air masses originally adjacent to each other. When one is dealing with air masses hundreds of miles in linear dimensions, horizontal diffusivity is not very effective, but distortion due to marked wind variation with height brings in the more effective process of diffusion in the vertical, due to the TURBULENCE which wind shearing tends to produce. Though these processes often limit the application of the idea of air mass, there are fortunately many cases of a nearly homogeneous mass, by which is implied a weak horizontal temperature gradient. This feature depends on various factors, involving the history of the air over periods extending to weeks. Regions where homogeneous air masses tend to be produced are known as "source regions." Uniformity of surface conditions is a favourable feature, since the surface influence is diffused slowly upwards. A quiet state of the atmosphere is another favourable factor. In the area of the sub-tropical "highs" both conditions are satisfied, and those regions are the source of TROPICAL AIR, which is the most generally homogeneous type of air (except quite near the fronts). In the arctic regions there are often rapid fluctuations of pressure and it is unlikely that the upper air is really homogeneous, but all air of arctic origin, until it has subsided, is cold aloft and is often found to be homogeneous over a reasonably large area. The term POLAR AIR is a wide one, implying a source region which includes areas of cold water in addition to ice-covered areas, but in winter most examples of polar air can be traced back to ice or snow-covered surfaces. Polar air in its various subdivisions is the most frequent type of air in our area, at least in the lowest 15,000 to 20,000 ft., partly because warm air is often displaced upwards, and also (in winter) because of circulation round the "Iceland low." Its characteristics are far more variable than those of tropical air.

Homogeneity in the air mass is also affected by vertical motion outside the "source region." In particular cold air tends to subside and be dynamically warmed, simultaneously with the formation of an anticyclone, and within an air mass of polar origin there is often a considerable gradient of temperature between an anticyclone or wedge and the rear of a depression. In the life history of a normal depression there are originally two very different air masses, but in the final stage a high degree of homogeneity is often attained. Both persistent (warm) anticyclones and old (cold) depressions are sources of homogeneous air.

In considering the classification of air masses it is important to note that there are no clearly defined categories which cover the infinite variations of nature, but that a classification is imposed for practical convenience. The particular system of classification must be based on the needs of each area, but normally the emphasis is on the relatively distant "source regions," which constitute the most important single factor, in spite of the other influences mentioned above, and also the complication of local surface conditions. In the British Isles the main categories are tropical and polar air; ARCTIC AIR is really a special type of polar air. Further details may be found under these headings. The two main categories are sub-divided into Maritime and Continental. In the British Isles air of a really continental source is rare. Air coming back from Europe is usually maritime in origin, and its varying length of continental life history is merely a complicating factor. The



expression "continental air" (without adding polar or tropical) is occasionally used, and there are also occasions, especially in summer, when an unqualified "maritime air" might be the best description.

Generally speaking, air-mass analysis is simplest in winter, when the exchange of air between high and low latitudes is most marked. In addition the continents are cold in winter in temperate latitudes, so that if air moving from the continents over the oceans is included in polar air, one has only the two main categories applicable to the Atlantic and to most conditions in the British Isles. The lapse rate of temperature in the lowest few thousand feet is the main distinguishing feature, and this is important in relation to cloud height and also to the height at which ice can form on aeroplanes. The difference between sea and air temperatures observed from ships is a useful practical criterion, but it should not be used too rigidly. In summer, when the continents are warm to about latitude  $65^{\circ}$  N, air moving from the continents to the oceans is cooled at the surface and becomes stable and damp in the lower layers. Such cases, which are by no means rare, are not adequately covered by any classification in general use.

**Air-Mass Climatology.**—With the passage of depressions and anticyclones any place in the temperate storm belt is successively covered by air masses of different origins. Five main types of air mass are recognised, Polar maritime (Pm), Polar continental (Pc), Tropical (or Equatorial) maritime (Tm), Tropical continental (Tc) and Indifferent or mixed (X). In any locality and season each of these types has its own special characteristics, in England in spring for example polar maritime air is cool and unstable, giving moderate precipitation in the form of rain or hail showers. Polar continental air is cold and dry, tropical maritime air is warm and moist. This type of climate is termed "collective"; the normal values of temperature, humidity, etc., give the result of averaging out the characteristics of the different air masses. A different and in some ways a more illuminating picture of the climate is obtained by setting out the frequencies of the different types of air mass and the characteristics of each type. This is "air-mass climatology." The subject has been extensively studied in Germany, see for example Dinies, E. "Luftkörper-Klimatologie," *Hamburg, Arch. Seewarte*, 50, No. 6, 1932.

**Air-meter.**—An instrument for measuring the flow of air. It consists of a light "windmill" in which inclined vanes are carried on the spokes of a wheel arranged to rotate about a horizontal axis. A system of counters is provided to show the number of rotations of the wheel. It forms a convenient portable ANEMOMETER for use in winds of any strength, but a meter designed for use in light winds would be damaged if exposed to strong winds.

**Air Pockets.**—Regions of relatively descending air, upon entering which an aircraft experiences a proportionate decrease of lift. Since air streams tend to follow the normal contour of the earth's surface, descending currents will naturally exist on the leeward side of hills, buildings and other obstructions. These descending currents will vary with the strength and character of the wind, and with strong and squally winds they are frequently considerable. The turbulence produced by an obstacle to the flow of the wind extends to a height depending on the lapse rate, but this height is seldom more than three or four times that of the obstacle. Well defined regions of descending air will be experienced in the turbulent conditions associated with thunderstorms, squalls and fronts of cold front type. See BUMPINESS.

**Air Trajectory.**—See TRAJECTORY.

**Albedo.**—The proportion of the radiation falling upon a non-luminous body which it diffusely reflects. The albedo of the earth is about 0.4, which means that four-tenths of the sun's radiation is reflected to space. The

greater part of this reflection is due to the clouds, which, according to Aldrich,\* have an albedo of about 0.78, but varying with the type and thickness of the cloud.

**Alpine Glow.**—A series of phenomena seen in mountainous regions about sunrise and sunset.

Two principal phases are generally recognised—

(a) *The true Alpine glow.*—At sunset this phase begins when the sun is about  $2^\circ$  above the horizon; snow-covered mountains in the east are seen to assume a series of tints from yellow to pink, and finally purple. As this phase is due mostly to direct illumination by the sun it terminates when the mountain tops pass into the earth's shadow. The Alpine glow is most striking when there are clouds in the western sky and the illumination of the mountains is intermittent.

(b) *The after glow* begins when the sun is well below the horizon,  $3^\circ$  or  $4^\circ$ . The lighting is faint and diffuse with no sharp boundary. It is said to occur only when the PURPLE LIGHT is manifest in the opposite sky.

**Altimeter.**—An aneroid barometer graduated to show approximate height instead of pressure. If  $p_0$  is the pressure on the ground and  $p$  the pressure at height  $h$ , then  $h$  can be calculated if the temperature of the air at every point between  $p_0$  and  $p$  is known. Altimeters are generally designed so that for a certain distribution of temperature with height the movement of the pointer is proportional to the change of height, and the dial is made adjustable so that the pointer can be made to show 0 when the instrument is at ground level. One of two arbitrary assumptions about the temperature of the air is adopted in this country.

(1) That temperature is  $10^\circ\text{C}$ . ( $50^\circ\text{F}$ .) at all heights, or

(2) That the distribution of temperature with height is that of the international standard atmosphere (see STANDARD ATMOSPHERE).

**Altitude.**—The angular distance of an object from the horizon, measured in a vertical plane. In meteorology, altitude generally means height above mean sea level. It is usually expressed in metres or feet, but for calculations involving pressures or other forces which depend on the value of GRAVITY it is often more convenient to adopt as a unit the "dynamic metre," equivalent to the standard metre multiplied by 1000/g. Surfaces of equal altitude in dynamic metres are surfaces of equal geopotential.

**Alto cumulus (Ac.).**—A layer, or patches composed of laminae or rather flattened globular masses, the smallest elements of the regularly arranged layer being fairly small and thin, with or without shading. These elements are arranged in groups, in lines or waves, following one or two directions and are sometimes so close together that their edges join.

The thin and translucent edges of the elements often show irisations which are rather characteristic of this class of cloud.

An important variety is known as alto cumulus castellatus. The grouping of the cloudlets is similar to that of ordinary alto cumulus, but many of them develop turreted tops like miniature cumulus. When seen moving from a southerly point during fine weather these clouds indicate an early change to thundery conditions. See CLOUDS.

**Altostratus (As.).**—Striated or fibrous veil, more or less grey or bluish in colour. This cloud is like thick cirrostratus but without halo phenomena; the sun or moon shows vaguely, with a gleam, as though through ground glass. Sometimes the sheet is thin with forms intermediate with cirrostratus (altostratus translucidus). Sometimes it is very thick and dark (altostratus opacus), sometimes even completely hiding the sun or moon. In this case differences of thickness

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\* Washington D.C., *Smithson. misc. Coll.*, 69, No. 10, 1919.

*may cause relatively light patches between very dark parts ; but the surface never shows real relief, and the striated or fibrous structure is always seen in places in the body of the cloud.*

**Amplitude.**—The amplitude of a harmonic motion is the maximum swing to either side of the mean position. A harmonic motion can be represented by a sine curve  $R\sin px$ , where  $x$  is the independent variable and  $R$  is the amplitude of the function, or of the motion which it represents. It should be noted that the total range of motion is twice the amplitude. See HARMONIC ANALYSIS.

**Anabatic.**—Referring to the upward motion of air due to CONVECTION. A local wind is called anabatic if it is caused by the convection of heated air : as, for example, the breeze that is supposed to blow up valleys when the sun warms the ground. See VALLEY BREEZE.

**Anemogram.**—The record of an ANEMOGRAPH.

**Anemograph.**—An instrument for recording the velocity or force, and sometimes also the direction, of the wind. The best known forms are the Robinson cup anemograph, the Dines tube anemograph, the "anemobiograph" designed by Halliwell for Negretti and Zambra, the Osler pressure-plate anemograph and the Richard "anémo-cinémograph."

The Robinson cup anemograph depends for its action on the rotation, under the action of the wind, of a group of hemispherical cups carried on arms attached to a vertical spindle. There is a nearly constant ratio (known as the "factor") between the travel of the wind and the travel of the cups. This factor depends upon the dimensions of the instrument and must be determined by test in a wind tunnel ; it is more nearly a true constant for the 3-cup than for the 4-cup anemometer.

The Dines anemograph makes use of the difference of pressure set up between two pipes, one of which is kept facing the wind, while the other is connected to a system of "suction holes" on a vertical tube. The difference of pressure so produced is arranged to raise a float carrying a pen, the height of which above the zero position is made proportional to the wind speed. By this method every gust and lull may be shown on the record. The **anemobiograph** works on similar principles.

The pressure-plate anemograph records the pressure of the wind on a vertical plate facing the wind, while the **anémo-cinémograph** records, by means of an ingenious system of electrical transmission, the rate of rotation of a cup system.

**Anemometer.**—An instrument for determining the velocity or force of the wind. As in the case of ANEMOGRAPHS various types are in use, the most important being those in which a system of cups is employed. In the Meteorological Office pattern "cup indicating" anemometer, the rotation of the cups operates a train of wheels designed to indicate the total flow of air in miles. In the "cup electric" anemometer an electrical circuit containing a buzzer is arranged to give an audible signal for a fixed flow of air. Similar anemometers have been designed to indicate the rate of rotation of the cups, and, therefore, the air velocity by means of a speed indicator.

**Anemoscope.**—An instrument for indicating the existence of wind and showing its direction.

**Aneroid Barometer.**—The aneroid barometer was invented by Lucien Vidie in about 1843. In its simplest form it consists of a shallow capsule of thin corrugated metal which is very nearly exhausted of air. The faces are kept apart by a spring. The residual air provides an automatic correction for temperatures. In some instruments a number of capsules are employed. The relative movements of the faces due to changes of atmospheric pressure are conveyed through a train of levers to a chain which actuates a pointer on a dial. An aneroid is light, portable and convenient, but should be compared occasionally with a mercury barometer, as an appreciable change

of zero sometimes occurs. Owing to errors introduced by the imperfect elasticity of the metal, etc., the use of aneroid barometers in meteorology is confined chiefly to cases where mercurial instruments are impracticable, e.g. on aircraft or in the construction of self-recording instruments where the highest order of accuracy is not expected. Owing to improved methods of manufacture, considerable progress has been made in recent years towards the production of aneroids comparable in accuracy with mercurial barometers.

**Aneroidograph.**—A self-recording aneroid. An aneroid barometer provided with mechanism for recording the variations of pressure of the atmosphere. See BAROGRAPH.

**Angular Velocity.**—The angular velocity of a moving line is the rate of change of the angle between the line and a fixed line in the same plane. A suitable convention is adopted as to which direction of rotation shall be considered positive. The angular velocity of a moving point about a fixed point is the angular velocity of the line joining the two points. The angular velocity of a moving point about a fixed axis, is the rate of change of the angle between a plane drawn through the fixed axis and the moving point, and a fixed plane passing through the axis; and the angular velocity of a solid body about an axis is the angular velocity of any point of the solid body about that axis. Angular velocity may be measured in revolutions per minute or per second; for many purposes it is more convenient to measure it in radians per second or per hour, the symbol for it being  $\omega$ . Since there are  $2\pi$  radians in a complete revolution, the connexion between  $\omega$  and the revolutions per minute,  $N$ , is  $\omega = \pi N/30$  radians per second. The linear velocity of a cloud is determined as a product of the angular velocity of the cloud about the point of the earth's surface vertically beneath it and the height of the cloud above that point. If the height of the cloud is given in miles and the angular velocity in radians per hour the linear velocity will be in miles per hour.

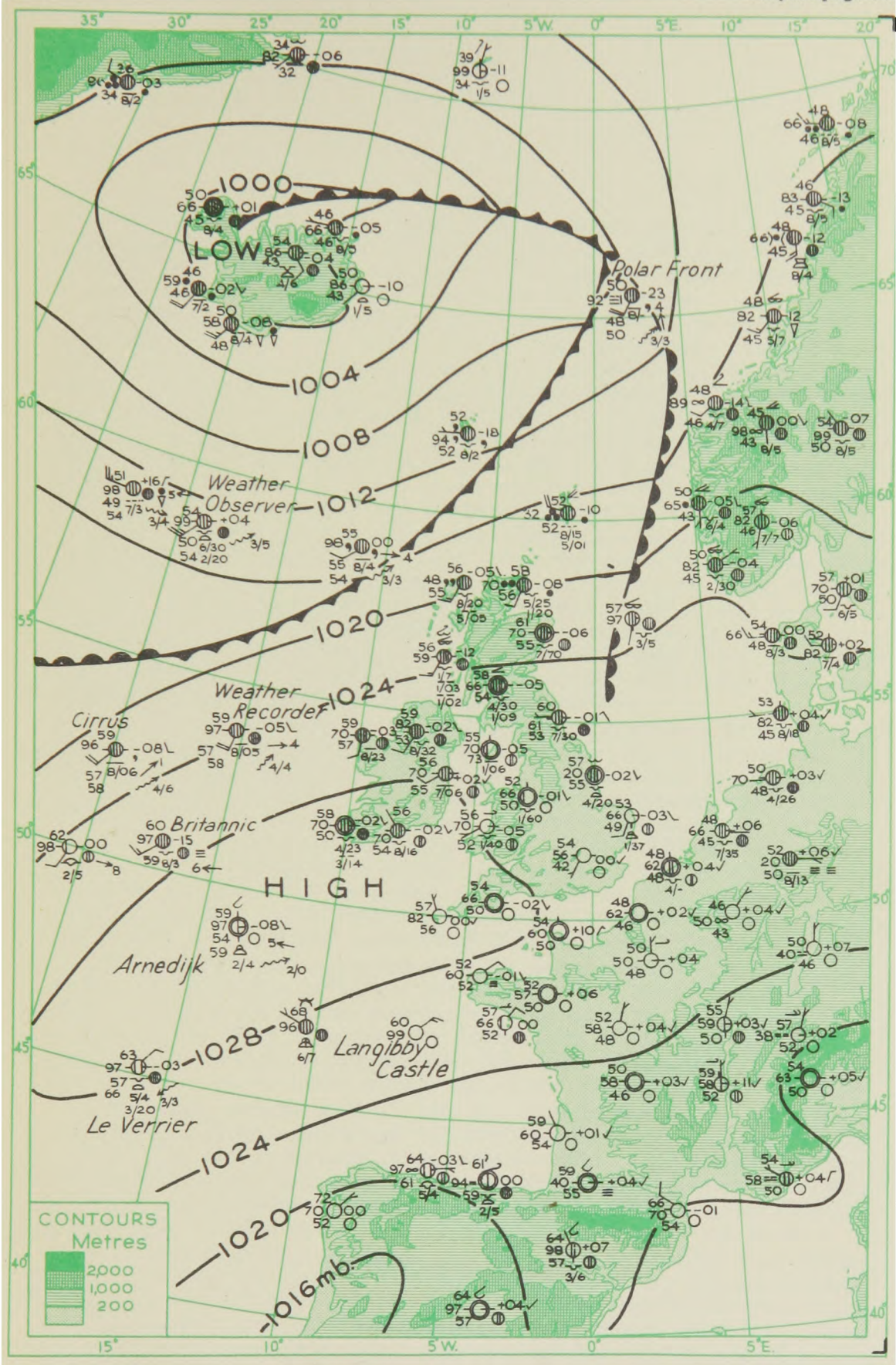
**Anomalous Radio Propagation.**—This term refers to the refraction by the atmosphere of radio waves of wave-lengths of a few metres or less transmitted in beams (e.g. radar) at a very small angle to the horizontal. "Super-refraction" is also used. Normally the waves are only refracted to a small extent and the transmission is practically the same as for light waves. When, however, there is an inversion of temperature or a rapid decrease of water vapour content with height there is considerable downward refraction which may be sufficient to make the waves follow the curvature of the earth and give transmission to far greater ranges than is normally possible. The most favourable conditions for long ranges occur in air moving out from a warm dry land over a cool sea. Thus in the NE. monsoon season of India very great radar ranges are obtained.

**Anomaly.**—The departure of a meteorological element from its normal value. In meteorology the word is used chiefly in connexion with temperature, to indicate the departure from the mean value for the latitude. Places that are relatively warm for their latitude, such as the Norwegian coast in winter, have a positive temperature anomaly; places that are relatively cold, such as Siberia in winter, have a negative temperature anomaly.

**Anthelion.**—A colourless mock sun appearing at the point of the sky opposite to and at the same altitude as the sun. The phenomenon is rare. Rather more frequently oblique arcs crossing at that point are reported. The phenomena are no doubt due to the reflection of light from ice crystals, but the exact explanation is in doubt.

**Anticyclone.**—An anticyclone is a region in which the barometric pressure is high relative to its surroundings (Plate I). In temperate latitudes anticyclones are usually isolated and are generally distinguished by a series of closed isobars of roughly circular or oval form, the region of highest pressure being the central region of the anticyclone. The term "anticyclone" was first introduced by Sir Francis Galton in 1861 with the intention not only





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of conveying the idea that it was an area of high pressure instead of low pressure as in a depression or cyclone, but also that the general weather in the two systems, that of high and low pressure, was entirely different in character. In the depression the wind circulation is, in the northern hemisphere, counter-clockwise, often approaching gale force, and the weather is usually of an unsettled type while in an anticyclone the wind circulation is clockwise and the weather of a quiet and settled type.

There are two extensive belts of anticyclones, approximately in lat.  $30^{\circ}$  N. and  $30^{\circ}$  S.; these almost completely encircle the earth and are more or less permanent; they usually drift a little northwards and a little southwards as the sun moves northwards and southwards in its path across the equator. Between these permanent anticyclonic belts there is a belt of low pressure which is relatively uniform and is known as the DOLDRUMS.

Anticyclones are also formed over continental areas in winter time, a noteworthy one being that over Siberia. In the Siberian anticyclone of winter the pressure is often as high as 1050 mb. or 31.00 in., while in another marked anticyclone—that occupying the North Atlantic in the region of the Azores—pressure is usually about 1025 mb. or 30.25 in. in the summer and 1020 mb. or 30.10 in. in winter. During an anticyclone the pressure is as a rule well above the normal for any given place in it and as a consequence pressures of 1020 mb. (30.10 in.) or over are frequent and such high pressures are usually taken alone as a sign of the presence of an anticyclone.

In a well-defined anticyclone the winds blow spirally outwards in accordance with BUYS BALLOT'S LAW. Near the centre, however, the winds are generally light and very variable in direction, calms being frequent. In the outer regions, away from the centre, the winds increase somewhat, arrange themselves in a clockwise direction, move outwards from the area of high pressure and generally cut the isobars at a small angle. It follows that, in the northern hemisphere, the winds on the northern side of an anticyclone are westerly and on the southern side easterly.

Anticyclonic weather is usually, and rightly, regarded as quiet and settled, but in practice considerable variations of weather may be experienced. In summer over the British Isles the weather in an anticyclone is generally fine, sunny and warm but much cloud may occur with some rain in its outer portions. On the other hand in winter there are two distinct types, in one the sky is covered with a layer of STRATOCUMULUS cloud, conditions which are sometimes referred to as "anticyclonic gloom," and in the other the sky is almost cloudless, the nights are frosty and, in the early morning, fog is thick and often widespread. In the former type the cloud height is often uniform over a large area. The cloud sheet is frequently thin and above it the sky is cloudless.

Temperature observations taken in the upper air show that there is a temperature inversion or rise of temperature with height just above the cloud. When in the London area in winter the cloud height is low the lower surface of the cloud becomes inky black; the inversion of temperature coupled with the light winds prevents the escape of London's smoke; the light from the sun is almost entirely cut off and the day becomes like night.

Anticyclones usually cover a larger area than depressions and move much more slowly. When once formed they often remain almost stationary for two or three days and sometimes for ten days or more. Their general direction of movement is from west to east. In an anticyclone the upper air layers very gradually sink and become heated by ADIABATIC compression. This results in the inversion of temperature to which reference has already been made.

Sir Napier Shaw has estimated that in a large anticyclone the velocity of the descending air currents is of the order of 300 ft. per day and in small anticyclones the velocity may be as great as 1,000 to 1,500 ft. per day. These velocities may be exceeded in the developing stage. (See SUBSIDENCE.) When the upper air temperatures in an anticyclone are low, that is, when the anticyclone is of little vertical depth, it usually travels more quickly than one which is of greater depth and warm in its upper layers.

There have been many theories as to the cause and method of formation of anticyclones but as yet there is no single satisfactory explanation. Temperature observations in the upper air, however, have shown that between the heights of two and ten kilometres (one and six miles) the temperature in an anticyclone is usually higher, and above ten kilometres lower, than the average for locality and season.

**Anti-Tradés.**—At a height of 2,000 metres or more above the surface in trade-wind regions the wind direction is sometimes reversed, giving for example a SW. wind on the Peak of Teneriffe. These winds are believed to be the return currents carrying the air of the TRADE WINDS back to higher latitudes, hence they are termed "anti-trades" or counter-trades, but they are not regularly developed. See also ATMOSPHERIC CIRCULATION.

**Anti-Twilight.**—See PURPLE LIGHT.

**Anvil Cloud.**—Cloud having a projecting point or wedge like an anvil. The form is usually assumed by the tops of fully developed CUMULONIMBUS clouds, causing heavy showers or thunderstorms. A small anvil is seen in Fig. 13. The anvil normally consists of ice crystals or snow flakes, and is fibrous or nebulous in appearance. The term is sometimes used for a large mass of cirriform cloud on the top of cumulonimbus, even when the lateral extension is slight. See CLOUDS.

**Aqueous Vapour.**—Aqueous vapour is always present in the atmosphere, but it never represents more than a small fraction of the whole. In spite of this fact its presence is of great importance on account of its physical properties.

On account of its ready absorption of long-wave RADIATION, such as is given out by objects at ordinary atmospheric temperatures,\* it exercises a strong control over the fall of temperature on clear nights; when present in large quantities it checks the loss of radiation from the ground and so prevents the surface air from being chilled to the extent that it would otherwise have been. Since, on the other hand, its absorption of the visible radiation of the sun is relatively small, it can to some extent act as a "trap" for the solar radiation. Even more important thermal effects arise from the fact that when water vapour is formed as a result of evaporation much heat is absorbed—597 CALORIES for each gram of water evaporated at 273°A—and an equal quantity is given out when condensation occurs. Now a large proportion of the evaporation from the whole earth takes place in the tropics, where most solar radiation reaches the surface; much of the water vapour so formed finds its way into middle and high latitudes and supplies most of the moisture for the clouds and rain associated with cyclonic depressions. In this process, heat is conveyed from low to high latitudes and the climates of both regions are rendered less extreme. The energy of many meteorological phenomena from the ordinary cumulus cloud to the thunderstorm, and probably of the tropical cyclone also, is derived from the sun only after first being stored as latent heat in water vapour; the latent heat set free during condensation tends to make the air where condensation is going on warmer than its environment, and so favours CONVECTION.

If air at a given temperature is confined in contact with pure water, some of the water will, in general, evaporate and the partial pressure of the water vapour in the air will increase. At any given temperature, however, there is a definite upper limit to the amount of water that can be taken up in this way. When this limit is reached the air is said to be saturated, and the partial pressure of the water vapour (commonly called the vapour pressure) is then equal to the saturation vapour pressure for that temperature. It will be seen from the table below that the saturation vapour pressure increases rapidly with the temperature.

Air is unsaturated if the actual partial pressure of the water vapour present is less than the saturation vapour pressure for the temperature of

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\*Spectrum analysis shows that it absorbs also a small part of the visible radiation of the sun.



the air. In these circumstances, the hygrometric state of the air may be expressed in the various ways implied by the following definitions:—

1. The “saturation deficit” is the difference between the actual vapour pressure and the saturation vapour pressure.

2. The “relative humidity” is the percentage degree of saturation, that is to say, the quotient of the actual vapour pressure divided by the saturation vapour pressure, multiplied by one hundred.

3. The “dew point” is the temperature for which the actual vapour pressure is equal to the saturation vapour pressure.

4. The “vapour density” or “absolute humidity” is the density of the water vapour present in the air, i.e. the weight per unit volume of air.

5. HUMIDITY-MIXING-RATIO (q.v.).

Averages of the vapour pressure, relative humidity and vapour density for a large selection of stations are given in “Averages of Humidity for the British Isles”, where charts of the monthly and annual distribution will also be found. Graphs of the seasonal and diurnal fluctuations are given in E. G. Bilham’s “Climate of the British Isles” (London, Macmillan, 1938). Data for foreign stations are given in Shaw’s “Manual of Meteorology” Vol. II (Cambridge University Press, 1936). Vapour density is termed “moisture content” in “Averages of humidity for the British Isles” and in “Climate of the British Isles.”

VALUES OF THE SATURATION VAPOUR PRESSURE AND VAPOUR DENSITY

Tempera- ture	Vapour pressure	Vapour density	Tempera- ture	Vapour pressure	Vapour density
° F.	mb.	gm./m <sup>3</sup> .	° F.	mb.	gm./m <sup>3</sup> .
5	1.93*	1.62*	60	17.68	13.26
10	2.42*	2.01*	65	21.08	15.70
15	3.01*	2.48*	70	25.05	18.47
20	3.73*	3.04*	75	29.65	21.64
25	4.59*	3.70*	80	34.98	25.29
30	5.63*	4.49*	85	41.12	29.48
35	6.89	5.44	90	48.17	34.20
40	8.40	6.56	95	56.25	39.60
45	10.18	7.87	100	65.49	45.66
50	12.28	9.41	105	76.02	52.53
55	14.76	11.19	110	87.96	60.26

\* Over supercooled water; the values over ice are lower (see “Averages of Humidity for the British Isles” p. 28).

**Arctic Air.**—Air arriving directly from arctic regions. The most notable outbreaks of arctic air occur in winter and spring, and they bring snow to those regions where the topography favours precipitation with northerly winds, and occasionally to most of the country. It is really a variety of POLAR AIR, and there is no sharp line of demarcation, since after a sufficient degree of warming over the sea, the arctic air becomes maritime polar air. See AIR MASS.

**Arctic Sea Smoke.**—A kind of FOG formed when the air is much colder than the sea surface. It is necessarily shallow. It forms over inlets of the sea in arctic waters when very cold air from the land moves out over the sea or when the opening of a rift in a solidly frozen sea surface exposes water to air cooled to a very low temperature by radiation.

**Arid.**—A climate in which the rainfall is insufficient to support vegetation is termed arid. W. Köppen and R. Geiger in their “Klimakarte der Erde” \* use the following formulae for the limits of rainfall for arid and semi-arid climates:—

Rainfall mainly in cold season .. .. .	$R = 2t$
Rainfall evenly distributed throughout the year ..	$R = 2t + 14$
Rainfall mainly in hot season .. .. .	$R = 2t + 28$

\* Gotta, Justus Perthes, 1928.

where  $t$  is the mean annual temperature in °C. If the annual rainfall in centimetres is less than  $R$  and greater than  $\frac{1}{2}R$  the climate is steppe or semi-arid; if it is less than  $\frac{1}{2}R$  the climate is desert or arid.

**Atlas, Climatological.**—An atlas showing the geographical distribution of some element or elements of climate. Temperature, rainfall and sunshine are most frequently shown, but other elements such as wind velocity and direction, cloudiness, humidity, etc., may be included.

The most usual method of representation is by means of isograms and sometimes in order to aid the eye the areas between consecutive isograms are shown in different colours. Isograms may be drawn to show the mean value of the particular element for any space of time, but the time units most frequently employed in a climatological atlas are the month and the year.

Many meteorological services have published a climatological atlas for their country. "The Climatological Atlas of the British Isles", H.M. Stationery Office, 1952, contains 220 maps dealing with pressure, wind, temperature, rainfall, snow, thunder, humidity, sunshine, fog and visibility. Numerous charts are also included in the "Manual of Meteorology," Vol. II, by Sir Napier Shaw. (Cambridge University Press, second edition, 1936.)

**Atmosphere.**—A name given to the air which surrounds us, and is carried along with the earth. It is a mixture of gases, and at levels accessible to measurement, the relative proportions of the permanent constituents show no appreciable variations, with the sole exception of water vapour. Local sources of pollution such as factory chimneys may give rise to enhanced proportions of non-permanent constituents, but these slight local variations are not of meteorological importance. It is therefore convenient in meteorology to regard the atmosphere as made up of a homogeneous mixture called "dry air," whose constitution is everywhere the same at least up to heights accessible to direct observation, to which is added water vapour in varying amounts.

The constitution of the atmosphere at heights above about 30 Km. is uncertain. Theoretical discussion of the change in constitution with height is based upon the assumption of Dalton's Law, which states that the distribution of each element at the higher levels is independent of all the other elements present. The partial pressure of any particular element at, say, 30 Km. must, therefore, support all the mass of that element above 30 Km. In the practical application of this rule, considerable importance attaches to whether hydrogen is regarded as a normal constituent of the atmosphere. In any case theory demands that nitrogen and oxygen should cease to account for an appreciable fraction of the atmosphere at heights of 160 Km. and above. According to Dobson, however, the observation of meteors indicates that up to the greatest heights at which meteors appear, about 160 Km., oxygen and nitrogen remain the chief constituents of the atmosphere.

The presence of OZONE in the atmosphere has been demonstrated spectroscopically by Fowler and Strutt, and observations of absorption of solar radiation in a restricted band of wave-lengths, by Dobson and others, confirm this, and indicate that the greater part of the ozone occurs in a layer 20 to 40 Km. above the earth's surface. The presence of ozone at these levels appears to be of some meteorological significance, Dobson having found that the pressure at 10 Km. is highly correlated with the amount of ozone.

The variability of water vapour is of the greatest importance in meteorology. The processes of evaporation and condensation of water vapour are among the most potent meteorological factors, not only because they produce a transport of water from one place to another but also because the evaporation of water to form water vapour requires the absorption of latent heat, which is finally liberated and used in heating the air when the water vapour again condenses into waterdrops or snow. The total amount of water vapour which the air could hold if saturated, under summer conditions for the British Isles, would yield 35 mm. of rain if it was all precipitated. The corresponding figure for winter is about 15 mm.

Nitrogen, which is a constituent of ammonia, nitric acid and the nitrates which are so important in gunpowder and nearly all other explosives, is quite inert in the atmosphere. It merely dilutes the more important constituent

oxygen, which forms about one fifth of the atmosphere. Without oxygen no fire can be maintained and the chemical processes in the body necessary for life cannot go on. But these characteristics of oxygen are of no special importance in meteorology.

The characteristics of the atmosphere which are of importance in meteorology are its pressure, temperature, and humidity. To a high degree of approximation the pressure of the atmosphere at any point is a measure of the mass of a cylinder of air of unit cross section extending to the top of the atmosphere. Increase or decrease of pressure therefore connotes respectively transport of air to, or from, the place of observation. The pressure of the atmosphere at sea level is equal to a pressure of about  $14\frac{1}{2}$  lbs. per sq. in.

The homogeneous atmosphere is the atmosphere which retains throughout the whole of its height the density at sea level, and yields normal atmospheric pressure at the ground. Its height is approximately 8 Km.

See also AIR, STANDARD ATMOSPHERE, STRATOSPHERE.

**Atmospheric Circulation.**—Used in the sense of “general circulation of the atmosphere” for the wind system of the earth as a whole. This wind system is related to the pressure distribution over the earth, and both depend ultimately on the sun’s heat. (The relation of wind to pressure distribution is described under BUYS BALLOT’S LAW.)

Examination of a series of synoptic maps of the hemispheres would show that certain features of the pressure and wind distribution over the world are much more variable from day to day than are others. In the northern parts of the British Isles, for example, pressure not infrequently varies by as much as 20 mb. in a day, and a day of strong south-easterly winds may be succeeded by a day of north-westerly gales, while over parts of the South Atlantic a fresh SE. wind blows with great regularity day after day. If, however, a series of charts is constructed from the prevailing winds for periods of a month, a greater degree of regularity appears, and in order to obtain a picture of the general circulation it is necessary to study such maps as those of Figs. 3 and 4. These maps represent the stream-lines in January and July; the course of the seasons may be considered as a change from one type to the other.

It is generally agreed that the “planetary circulation,” appropriate to a planet like the earth but of uniform surface, would comprise, at the surface—

(a) A belt of low pressure, calms or of light variable winds, with converging air on the equator (DOLDRUMS).

(b) Belts of TRADE WINDS between the doldrums and lat.  $30^{\circ}$  N. and  $30^{\circ}$  S. blowing from the north-east in the northern and from the south-east in the southern hemisphere.

(c) Belts of light variable winds, with diverging air which descends from higher levels in about lat.  $30^{\circ}$  N. and  $30^{\circ}$  S. (HORSE LATITUDES).

(d) Regions of prevailing south-westerly winds in middle latitudes of the northern hemisphere and north-westerly winds in middle latitudes of the southern hemisphere.

(e) Regions round the poles of outflowing winds with a component from E.

The transitions between (d) and (e) are regions of variable winds forming the “temperate storm belts.”

Over the oceans (except the Indian Ocean in July) an approximation to the planetary circulation is observed. The maps show centres of divergence in about latitude  $30^{\circ}$ , on the equatorial side of which the trade winds converge towards a line (the “intertropical front”) a little north of the equator, while the great south-westerly currents in the northern hemisphere and north-westerly currents in the southern hemisphere are also clearly marked. In January in the northern hemisphere there are centres of convergence at the Aleutian and Icelandic lows but in July these are less clearly marked, and take the form of a front (the POLAR FRONT). In the southern hemisphere there is a great system of westerly winds in about  $40^{\circ}$  S, known as the ROARING FORTIES.

Over the continents (and the Indian Ocean) there is a much greater annual variation. In January a wind axis extends from west-south-west to

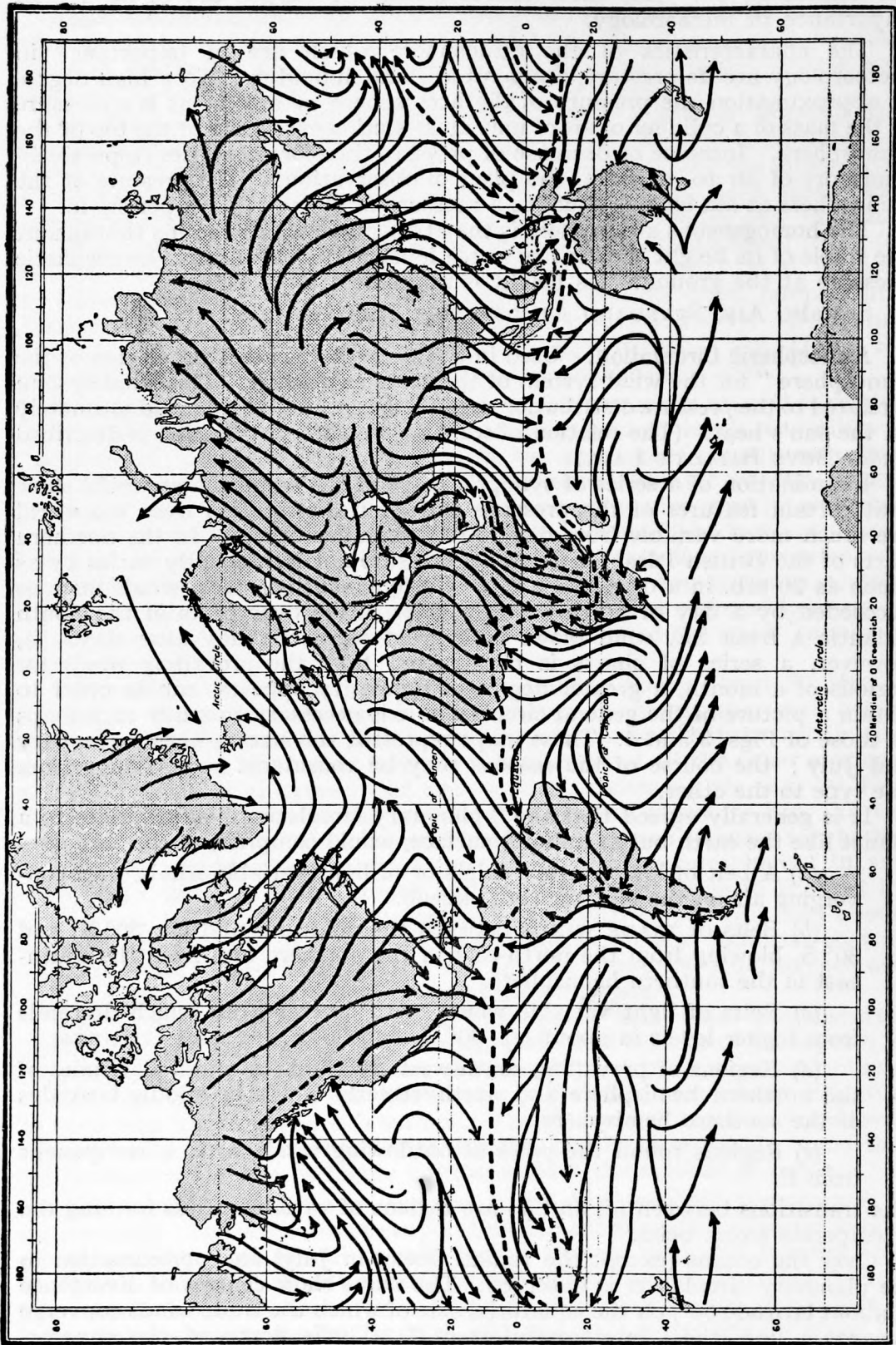


FIG. 3—Mean surface winds in January

east-north-east across Europe and Asia, separating the south-westerly winds blowing towards the Arctic from northerly winds which give rise to the HARMATTAN of north Africa and the winter monsoon of Asia. Africa is

occupied by four great systems of winds, blowing from the Mediterranean, south-west Asia, the south Indian Ocean and the south-east Atlantic. Most

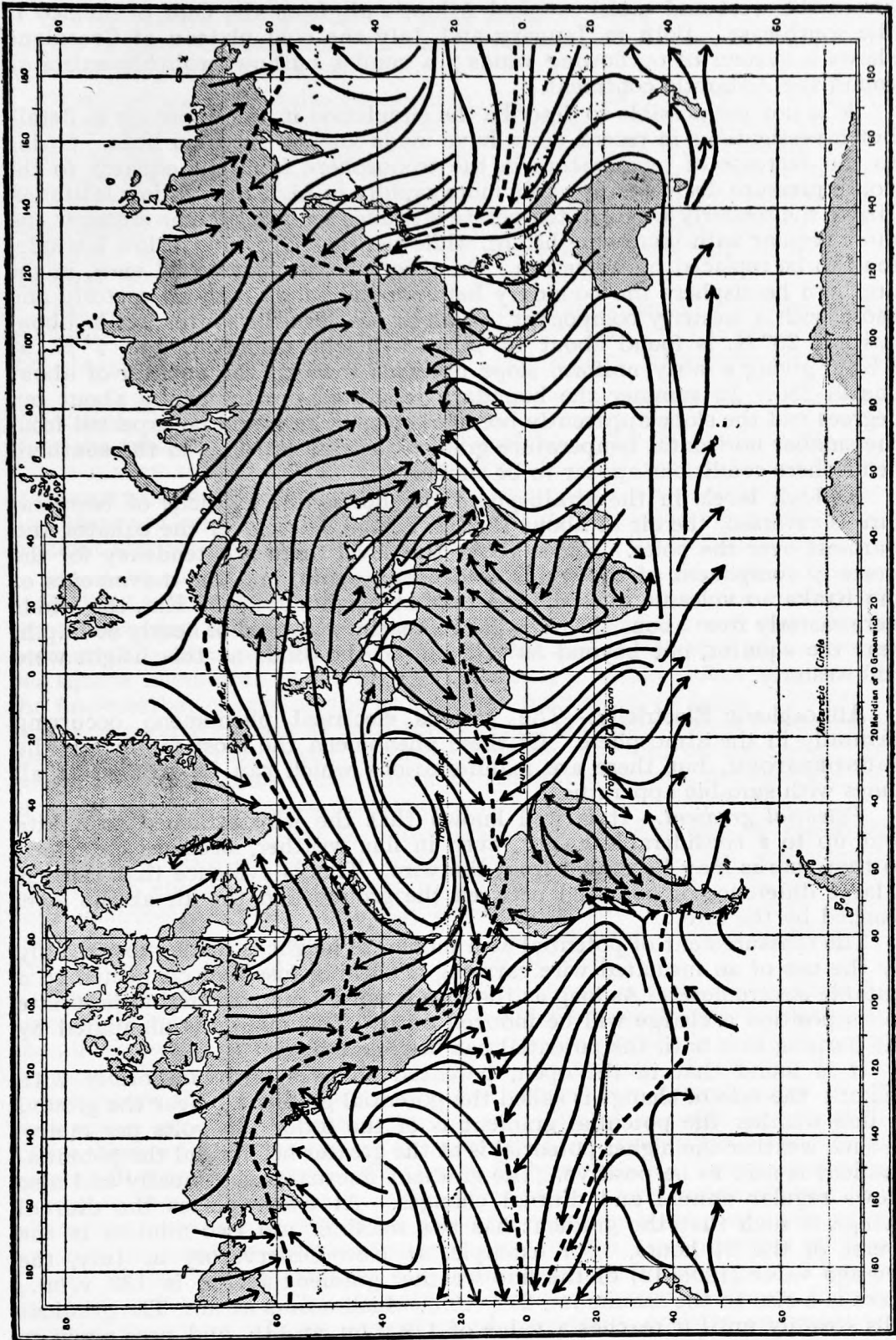


FIG. 4—Mean surface winds in July

of North America shows a fairly simple outflow of polar air while the greater part of South America is occupied by air from the Atlantic. The main "fronts" between the various air masses are shown by broken lines.



In July southern and eastern Asia are occupied by tropical monsoon air, but most of Asia and the whole of Europe come under the influence of temperate W. or NW. winds. North America has Arctic air in the north, Pacific air in the west and moist tropical Atlantic air from the Gulf of Mexico in the south-east. Both in January and July the cold plateau of Greenland shows a system of outflowing winds; a similar outflow probably exists all round the Antarctic continent.

It is not yet possible to describe the circulation in the upper air in detail, but investigations in recent years have made known the main lines. Owing to the decrease of temperature in the troposphere from the equator to the poles, pressure decreases upwards more rapidly in high than in low latitudes. Hence the westerly winds of temperate latitudes tend to become stronger and more regular with increasing height, while the easterly winds of low latitudes tend to be replaced by westerlies. On a very broad generalised view, in the northern hemisphere the boundary between the winds with an easterly and those with a westerly component, which at sea level in winter lies in about latitude  $25^{\circ}$  N. is found about  $15^{\circ}$  N. at a height of 5 Km. and  $7^{\circ}$  N. at 8 Km., giving a fairly uniform slope upwards towards the equator of about one in 250. In summer the boundary is shifted northward by about ten degrees and the slope apparently becomes steeper, as would be expected from the smaller horizontal temperature gradient at this season. In the southern hemisphere conditions appear to be similar.

At high levels in the stratosphere the horizontal gradient of temperature is reversed, the air at about 13 Km. being coldest over the equator and warmest over the poles. Hence above this level there is a tendency for the westerly component of the winds to decrease again, and the movements of the Krakatao volcanic dust showed that at heights of 27–33 Km. the winds were easterly from about  $25^{\circ}$  N. to  $25^{\circ}$  S., reaching a speed of nearly 80 m.p.h. near the equator, but beyond  $30^{\circ}$  N. and S. the winds at this height were still westerly.

**Atmospheric Electricity.**—The various electrical phenomena occurring naturally in the atmosphere. Of these phenomena the most familiar is the THUNDERSTORM, but there are manifestations which can be studied at all times with suitable apparatus.

*Potential gradient.*—It is well known that the wire attached to a kite sent up to a considerable height, even in fine weather, becomes electrified so that sparks may be drawn from the wire. This is evidence that there is a large difference of potential between the ground and the air at the level reached by the kite.

The measurement of potential at a moderate height is made most readily by the use of an insulated wire carrying a burning fuse and connected to a suitable electrometer. As long as the fuse is not at the potential appropriate to its position a charge will be induced on it. This charge is dissipated by the burning fuse until the potential has been equalised.

It is found that in the open, potential changes fairly uniformly with height; the rate of change is called the potential gradient. Near the ground in fine weather the potential gradient is of the order 150 volts per metre. In such weather the higher potential is at the greater height and the potential gradient is said to be positive. The gradient fluctuates continually and also shows regular annual and diurnal changes. At many places the diurnal change is such that the gradient has two maxima and two minima in the course of the 24 hours. For example, at Kew Observatory in July, the average value (1905–12) of the fine weather gradient at 3h. is 153 v./m.; there is a rise to the maximum, 272 v./m., which occurs at 9h. The gradient falls steadily until it reaches a value of 179 v./m. at 14h. and rises again to 266 v./m. at 21h.

The gradient depends to a great extent on the condition of the atmosphere. It is low when the air is clear, higher when there is haze and very high when fog prevails. In fog the gradient at Kew may be as high as 2,000 v./m.

Over the oceans and in polar regions the diurnal variation of potential gradient is governed by world-time, the minimum occurring about 3h. G.M.T., the maximum about 19h. G.M.T.

During rainfall and especially during thunderstorms potential gradient is subject to great fluctuations. In thunderstorms the gradient is of the order 10,000 v./m. positive or negative.

Observations from balloons indicate that on the average as we go up from the earth the potential gradient diminishes. As, however, the contributions are in the same direction, the potential goes on mounting and at the levels attained by aircraft it may reach hundreds of thousands of volts. (In the case of a kite-balloon tethered to the ground by conducting wires the potential of the balloon is practically zero and, therefore, departs widely from that of the surrounding air. In an extreme case this may lead to discharge by sparking and great danger to the kite-balloon.)

*The earth charge.*—The existence of a positive potential gradient implies the presence of a negative charge on the ground. With a gradient 100 v./m. the charge is roughly 1 coulomb per 1,000 square kilometres (accurately

$\frac{1}{36\pi \times 10^{11}}$  coulomb per cm.<sup>2</sup>). If the same gradient prevailed over the whole globe the total charge would be 450,000 coulombs. To the electrical engineer this is a very small quantity of electricity. It could only supply a current of one ampère for five days. Of course the gradient is not uniform; at any time there are large areas with negative gradient. We cannot give the average gradient and we are, therefore, unable to determine the total charge.

*Air-earth current.*—The charge on the earth's surface is continually being neutralised by the communication of positive electricity from the atmosphere. By substituting a metal plate for part of the ground we can measure the current. The average current over flat ground is of the order 2 microampères per square kilometre. Small as this current is it would suffice to neutralise the fine-weather charge on the ground in a fraction of an hour. There is, of course, a reverse current at such times as the potential gradient is negative. Electricity is also conveyed to the ground by rain and by lightning. The question whether these causes suffice to preserve a balance between the flow of positive and of negative electricity is still open.

*Electricity on rain.*—It is found that raindrops are usually electrified. The charges may be positive or negative but positive ones predominate. Drops with charges of either sign may fall simultaneously. The charge per cubic centimetre of rain is generally less than one electrostatic unit ( $\frac{1}{3} \times 10^{-9}$  coulomb) but charges approaching 20 e.s.u. per cm.<sup>3</sup> have been observed. The charges on snow are of the same order of magnitude.

The principal cause of the electrification of rain is probably the breaking up of the drops.\* When the velocity with which a large drop is falling through the air exceeds a certain limit the drop is broken up into a number of small drops which become positively charged in the process. According to some investigators the corresponding negative charges are carried away by the finer spray, according to others by the air. The process will be accelerated where there are powerful upward currents of air to break up the drops. Similar effects will occur with snow. Sir George Simpson based a theory of thunderstorms on these phenomena. In the parts of an active cumulonimbus cloud where the upward currents of air are most vigorous large drops are formed by the condensation of water vapour and by the amalgamation of small drops. In the strong currents the large drops are broken up and become positively electrified. The air with its negative charge passes on to other parts of the cloud. Large quantities of electricity, positive and negative, accumulate in different regions and the electric forces increase until a lightning flash occurs. The process is repeated as long as the storm lasts.

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\* "On the electricity of rain and its origin in thunderstorms," by G. C. Simpson, *London Philos. Trans.*, A. 209, 1909, pp. 379–413.

Soundings with the altielectrograph—an instrument designed to record the sign of the potential gradient aloft—have indicated, however, that very frequently the charges in the upper parts of thunder clouds are positive. The temperature at such heights is well below the freezing point and it appears that some process in which snow plays an important part is responsible for the greater part of the electrification. It may be that the impact of snow particles on one another suffices, the particles acquiring negative charges which they carry downwards while the air, streaming upwards, retains a positive charge.

*Ionization of the atmosphere.*—The conductivity of the air is due to the presence of charged particles known as ions. The ions which are effective in carrying the current are probably clusters of molecules of the atmospheric gases. On the average there are five or six hundred of these small ions of each sign in a cubic centimetre of air, each small ion carrying the electronic charge. The mobility of the small ions is such that they move about one centimetre per second in an electric field of 1 volt per centimetre. The atmosphere contains also more numerous ions (the Langevin ions) with much less mobility. It is thought that these sluggish ions are charges attached to Aitken nuclei, the hygroscopic particles on which moisture condenses when clouds are formed. The fact that in general potential gradient falls off as we ascend in the atmosphere is evidence that the net charge on the air is positive. This implies that there must be an excess of positive ions.

The variations in the conductivity of the air are explained by the different proportions of large and small ions. In places where the atmosphere is polluted by the products of combustion of coal Aitken nuclei are frequent, large ions are formed at the expense of small ones, the effective conductivity is reduced and the air-earth current is maintained by a higher potential gradient.

At appreciable heights above ground the conductivity of the air is considerable. At 9 Km. Wigand found the conductivity to be 26 times as great as near the ground. Gish and Sherman found that the increase from the ground up to 18 Km. was about one hundredfold. The great conductivity of the Heaviside layer is due to high ionization.

Since free ions of opposite sign will tend to recombine and give up their charges there must be active causes of ionization at work. Of known causes the radiation from radio-active gases and the COSMIC RADIATION from outer space may be mentioned. Combustion and similar processes are also effective and under certain circumstances the breaking of waterdrops and the friction of snow or dust driven by the wind. Over the land most of these causes are in operation, over the sea the cosmic radiation is the only one which is known to be effective, but this may suffice to maintain the observed ionization.

**Atmospheric Pollution.**—The principal source of the pollution of the atmosphere is the burning of coal under such conditions that the combustion is incomplete. When a hydrocarbon, such as one of the constituents of coal, is burned, the hydrogen combines with oxygen to form water vapour, the carbon combines with oxygen to form carbon dioxide. If, however, the temperature is not high enough the second half of the process does not take place; some of the carbon is carried up with the rising air and coagulates into particles of soot. The smoke from a coal fire consists in the main of such particles.

The pollution of the air of cities has been reduced by the introduction for industrial processes of more efficient furnaces in which the coal is completely burned and very little smoke is produced. Further great quantities of coal are treated in gas works. By heating the coal in retorts the hydrocarbons are broken up; the hydrogen with other constituents of coal gas is distributed through mains and the coke, which is mostly carbon, is sold separately. Both the coal gas and the coke will burn without the production of smoke. The substitution of the gas-cooker for the kitchen range has led to a great reduction in the amount of domestic smoke.



The gaseous products of combustion are mostly water vapour and carbon dioxide, both normal constituents of the atmosphere; but coal generally contains sulphur and the burning of sulphur produces the essential constituents of sulphureous and sulphuric acids. Most of the damage done to buildings by atmospheric pollution is attributed to the action of sulphuric acid.

A Committee of Investigation having been appointed at a Conference held in London in 1912 systematic records of atmospheric pollution have been kept in Great Britain since 1914.

The estimation of the quality and amount of polluting substances in the air at any time presents great difficulties. It is easier and no less instructive to measure the pollution which is deposited. For this purpose a large gauge is used in which rain is collected and also the foreign matter which falls as dust or is brought down with the rain. Month by month the contents of the gauge are taken away for analysis.

As an example of the results the 5-year averages for a gauge in the City of London may be quoted. The quantity of matter deposited in the gauge in the solid form was 82 grams per square metre per annum. Of this total only 32 gm. was carbonaceous insoluble matter; as such things as pollen would be included in this 32 gm. the amount of soot would be rather less than 32 gm. The amount of insoluble ash, i.e. dust from the roads as well as from fires was 50 gm. The solid matter in solution in the rain water was nearly equal to the insoluble matter. The soluble matter included a high proportion of sulphates; it is the practice of chemists in such cases to estimate the acid without regard to the base with which it may be associated. In this case the average amount of  $\text{SO}_3$  was 25 gm. It will be seen that the quantity of  $\text{SO}_3$  is not much less than the quantity of soot.

It is found that in places with less pollution than London the ratio of the amount of soluble matter to the amount of insoluble is higher.

At seaside places such as Southport a considerable amount of sea salt is included in the soluble matter.

For estimating the amount of solid matter in suspension in the atmosphere it is found convenient to aspirate a known quantity of air through filter paper and to compare with a set of standard shades the stain left on the filter paper. Dr. J. S. Owens has devised automatic apparatus for making records which are practically continuous.

It is found that in foggy weather the quantity of suspended solid matter in London air may amount to four milligrams per cubic metre. Generally the maximum on a foggy day is about 2 mg./m.<sup>3</sup> whilst the maximum on a non-foggy day in winter is about 0.8 mg./m.<sup>3</sup>

Pollution varies systematically through the 24 hours; normally the least pollution is in the early morning, when few fires are in operation. There is also a secondary minimum in the middle of the day at the time when the air currents are strongest. The times of maximum pollution are generally about 9 a.m. and 7 p.m.

Dr. Owens has also developed a method of counting the number of solid particles in the air. For this purpose a jet of air is pumped through a slit on to a piece of glass which can be examined under the microscope. The number of particles in fog may be as high as 20 per cubic millimetre. The particles are generally ultra-microscopic.

**Atmospheric Pressure.**—The pressure of the atmosphere is produced by the weight of the overlying air. If a vertical tube were placed over one square inch of the earth's surface extending to the top of the atmosphere, the air contained within it would weigh about  $14\frac{1}{2}$  lb. As the weight of the column is borne by the earth's surface at the bottom, the pressure exerted on the earth by the air is therefore about  $14\frac{1}{2}$  lb. to the square inch. The pressure exerted by a gas is the same in all directions, and it is this pressure of approximately  $14\frac{1}{2}$  lb. to the square inch but varying a little from day to day and from place to place which is measured by the mercurial or aneroid barometers in ordinary use.

**Atmospherics.**—Electrical impulses of natural origin which cause crashing or grinding noises in a wireless receiving set. They are believed to originate in the earth's atmosphere, most probably in discharges of the same nature as lightning. Atmospherics of measurable strength are received in England at the rate of about 50 per second at night, and in the tropics about 50 per second during the day and a few hundred, rising occasionally to a few thousand, per second, during the night. By means of radio direction recorders, the sources of many atmospherics have been determined, and it has been found that some radiate from centres 4,000 miles away. The average strength of atmospherics received in England is consistent with their radiation from centres 2,000 miles away, which in turn is consistent with their origin in regions in which thunderstorms are frequent.

**Attached Thermometer.**—A thermometer attached to a mercurial barometer for the purpose of ascertaining its temperature. When used in conjunction with a marine barometer the attached thermometer may conveniently be mounted in a GOLD SLIDE.

**Audibility.**—The audibility of a sound in the atmosphere is measured by the distance from its source at which it becomes inaudible. On a perfectly clear, calm day the sound of a man's voice may be heard for several miles, provided there are no obstructions between the source of sound and the listener ; but quite a small amount of wind will cut down the range of audibility enormously.

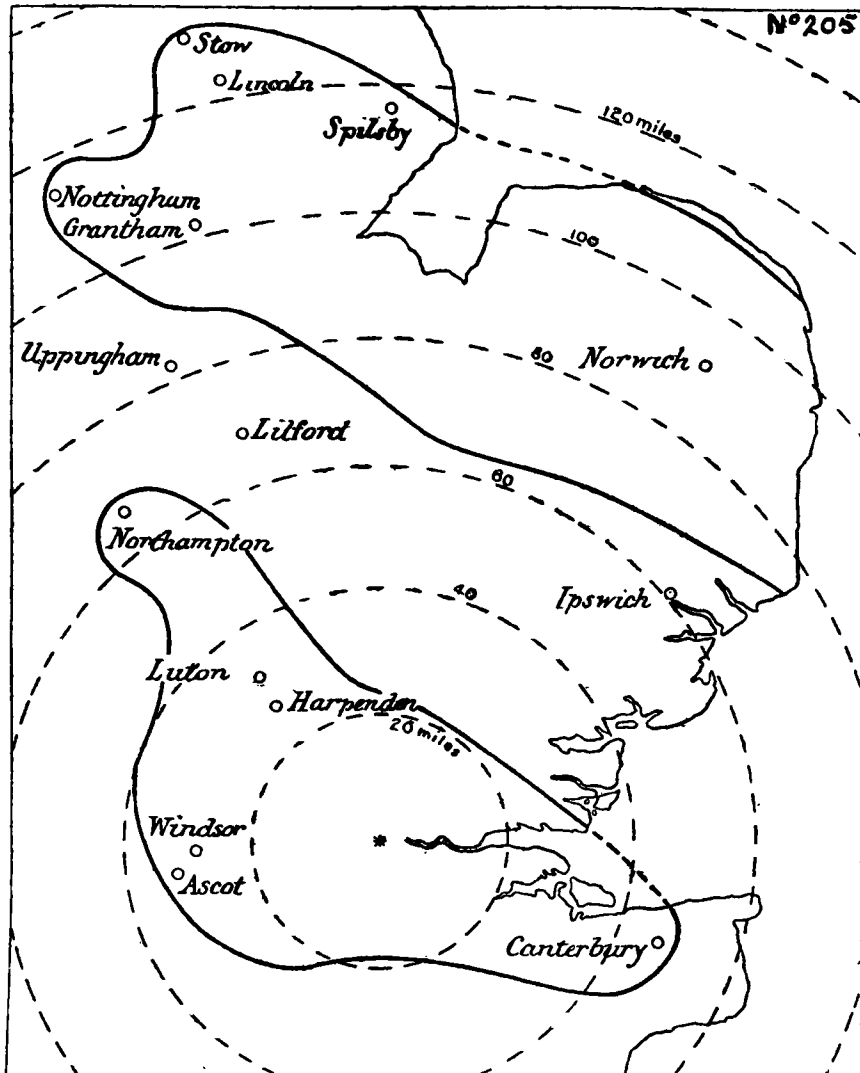
The sound is not cut down equally in all directions ; to leeward, for instance, a sound can usually be heard at a greater distance than it can to windward of the source. This is accounted for by the bending which the sound rays undergo, owing to the increase in wind velocity with height above the ground, the rays to leeward of the source being bent downwards while those to windward are bent upwards so that they pass over the head of an observer stationed on the ground. The decrease in all directions in the range of audibility of a sound when there is a wind, appears to be due chiefly to the dissipation in the energy of sound as it passes through eddying air. A plane wave-front becomes bent in an irregular manner when it passes through air in irregular or eddying movement. It, therefore, ceases to travel uniformly forward. Part of its energy is carried forward, while the rest is dissipated laterally.

Another process must also be taken into account. It has been found by V. O. Knudsen that, when a noise is produced in a small room the rate at which the reverberation dies out depends on the humidity of the air, and further that when oxygen is substituted for air the damping is more rapid whereas when nitrogen is substituted there is practically no damping. An explanation of the phenomena has been given by H. O. Kneser. Molecules of oxygen are liable to pulsations in which the distance between the nuclei of the constituent atoms is variable. The pulsations are produced by encounters between the oxygen molecules and molecules of water vapour, but the pulsations are not very readily started and when they do start they are not readily stopped. This sluggish transfer of motion robs a sound wave passing through the atmosphere of part of its energy. How effective the Knudsen-Kneser phenomenon may be in producing the absorption of sound in the open air is not known yet, i.e. at the end of 1938.

If there were no dissipation of energy in a sound wave the intensity of the sound would decrease inversely as the square of the distance from the source. Experiments show that, under normal conditions when there is a light wind blowing, the rate of decrease in intensity of sound at a distance of half a mile or more is considerably greater owing to the dissipation of energy than would be expected from the inverse square law. If, for instance, a whistle can be heard at a distance of half a mile, four whistles blown simultaneously should be audible at a distance of a mile ; but the range is actually only increased to about three quarters of a mile.

Sounds are usually heard at greater distances during the night than during the day. On calm nights the range of audibility of a sound may be as much as 10 or 20 times as great as it is during the day. This effect is due partly to the increased sensitiveness of the ear at night owing to the decrease in the amount of accidental disturbing sounds, partly to the inversion of temperature which commonly occurs on calm, clear nights, and has the effect of bending the sound waves downwards, but chiefly to the diminution of the amount of disturbance in the atmosphere at night.

Between the source of sound and the extreme range of audibility, areas of silence sometimes appear, in which the sound cannot be heard. This



(Reproduced by permission from the Quarterly Review, July, 1917.)

FIG. 5.—Areas of audibility of the explosion at Silvertown on January 19, 1917.

effect has in some cases been attributed to a reversal in the direction of the wind in the upper layers of the atmosphere. The lower wind would bend the sound rays upwards to windward of the source. On entering the reversed upper wind current these rays would be bent down to the earth again, and would reach it at a point separated from the source of sound by an area of silence. This explanation is quite adequate in many cases in which the places, where the sound is heard again, are to the windward of the source. There are, however, many cases in which areas of silence appear to leeward of the source, and many others in which an area of silence occurs in the form of a ring enclosing the source and surrounded by an area of distinct audibility.

In most of the cases where a ring-shaped area of silence has been observed the outer region of distinct audibility begins at a distance of about 100 miles from the source, and may extend to 150 miles or more. The explosion at Silvertown on January 19, 1917, is a good example of a case in which a detached area of audibility was separated from the source of sound by an area of silence. In the accompanying map (Fig. 5), which is reproduced by permission from the *Quarterly Review*, the two areas of audibility are shown. It will be seen that the outer area, which includes Lincoln, Nottingham and Norwich, lies about 100 miles from the source of sound. The inner area surrounding the source is not symmetrical, being spread out towards the north-west and south-east. Definite evidence was obtained that no sound was heard at various points within the area of silence.

The study of observations made on artificial explosions has shown that the time which the sound takes to reach a point in the inner zone of audibility near the source is such that the apparent velocity differs but little from the ordinary velocity of sound, but that the apparent velocity with which the sound reaches a point in the outer zone is much less. For this reason the outer zone is known as the "zone of abnormal audibility." The probable explanation of abnormal audibility is the presence of a region of high temperature at a considerable height above the ground. Owing to the way in which temperature falls off in the lower atmosphere sound rays are generally bent upwards; in the stratosphere in so far as it is a region of uniform temperature the rays will be straight. For the rays to recurve sufficiently to bring them down again they must enter a region where the temperature is at least as high as that which prevails on the ground. The observations indicate that the rays reach heights of 40 Km. or more. That high temperatures prevail at such levels was first suggested as an explanation of the behaviour of METEORS. The observations of audibility have confirmed the theory.

**Aureole.**—A luminous area surrounding a source of light. The name is used especially with reference to coronae. When there is a corona round the sun or moon a clear space in which the cloud seems to be transparent is seen near the luminary. The first coloured ring, usually a brownish-red, bounds this clear space. The clear space is the aureole. The term may be used legitimately when the corona is not developed beyond the first coloured ring.

The name aureole is also used by some authors for the bright area with no definite boundary seen round the sun when no clouds are present.

**Aurora.**—In Latin the word *aurora* stands for dawn. According to the Oxford Dictionary the term *aurora borealis* was introduced by Gassendi in 1621. This term, the northern dawn, is apt enough for a faint glow seen at night near the northern horizon. The same name is given, however, to a wider class of luminous phenomena. On the recognition of similar phenomena in the Antarctic regions, these were called *aurora australis*. The single word *aurora* is now in general use in either hemisphere.

Aurora takes many forms. Of the accompanying figures one shows an arc with rays, the other a curtain. The quiet arc is the most symmetrical and stable form of aurora, sometimes persisting with little visible variation for several hours, but an arc with ray structure such as is shown in the illustration undergoes rapid changes. The lower edge, both of arcs and curtains, is usually much the better defined. Another striking form of aurora is that known as a corona, in which several beams of luminescence radiate from a point high in the sky. Several forms may occur simultaneously or successively during any auroral display.

Aurora is very rare in southern Europe, and is but seldom seen in the south of England. But the frequency increases rapidly as we go north, and in Orkney and Shetland aurora is a common phenomenon. In those regions it may occasionally be observed to the south as well as to the north.

A zone of maximum frequency passes across the north of Norway, the south of Iceland and of Greenland and surrounds the north magnetic pole; the distribution in the Antarctic is more or less similar. Cape Evans, the

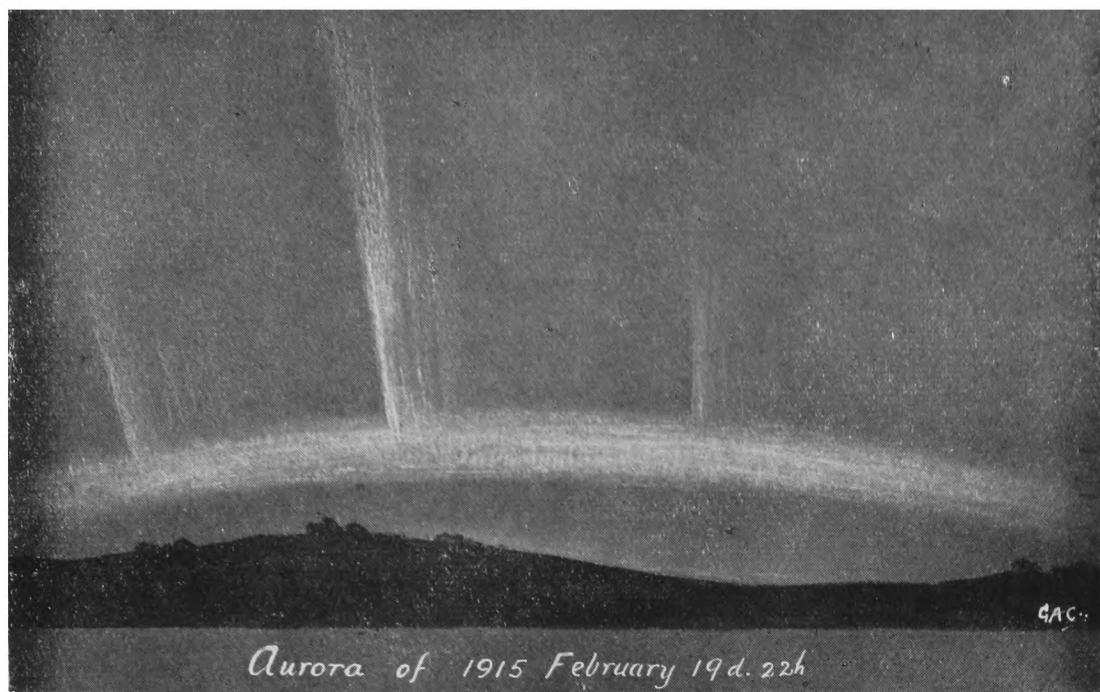


FIG. 6.—Aurora of February 19, 1915 22h.

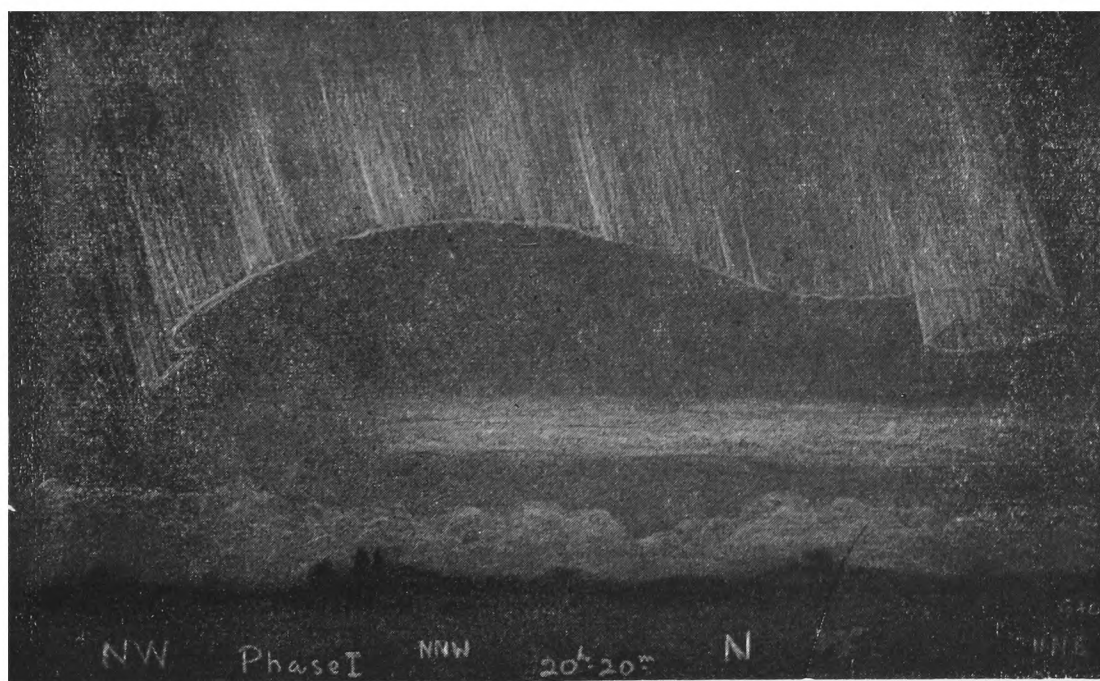


FIG. 7.—Aurora of January 4, 1917. Sketched at Aberdeen by G. A. Clarke.  
Phase I. 20h. 20m.



headquarters of Scott's last expedition, was within the auroral zone ; aurora was seen frequently to east-north-east and comparatively rarely overhead. It is difficult to assign laws for the frequency of occurrence of aurora as weak displays are obscured by moonlight or twilight ; also, in daylight or on nights when the sky is heavily clouded observations of aurora are impossible. In the British Isles and similar northern latitudes it is most common in the late evenings and near the equinoxes ; but in the north of Norway and Greenland it appears to be most frequent near mid-winter. Of late years Professor Störmer has devised a method of photographing aurora, including reference stars in the photograph, and by means of photographs taken simultaneously at the two ends of a measured base he has obtained numerous results for the altitude. Heights exceeding 200 Km. are not unusual, but a great majority of the heights lie between 90 Km. and 130 Km.

Aurora is undoubtedly an electrical discharge, and we thus infer that at heights of 100 Km.—at least in high latitudes—the atmosphere must often, if not always, be a vastly better conductor of electricity than it is near the ground. Some distinguished travellers have claimed to see aurora come down between them and distant mountains. Such observations are generally regarded as illusions. Reports of the audibility of aurora must be placed in the same category.

When visible in England aurora is nearly always accompanied by a magnetic storm, but this is not the case when it is confined to high latitudes.

The spectrum of aurora consists of a number of lines, one of which in the green is particularly characteristic. This line, the wave length of which is  $5,577\text{\AA}$ , has been shown by McLennan\* and his collaborators at Toronto to be due to oxygen. The great height to which aurora is visible is evidence that oxygen extends to 200 Km. or more above the ground.

**Aurora, Permanent.**—A photograph of the spectrum of the night sky will always show the green auroral line at  $5,577\text{\AA}$ . Careful observation will show that the background of the starlit sky is not always equally bright, even where there is no interference from mist or haze. Sometimes a faint illumination of patches of the sky may be seen in situations where there is no possibility of any source of light in the sky other than auroral. These patches are sometimes referred to as "earthlight." All this points to the existence of some form of faint permanent aurora, of variable intensity.

The permanent aurora is considered to be unconnected with the solar disturbances producing aurorae and magnetic storms. Radio investigation has shown that an electrically conducting layer exists at a height of about 100 miles above the earth's surface, with other similar layers at higher altitudes. The electrical conductivity is produced by ionization of the atoms of the atmosphere by the ultra-violet radiation from the sun. During the night there is a slow reversal of the process producing a faint emission of light.

Since the emission of ultra-violet radiation by the sun is greatest about the period of maximum solar activity the permanent aurora should, in general, be brightest at this time.

**Autumn.**—Autumn in meteorology comprises (for the northern hemisphere) the months of September, October and November. See SEASONS.

**Avalanche Wind.**—An avalanche often causes a high wind known as the avalanche wind or avalanche blast. It sometimes causes destruction at a considerable distance from the avalanche itself.

**Average.**—This term originally meant the adjustment between the interested parties of the charges for loss or damage to a ship or cargo at sea. It is now used in another sense. By the average of a series of numerical quantities is understood the result of summing the quantities and dividing

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\* "The spectrum of the aurora and the constitution of the upper atmosphere," *London. Proc. roy. Soc., A*, 108, 1925, p. 501.

the total by their number. The term is thus synonymous with the arithmetic mean. The average value of any meteorological element for a particular station is obtained in this way by making use of a long and complete series of observations of the element. Provided there is no reason to believe that the climate of the station is changing, this average value can be used as the NORMAL with which individual values of the element can be compared. In taking the average of a series of quantities in this way it is necessary that all the quantities should have equal weight, that is, all should be observed equally carefully and in an identical manner. If the observations are not all strictly comparable it may be necessary to give greater stress to those thought to be the best, a process technically known as WEIGHTING.

**Azimuth.**—The arc of the horizon intercepted between the vertical plane passing through the observer and the poles of the earth and the vertical plane passing through the observer and an object.

In nautical astronomy it is measured in degrees (0–180°) eastward or westward from the elevated pole, but in meteorology it is given in degrees (0–360°) clockwise from the true north.

**Azores Anticyclone.**—Or North Atlantic anticyclone, part of the sub-tropical, high-pressure belt of the northern hemisphere. See ATMOSPHERIC CIRCULATION, ANTICYCLONE.

Isobaric maps of normal pressure show in summer an area of high pressure centred about lat. 35° N., extending across the Atlantic to south-western Europe and the western Mediterranean. In winter the anticyclone is centred somewhat further south, about lat. 30° N., and is less intense. See CENTRE OF ACTION.

**Backing.**—A wind is said to “back” when it is changing in the opposite direction to the hands of a watch. Thus the wind backs at a place north of the centre of a depression travelling eastwards in the northern hemisphere. The same definition of backing applies to the southern hemisphere but as wind direction in relation to systems of closed isobars is there reversed, a backing wind in the southern hemisphere is equivalent to a veering wind in the northern hemisphere, and conversely.

**Baguio.**—A local name by which the tropical cyclones experienced in the Philippine Islands are known. A number of the cyclones or typhoons of the western Pacific cross the Philippines, and in addition there is a class of cyclone which is especially associated with these islands, occurring from July to November.

**Ball Lightning.**—An occasional incident during thunderstorms is the appearance of ball lightning. The circumstances vary considerably. The size of the balls varies greatly, from the size of nuts to spheres a foot or two in diameter. The most frequent balls are between 10 cm. and 20 cm. in diameter. Sometimes they occur immediately after a brilliant flash of ordinary lightning, at other times when there has been no flash at all. Sometimes only a single ball is seen, at other times the same observer sees two or three and several are reported in one locality. Sometimes the balls drift through the air and vanish harmlessly, but in some cases a ball has exploded on reaching the ground. Usually there is no sign of heating where a ball has passed, yet there is one case where clean holes were bored through several window panes, the glass appearing to have been melted. Ball lightning has been observed in closed rooms, but whether it penetrates the walls or forms inside is not quite certain. The light is seldom brilliant, though occasionally observers have been dazzled. Cases are on record where a ball has broken up into smaller ones, but these are rare. In some cases the balls develop during very heavy rain; in other cases when there has been no rain for several minutes. A ball may last for a few seconds or several minutes.



Its movement is never fast, generally the speed is comparable with a walking pace, but it is not clear how the ball lightning is propelled. Probably in most cases it is carried by air currents. Apparently ball lightning does not occur when there is much wind.

*Pearl-necklace lightning.*—Ball lightning has been associated occasionally with pearl-necklace lightning. This phenomenon is a development of an ordinary lightning flash. Immediately after the flash a number of bright lights are seen. These lights are of uniform size and appear like pearls on a string. They last about a couple of seconds.

Phenomena with some likeness to ball lightning have been produced artificially by the use of very powerful electric machines. N. Hesehus\* used a transformer giving 10,000 volts and connected one pole to a vessel containing water, the other to a copper plate 2 to 4 cm. above the water. The discharge between the plate and the water took the form of flames, now conical, now spheroidal. The fiery spheroids were very mobile, going from side to side of the copper plate at a breath. In these flames atmospheric nitrogen was being burned to nitric oxide, NO, as in one of the industrial processes for "fixing" nitrogen, but the flames did not float away into the free atmosphere. There is therefore no reason to assume that ball lightning is a globe of nitric oxide. The fact that the globular form is maintained by ball lightning seems to require an electrical attraction between the outer layers and a central nucleus so that the mechanism can not be merely chemical. At present the phenomenon is entirely inexplicable.

**Ballistics.**—The science of gunnery. Range tables for ordnance are constructed on the assumption that certain standard meteorological conditions are applicable. In actual firings, variations from these conditions will occur and corrections must be applied when laying the gun, or the shell will not hit the desired target. The application of meteorology to gunnery came into great importance during the First World War and a specialised branch of the subject grew out of the requirements of artillery units for upper air data. Methods for computing EQUIVALENT CONSTANT WIND and BALLISTIC TEMPERATURE are now in common use at army meteorological stations.

**Ballistic Temperature.**—A particular type of mean temperature of great importance in BALLISTICS. A shell in flight meets air of various temperatures and in computing the ballistic temperature different weights have to be given to the temperatures experienced, according to the type of shell and the circumstances of the firing. In any particular case the effect upon the motion of the shell of the varying temperature distribution observed is the same as the effect which would be produced if the temperature at the ground were equal to the ballistic temperature, and the lapse rate had a certain standard value.

**Balloon.**—A bag of impermeable fabric, usually spherical in form, and inflated with a gas lighter than air. The modern balloon is usually made of varnished cloth or gold-beater's skin, while over the envelope is a network of fine cord, from which is suspended the passenger car or basket. At the top of the envelope is a gas release valve, operated by means of a cord which hangs down inside the balloon and passes through the neck. A "ripping panel" is fitted for the release of the gas in emergency. An anchor, guide rope, and bags filled with sand for ballast are provided. The modern balloon owes its inception in a practical form to the brothers Montgolfier, who experimented with hot-air or fire balloons in 1783. Many notable ascents have been made in free balloons, in connexion with meteorological observations, some of the earliest being made by John Welsh in 1852, and James Glaisher between 1862 and 1866.

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\* *Phys. Z., Leipzig*, 2, 1901, p. 579.

Although the spherical balloon may be held captive, at small altitudes and during light to moderate winds, it is usual to employ the kite-balloon for this purpose. In connexion with the investigation of the upper air at considerable altitudes, small rubber balloons are used, having a diameter of about four feet when filled with hydrogen (see SOUNDING BALLOON). These balloons carry self-recording instruments, or METEOROGRAPHS. By this method it is possible to obtain information at far greater altitudes than can be reached with balloons carrying an observer. For observations of the direction and velocity of upper winds small rubber balloons are employed, having a diameter of about 18 inches when filled with hydrogen. They are liberated from the observing station, and observed, during free ascent, by means of a theodolite. See PILOT BALLOON.

Larger balloons carrying radar targets are also used and are observed by radar. By their use the wind may be measured above and in cloud and to heights of 60,000 ft.

**Banner Cloud.**—A lenticular cloud that forms in the lee of an obstruction which causes a forced up-draught of wind, the clear but damp air being then dynamically cooled by its ascent to the point of cloud formation. Usually a descent and re-heating of the air will follow at some distance further down wind, and there the banner terminates. The banner cloud though stationary itself has a free flow of air constantly through it. The Helm Cloud over Crossfell Range, the Table Cloth over Table Mountain, Tursui over Mount Fuji and the cloud over the Rock of Gibraltar during the Levanter, are all well-known examples of banner cloud.

**Bar.**—The unit of atmospheric pressure, being equal to the pressure of one million dynes (one megadyne) per square centimetre. The bar is equal to the pressure of 29.530 in. or 750.062 mm. of mercury under the standard conditions of temperature 0°C. (density of mercury 13.5951 gm./c.c.) and acceleration of gravity 980.665 cm./sec.<sup>2</sup>. The name was introduced into practical meteorology by V. Bjerknes, and objection has been raised by McAdie, of Harvard College, on the ground that the name had been previously appropriated by chemists to the C.G.S. unit of pressure, the dyne per square centimetre. The meteorological bar is thus one million chemical bars, and what chemists call a bar we should call a microbar. One bar is 100 centibars or 1,000 MILLIBARS.

**Baroclinic.**—A term used in dynamical meteorology for the field of mass when the surfaces of equal density or of equal specific volume cut the isobaric surfaces in a well-defined system of curves of intersection. A field of mass may be represented by either of two variables, the density, defined as the mass per unit volume, or its reciprocal value the specific volume, which is the volume of unit mass. Both are represented by the same family of equiscalar surfaces. When the equisubstantial surfaces coincide with the isobaric, i.e. when the specific volume or density is a function of the pressure, then the field of mass is *barotropic*.

**Barograph.**—A self-recording barometer, an instrument which records automatically the changes of atmospheric pressure. In one form of mercury barograph the movements of the mercury in a barometer are communicated by a float to a pen in contact with a moving sheet of paper carried by a revolving drum which is driven by clockwork. In another form in use at Kew and other observatories, the position of the mercury MENISCUS is recorded photographically.

The portable barographs which are in common use are arranged to record the variations of pressure shown by an aneroid barometer, and on that account they are sometimes referred to as ANEROIDOGRAPHS. Particulars as to the method of using these instruments are given in the "Observer's Handbook."

**Barometer.**—An instrument for measuring the pressure of the atmosphere. The mercury barometer has been found to be the most satisfactory form for

general use. The principle underlying this type of instrument is quite simple. If a glass tube, 3 ft. long, closed at one end, is filled with mercury and the open end is temporarily stopped up and immersed in an open vessel of the same liquid, then if the tube is held in a vertical position and the immersed end is re-opened, the mercury will fall until the level inside the tube stands at a height of about 30 in. above the mercury in the open vessel. The pressure of the atmosphere on the lower mercury surface balances the tendency of the enclosed column to fall, and the height supported in this way represents the atmospheric pressure at the time. In order to compute the pressure, the length or height of the column of mercury has to be measured. Different mercury barometers vary as regards the method of reading this height, and in all, the temperature of the mercury and the latitude of the place must be taken into account. Most barometers are now graduated in millibars. See MILLIBAR, STANDARD TEMPERATURE.

In the "Fortin" barometer, the zero of the scale consists of a fixed pointer and the cistern is made flexible so that the mercury level in the cistern may be brought into coincidence with the zero before a reading is taken. In the "Newman" pattern the cistern is rigid but the scale is mounted on a movable rod so that a similar zero adjustment may be made by moving the scale instead of the mercury. In the Kew pattern barometer, no zero adjustment is provided, but the scale is graduated in such a way that the changes of level in the cistern are automatically allowed for. Since in such barometers it is not necessary to see the mercury in the cistern, the latter may consist of a solid cup, preferably of stainless steel.

In the ANEROID BAROMETER, changes in the pressure of the atmosphere cause changes in the distance apart of the opposite faces of a closed shallow metallic box, nearly exhausted of air. These changes are communicated to a pointer moving over a suitably engraved scale.

For the purposes of meteorology, the pressure of the atmosphere has to be determined to the ten-thousandth part, which is a much higher degree of accuracy than is required in other meteorological measurements. Special contrivances and precautions are therefore required, a description of which will be found in the "Meteorological Observer's Handbook."

**Barometric Tendency.**—A term used to denote the change in the barometric pressure within the three hours preceding an observation. Entered upon synoptic charts, barometric tendencies are of the greatest value in affording a ready means of identifying the regions where the barometer is in process of rising or in process of falling. Lines drawn through places of equal barometric tendency are termed ISALLOBARS and charts of isallobars are useful for indicating in a clear way the changes in pressure which are taking place.

**Barothermograph.**—An instrument registering temperature and pressure simultaneously. The best known form is the Dines balloon meteorograph, in which a single recording stylus is caused to move in one direction by a change of pressure and in a direction almost at right angles by a change of temperature. The trace, therefore, shows corresponding values of temperature and pressure, from which the height can be computed. The name has also been applied to instruments in which separate barograph and thermograph movements are arranged to record on the same chart.

**Barotropic.**—See BAROCLINIC.

**Bearing.**—True bearing is the horizontal angle between the direction of an object and the observer's meridian, measured in degrees (0–360°) clockwise from the true north. Magnetic bearing is the corresponding angle measured clockwise from the magnetic north.

Approximate bearings may be named as the compass points, N., NE., etc.

**Beaufort Notation.**—A code of letters indicating the state of the weather which was originally introduced by Admiral Sir Francis Beaufort for use at

sea, but which is equally convenient for use on land. Some additions have been made to the original schedule and it now stands as follows :—

b	blue sky, whether with clear or hazy atmosphere.	o	overcast, i.e., the whole sky covered with a uniform layer of thick or heavy cloud.
c	cloudy, i.e., either detached clouds, or a cloud layer with openings.	p*	showers.
d	drizzle.	q	squalls.
e	wet air without rain falling, a copious deposit of water on trees, buildings or rigging.	r	rain.
f	fog.	rs	sleet, i.e., rain and snow together.
f <sub>g</sub>	ground fog.	s	snow.
f <sub>s</sub>	shallow fog.	t	thunder.
fe	wet fog.	tl	thunderstorm.
g	gale.	u	ugly, threatening sky.
h	hail.	v	unusual visibility of distant objects.
ks	drifting snow.	w	dew.
kz	duststorm or sandstorm.	x	hoar frost.
l	distant lightning.	y	dry air (less than 60 per cent. relative humidity).
m	mist ; range of visibility 1,100 yd. or more, but less than 2,200 yd.	z	haze ; range of visibility 1,100 yd. or more, but less than 2,200 yd.

Beaufort used small letters in his notation but under the new convention a capital letter is used to denote intensity of the phenomenon to be noted ; at the other end of the scale occasions of slight intensity are indicated by a small suffix <sub>o</sub>. Continuity is indicated by a repetition of the letter, intermittence by prefixing the letter i and showers by prefixing the letter p. Thus we have :—

R	heavy rain.	RR	continuous heavy rain.
r	(moderate) rain.	rr	continuous (moderate) rain.
r <sub>o</sub>	slight rain.	ir <sub>o</sub>	intermittent slight rain.
pr	rain showers.	pS	heavy snow showers.

For further details in the interpretation of the Beaufort Notation see the "Observer's Handbook."

**Beaufort Scale of Wind Force.**—Wind force is estimated on a numerical scale ranging from 0, calm, to 12, hurricane, first adopted by Admiral Beaufort. The specification of the steps of the scale originally given had reference to a man-of-war of the period 1800–50 and therefore now possesses little more than historic interest. Full details of the Beaufort scale, including the original specification are given in the following table. The introduction of anemometers led to the necessity for a scale of equivalents between Beaufort numbers estimated by experienced observers and the velocity of the wind in miles per hour. Experiments in this country showed that the relation could be expressed approximately by the equation  $V = 1.87 \sqrt{B^3}$  where  $V$  is expressed in miles per hour and  $B$  is the corresponding Beaufort number ; the velocity equivalents in the table are based on this formula. The pressure equivalents are derived from the formula  $P = .003 V^2$  where  $P$  is expressed in pounds per square foot and  $V$  in miles per hour.

As the use of the Beaufort numbers spread to other nations it was apparent that different countries were using different scales of equivalents ; accordingly

\* Except for jp, precipitation within sight either not at the station or not reaching the ground, p is only used as a prefix.

at the meeting of the International Meteorological Committee in 1921, Dr. (now Sir George) Simpson was asked to look into the matter of proposing a definite scale of equivalents. Simpson's proposal as set out in *Professional Notes* No. 44, was adopted by the International Meteorological Committee at its meeting in Vienna in 1926. The following table gives the equivalents proposed by Simpson for an anemometer at a height of 6 metres above a level surface.

Code Number	Limits of velocity	
	Metres per second	Miles per hour
0	0- 0.5	0- 1
1	0.6- 1.7	2- 3
2	1.8- 3.3	4- 7
3	3.4- 5.2	8-11
4	5.3- 7.4	12-16
5	7.5- 9.8	17-21
6	9.9-12.4	22-27
7	12.5-15.2	28-33
8	15.3-18.2	34-40
9	18.3-21.5	41-48
10	21.6-25.1	49-56
11	25.2-29.0	57-65

When an appropriate allowance is made for the height of the anemometer, these values agree very nearly with those adopted by the Meteorological Office and given in the table on p. 36.

**Bénard Cell.**—A type of EDDY which has been observed in fluids cooled rapidly at the top in the laboratory and believed to exist also in the atmosphere. The actual form of the motion in the cell depends upon the variation of horizontal velocity with height in the fluid.

**Bioclimatology.**—The study of climate in relation to life and health. With due attention to housing, clothing, diet and general hygiene nearly the whole of the earth's surface may be said to be habitable by healthy human beings, but it is well recognised that in the tropics or in high northern and southern latitudes conditions are only reasonably tolerable over limited areas, and that the optimum conditions are found in the temperate zones. In the case of invalids, particularly those suffering from respiratory or rheumatic diseases, the permissible variations of temperature and humidity may be relatively narrow. One of the aims of bioclimatology is to ascertain the climatic conditions most favourable for these and other conditions, and to define the areas where such climates exist.

**Bishop's Ring.**—A dull reddish-brown ring which is seen at certain periods round the sun in a clear sky. In the middle of the day the inner radius of the ring is about 10°, the outer 20°, but when the sun is low the ring becomes larger, the brightest part being about 19° from the sun. After sunset the ring is lost in the warm colours of the sky. Bishop's ring was first observed after the great eruption of Krakatoa in 1883 and remained visible till the spring of 1886, and is generally attributed to minute particles shot out by the eruption and remaining in the atmosphere at great heights. Bishop's ring was seen again after the eruptions of the Souffrière in St. Vincent and Mount Pelée, in Martinique, in 1902. Like the brownish ring surrounding the AUREOLE observed in clouds the phenomenon is explained by diffraction.

**Bize.**—A cold, dry wind which blows in the winter in the mountainous regions of southern France from the N., NE. or NW. The cold NW. wind which occurs in Languedoc, near the Mediterranean coast, and differs from the MISTRAL in that it is accompanied by heavy clouds has been given the name of "bise noire."

SPECIFICATION OF THE BEAUFORT SCALE WITH PROBABLE EQUIVALENTS OF THE NUMBERS OF THE SCALE

Beaufort Number	Specification of Beaufort Scale for use on land, based on observations made at land stations	* Mean pressure (at standard density) on a disc of 1 sq. ft.		Equivalent speed at 33 ft.		Limits of speed		
		mb†	Lb. per sq. ft.	Knots	Miles per hour	Knots	Miles per hour	Metres per second
0	Calm ; smoke rises vertically	0	0	0	0	<1	<1	0-0-2
1	Direction of wind shown by smoke drift, but not by wind vanes	.01	.01	2	2	1-3	1-3	0-3-1-5
2	Wind felt on face ; leaves rustle ; ordinary vane moved by wind	.04	.08	5	5	4-6	4-7	1-6-3-3
3	Leaves and small twigs in constant motion ; wind extends light flag	.13	.28	9	10	7-10	8-12	3-4-5-4
4	Raises dust and loose paper ; small branches are moved	.32	.67	13	15	11-16	13-18	5-5-7-9
5	Small trees in leaf begin to sway ; crested wavelets form on inland waters	.62	1-31	19	21	17-21	19-24	8-0-10-7
6	Large branches in motion ; whistling heard in telegraph wires ; umbrellas used with difficulty	1-1	2-3	24	28	22-27	25-31	10-8-13-8
7	Whole trees in motion ; inconvenience felt when walking against wind	1-7	3-6	30	35	28-33	32-38	13-9-17-1
8	Breaks twigs off trees ; generally impedes progress	2-6	5-4	37	42	34-40	39-46	17-2-20-7
9	Slight structural damage occurs (chimney pots and slates removed)	3-7	7-7	44	50	41-47	47-54	20-8-24-4
10	Seldom experienced inland ; trees uprooted ; considerable structural damage occurs	5-0	10-5	52	59	48-55	55-63	24-5-28-4
11	Very rarely experienced ; accompanied by widespread damage	6-7	14-0	60	68	56-63	64-72	28-5-32-6
12	.. .. .	>8.1	>17.0	68	78	64-71	73-82	32-7-36-9
13	.. .. .	..	..	76	88	72-80	83-92	37-0-41-4
14	.. .. .	..	..	85	98	81-89	93-103	41-5-46-1
15	.. .. .	..	..	94	109	90-99	104-114	46-2-50-9
16	.. .. .	..	..	104	120	100-108	115-125	51-0-56-0
17	.. .. .	..	..	114	131	109-118	126-136	56-1-61-2

\* The pressure due to the wind on any object exposed to it arises from the impact of the air on the windward side and suction on the leeward side ; the mean pressure depends on the shape and size of the object. The values given are for a disc of one square foot in area but they apply with fair approximation for circular or square plates from 1 sq. ft. to 100 sq. ft. in area.

† One millibar = 10<sup>3</sup> dynes per square centimetre = approx. 10 kilograms per square metre.

Beaufort Number, International	Beaufort's description of wind, International	Specification of the Beaufort Scale for use at sea (provisional)	Specification of the Beaufort Scale for coast use
0	Calm	Sea like a mirror	Calm.
1	Light air	Ripples with the appearance of scales are formed, but without foam crests.	Fishing smack† just has steerage way.
2	Light breeze	Small wavelets, still short but more pronounced. Crests have a glassy appearance and do not break.	Wind fills the sails of smacks which then travel at about 1-2 miles per hour.
3	Gentle breeze	Large wavelets. Crests being to break. Foam of glassy appearance. Perhaps scattered white horses.	Smacks begin to careen and travel about 3-4 miles per hour.
4	Moderate breeze	Small waves, becoming longer; fairly frequent white horses	Good working breeze, smacks carry all canvas with good list.
5	Fresh breeze	Moderate waves, taking a more pronounced long form; many white horses are formed. Chance of some spray.	Smacks shorten sail.
6	Strong breeze	Large waves begin to form; the white foam crests are more extensive everywhere. Probably some spray.	Smacks have double reef in mainsail. Care required when fishing.
7	Moderate gale*	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind.	Smacks remain in harbour and those at sea lie-to.
8	Fresh gale	Moderately high waves of greater length; edges of crests begin to break into the spindrift. The foam is blown in well marked streaks along the direction of the wind.	All smacks make for harbour, if near.
9	Strong gale	High waves. Dense streaks of foam along the direction of the wind. Sea begins to "roll." Spray may affect visibility.	—
10	Whole gale	Very high waves with long overhanging crests. The resulting foam, in great patches, is blown in dense white streaks along the direction of the wind. On the whole the surface of the sea takes a white appearance. The rolling of the sea becomes heavy and shock-like. Visibility affected.	—
11	Storm	Exceptionally high waves (small and medium-sized ships might be for a time lost to view behind the waves). The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected.	—
12	Hurricane	The air is filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.	—

For the purpose of showing the forces of winds by wind roses on Meteorological Charts, winds are grouped as follows :—  
Scale Numbers.

0	..	..	..	..	..	Calm.
1 to 3	..	..	..	..	..	Light winds.
4 to 7	..	..	..	..	..	Moderate winds.
8 and above	..	..	..	..	..	Gales.

\* For statistical purposes force 7 is not reckoned as a gale.

† The fishing smack in this table may be taken as representing a trawler of average type and trim. For larger or smaller boats and for special circumstances, allowance must be made.

**Black-bulb Thermometer.**—A mercurial maximum thermometer with blackened bulb, mounted in an evacuated outer glass sheath and exposed horizontally to the sun's rays for the purpose of ascertaining the maximum temperature "in the sun." On account of the difficulty of obtaining comparable results with different instruments and of interpreting the indications of an individual instrument, black bulb thermometers are not now recommended as a means of measuring solar radiation. Such measurements are carried out with a PYRHELIOMETER.

**Blizzard.**—A term originally applied to the intensely cold north-westerly gales accompanied by fine drifting snow which may set in with the passage of a depression across the United States in winter.

The term has come to be applied to any high wind accompanied by great cold and drifting or falling snow, especially in the Antarctic, where, however, the blizzards often cause a rise of temperature by removing the surface layer of very cold air formed during calms.

**Blood-rain.**—Rain of a red colour which leaves a red stain on the ground. The colouration is due to the drops containing small dust particles which have been carried by currents in the upper air, sometimes for long distances, from some sandy region. The phenomenon has been most frequently observed in Italy, but it has been known to occur in this country.\*

**Blue of the Sky.**—The blue of the sky is due mainly to the scattering of sunlight by the individual molecules constituting the air. It was demonstrated mathematically by the fifth Lord Rayleigh that if light of different wave-lengths were to pass through a medium containing very small particles the proportion to be scattered would be greater the shorter the wave-length of the light. Thus the short waves composing the blue and violet end of the spectrum are scattered more than the long red and yellow waves. Hence light passing through a medium containing a great number of such particles is left with an excess of red, whilst light emerging laterally has an excess of blue. It is for this reason that soapy water looks yellowish when one looks through it at a source of white light and bluish when one looks across the direction of illumination.

That a column of air viewed across the direction of illumination also appears blue was demonstrated in the laboratory by the present Lord Rayleigh. Accordingly there is no need to assume the existence of grosser particles suspended in the air to explain the normal blue of the sky. Where large particles due to smoke or dust are present the light scattered by them does not contain so high a proportion of blue, in other words the blue of the sky is diluted with white. The sky as seen from high mountains is of a deeper but purer blue because there are fewer large particles in suspension than at lower altitudes.

For systematic comparisons of the depth of colour in the blue sky, a scale has been devised by F. Linke, of the Meteorologische-Geophysikalische Institut, Frankfurt. On this scale white is 0 and ultramarine blue is 14. The scale is used in book form. By this means sky colour can be compared with other variables such as the amount of dust in the atmosphere.

**Board of Trade Unit.**—See KILOWATT-HOUR.

**Bolometer.**—An instrument for the determination of the intensity of radiation of a definite wave-length, employing a blackened conductor whose change of resistance with temperature furnishes a measure of the quantity required. The instrument is largely employed in the investigation of the distribution of energy in the spectrum, especially in the infra-red region.

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\* See *London, Quart J.R. met. Soc.*, 28, 1902, pp. 229-52 and 30, 1904, pp. 57-91.



**Bora.**—A cold, often very dry, north-easterly wind which blows, sometimes in violent gusts and squalls, down from the mountains on the eastern shore of the Adriatic. It is strongest and most frequent in winter, and on the northern part of the shore. It occurs when pressure is high over central Europe and the Balkans and low to the south over the Mediterranean. With the establishment of an anticyclone to the north and north-east the bora may continue for several days; in such circumstances it shows a marked diurnal variation, being at a maximum in the morning and a minimum about midnight. During the bora the wind speed at Trieste has averaged over 80 miles per hour with gusts exceeding 125 miles per hour; temperature has fallen to 14° F., and humidity to 15 per cent. The bora is sometimes associated with a depression over the Adriatic and is then accompanied by heavy cloud and rain or snow.

**Bouguer's Halo.**—In the eighteenth century descriptions were published independently by Bouguer and by Antonio de Ulloa of a phenomenon which they had seen together on near-by clouds on the Andes. Each observer reports seeing on many occasions his shadow (which we should call the Brocken Spectre), rainbow-coloured rings round the shadow of his head (i.e., a glory), and outside the coloured rings and somewhat removed from them a fourth ring of pure white. This outer ring, which has been called Ulloa's Ring, and also Bouguer's halo, was presumably a fog bow or white rainbow. The theory of Bidhu Bhusan Ray\* explains how the reflection of light from small drops should produce simultaneously a glory and a white rainbow. In Bouguer's description it is stated that the phenomenon was to be seen only on clouds and even (même) on those of which the particles were frozen, not on drops of rain. It was, therefore, assumed that the outer ring was produced by reflection from ice crystals. This idea is embodied in the name Bouguer's halo, and numerous attempts have been made to determine the shape of crystals which would serve to reflect the light in the right way. It is likely, however, that even though crystals were present the clouds which Bouguer observed consisted mostly of supercooled water drops. There is no mention of simultaneous observations of an ordinary halo round the sun, and Bouguer's wording implies that on some occasions at least the particles were not frozen.

**Boys Camera.**—A special type of camera first introduced by Sir Charles Boys for the study of LIGHTNING. Originally, two lenses were rapidly rotated at opposite ends of a diameter of a circle and gave two distorted photographs of a flash of lightning. From these the direction of the discharge and its velocity of travel could be calculated. A later development was to have the lenses fixed and the film mounted on a large and rapidly rotating drum.

**Brave West Winds.**—A nautical expression denoting the prevailing westerly winds of temperate latitudes. The region of westerly winds of the southern hemisphere is termed the ROARING FORTIES.

**Breeze.**—A wind of moderate strength. (See BEAUFORT SCALE.)

The word is generally applied to winds due to CONVECTION, which occur regularly during the day or night; of this type the following may be mentioned—LAND AND SEA BREEZES, MOUNTAIN BREEZE, VALLEY BREEZE, GLACIER BREEZE.

**British Summer Time (B.S.T.).**—The standard of time in common use and that to which all legal and business transactions are referred in the British Isles during a period in summer which is defined by the Summer Time Act, 1925. British summer time is one hour in advance of Greenwich mean civil time, so that 9 h. G.M.T. is the same as 10 h. B.S.T.

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\* *Calcutta, Proc. Indian Ass. Cult. Sci.* 8, 1923, pp. 23–46.

Summer time was first introduced in 1916. From 1916 to 1925 the periods during which summer time was in operation were fixed year by year by Orders in Council and were as follows :—

	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925
From—	May 21	Apr. 8	Mar. 24	Mar. 30	Mar. 28	Apr. 3	Mar. 26	Apr. 22	Apr. 13	Apr. 19.
to —	Oct. 1	Sept. 17	Sept. 30	Sept. 29	Oct. 25	Oct. 3	Oct. 8	Sept. 16	Sept. 21	Oct. 4

From 1926 to 1938 the period of summer time in Great Britain, Northern Ireland, the Channel Isles and the Isle of Man began at 2 h. Greenwich mean time on the morning of the day next following the third Saturday in April (or if that day was Easter Day the day next following the second Saturday in April) and ended at 2 h. Greenwich mean time (3 h. B.S.T.) on the morning of the day next following the first Saturday in October.

From 1939 the periods during which summer time was in operation were again fixed year by year, and summer time was kept continuously in operation from February 25, 1940 to October 7, 1945. Double summer time was first introduced in 1941 and the periods when the clocks were kept two hours ahead of Greenwich mean time were fixed year by year.

The times when summer time and double summer time (marked with an asterisk) began and ended are as follows :—

	1939	1940	1941	1942	1943	1944	1945	1946	1947
From—	Apr. 16	Feb. 25	May 4*	Apr. 5*	Apr. 4*	Apr. 2*	Apr. 2*	Apr. 14	Mar. 16
to—	Nov. 19	—	Aug. 10*	Aug. 9*	Aug. 15*	Sept. 17*	July 15*	Oct. 6	Aug. 10*
							Oct. 7		Nov. 2
	1948	1949	1950	1951	1952	1953	1954	1955	1956
From—	Mar. 14	Apr. 3	Apr. 16	Apr. 15	Apr. 20	Apr. 19	Apr. 11	Apr. 17	Apr. 22
to—	Oct. 31	Oct. 30	Oct. 22	Oct. 21	Oct. 26	Oct. 4	Oct. 3	Oct. 2	Oct. 27

In order that the statistics for the diurnal variation of meteorological phenomena may not be affected by the introduction of the disturbing effect of summer time, and to facilitate the international exchange of information, meteorological observations are normally made at fixed hours by G.M.T. throughout the year.

**Brocken Spectre.**—When an observer stands on a hill partially enveloped in mist and in such a position that his shadow is thrown on to the mist he may get the illusion that the shadow is a person seen dimly through the mist. The illusion that this person or “spectre” is at a considerable distance is accompanied by the illusion that he is gigantic. The Brocken is a hill in Germany. See GLORY.

**Brontometer,** from *bronte*, a thunderstorm, a combination of apparatus for following and noting all the details of the phenomena of weather during a thunderstorm.

**Brückner Cycle.**—A recurrence of periods of cold and damp alternating with warm and dry years, the average interval between two successive maxima being 35 years, though individual cycles may range in length from 25 to 50 years. A belief in a cycle of 35 to 40 years in Holland was known to Sir Francis Bacon in 1625 but the periodicity was rediscovered in 1890 by A. Brückner, who calculated its average length as 34·8 years. Since then periodicities of about this length have been found in many series of meteorological data. The last epoch of cold and rain was due in Europe about 1916 to 1920, but the amplitude is not large enough to dominate the irregular year to year variations.

**Brush Discharge (Electricity).**—See ST. ELMO'S FIRE.

**Bumpiness.**—A word used to define the sensation experienced when flying in an unstable atmosphere. A state of turbulence of the atmosphere, in which both ascending and descending currents occur. Bumpiness may be due to vertical currents, set up as the result of irregular heating of the earth's surface,

or to air streams following the well-defined contours and irregularities of the ground. It may extend to considerable altitudes, but generally it is greatest in the lower layers up to about 3,000 ft. It varies with the character and strength of the wind, and is more common over the land than over the sea. Surface irregularities seldom affect the upper air to a height greater than three to four times that of the obstruction. See AIR POCKETS.

**Buoyancy.**—A term used to denote the load, including the envelope and fittings, which can just be supported by a balloon or an airship. This buoyancy arises from the difference between the density of the light gas inside the envelope and the heavier air outside. The vessel will just rest in equilibrium when the total weight is the same as that of the air displaced; the load which can just be supported is thus the difference between the weight of the gas in the envelope and that of the volume of air displaced.

**Buran.**—A strong NE. wind which occurs in Russia and central Asia. It is most frequent in winter, when it is very cold and often raises a drift of snow, but strong NE. winds in summer are also termed buran. The winter snow-bearing wind is also termed *poorga*.

**Buys Ballot's Law.**—A study of synoptic charts caused Professor Buys Ballot, of Utrecht, to enunciate, in 1857, the law which states that if, in the northern hemisphere, you stand with your back to the wind, pressure is lower on your left hand than on your right, whilst in the southern hemisphere the reverse is true. Meteorologists often put the same law in a slightly different way by saying that in the northern hemisphere winds go anticlockwise around low-pressure centres and clockwise around high-pressure centres, the reverse holding true in the southern hemisphere.

**Calendar.**—The word is derived from the Roman "Kalends," and connotes an arrangement of time into ordered sequences of hours, days, months, years, etc. Many attempts to secure simple calendars have been made and the form of the calendar has been frequently changed. There are three principal natural periods of time which have been used for the purposes of the calendar from time immemorial, viz., the (solar) day, the month and the year; corresponding respectively and more or less exactly with the mean period of rotation of the earth in reference to the sun, the period of the revolution of the moon round the earth (about  $29\frac{1}{2}$  days), and the period required by the earth to revolve in its orbit around the sun (365 days, 5 hours, 48 min. and 46 sec.). Difficulties in constructing calendars arise from the facts that the year is an exact multiple neither of the solar day nor of the period of the moon's revolution.

The early history of the calendar, and of the origin of the names of the days of the week and of the months is interesting, but need not be pursued here. The most recent great reform of the civil calendar was that carried out by Pope Gregory XIII in 1582. The Gregorian calendar now used for civil purposes by all nations, superseded that introduced by Julius Caesar, who was the first to give effect to the general principle of regulating the civil year by the sun rather than the moon. At the time of Caesar an error of three months had arisen in the dating of the vernal equinox, then fixed at March 25. He corrected this error by the intercalation of 90 days into the current year (the last "year of confusion") and fixed the date of commencement of the first Julian year as January 1 of the 708th year after the founding of Rome (equivalent to 46 B.C.). He also ordained that the "odd" months, January, March, May, July, September and November, should each consist of 31 days, and the other months 30 days, except February, which in common years should have 29 days and every fourth year 30 days. This simple and sensible arrangement was subsequently altered to gratify the vanity of Augustus, by giving the month bearing his name 31 days. To effect this, a day was taken from February and added to August, and then to avoid the inconvenience of having three successive months with 31 days the durations of the last four months were altered to their present values.

The Julian calendar was based on a solar year of  $365\frac{1}{4}$  days, which exceeds the true value by 11 minutes 14 seconds. This involved an error of one day in 128 years. The reform introduced by Pope Gregory XIII in 1582 aimed at fixing the date of the vernal equinox as March 21. He corrected the accumulated error of the Julian calendar by suppressing ten days, and also ordained that in future centurial years should be ordinary years unless they were divisible by 400 without remainder. Thus 1600 would be a leap year, but 1700, 1800 and 1900 would be ordinary years. This refinement reduces the error to one day in 3,323 years. The Gregorian calendar (known as New Style) was introduced into Rome, Spain, Portugal and part of Italy in March 1582, and had become generally current in Europe by 1700. In Great Britain the change was made in 1752. It was ordained that the day following September 2 in that year should be called the 14th of that month, and that the Gregorian system of fixing leap years should in future be adopted.

For meteorological purposes it is usual to adhere to the civil calendar, and to publish summaries of climatological data for ordinary civil months or weeks. For certain purposes, however, there are advantages in selecting an epoch other than January 1 as the date of commencement of the year. Thus the "farmer's year" adopted for the *Weekly Weather Report* begins on the Sunday nearest to March 1, while for the purpose of the Crop Weather Scheme, a "grower's year" beginning November 6 has been adopted at the suggestion of Sir Napier Shaw. The "water year" beginning October 1 has been adopted for the summarization of data of surface and underground water by the Inland Water Survey (Ministry of Health).

**Calibration.**—Originally the name given to the process of finding the calibre (or area of cross-section) of a tube. When a tube is not of uniform cross-section, marks so spaced that the volume of the tube between consecutive marks is everywhere the same, are calibration marks. The use of the word has been greatly extended, e.g. the calibration of the Dines meteorograph consists of making marks on the recording plate corresponding with various pressures, the temperature being kept constant, and repeating the process at other temperatures so as to obtain a framework of isothermal and isobaric lines that indicate the pressure and temperature corresponding with any point on the record.

**Calm.**—Absence of appreciable wind. Smoke rises vertically. On the BEAUFORT SCALE OF WIND FORCE calm is accorded the figure 0.

**Calorie**—or **gram-calorie.**—The heat required to raise the temperature of 1 gram of water by  $1^{\circ}$  A. at  $288^{\circ}$  A. The calorie is often used in connexion with measurements of solar radiation. Thus the SOLAR CONSTANT is usually expressed as having a mean value of 1.93 calories per square centimetre per minute.

A "large calorie" or "kilogram-calorie" is the heat required to raise the temperature of 1 kilogram of water by  $1^{\circ}$  A. at  $288^{\circ}$  A.

1 gram calorie =  $4.18$  joules =  $4.18 \times 10^7$  ergs =  $4.18$  watt-sec. =  $.004$  British thermal units.

**Cap.**—A name frequently given to the transient patches of cloud which sometimes form on or just above the tops of growing cumulus clouds, and are soon absorbed into them. It is also used for clouds on hill tops. It is technically known as pileus. See LENTICULAR.

**Catchment Area.**—Defined for administrative purposes as the area within the jurisdiction of a Catchment Board under the Land Draining Act of 1930. The term is also commonly used with the same meaning as DRAINAGE AREA.

**Celsius, Anders.**—A Swedish astronomer and physicist, born at Upsala November 27, 1701. He held the chair of astronomy at the University of his native town from 1730 until his death in 1744. His thermometer was first described in a paper to the Swedish Academy of Science in 1742. He divided the interval between the freezing and boiling points of water into

100 parts, the lower fixed point being marked 100. The present system whereby the freezing point is marked 0 and the boiling point 100 was introduced by Christin, of Lyons, in 1743.

This particular scale is now generally referred to as the CELSIUS scale or the Centigrade scale, and sometimes the centesimal scale.

**Centigrade.**—A modification of the thermometric scale introduced by ANDERS CELSIUS. It has its zero at the melting point of ice, while 100° represents the boiling point of pure water at a pressure of 760 mm. of mercury. A centigrade degree is  $\frac{5}{9}$  of a Fahrenheit degree. The Centigrade scale and the Absolute scale are alike to the extent that on both the interval between the freezing and boiling points of water is divided into a hundred degrees. See ABSOLUTE TEMPERATURE.

**Centre of Action.**—In discussing the abnormally cold winter of 1879–80 in France, Teisserenc de Bort concluded that the character of any winter was determined by the relative positions and intensities of the Icelandic "low" and the Azores and Siberian anticyclones. He accordingly (in 1881) designated these and similar areas of low and high pressure as "the great centres of action of the atmosphere." The term was brought into general use by the writings of H. H. Hildebrandsson; originally it was applied to depressions and anticyclones seen on an ordinary daily synoptic chart, as well as to those more permanent lows and highs represented on charts of monthly averages, but the former, transitory features are not now generally included in the term "centre of action." On the other hand, the term is sometimes extended to include areas such as South America or the Mediterranean, which are not occupied by semi-permanent lows or anticyclones, but where the barometric pressure is closely correlated with the contemporary or subsequent pressure of many other parts of the world. The idea may be extended still further to include areas where the important element is not pressure, but temperature, rainfall or ice. Sir Gilbert Walker defines centres as "active" if they are highly correlated with subsequent conditions at other centres, and "passive" if they are correlated with preceding conditions.

**Chart.**—A map of an area of the earth showing lines of latitude and longitude, and the more important physical features of the area (sometimes only the coast line appears), upon which is superposed a representation of the distribution of some physical quantity over the area. Examples are weather charts, isobaric charts, charts of ocean currents, etc. Sometimes the word chart is applied also to what are more properly termed diagrams or graphs.

**Chinook.**—A warm dry wind, similar in character to the FÖHN, which occurs on the eastern side of the Rocky Mountains. It blows from the west across the mountains and is warmed adiabatically; it usually occurs suddenly, a large rise in temperature takes place, and the snow melts very rapidly.

**Cinematography, Meteorological.**—In recent years the motion picture camera has been added to the list of apparatus available to the meteorologist for the purpose of giving a continuous record of observations. The most striking results have been achieved in recording the changing structure of cloud in the process of development or dissipation. By the choice of a suitable ratio of camera speed to ultimate projection speed the movements of the cloud can be shown speeded up to any desired extent. An example of the result produced is provided by a picture of cumulus cloud in continuous everchanging movement as though it were a huge mass of steam. Great clarity and revelation of detail are obtained by the use of modern photographic technique. Professor Mügge has made a series of meteorological films in Germany illustrating the development of clouds in this manner, and there are a few such films in England incorporating sections employing a similar technique.

Apart from its use as an instrument for recording the changing structure of actual cloud the ciné-camera has been employed in the research laboratory

to record observations more fully than could otherwise have been done. In particular it has been employed to record the changing patterns formed by artificially produced cloud to support views put forward in explanation of particular types and patterns of cloud found in the atmosphere. A special advantage of the film record of any series of events such as takes place in the movements of a cloud is that there is no limit to the number of times which the same movements can be studied since the film can be projected as often as necessary.

Since the processes involved in meteorological phenomena are frequently complicated the film is a particularly suitable medium of instruction because the ideas it is desired to convey must first be simplified so as to be readily assimilable in the form of pictures. A number of educational films on meteorological subjects have been made in England.

**Circulation of the Atmosphere.**—See ATMOSPHERIC CIRCULATION.

**Cirrocumulus (Cc).**—*A cirriform layer or patch composed of small white flakes or of very globular masses, without shadows, which are arranged in groups or lines, or more often in ripples resembling those of the sand on the sea shore.*

*In general cirrocumulus represents a degraded state of cirrus and cirrostratus both of which may change into it. In this case the changing patches often retain some fibrous structure in places.*

*Real cirrocumulus is uncommon. It must not be confused with small altocumulus on the edges of altocumulus sheets.*

**Cirrostratus (Cs).**—*A thin whitish veil, which does not blur the outlines of the sun or moon, but gives rise to halos. Sometimes it is quite diffuse and merely gives the sky a milky look; sometimes it more or less distinctly shows a fibrous structure with disordered filaments.*

**Cirrus (Ci).**—*Detached clouds of delicate and fibrous appearance, without shading, generally white in colour, often of a silky appearance.*

*Cirrus appears in the most varied forms such as isolated tufts, lines drawn across a blue sky, branching feather-like plumes, curved lines ending in tufts, etc.; they are often arranged in bands which cross the sky like meridian lines, and which, owing to the effect of perspective, converge to a point on the horizon, or to two opposite points (cirrostratus and cirrocumulus often take part in the formation of these bands).*

**Clear Sky, Day of.**—In a resolution adopted at the International Meteorological Meeting at Utrecht in 1874, a "day of clear sky" was defined as one on which the average CLOUDINESS at the hours of observation is less than two-tenths of the sky.

On January 1, 1949 OKTAS were first adopted, and since then a "day of clear sky" is defined in Great Britain as one on which the average CLOUDINESS at the hours of observation is less than 2 oktas of the sky.

**Climate.**—The average weather conditions of any locality. The climate of a locality is governed by three factors, its latitude (see CLIMATIC ZONES), its position relative to the continents and oceans, and the local geographical conditions. The interiors and eastern parts of the great continents generally have a small rainfall, a low humidity and a great range of temperature, both from day to night and from summer to winter, giving a *continental* climate. Oceanic islands and the western parts of the continents generally have a heavier rainfall, a greater humidity, and a more uniform temperature, forming an *oceanic* or *insular* climate, but there are numerous exceptions, as on the western coasts of continents in sub-tropical latitudes, which have a desert climate. Local climates are modified by altitude above sea level and by the neighbourhood of mountain ranges or large lakes. Great towns are usually characterised by a local deficiency of bright sunshine due to the presence of smoke. A climatic table should include data for each month and for the year, for all the elements of weather which affect human health or activity. Under temperature should be given the mean daily temperature, the mean daily maximum and minimum, the average extreme values and the

highest maximum and lowest minimum temperatures recorded in each month; temperatures at different depths in the soil are also useful if available. Other data are the average relative humidity and amount of cloud at different hours, the duration of bright sunshine, the average rainfall with the maximum amount recorded in 24 hours, the frequencies of days of rain, snow, hail, thunder, frost, fog and gale, and the frequencies of winds from different directions, with the average velocity of the wind. Barometric pressure is not an important climatic element except at great altitudes. The table should be accompanied by a description of the characteristic weather of the different seasons, the average and extreme dates of first and last frosts and falls of snow, the duration of the snow cover, or in regions with definite wet and dry seasons, the onset of the rains. In some places the weather goes through a fairly regular series of daily changes, especially in connexion with the alternation of land and sea breezes, and this should be noted.

**Climatic Changes.**—During geological ages, the climate of any area such as England has not remained constant, but has varied over a wide range. Twenty million years or so ago the climate of England was warmer than at present, but a few hundred thousand years ago the climate was glacial. It is now generally admitted that there have been variations of temperature and rainfall in north-western Europe since the close of the ICE AGE, and that about 5,000 to 3,000 B.C. the temperature was higher than at present, forming the "Climatic Optimum," while a period of cold rainy weather began about 850 B.C. There are indications of a dry period in the north temperate belt in the sixth to eighth centuries, and of a period of great storminess and heavy rainfall in the twelfth to fourteenth centuries, but the changes during the Christian era are not universally accepted. The principal evidence for them is, in Europe, fluctuations of Alpine glaciers and in the traffic across Alpine passes; in Asia, variations in the level of the Caspian Sea and other salt lakes; in North America, variations in the rate of growth of the *Sequoias* of California, some of which are more than 3,000 years old. As a rule instrumental meteorological observations do not reveal any indications of climatic changes, but the series of rainfall measurements in England, which have been standardised over a period of 200 years, point to a pronounced dry period in the first half of the eighteenth century. A number of theories have been put forward as to the causes of geological changes of climate, including changes of solar radiation, variations in the elements of the earth's orbit, changes in the land and sea distribution, mountain building and volcanic eruptions.

**Climatic Zones.**—The word CLIMATE is derived from a Greek word meaning "to incline," and the original zones of climate were zones in which the inclination of the sun's rays at noon was the same; that is, zones of latitude. The accumulation of meteorological data has shown that winds and rainfall, as well as temperature, have a zonal arrangement, but that the true climatic zones do not run strictly parallel with lines of latitude. Eight principal zones are distinguished:—near the equator a zone of tropical rain climate, then two sub-tropical zones of STEPPE and DESERT climate, then two zones of temperate rain climate and, in the northern hemisphere only, an incomplete zone of boreal climate with a great annual range of temperature; finally, two polar caps of snow climate. The equatorial zone is divided into the equatorial rain-forest zone, which extends over the Atlantic and Pacific Oceans as the DOLDRUMS, with rain in all seasons, and a belt of Savanna climate on either side, with a well-marked alternation of dry and rainy seasons, the latter occurring in the "summer" months. The sub-tropical zones include most of the world's great deserts—the Sahara and Arabia, Arizona, the Kalahari and the deserts of South America and Australia; over the oceans they include the TRADE WIND belts and the HORSE LATITUDES. The temperate zones are divided into the Mediterranean climates with mild rainy winters and hot dry summers, and the temperate rain belts with rain in all seasons. On the eastern margins of the continents, especially in Asia, the sub-tropical

desert zone and the Mediterranean climate are replaced by areas with a MONSOON climate. For a detailed classification of climates consult "Die Klimate der Erde," by W. Köppen, Berlin and Leipzig, 1923.

**Climatology.**—The study of CLIMATE.

**Climatotherapy.**—The treatment of disease by suitable climatic environment. Such environment is often to be found in so-called health resorts but not exclusively, as even the warmth and shelter of large towns, for instance, may be advantageous in certain cases. Owing to the seasonal variations of climate the required conditions may have to be sought in different localities at different times of the year. In brief, climatotherapy may be described as applied bioclimatology.

A considerable amount of literature on medical climatology has appeared in recent years, one of the most comprehensive works being the "Traité de climatologie biologique et médicale,"\* a publication of over 2,600 pages in three volumes to which some 140 collaborators contributed.

It may be of interest to recall that the second part of the word is connected with the Greek for "service" or "nurture," so that etymologically climatotherapy is capable of a far wider interpretation than that of the usual definition.

**Cloud-burst.**—A term commonly used for very heavy rain, usually associated with thunderstorms. Extremely heavy downpours are sometimes recorded, which in the course of a very short time tear up the ground and fill up gulleys and watercourses; this may happen at any place, but it occurs frequently in hilly and mountainous districts, where it may sometimes be due to the sudden cessation of convectional movement, caused by the supply of warm air from the lower part of the atmosphere being cut off as the storm moves over a mountain range. With the cessation of the upward current, the raindrops and hailstones which it had been supporting must fall in a much shorter time than they would have done had the ascensional movement continued.

**Cloudiness.**—Amount of sky covered by cloud, irrespective of the type of cloud. It is estimated by eye-observation and usually expressed by a scale of eighths (OKTAS) of sky covered. On this scale 8 represents a sky totally covered by cloud in which no particles of blue sky are visible, and 0 an entirely cloudless sky. Observers are usually advised to subdivide the sky mentally into four quadrants, and to combine estimates of the amount of sky covered in each quadrant.

Charts showing the distribution of mean cloudiness over the earth in each month and the year are given in the "Manual of Meteorology," Vol. 2, by Sir Napier Shaw (Cambridge University Press, 1928).

**Clouds.**—The number of forms which clouds may take is almost infinite, but for purposes of description it is necessary to adopt some kind of classification, though whatever classification is used there must at times be border-line cases when a cloud seems to fall half-way between two classes and perhaps to belong to neither.

The systems of classification which have been proposed have sometimes been based on the observed appearance of the cloud and at other times on the supposed method of formation. There can be no doubt that the former is the correct method since an observer is able to judge definitely of the appearance while the method of formation of a given cloud must be to some extent a matter of opinion. The international cloud classification is based upon the appearance of clouds and consists of 10 forms which for convenience are sometimes separated into three classes of high clouds, medium clouds and low clouds as follows:—

High clouds—cirrus, cirrostratus, cirrocumulus.

Medium clouds—altocumulus, altostratus.

Low clouds—stratocumulus, nimbostratus, cumulus, cumulonimbus, stratus.

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\* By Piéry et alii. Paris (Masson et Cie), 1934.





FIG. 8.—Cirrus clouds, thread or feather clouds at a height of from five to six miles, and generally of a white colour. They are composed of ice crystals.

The picture gives an idea of rather more massive structure than is usual with cirrus clouds, but the sweeps and wisps are very characteristic.



FIG. 9.—Altostratus.



FIG. 10.—Altocumulus.



FIG. 11.—Stratocumulus from an aeroplane.

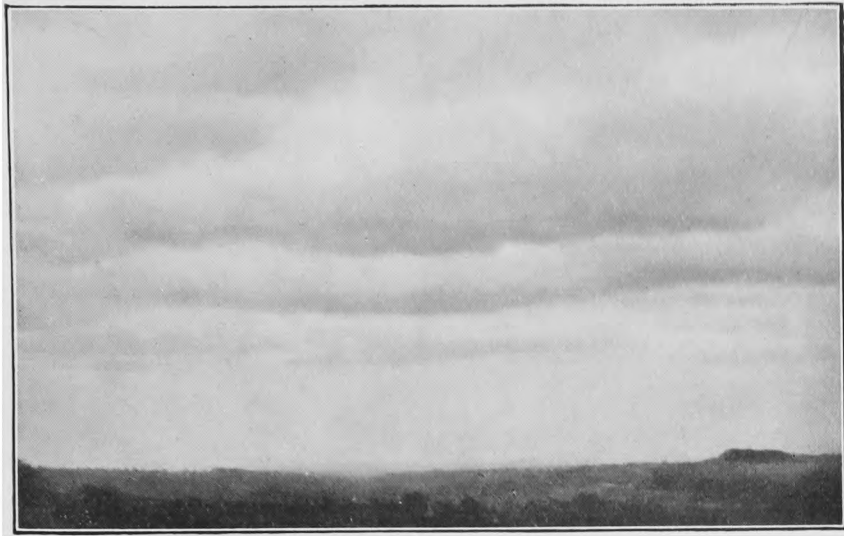


FIG. 12.—Stratocumulus from below.



FIG. 13.—Cumulonimbus (Thunder-cloud) with “Anvil”  
extension of cirrus nothus, October 30, 1915.

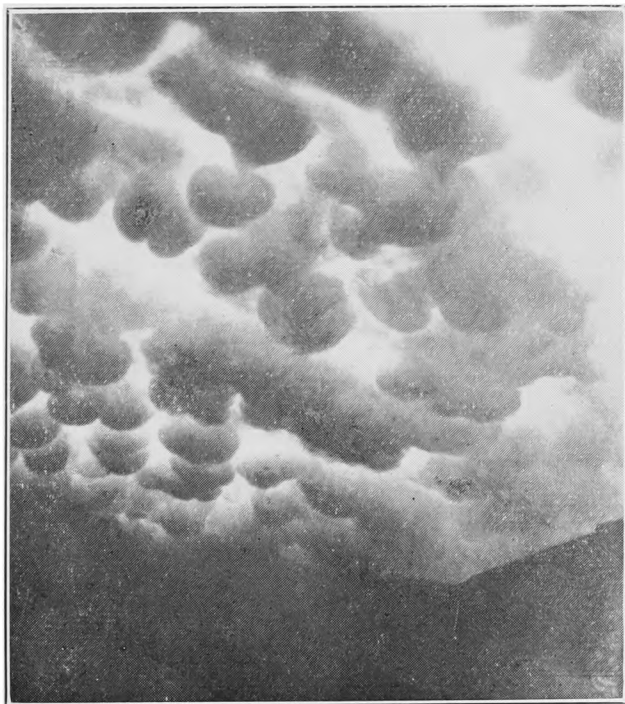


FIG. 14.—Mammillated clouds (adjective mammatus).

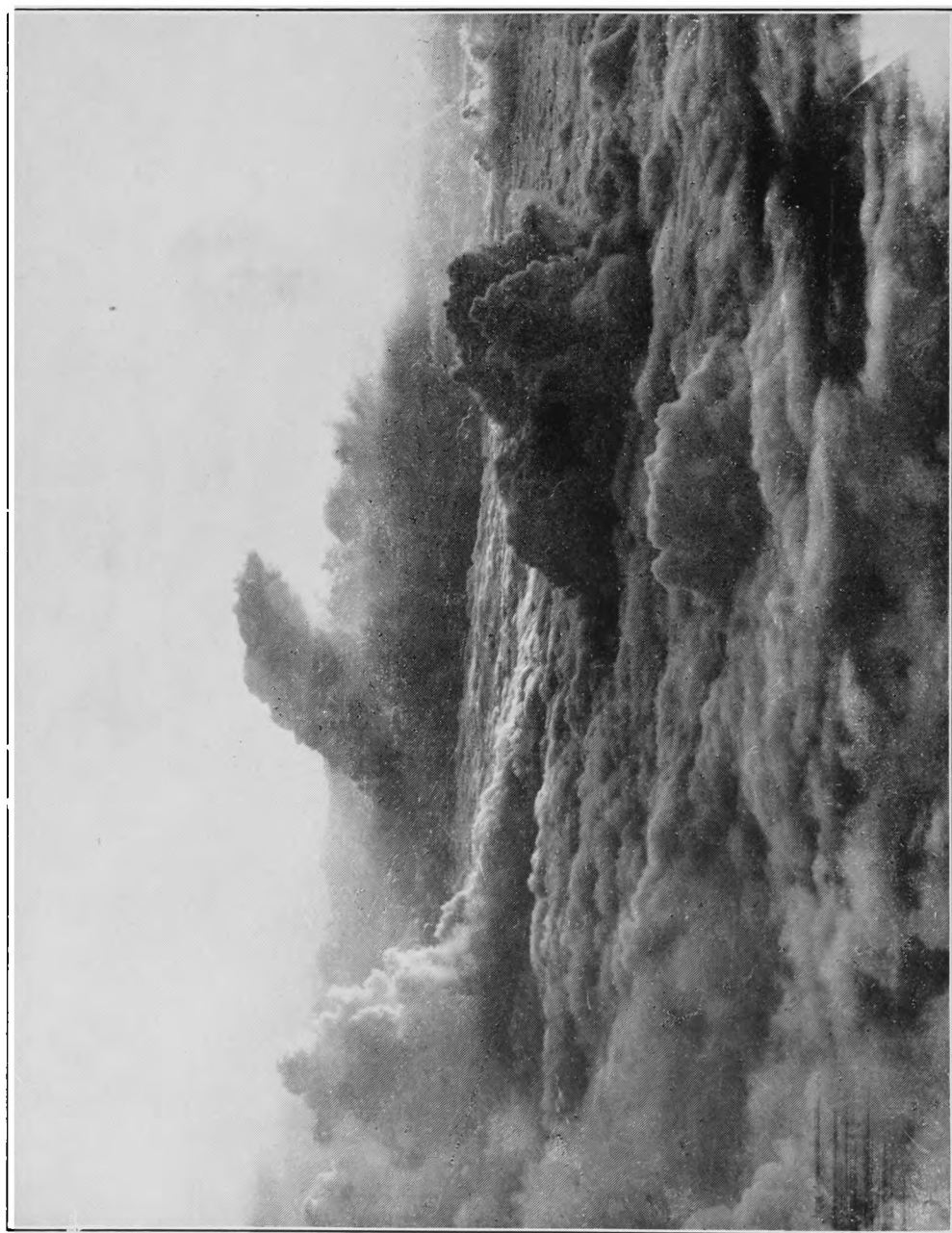


FIG. 15.—Cumulus protruding through stratocumulus.

The definitions of these various cloud forms will be found under the individual names. Some general remarks on clouds and their method of formation are given here. The heights of clouds, even of one type, vary within very wide limits, and "high clouds" of the above classification may sometimes be found below "medium clouds." The level at which high clouds are generally found is between 25,000 ft. and 35,000 ft., while medium clouds are found between 10,000 ft. and 25,000 ft., and low clouds are usually below 10,000 ft. although the tops of large cumulus and cumulonimbus may rise much above this level. These average heights refer to temperate latitudes. The heights of clouds tend to be greater in summer than in winter, and greater in the tropics than in high latitudes. Clouds are almost entirely confined to the TROPOSPHERE and seldom penetrate into the STRATOSPHERE. In the tropics cumulonimbus cloud may reach to over 50,000 ft.

Apart from surface fogs, clouds are due mainly to the air being cooled below its DEW-POINT by a reduction of pressure (see ADIABATIC), and by far the most effective cause of this is upward movement. There are three main types of vertical movement, and observations of the three-dimensional structure of clouds, which aviation has rendered possible, show that many of the more important cloud forms can be grouped together according to the nature of the vertical motion, in the following manner :—

(a) Slow upward movement of a large mass of air, due to orographic causes or to CONVERGENCE in the horizontal motion of the air underneath. This process is responsible for clouds of altostratus and nimbostratus type and for continuous precipitation.

(b) Small air masses rising up through the atmosphere causing cumulus or cumulonimbus clouds and showers.

(c) Churning up of a layer of air by small eddies, which increases the moisture content of the upper part of the layer and may cause cloud to be formed. This gives rise to horizontal cloud sheets, i.e., stratus, stratocumulus, altocumulus, cirrocumulus.

In some cases two or three of these types of vertical motion operate together, and there are no sharply defined limits which separate the one from the other. If we try to trace out the life history of any particular cloud with the factors which have operated in the more remote as well as the immediate past to lead to its formation, we shall frequently find that more than one of the above processes must be involved.

The clouds associated with the three methods of formation may be considered in greater detail :—

(a) Altostratus clouds are some thousands of feet thick, usually continuous but occasionally in a succession of layers. If the clouds are nebulous or fibrous in appearance, they normally consist entirely of ice crystals or snowflakes. There is some reason to think that the blurred appearance of the sun or moon (see Fig. 9) can only be produced by ice-crystal clouds; when seen through clouds of waterdrops, the edges of the disc are sharp. There is often an ill-defined base to the cloud where falling snowflakes evaporate or melt into rain. The clouds have no great opacity, and the sun can usually be seen dimly through several thousand feet of cloud.

Cirrostratus cloud is of the same type as altostratus but is higher and more nebulous. It is frequently the advance guard of a large cloud mass which is formed in a current of air rising up a surface of DISCONTINUITY.

(b) Heap clouds : cumulus and cumulonimbus. Cumulus clouds are normally formed when the LAPSE rate of temperature below them is equal to the dry ADIABATIC rate (near the earth's surface this rate may be exceeded) so that air slightly warmer than its surroundings rises up like a bubble. They develop over the land on the majority of summer days, and dissolve in the evening. They also form in a cold current



passing over a warmer sea surface. Once condensation takes place in a mass of rising air, latent heat is set free and the air cools at the adiabatic rate for saturated air. The growth of the cloud depends on whether the lapse-rate of temperature in the surrounding air is greater or less than the saturated adiabatic rate. If it is less, conditions are stable, since the rising air becomes colder and therefore heavier than its surroundings and tends to fall back again. The clouds then tend to assume flat shapes and often spread out into a layer of stratocumulus or altocumulus. If, however, the lapse-rate is greater than the saturated adiabatic the rising air remains warmer and lighter than its surroundings so that conditions are unstable, the clouds tend to tower upwards and develop into cumulonimbus. The cumulonimbus clouds usually develop from large masses or long banks of cumulus, and a group of clouds often amalgamates into one large mass, the whole process being spread over a few hours. It is not easy to fix the limit between large cumulus and cumulonimbus. Probably the occurrence of heavy precipitation furnishes the best criterion, but this cannot always be seen from a distance, and the development of precipitation does not depend only on the height attained by the cloud summit, which may considerably exceed 10,000 ft. without showers. If the top becomes cirriform (fibrous), the cloud is certainly cumulonimbus, but in the case of some heavy showers there is no cirriform top. The tops of severe summer thunderstorms frequently reach a height of 25,000 ft., and probably sometimes 35,000 ft. or even more. The ANVILS consist mainly of snow and may remain after the storms die out, in the form of dense masses of cirrus or altostratus.

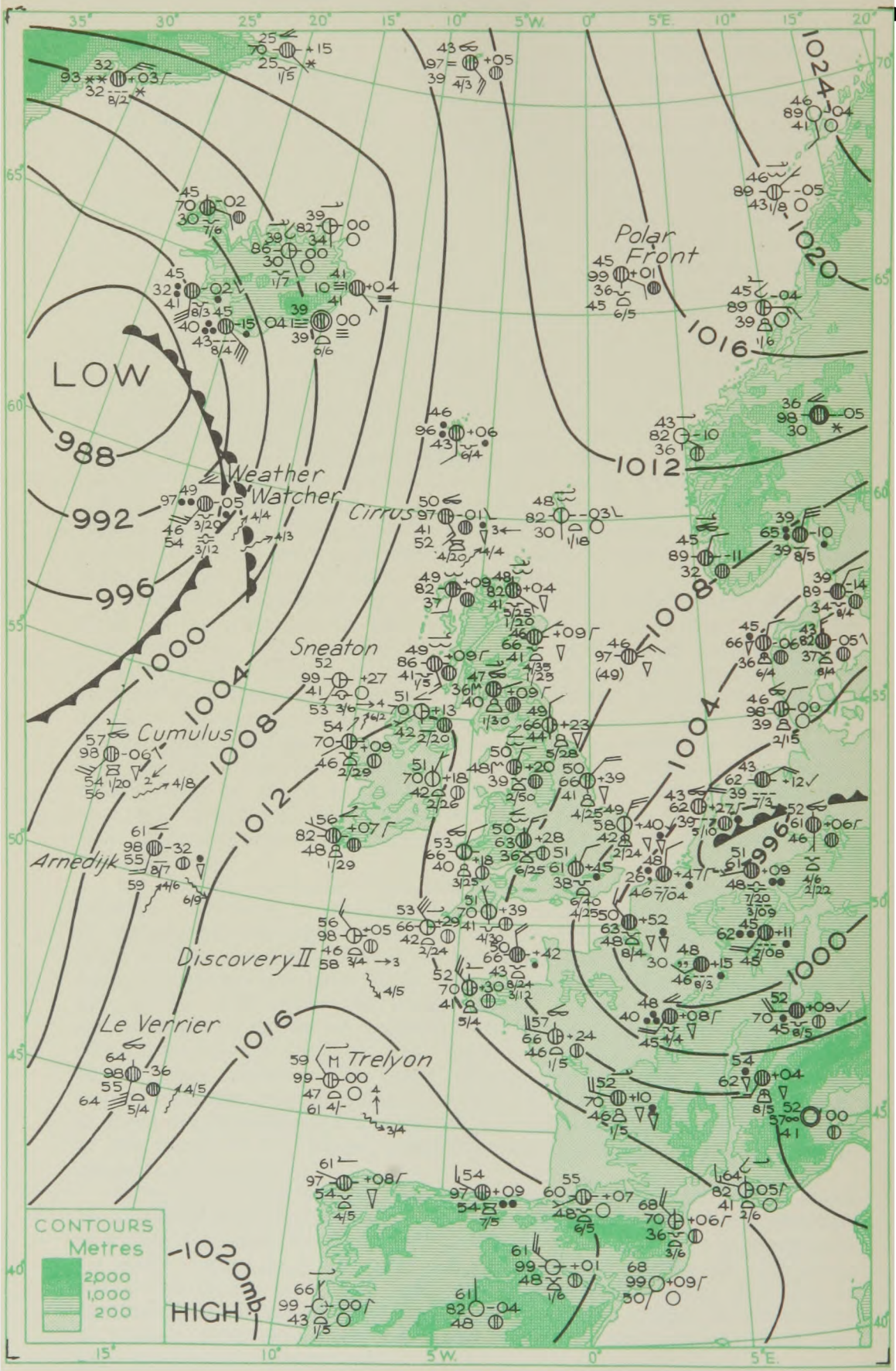
When the atmosphere is stable in the lower layers, but damp and unstable for saturated air above, cumulus clouds, and often eventually cumulonimbus, may develop from a layer of stratified clouds (formed by process (a) or (c) or both combined). The cloud known as altocumulus castellatus consists of a layer of small turreted clouds grouped like ordinary altocumulus and formed in this way. It is also possible for large cumulus or cumulonimbus to develop at relatively high levels, independent of convection from the earth's surface. The base of cumulonimbus may be above 10,000 ft., but in the British Isles such cases are rare and thunder and lightning are unlikely to develop. Clouds developed in a similar manner with a base at about 6,000 ft. may give rise to severe thunderstorms.

(c) Flat cloud sheets: stratus, stratocumulus, altocumulus, cirrocumulus. There is an essential similarity of structure between all these clouds, though the higher sheets are usually thinner than the lower, and have smaller cloudlets. The lower sheets often exceed 1,000 ft. in thickness, but layers less than 50 ft. thick may occur over limited areas at any height, often with quite small ripples. As a rule there is a definite arrangement of ripples or rounded cloudlets, and from above the clouds often resemble the sea (Fig. 10). Even low stratus is frequently rippled on its upper surface. The lower surface usually appears uniform, but even if structure existed it might be difficult to see, owing to bad lighting. If there are definite ripples or waves, the maximum condensation occurs at the crests of the waves, where the air is subject to the maximum decrease of pressure.

It is found that the lapse-rate of temperature is high below these cloud sheets but relatively low just above them, often with an INVERSION (see also SURFACE OF SUBSIDENCE). Such a condition is accompanied by much TURBULENCE (i.e., a thorough churning up of the air by eddies) below the clouds and very little turbulence above them, and this is verified by observations of bumpiness by aeroplane pilots. It can readily be shown that this state of affairs favours the development and maintenance of a cloud sheet.

Sometimes a single sheet of stratocumulus cloud causes dull weather for several successive days, especially in winter anticyclones. On summer







days, and in suitable conditions over the sea, independently of time of day or season, there are frequently cumulus clouds below the stratocumulus, whose tops may protrude through the latter (Fig. 15) breaking up the regularity of the sheet to some extent.

Cirrus clouds cannot at present be adequately discussed from the point of view of physical causes, though certain large tufts of great vertical extent have evidently a cumuliform structure, whether or not they are developed from the tops of cumulonimbus. A well-marked thread-like structure indicates ice crystals, and sometimes cirrus clouds are formed by snow falling from altocumulus clouds, which consist of supercooled water drops. There are certain very delicate forms of cirrus and cirrostratus (with no long threads) which may cause brilliant CORONAE and IRIDESCENCE, and probably consist of very small spherical globules, and not of ice crystals. Cirrocumulus clouds are also normally of this type.

Since 1943 radar has been used for the study of cloud structure. The pulses of the ultra-short waves used in radar are reflected by clouds and precipitation to a degree proportional to  $ND^6$  where  $N$  is the number of droplets in unit volume and  $D$  their diameter. Parts of cumulonimbus clouds give a strong reflection. Stratiform clouds give little, if any, reflection.

**Clouds, Weight of Water in.**—Measurements on the Austrian Alps of the quantity of water suspended in clouds have given 0.35 gm./m<sup>3</sup> to 4.8 gm./m.<sup>3</sup> The water suspended as mist, fog or cloud may be taken as ranging from 0.1 to 5 gm./m.<sup>3</sup> (see A. Wegener, "Thermodynamik der Atmosphäre," Leipzig, 1911, p. 262).

**Col.**—The saddle-backed region occurring between two anticyclones and two depressions, arranged alternately. Frequently on a weather map only two anticyclones appear, then the col is the region of relatively low pressure between them and may be likened to a mountain pass between two peaks. In a similar way the col may appear when only two depressions are shown on the weather map.

The wind circulations associated with the neighbouring anticyclones or depressions bring light airs from very different directions into close contact with one another in the col. In summer the weather which results is occasionally brilliantly fine, but thunderstorms are frequent and may occur in any part of the col. In winter conditions are apt to be dull or foggy.

The anticyclones, between which a col lies, are generally stationary or slow-moving, and the col occupies a region through which an approaching depression may readily pass. Hence, although a col does not usually move rapidly in itself, it does not as a rule form an abiding feature on the pressure map. (Plate II.)

**Cold Front.**—The boundary line between advancing cold air and a mass of warm air under which the cold air pushes like a wedge. The surface of separation is called the frontal surface and this meets the earth in the cold front. Its passage is normally accompanied by a rise of pressure, a fall of temperature, a veer of wind, a heavy shower and sometimes a LINE-SQUALL, perhaps with thunder. The front is not always sharply defined, and sometimes it is not clearly shown by surface temperatures, but only by upper air temperatures, weather, wind and barometric tendencies. Occasionally the barometer continues to fall behind the front, though at a much reduced rate.

The normal direction of slope of the frontal surface is at about 1 in 50 back from the cold front, but the point of the wedge may become rounded owing to friction holding back the advance of the cold air on the surface so that the direction of slope is reversed below about 2,000 ft. The rate of advance of a cold front is roughly that of the component of geostrophic wind at right angles to it. See DEPRESSION, FRONT.

**Cold Sector.**—That part of a DEPRESSION occupied by cold air on the earth's surface, usually about half to three-quarters of a recently formed depression, and the whole of an old one.

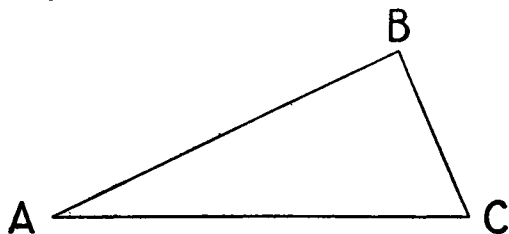
**Cold Wave.**—The fall of temperature associated with the air behind the cold front of a passing depression. The term is used in a technical sense by the United States Weather Bureau, with the meaning of a fall of temperature by a specified amount in 24 hours, to a minimum below a certain temperature. The amount of fall and the limit of minimum are different for different times of the year and for different parts of the country.

**Compass.**—The magnetic or mariner's compass consists in its simplest form of a graduated circular card at the centre of which a magnetized steel needle is suspended so that it may turn freely in a horizontal plane. The card is divided into 32 equal parts of  $11\frac{1}{4}^\circ$  each, called points. The points are N., N. by E., NNE., NE. by N., NE. and so on. They are often called orientation points. The compass needle points to the magnetic north (see TERRESTRIAL MAGNETISM), not to the geographical north. At the present time (1957) the magnetic north lies  $8^\circ$  to the west of true north in London and  $14^\circ$  west in the west of Ireland. Along two irregular *agonic* lines, one passing through North and South America and the other through parts of Europe, Asia and Australia there is at present no variation. In Arctic and Antarctic regions the variation is very large and in places the direction may even be entirely reversed, the north-pointing end of the needle indicating the south.

Magnetic compasses have now largely given way to the gyrostatic compass. This compass is one of several devices which utilise the property of a spinning flywheel, of maintaining its axis in space. The gyro is maintained electrically, and has been used in aeroplanes and on board ship, having the advantage of being independent of both magnetic and electrical disturbances.

**Compensation of Instruments.**—An instrument designed to measure changes in a particular physical quantity (e.g. pressure) may be affected also by some other influence (e.g. temperature). To eliminate or minimise the influence of the disturbing element, a device may be introduced for the purpose of rendering the instrument insensitive to changes in the latter, in which case it is said to be compensated. Thus, chronometers and aneroid barometers are ordinarily compensated for temperature.

**Component.**—A word used to indicate the steps, in their various directions, which must be compounded or combined geometrically in order to produce a given displacement. In the diagram, AC is the geometrical sum or resultant of the two components AB, BC wherever B may be. It is not necessary that the components should be at right-angles to each other. The above law of the composition of displacements is applicable to the composition of velocities, accelerations and forces.



**Condensation.**—The process of formation of a liquid from its vapour. In a closed space wherever there is a free surface of ice or water, EVAPORATION or condensation takes place until the water vapour exerts a definite "pressure of saturation," depending only upon the temperature, and not upon the pressure of the surrounding air. This pressure of saturation is very much greater at high than at low temperatures, as is shown in the table on p. 17.

Aitken has shown that condensation occurs when saturated air is cooled, provided suitable nuclei are present, but not otherwise. In the atmosphere such nuclei are rarely if ever absent. Condensation therefore occurs when air is cooled below the dew point.

In the passage from the liquid to the gaseous state great quantities of heat are absorbed, 539 calories for every gram of water evaporated at the boiling point, and even more if the water is initially cold. Conversely much heat is yielded up when condensation occurs, and this is an important factor in controlling the rate of cooling.

The principal causes of cooling, such as may lead to condensation, are :—

- (1) contact with solid bodies which are at a lower temperature,
- (2) dynamical cooling due to rarefaction,
- (3) mixing with air at a lower temperature.

The result of (1) is most often visible as dew or hoar frost, while (2) and (3) yield cloud or fog, and if carried far enough (2) will yield rain, snow, etc.

The physics of cloud formation and precipitation are still (1949) not fully understood particularly as regards the development of RAINDROPS from the very small droplets or ice crystals which are first produced in condensation. It is very doubtful if growth depends upon the fusion of individual particles.

In 1933 Bergeron put forward a theory, based on the fact that the saturation vapour pressure over water is greater than over ice, according to which all raindrops are melted large ice crystals. The difference between the saturation vapour pressures produces this effect because in Bergeron's view in a cloud of mixed water droplets and ice crystals the crystals will tend to grow at the expense of the water droplets and ultimately fall and melt when air at above freezing point is reached.

Much work has been done since 1939 on condensation processes at below freezing point in "cloud chambers" though the application of all the results to the free atmosphere is uncertain. A valuable summary is given by Dobson.\* The details are complex but, briefly, as the humidity is increased by cooling below freezing point only water droplets are formed down to about  $-10^{\circ}\text{C}$ ., and below that temperature ice particles begin to form in increasing numbers until below  $-41^{\circ}\text{C}$ . condensation is mainly ice. An important fact is that the ice particles form on natural nuclei, apart from existing ice crystals, at these low temperatures at saturation with respect to water. A few substances, e.g. cadmium iodide treated in a special way, are known which can produce ice condensation at saturation with respect to ice, but they do not occur naturally in the air so far as is known. In the atmosphere ice particles have, however, been found at higher temperatures than in condensation chambers, even at  $-4^{\circ}\text{C}$ .

Since 1947 the effects produced by dropping solid carbon dioxide, a procedure called "artificial nucleation" or "cloud seeding", which has a temperature not higher than  $-65^{\circ}\text{C}$ ., into clouds have attracted much attention. Rain has been observed to fall from clouds treated in this way. Most results have been obtained with clouds of supercooled water drops but similar results have been claimed for clouds at above freezing point. The process, at below freezing point, appears to be due to the formation of large numbers of tiny ice crystals by the solid  $\text{CO}_2$  pellets in the saturated air which then act as suggested by Bergeron. The process suggested by Langmuir for the effects at above freezing point is a complex chain reaction described in his General Electric Company Report, New York, 1948. The scientific interest of these experiments is great but their practical use in rain-making is, at least, very doubtful. An essential requirement is the existence of naturally formed clouds developed to the point at which "seeding" just gives the final impulse. Seeding may have a use in clearing gaps in anticyclonic stratocumulus cloud.

**Condensation Trails.**—Persistent condensation trails are long, initially thin clouds produced by aircraft engine exhausts when the humidifying effect of the water vapour in the exhaust overpowers the opposed heating effect. For a given engine there is for a given pressure a critical air temperature above which trails cannot form. This theoretical result has been confirmed in practice. The critical temperature is such that over Great Britain trails rarely form below 28,000 ft. in summer and about 20,000 ft. in winter. In tropical areas the heights are greater but in very cold conditions, such as winter in central Canada, trails can form at ground level.

\* DOBSON, G. M. B.; Ice in the atmosphere. *Quart. J.R. met. Soc., London*, **75**, 1949 p. 117.

There is another non-persistent type of trail which may be formed at wing tips and propellers of aircraft in damp air. The theory of persistent trail formation does not apply to this type.

**Conduction.**—The process by which HEAT is transferred by and through matter, from places of high to places of low temperature, without transfer of the matter itself, the process being one of "handing on" of the heat-energy between adjacent portions of matter. It is the process by which heat passes through solids; in fluids, although it occurs, its effects are usually negligible in comparison with those of CONVECTION.

**Constant.**—A quantity which does not vary within the limits of space or time (or both) under consideration. See also SOLAR CONSTANT and RADIATION (Stefan's Constant).

**Constant Pressure Chart.**—A chart on which are drawn the synoptic contour lines of the height above sea level of a selected isobaric surface in the free atmosphere. Such charts are advantageous for the calculation of wind velocity from the GRADIENT WIND relation since

$$\gamma / D = g \times \text{slope of isobaric surface}$$

where  $\gamma$  is pressure gradient,  $D$ , air density and  $g$ , the acceleration due to gravity. The slope is measured from the distance between the standard contour lines. It is not necessary to know the air density as it is in using constant level charts for the same purpose. Other elements, e.g. temperature, winds observed at the given pressure, may be entered on the same chart.

**Contessa del Vento.**—A type of eddy cloud frequently found to the lee side of isolated mountains. It is often observed over Mount Etna with a westerly wind. In its most characteristic form it consists of a rounded base surmounted by a protuberance directed up-wind.

**Continentality.**—In meteorology, a measure of the extent to which the climate of any place is influenced by its distance from the sea. The influence of continentality is most clearly shown on the diurnal and annual ranges of temperature which are large in continental climates. Since water has a high specific heat and still more because the exchange of heat goes to a much greater depth in water than in land, the temperature of a water surface can vary only slowly compared with the temperature of a land surface. The latter absorbs and radiates heat readily, and its temperature can therefore vary through a considerable range even within 24 hours. Measures of meteorological continentality have been derived by Brunt and others, based on either the mean daily range of temperature or the mean annual range in relation to the latitude.

**Contour Lines.**—In synoptic meteorology this term generally means synoptic lines of constant height of isobaric surfaces. Isohypsies is sometimes used. See CONSTANT PRESSURE CHART.

**Convection.**—In convection heat is carried from one place to another by the bodily transfer of the matter containing it. In general, if a part of a fluid, whether liquid or gaseous, is warmed, its volume is increased, and the weight per unit of volume is less than before. The warmed part therefore rises and its place is taken by fresh fluid which is warmed in turn. Conversely, if it is cooled it sinks. Consequently, if heat is supplied to the lower part of a mass of fluid, the heat is disseminated throughout the whole mass by convection, or if the upper part is cooled the temperature of the whole mass is lowered by a similar process.

There are two apparent and important exceptions in meteorology. Fresh water, when below the temperature of  $39.1^{\circ}\text{F.}$ ,  $277^{\circ}\text{A.}$ , expands instead of contracting on being further cooled. Hence a pond or lake is cooled bodily down to  $39.1^{\circ}$  but no further, as winter chills the surface before it freezes. Secondly, heat applied to the bottom of the atmosphere may stay there without being disseminated upwards when the atmosphere is exceptionally stable in the circumstances explained under ENTROPY.

**Convictional Rain.**—Caused by the heating of the surface layers of the atmosphere which expand and rise, giving place to denser cool air. The warm air is frequently heavily charged with moisture taken up from the ground or vegetation. The THUNDERSTORM rain of the summer afternoon is typically convectional rain. As in the case of OROGRAPHIC RAIN, condensation occurs when the process of expansion under diminishing pressure has reduced the temperature of the rising mass beyond its dew point. The intensity of the rain in severe thunderstorms is much greater than that in any other type of rainfall. In the British Isles the intensity for a few minutes in a few cases has exceeded the rate of 10 in. per hour. (See also INSTABILITY SHOWERS, RAINFALL.)

**Convergence.**—Consider a portion of the earth's surface, for convenience a square with sides 100 miles long running north to south and east to west, though the argument is applicable to any area. If the wind is uniform over the whole area as much air will flow into it on the sides which face the wind as flows out of it on the other sides. If, however, the wind is not uniform a case may arise when more air flows in than flows out. There is then said to be convergence. For example, suppose the wind is on the whole westerly. If along the south side of the square the wind is blowing a little from S. of W. while along the north side it is blowing from N. of W., there will be an inflow along both these sides. The amount of air which flows out on the eastern side of the square will, however, be equal to that flowing in on the western side, assuming the wind to be the same in both regions. Taking account of all four sides more air will therefore flow into the square than flows out of it, and there will be convergence over the area. The air cannot go on accumulating, and the excess will have to flow out at the top, thus leading to a rising air current. It is this which gives convergence its importance. Rising air expands and is cooled (see ADIABATIC). If the cooling is continued long enough and the air contains moisture, this moisture will condense and cause cloud and rain. Except in arid climates, prolonged convergence of the lower currents of the atmosphere must therefore eventually give precipitation. Further, since these layers hold more moisture than those above, convergence without precipitation steadily increases the total water content contained in the whole column of air over a given area. It is important to note that geostrophic winds (see GRADIENT WIND) can give no appreciable convergence, for if the wind obeys the geostrophic law the amount of air which flows out of any area will be almost exactly equal to the amount which flows into it. There are two main causes of convergence. One is surface friction, which causes a flow of air near the ground across the isobars from high to low pressure, resulting in convergence in certain conditions, notably in the centre of a depression or along a trough of low pressure. Secondly, convergence takes place into a region of falling barometer, owing to lack of perfect balance between the wind and pressure gradient. This effect is smaller at the earth's surface than the frictional inflow into a depression, but as it extends much higher it is probably often more important. See also ISALLO-BARIC WIND

**Coriolis Acceleration.**—For the application of Newton's second law of motion,

$$mf = P, \dots \dots \dots (1)$$

where  $f$  is acceleration,  $m$  mass and  $P$  the applied force the system of measurement of the acceleration must itself be unaccelerated. To do this the system must be fixed relative to the "fixed" stars. A system of measurement fixed to the earth, say the floor and walls of a room, is an accelerated system because the earth is rotating relative to the "fixed" stars. In studying motions over the earth on the scale of up to a few miles (short-range guns, lee-waves) Newton's law can be applied to the accelerations relative to the earth but with long-range missiles or large-scale air currents this does not give accurate predictions of the movements.

It can be shown that relative to fixed axes Newton's second law can be written :

$$m (f(R) + f(CE) + f(CO)) = P. \quad \dots \quad (2)$$

Here  $f(R)$  is the acceleration relative to the earth;  $f(CE)$  is the centripetal acceleration towards the earth's axis due to the earth's rotation which is small and absorbed in gravity;  $f(CO)$  is the Coriolis acceleration, named after its discoverer, which is at right angles to both the earth's axis and the velocity of the body (or wind) over the earth and equal to  $2\Omega V \sin \psi$  where  $\Omega$  is the earth's angular speed,  $V$  the speed of the body or wind and  $\psi$  the angle between the earth's axis and the velocity of the body or wind. The direction of  $f(CO)$  in the northern hemisphere is to the left looking along the motion and to the right in the southern hemisphere.  $P$  for winds is the sum of the forces of the pressure gradient, friction, and gravity. For a rectangular coordinate system fixed at a point on the earth's surface in north latitude  $\phi$  with the  $x$  axis to the east,  $y$  axis to the north and  $z$  axis upwards the components of  $f(CO)$  are

$$\begin{aligned} & 2 \Omega (w \cos \phi - v \sin \phi), \\ & 2 \Omega u \sin \phi, \\ & -2 \Omega u \cos \phi, \end{aligned}$$

where  $u, v, w$  are the component velocities of the body or wind.

If  $f(CO)$  is taken to the other side of equation (2) with reversed sign it is termed Coriolis force per unit mass.

**Corona.**—A series of coloured rings surrounding the sun or moon. The space immediately adjacent to the luminary is bluish white, while this region is bounded on the outside by a brownish red ring, these two together forming the aureole. In most cases the aureole alone appears, but a complete corona has a set of coloured rings surrounding the aureole, violet inside followed by blue, green, yellow to red on the outside. The series may be repeated more than once, but the colours are usually represented merely by greenish and pinkish tints.

The corona is produced by DIFFRACTION of the light by waterdrops. If the colours are pure it is an indication that the drops are uniform in size. The radius of the corona is inversely proportional to the size of the droplets. Thus a corona, whose size is increasing, indicates that the water particles are diminishing in size.

A corona is distinguished from a halo which is due to REFRACTION by the fact that the colour sequence is opposite in the two, the red of the halo being inside, that of the corona outside. In applying this criterion it must be remembered, however, that the dull red which is the first notable colour in the aureole ranks as outside the bluish tint near the luminary. An alternative criterion is that the colours of the halo are at the inner edge of a luminous area, whilst those of a corona are at the outer edge.

The term corona is also used to describe a particular form of AURORA present only in the most active displays. When there are bundles of auroral rays along the lines of force of the earth's magnetic field the effect of perspective makes them appear to converge to the magnetic zenith.

**Correction.**—Almost all measurements are ultimately reduced to reading a position or length on a graduated scale. Generally speaking, the reading depends mainly on the quantity which the instrument is intended to measure, but also partly upon other quantities. Thus the readings of barometers are generally affected by temperature as well as pressure, those of thermometers by alterations in the glass containing the mercury or spirit.

In most cases the amount of the error has to be determined and allowed for by a suitable "correction." An ANEROID BAROMETER is often compensated for temperature (see COMPENSATION OF INSTRUMENTS), and for a mercury barometer the effect of temperature is made out and tabulated and a correction introduced, which is derived from a table, when the temperature

of the "ATTACHED THERMOMETER" has been noted. In a similar manner the correction of a barometer reading for the variation of GRAVITY at different parts of the earth's surface is worked by means of tables, the variation of gravity with latitude having been previously reduced to a formula, by means of observations from which the figure of the earth has been determined and the change of gravity has been ascertained.

In some measurements, such as the determination of height by the use of an aneroid barometer, corrections are numerous and complicated; the uncorrected reading may even be only a rough approximation not sufficiently accurate for practical purposes.

**Correlation.**—The method of correlation is a mathematical process for determining the degree of relationship between two variable quantities or *variates*. For example, it is found that when pressure at sea level at any place in Europe is unusually high, pressure at a height of 9 Km. above that place is generally high also. Let  $x_1, x_2, \dots, x_n$  be the departures of  $n$  values of pressure at sea level from their mean, and  $y_1, y_2, \dots, y_n$  the corresponding departures of the pressures at 9 Km. The average variation of the  $y$ 's about their mean is smaller than the average variation of the  $x$ 's, but we can make the figures comparable by dividing each series by its "standard deviation" given by the expression:—

$$\sigma_x = \left\{ (x_1^2 + x_2^2 + \dots + x_n^2) / n \right\}^{\frac{1}{2}} = \left\{ \Sigma (x^2) / n \right\}^{\frac{1}{2}} \dots (1)$$

The square of the standard deviation,  $\sigma_x^2 = \Sigma (x^2) / n$ , is known as the *variance*.

If now the variations of  $x$  were strictly proportional to the values of  $y$ , knowing the one we could calculate the values of the other exactly, by means of the relationship:—

$$x / \sigma_x = y / \sigma_y \dots \dots (2)$$

Such exact relationships rarely if ever occur in meteorology, but we can regard the variations of  $x$  as made up of two components, a part  $r$  which is strictly proportional to the variations of  $y$ , and another part  $e$ , which is independent of  $y$ . That is to say, we can write:—

$$x / \sigma_x = r y / \sigma_y + e \dots \dots (3)$$

The figure  $r$  is a measure of the closeness of the relation between the two quantities  $x$  and  $y$ . It is accepted that the best value which can be given to  $r$  is that which gives the smallest possible figure for the sum of the squares of the values  $e_1, e_2, \dots, e_n$  resulting from the substitution of  $x_1, x_2, \dots, x_n$  and  $y_1, y_2, \dots, y_n$  in (3), and this value of  $r$  is known as the *Correlation Coefficient*. When the two quantities  $x$  and  $y$  are exactly proportional,  $e$  is always zero, equation (3) reduces to (2) and  $r$  becomes +1. On the other hand if the two quantities are inversely proportional,  $e$  is again zero, but  $r$  is -1. If there is no relationship at all between  $x$  and  $y$ ,  $r$  is zero and  $e = x$ . The correlation coefficient obtained by the late W. H. Dines between pressure at sea level and that at 9 Km., was +0.68.

The value of the correlation coefficient  $r$  is given by the expression:—

$$r_{xy} = \frac{\Sigma (xy)}{n\sigma_x\sigma_y} \dots \dots (4)$$

where  $\Sigma (xy)$  is the sum of the products  $x_1, y_1, x_2, y_2, \dots, x_n, y_n$ ;  $n$  is the number of observations and  $\sigma_x, \sigma_y$  are the standard deviations of  $x$  and  $y$  obtained by (1).

The relation between  $x$  and  $y$  is generally expressed in the form:—

$$x = b_{xy} y \dots \dots (5)$$

where  $b_{xy} = r \sigma_x / \sigma_y$

Equation (5) is the REGRESSION EQUATION of  $x$  on  $y$ , and  $b$  is known as the regression coefficient.

It should be noted that while the correlation coefficient between  $x$  and  $y$  is the same as that between  $y$  and  $x$ , and is independent of the units in which  $x$  and  $y$  are expressed, the regression coefficient of  $x$  on  $y$  is not the same as the regression coefficient of  $y$  on  $x$ , and neither is independent of the units.

It sometimes happens that we wish to take account of the effect of some third variate. For example, theoretically the pressure at sea level should be determined almost entirely by the pressure at 9 Km. and the temperature of the air between sea level and 9 Km. If we wish to see how far this is shown by the observations, we must calculate the partial correlation coefficient between pressure at sea level ( $x$ ) and pressure at 9 Km. ( $y$ ), eliminating the effect of variations of temperature in the intervening air layer ( $z$ ). This partial correlation coefficient is usually denoted by  $r_{xy \cdot z}$  and is given by the expression :—

$$r_{xy \cdot z} = \frac{r_{xy} - r_{xz} r_{yz}}{(1 - r_{xz}^2)^{\frac{1}{2}} (1 - r_{yz}^2)^{\frac{1}{2}}} \quad \dots \dots (6)$$

The values found by W. H. Dines were :  $r_{xy} = +0.68$ ,  $r_{xz} = +0.47$ ,  $r_{yz} = +0.95$ . To calculate the partial coefficient accurately it would be necessary to employ three places of decimals in the original correlation coefficients or *coefficients of zero order* as they are called, but using the figures as given we find from (6) that  $r_{xy \cdot z} = +0.85$ . The result obtained shows that when allowance is made for variations of temperature, the agreement between pressure at sea level and at 9 Km. is much closer than when no such allowance is made.

The regression equation of  $x$  on  $y$  and  $z$  gives the amount of variation of  $x$  which is associated with the variation of  $y$ ,  $z$  being supposed constant, *plus* the amount of variation of  $x$  which is associated with the variation of  $z$ ,  $y$  being supposed constant. It thus takes the form :—

$$x = b_{xy \cdot z} y + b_{xz \cdot y} z \quad \dots \dots (7)$$

$$\text{where } b_{xy \cdot z} = r_{xy \cdot z} \frac{\sigma_x (1 - r_{xz}^2)^{\frac{1}{2}}}{\sigma_y (1 - r_{yz}^2)^{\frac{1}{2}}} \quad \dots \dots (8)$$

Partial correlation coefficients and regression equations between four or more variates can be obtained by an extension of the method given above, but as the number of variates becomes greater, the amount of arithmetic involved increases at a very rapid rate, and it is not usually practicable to work with more than six quantities.

Care needs to be exercised in attaching significance to correlation coefficients. If two random and entirely unrelated series of figures are correlated, the coefficient obtained will not usually be zero ; if a large number of such trials be made it will be found that half of the coefficients are numerically larger than  $0.67/\sqrt{n}$  where  $n$  is the number of observations in each series. Any one coefficient, therefore, has an even chance of reaching or exceeding this value, so that with a small number of observations appreciable coefficients may occur between unrelated series. Similarly, if between two sets of related observations we obtain a correlation coefficient  $r$ , the most we can say is that the true correlation coefficient, which would be given by an infinitely large number of pairs of observations, has an even chance of being within the range  $0.67 (1 - r^2)/\sqrt{n}$  on either side of the coefficient  $r$  actually found. This is known as the *probable error* of the coefficient.

Unless it is confirmed by physical reasoning or other independent evidence, a correlation coefficient should not be accepted as significant unless it exceeds three times its probable error, in which case the odds in favour of significance are 20 to 1. If a number of trial correlations are made, the chance of obtaining a single large coefficient is obviously greatly increased, and such an isolated coefficient should not be accepted unless it is four or five times its probable error.



If we calculate a series of values of  $r$  by means of the regression equation (5), the standard deviation of the difference between these calculated values and the observed values is  $\sqrt{1 - r^2}$  of the standard deviation of the latter. Since this expression only differs appreciably from unity when  $r$  is large, it follows that single small correlation coefficients are of little value for forecasting purposes.

Examples of some large coefficients in meteorological work are :—

Between mean temperature of the air from 1 to 9 Km. and pressure at 9 Km., + 0.95.

Between change of barometric pressure in 3 hours and corresponding change in level of water in a well at Richmond, — 0.88.

Between the number of thunderstorms in central Siberia and the square root of the sunspot number, + 0.92.

**Cosmic Radiation.**—It being known that air is a poor conductor of electricity it is natural to endeavour to determine the conductivity by utilising a closed metal vessel with an internal insulated electrode, a battery and an electrometer. Such experiments indicate that any current through the vessel is carried by ions which are being produced inside it and that the rate of production of ions is governed, to a certain extent, by a penetrating radiation from outside. The penetrating radiation diminishes at first when the apparatus is taken up in a balloon and at greater heights it increases rapidly. As was first pointed out by Victor Hess, this indicates that the penetrating radiation has a component which originates outside the earth's atmosphere. This cosmic component is far more penetrating than that from radioactive substances, as may be demonstrated by sheathing the receiver with many layers of lead or by sinking it in deep water. The radiation does not come from the sun, for the intensity is independent of the time of day, and it does not come from the stars of our galaxy, for the intensity is independent of sidereal time. The radiation appears to be constituted by corpuscles endowed with electric charges, for it reaches the earth in diminished strength in the zone remote from the magnetic poles. Further, more radiation reaches the earth from the west than from the east and this is interpreted as a proof that a majority of the incident corpuscles are positively charged. The corpuscles are thought to be positrons, each having the same mass as an electron and an equal charge though of the opposite sign. As to the ultimate nature of the cosmic radiation Prof. P. M. S. Blackett\* writes :—"The fastest atomic particles produced hitherto have energies of a few million volt-electrons. The particles emitted spontaneously by radioactive substances have energies of the same order of magnitude. But the particles which are always travelling through space, and which are continually bombarding the terrestrial atmosphere have energies which are certainly greater than 10,000 million volt-electrons and are probably greater than 100,000 million volt-electrons. As to whence these particles come we know nothing. As to how they are produced we know even less. That is not because we have an embarrassing choice between several plausible theories ; it is simply because we have not any theory. We do not even know whether these particles have been produced by matter subject to the laws with which we are acquainted. It may be that the cosmic rays are to be regarded as archaeological remains dating from a time when the universe was young and very different."

**Crepuscular Rays.**—Occasionally soon after sunset the sky is divided up into lighter and darker areas by lines which diverge from the position (below the horizon) of the sun. The lighter areas indicate parts of the atmosphere illuminated by sunshine, the darker areas those from which the sunshine is cut off by intervening mountains or by clouds. The phenomenon is essentially the same as that seen in the day-time when the sun is hidden by cloud and "ladders" diverging from the sun appear where there are gaps in the cloud. The "crepuscular rays" are coloured, the illuminated areas being pink and

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\* "La Radiation Cosmique" Paris, 1935.

the shadows appearing greenish by contrast. The divergence of the "crepuscular rays" is an optical illusion as light rays from the sun are practically parallel.

Under favourable circumstances the shadows are thrown right across the sky and to an observer with his back to the sun the rays appear to converge to a point which is a little above the horizon. These anti-crepuscular rays are generally ill-defined and may be mistaken for patches of cloud.

**Crop Weather.**—For the study of meteorological factors in the growth and yield of crops "Crop Weather" stations were established in 1924 at various Agricultural Colleges, Research Centres and Farm Institutes. In general, the stations are sited in juxtaposition to growing crops upon which measurements are made, so that the meteorological and plant observations may be closely correlated. In addition, phenological observations are made at certain centres. The scheme is under the control of the Meteorological Office, the Ministry of Agriculture and Fisheries, and the Department of Agriculture for Scotland. In recent years the scheme has been extended to include observations of forest trees, and the Forestry Commission has established stations at certain nurseries.

**Cross Section.**—As used in meteorology the term means the representation in schematic form of conditions prevailing in the atmosphere in a vertical plane from the surface up to any desired height along a line from one point to another. The information plotted on the cross section depends upon the purpose for which it is required. Cross sections for the use of aircraft pilots flying between specified points show frontal surfaces, winds, diagrammatic clouds, liability to icing etc. according to a conventional scheme laid down by the International Civil Aviation Organization.

**Cumulonimbus (Cb.).**—*Heavy masses of cloud, with great vertical development, whose cumuliform summits rise in the form of mountains or towers, the upper parts having a fibrous texture and often spreading out in the shape of an anvil.*

*The base resembles nimbostratus, and one generally notices virga. This base has often a layer of very low ragged clouds below it (fractostratus fractocumulus).*

*Cumulonimbus clouds generally produce showers of rain or snow and sometimes of hail or soft hail, and often thunderstorms as well.*

*If the whole of the cloud cannot be seen the fall of a real shower is enough to characterise the cloud as a cumulonimbus.*

**Cumulus (Cu.).**—*Thick clouds with vertical development; the upper surface is dome shaped and exhibits rounded protuberances, while the base is nearly horizontal.*

*When the cloud is opposite to the sun the surfaces normal to the observer are brighter than the edges of the protuberances. When the light comes from the side, the clouds exhibit strong contrasts of light and shade; against the sun, on the other hand, they look dark with a bright edge.*

*True cumulus is definitely limited above and below, its surface often appears hard and clear cut. But one may also observe a cloud resembling ragged cumulus in which the different parts show constant change. This cloud is designated fractocumulus (Fc.).*

**Current, Ocean.**—A general movement of a permanent or semi-permanent nature of the surface water of the ocean. The term must not be used to denote tidal streams, which change direction and velocity hour by hour. A *drift current* is a drift of the surface water, which is dragged along by a wind blowing over it. If a drift current meets an obstruction, such as a shoal or land, it will be deflected but will be carried on by its momentum in a new direction, forming a *stream current*. A stream current may be formed as a counter or compensating current to another current, to replace the water displaced by the primary current. The *set* of a current or tidal stream is the direction in which it is going. The distance through which a current flows in a given time is sometimes called the *drift*, but this term has dropped out of use in the Royal Navy.

Owing to the high specific heat of water, the main ocean currents are of great climatic importance. Ocean currents result from several causes, the most important being wind and differences of density resulting from differences of temperature and salinity. The best known currents are those of the North Atlantic. The north-east and south-east TRADE WINDS give rise to currents directed south-westwards and north-westwards respectively, which combine near the equator and turn westwards as the Equatorial Current. This divides off the coast of Brazil, the greater part passing northwards by the Gulf of Mexico and the West Indies to form the Gulf Stream which moves north-eastward along the east coast of America at a speed of about 70 miles a day. Off the Newfoundland Banks the Gulf Stream meets the cold Labrador Current, which greatly lowers its temperature. At Newfoundland it breaks up, branches going to Greenland and Iceland while the main current continues towards Europe. About  $40^{\circ}$  N.  $40^{\circ}$  W. the latter again divides; the southern branch runs along the coast of north-west Africa as a cold current, while the northern branch, under the influence of the prevailing SW. winds, traverses the western coasts of Europe from Iceland to Norway as a warm current, finally passing into the Arctic Ocean where it is overlain by colder but fresher water which originates mainly in the great rivers of Siberia.

From the Arctic Ocean a cold ice-bearing current flows down the east coast of Greenland, round Cape Farewell and up the west coast of Greenland as far as Disco Island. Here it turns westward and then again southward as the Labrador Current to Newfoundland. The cold but relatively fresh Labrador Current and the warm saline Gulf Stream have nearly the same density and flow alongside for some distance, gradually intermixing. The mixture is slightly heavier than either of the original currents, and this produces a "density wall," on either side of which the currents are opposed.

In the other oceans the currents are simpler. There are warm currents resembling the Gulf Stream in the western parts of the North Pacific (the Kuro Shiwo), the South Atlantic and less definitely the South Pacific. In the North Pacific the warm current is unable to pass through Bering Strait but turns south-eastward along the west coast of North America. In the South Atlantic and South Pacific the warm currents join a great stream of water which travels round the globe from west to east in about  $50^{\circ}$  S., picking up ice from the Antarctic and sending branches northward along the west coasts of South America, South Africa and Australia. In the Indian Ocean the currents are seasonal, governed by the monsoon.

**Curve Fitting.**—Two main types of problems arise in connexion with curve fitting. We may either require to represent a variable quantity as a function of some independent variable such as time, distance, latitude, etc., by drawing a curve to represent the functional relationship, or we may require to represent the frequency of occurrence of different values of a quantity, whether measured directly or indirectly, by means of a curve whose formula must be obtained. The simplest example of the first type is the fitting of a straight line to represent the relationship between pairs of measurements of two quantities, as is done in the normal treatment of CORRELATION between two variables. When the graphical representation of the observations indicates that the relationship is not linear, no general rule can be laid down for the subsequent procedure. Examination of the graph will in some cases indicate what must be the next step. If, for example, the graph indicates a repetition of the values of one variable at equal intervals of the other variable, there is a periodic relationship between them, and the data can be analysed by the methods of HARMONIC ANALYSIS. If the relationship is represented by a fairly smooth curve, it is frequently possible to derive an idea of the exact nature of the curve by plotting the data on logarithmic or semi-logarithmic paper. If the relationship is of the nature  $y = Ax^n$ , plotting on logarithmic paper will yield the values of  $A$  and  $n$ ; while if it is of the nature of  $y = Ae^{bx}$ , plotting on semi-logarithmic paper will yield the values of  $A$  and  $b$ .

In fitting curves to frequency distributions, we look in vain for any general rule. The method of least squares lays down a procedure for fitting the closest fitting normal error curve. Pearson has also developed a general formula :

$$\frac{1}{y} \cdot \frac{dy}{dx} = \frac{x + a}{b_0 + b_1x + b_2x^2}$$

which can be made to fit a wide variety of frequency curves by the choice of appropriate values for  $a$ ,  $b_0$ ,  $b_1$ ,  $b_2$  etc. For details of this type of treatment reference should be made to Elderton's "Frequency Curves and Correlation" (C. and E. Layton).

**Cyclone.**—A name given to a region of low barometric pressure. In temperate latitudes the cyclone is now usually spoken of as a DEPRESSION and the term "cyclone" is taken to refer only to a "tropical cyclone." In this restricted form the term cyclone reverts to its original meaning. Cyclonic storms are confined to very definite regions and occur on the western sides of the great oceans. The principal regions where these storms occur and the names by which they are known are :—(a) The Gulf of Mexico, the West Indies and the coasts of Florida where they are known as HURRICANES ; (b) the Arabian Sea and the Bay of Bengal (cyclones) ; (c) the China Sea and the coasts of Japan (TYPHOONS) ; (d) the Indian Ocean to the east of Mauritius and Madagascar (cyclones), and (e) the Pacific Ocean to the east of Australia and Samoa (hurricanes). In the Philippines they are known as BAGUIOS. The storms usually originate over the ocean and their paths generally keep to the ocean ; if the path crosses from the ocean to the land the storms soon die out and they quickly lose their destructiveness.

The cyclone and the depression are in essentials alike ; their winds in the northern hemisphere circulate in a counter-clockwise direction and in the southern hemisphere clockwise, the only difference being that of their strength. Winds of force 12 on the BEAUFORT SCALE of wind force frequently accompany the cyclone while in the depression winds of this strength are rare. This difference is due largely to the difference in pressure gradient.

At the centre of a cyclone the pressure is frequently about 960 mb. and in its outer edge about 1,020 mb. The diameter of such a storm may reach 600 miles, but it is more often much less. In a depression similar differences of pressure occur between the centre and the outer edge, but the diameter of the depression may be 1,000 or even 2,000 miles.

In the centre of a cyclone there is usually a very limited region, only a few square miles, in which there is a complete calm with only a narrow strip of moderate winds separating it from the winds of hurricane force. This calm region is recognised as the EYE of the cyclone. In it the weather is usually fine while in the other parts of the cyclone there are cloudy skies and torrential rain. Frequently before a cyclone approaches the weather is fine and quiet, but the skies soon cloud over, the barometer falls quickly and the air becomes oppressive and sultry, the wind freshens rapidly and soon heavy rain commences. After the passage of the storm the weather quickly resumes its peaceful form.

The velocity of translation of the cyclone is usually under 15 miles per hour ; the velocity varies in different cyclones as in depressions in temperate latitudes, but the velocity of translation is generally less than that of the depression.

Cyclones are of a seasonal nature, they occur principally towards the end of the hot seasons. In the West Indies August to October are the months of greatest frequency. In the Southern Pacific and in the South Indian Ocean they occur most frequently between December and March, in the Bay of Bengal and in the Arabian Sea between April and June and again between September and December. In the China Sea and the Antilles they occur between July and October. These are the principal periods for the occurrences of cyclones, but they may occur also in the months adjacent to

those mentioned above. The following table, compiled from various sources, shows the numbers of recorded occurrences of cyclones, hurricanes and typhoons in different parts of the world.

*Numbers of Occurrences of Cyclones, Hurricanes, and Typhoons in Various Parts of the World*

Region and Period	January	February	March	April	May	June	July	August	September	October	November	December	Total
West Indies, 1887–1923.	0	0	0	0	1	16	17	39	78	71	15	2	239
South Indian Ocean, 1848–1917, omitting 1849, 50, 53.	113	115	98	68	25	3	2	0	0	7	33	58	522
Bombay, 25 years . .	1	1	1	5	9	2	4	5	8	12	9	5	62
China Sea, 1880–1901.	9	2	5	10	25	41	74	74	88	65	51	24	468
Arabian Sea, 1890–1912.	2	0	0	2	5	11	3	0	2	10	8	2	45
Bay of Bengal, 1877–1912.	0	0	0	7	21	42	65	55	70	51	37	17	365
South Pacific 160° E. to 140° W., 1789–1923.	69	48	64	18	2	2	1	1	2	4	8	31	250

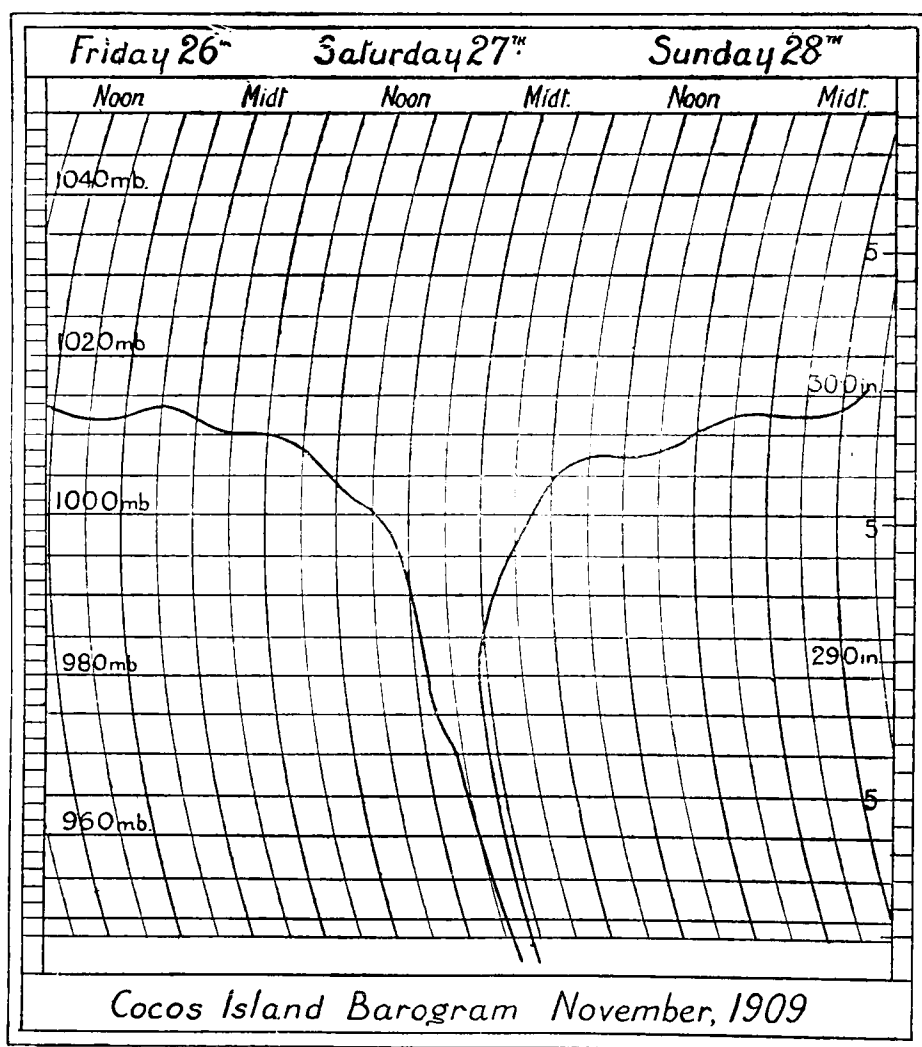


FIG. 16.

Near the centre of a cyclone the fall of pressure is often very rapid. Fig. 16 shows a reproduction of a barogram during a cyclone which passed over Cocos Island (Keeling Is.), on November 27, 1909. It is interesting to notice that in spite of the rapid fall of pressure with the onset of the cyclone the diurnal variation of the barometer is still apparent and it reappears before the normal level is recovered.

The lowest known pressure in the centre of a cyclone is 886.8 mb., reduced to mean sea level; it was recorded about 400 nautical miles east of Luzon (Philippines) on August 18, 1927.

**Cyclonic Rain.**—The rainfall associated with the passage of atmospheric low pressure systems and due to the vertical motion set up by an air mass rising over another air mass of different temperature. See DEPRESSION, CONVECTIONAL RAIN, OROGRAPHIC RAIN.

**Cyclostrophic.**—See GRADIENT WIND.

**Damp Air**—As distinguished from dry air, damp air implies in meteorology a high degree of RELATIVE HUMIDITY. When its relative humidity equals or exceeds 85 per cent. of saturation air may fairly be called damp. It will deposit some of its moisture in dry woollen fabrics, cordage or other fibrous material, though its water will not condense upon an exposed surface until 100 per cent. is reached.

**Dawn.**—(O.E. *dagian*, to become day), the time when light appears (*daws*) in the sky in the morning or the interval between the first appearance of light and the rising of the sun. See TWILIGHT.

**Day.**—A solar day is the interval of time which elapses between successive occasions on which the sun is in the meridian of any fixed place. These occasions are known as “transits” of the sun. A sidereal day is the corresponding interval between successive transits of a distant fixed star. Since the earth moves in an orbit round the sun in the same sense of rotation as that of its rotation about its axis, the length of the solar day is slightly greater than that of the sidereal day.

Owing to the eccentricity of the earth's orbit and to the inclination of the equator to the ecliptic, solar days are of slightly unequal lengths at different times of the year. The average length of the solar day is 86,400 seconds. This is called the “mean solar day” and it is taken as the length of the civil day, or, the “day” of ordinary parlance. The sidereal day contains 86,164 seconds nearly.

The epoch of the beginning and end of the civil day is fixed by the civil power. In this country a civil day in winter begins and ends at midnight *Greenwich Mean Time*; in other words, the standard longitude for purposes of civil time reckoning is that of Greenwich. During the operation of BRITISH SUMMER TIME, however, the civil day begins and ends at 23 h. G.M.T.

**Débâcle.**—The breaking up in the spring of the ice in the rivers. The term is chiefly applied to the great rivers of Russia and Siberia and of the North American continent. Débâcle lasts from two to six weeks; during the period the rivers often overflow their banks, inundating the surrounding country. In southern Russia débâcle begins about the middle of March, in latitude 55°–60° N., it begins early in April, but in the north it does not begin until May and in the extreme north of Siberia not until June. In Canada in Ontario the débâcle takes place in March and the water is free by April, in the St. Lawrence it is a little later, the river being free of ice in May.

**Declination, Magnetic.**—The angle between the magnetic meridian (the direction of the magnetic axis of a freely suspended or pivoted magnetic “needle”) and the geographical meridian. By some users this angle is called the “magnetic variation.” Declination is subject to a regular diurnal variation, to irregular comparatively short-period changes, and to secular change. See TERRESTRIAL MAGNETISM.

**Dekad.**—In meteorology, a period of ten days, but *decade* is often used for ten years.

**Density.**—The mass of unit volume of a substance. The density of pure water, for example, is 1.000 gram\* per cubic centimetre at a temperature of 277°A. It is necessary to specify the temperature in stating the density as at any other temperature the same sample of water will occupy a greater volume, so that the mass per cubic centimetre is then less. At 283°A. the density is 0.998 gm./cm<sup>3</sup>. Strictly, the pressure also should be stated, as the volume of a sample of water alters with the pressure to which it is subjected; but for ordinary pressure changes these alterations in the case of a liquid or of a solid are so slight as to be of no practical consequence.

In meteorology we are concerned more particularly with the density of the air, and it is necessary to specify not only the temperature and pressure when stating a numerical value for it, but also its constitution. Dry air is a mixture of gases of which oxygen and nitrogen form about 99 per cent., the remainder consisting of carbon dioxide and a number of rare gases of which argon is the chief (see ATMOSPHERE). For all practical purposes the relative proportions of these gases in the atmosphere remain constant, so that dry air may be regarded as a single gas when considering questions of density; but atmospheric air is never completely dry, as it always contains a quantity of water vapour which, though relatively small, is variable and, in consequence, causes appreciable changes in the density.

The factors which affect air density are, therefore, pressure, temperature and the proportion of water vapour present. An increase of pressure, if temperature and water vapour content remain unaltered, will increase the density. An increase of temperature, if pressure and water vapour content remain the same, will result in a decrease in the density. If the proportion of water vapour is increased, temperature and pressure remaining the same, the density will be diminished; the pressure in this case is the sum of the air pressure and the pressure exerted by the water vapour, so that for the total pressure to remain unaltered the addition of water vapour, which exerts its own pressure, must be made by displacing some of the air. As the density of water vapour is less than that of air at the same pressure the average density of the mixture after the introduction of more water vapour is lower than the original density. A more usual feature of the practical problem is perhaps the loss of water vapour by condensation. If the original sample of air is saturated a fall of temperature will result in an increase of density if pressure remains the same, not merely on account of the direct effect of the lower temperature alone, but also by the lowering of the proportion of water vapour present in the sample, following the condensation which results from the fall of the temperature below the dew point.

The effect of each of these factors is quite definite and has been determined by measurements. These measurements result in the following formula for the calculation of the density of any given sample of air, or the density of atmospheric air, when the temperature, pressure, and pressure of the aqueous vapour present is known :—

$$\Delta = \Delta_0 \frac{p - \frac{3}{8}e}{p_0} \cdot \frac{T_0}{T}$$

where

- $\Delta$  is the density of the sample of air to be computed,
- $\Delta_0$  is the density of dry air at pressure  $p_0$  and temperature  $T_0$ , absolute,
- $p$  is the barometric pressure of the sample,
- $T$  is the temperature, in degrees absolute, of the sample,
- $e$  is the pressure of aqueous vapour in the sample.

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\* The authors of the metric system intended the relation to be precise, but it is now accepted that the maximum density of water is .999972 gram per cubic centimetre.

The density of dry air at a pressure of 1000 mb. and a temperature of 290°A. is 1,201 grams per cubic metre, so that the formula may be written :—

$$\Delta = 1201 \cdot \frac{p - \frac{3}{8}e}{1000} \cdot \frac{290}{T}$$

$p$  and  $e$  being measured in millibars.

The numerical value of  $e$  is readily determined from the readings of a dry- and wet-bulb psychrometer, from which the vapour pressure for the temperature of the sample, that is, the dry-bulb reading, is obtained by reference to suitable hygrometric tables.

The question of air density is of importance in meteorology, as it is because of the different densities of adjacent masses or converging currents of air that convection takes place in the atmosphere; the less dense air rising while that with the greater density tends to descend. In this way vertical circulation, as seen in such phenomena as land and sea breezes, is brought about. The rain and cloud in certain parts of low-pressure systems, or depressions, are also due to the rising of air of comparatively low density over currents of denser and usually cooler air. KATABATIC winds may also be mentioned as important meteorological phenomena due primarily to a difference between the density of the air on the slopes of a hill and that of the air at the same level above the valley.

Atmospheric density varies with both time and place. At a height of about eight kilometres, however, the density is uniform. Above this height the density at any level decreases as we go from the equator to either pole, while below this height the density increases from equator to pole. At a height of eight kilometres, also, the density does not change appreciably throughout the year. Above this height density is normally greatest in summer, while below this level density is at its maximum in winter.\*

Normally density is approximately uniform in a horizontal plane, but this does not hold where local circulations exist. For different types of pressure distribution the late W. H. Dines has given the following values for the density at the heights stated over the British Isles. The relative humidity is assumed to be 75 per cent.

Height	Anticyclone	Depression	Height	Anticyclone	Depression
Km.	gm./m <sup>3</sup> .	gm./m <sup>3</sup> .	Km.	gm./m <sup>3</sup> .	gm./m <sup>3</sup> .
10	421	382	5	736	724
9	474	444	4	818	807
8	531	514	3	911	893
7	595	583	2	1,012	992
6	662	652	1	1,137	1,100

**Depression.**—A depression is a part of the atmosphere where the barometer is lower than in the surrounding parts. It is occasionally called a “ cyclone ” or simply a “ low.” The isobars round such an area of low pressure are more or less circular or oval. Depressions vary enormously in size, one may be only a hundred miles in diameter and another over two thousand miles; some are deeper than others, a deep depression being one in which the pressure is very much lower near the centre than on the outside while, on the other hand, a shallow depression is one where the pressure, although perhaps low near the centre, is not very much lower than in the surrounding districts. North of the equator the wind blows round the depression in a counter-clockwise direction, with some motion inwards across the isobars; its strength is in all cases closely related to the steepness of the barometric gradient, the steeper the gradient the stronger the wind. The weather in a depression is of

\* S. N. Sen.: “ On the distribution of air density over the globe.” *London, Quart. J.R. met. Soc.*, 50, 1924, pp. 29-51.



an unsettled type. Depressions in middle latitudes usually move in an east to north-east direction but any direction may be followed. The velocity of translation varies with each depression, and in any single one the velocity is never constant. Some depressions may move as much as 600 or 700 miles per day, while others remain practically stationary. Depressions, in their movement, carry their weather with them, but the weather is subject to changes due to changes which take place in the depression itself.

The origin of a depression has formed an interesting study to many investigators. It used to be thought that some local cause of heating of the air led to a rising column of warm air which owing to its reduced weight gave low pressure at the base. A wind circulation was set up around the area of low pressure and the depression was formed. This theory was generally held until upper air observations showed that in the free air depressions tend, on the average, to be cold not warm, and that at the centre of a well-marked depression, pressure is low not only on the surface of the earth but at the base of the STRATOSPHERE, which in well-marked depressions is found some five miles above the surface. This suggested that depressions were not phenomena of the lower atmosphere only, and that it might be necessary to seek their cause either in the layers above a height of five miles which form the stratosphere or at the surface of separation between the lower layers, the TROPOSPHERE and the upper layers, the stratosphere. The impossibility of obtaining a network of day-to-day observations in the stratosphere hampered and still hampers investigation on these lines, and in the last twenty years attention has again been concentrated on the troposphere by the ingenious theories put forward by V. and J. Bjerknes, father and son, of Bergen and by Professor Exner, of Vienna. Both these theories ascribe depressions to the interaction between warm and cold air masses, and as the Bjerknes theory has been widely adopted among European meteorologists, a brief account of it will be given. It is based on the observed fact that most depressions originate on a comparatively straight FRONT. In the simplest case, which is illustrated in Fig. 17 (a), the cold and warm currents are flowing in opposite directions. In all cases there is a wind discontinuity at the front of cyclonic type (i.e. if the directions are the same, the stronger wind is on the side of the higher pressure). From the front a SURFACE OF DISCONTINUITY slopes upwards over the cold air. The stability of the system pictured is easily disturbed, and waves develop on the surface of separation which are shown on the earth by tongues of warm air projecting into the polar air and deflecting the polar front as in Fig. 17 (b). Under these conditions the currents no longer flow parallel and side by side. The warm air current climbs over the colder air in front, while the cold air in the rear undercuts the warm air. Pressure falls at the tip of the tongue of warm air and the isobars begin to assume the form associated with depressions. The line where warm air is climbing over cold air is termed the WARM FRONT of the depression, the line where cold air undercuts warm, the COLD FRONT. The ascent of the warm air tends to narrow down the tongue of warm air and ultimately the warm air is driven from the surface altogether, the cold air in the rear catching up the cold air in the front. The depression is then said to be occluded (see OCCLUSION), and soon begins to decrease in intensity. The portion of the front AB in Fig. 17 (c) is an occlusion. Such in brief outline is the life history of a depression as viewed by the Bergen School. The rainfall, which forms such a notable feature of most depressions, is chiefly confined to the region along the fronts. Warm-front rain falls ahead of the line where warm air is rising over cold, and cold-front rain, which often takes the form of short heavy showers accompanied by squalls, falls where the cold air is undercutting the warm.

It may be asked why, if depressions can be divided into warm and cold sectors in this way, synoptic charts had been drawn daily for some 40 or 50 years before meteorologists discovered the fact. The answer undoubtedly is that depressions generally reach Europe from the Atlantic and are nearly

always occluded before entering the land area where detailed analysis of the conditions becomes possible. It is thus rare to find well-marked warm sectors with their attendant warm and cold fronts on the daily weather maps prepared by the European meteorological services, and only by careful study and expert knowledge can the position of the fronts be located.

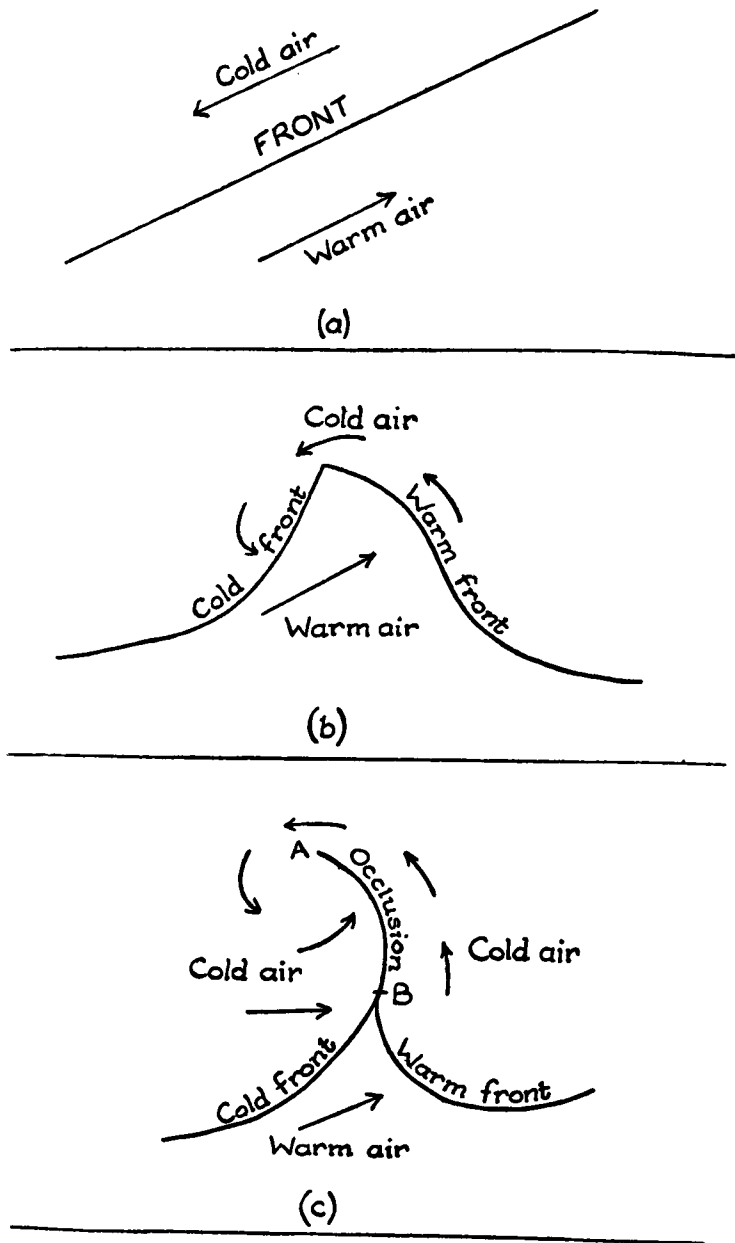
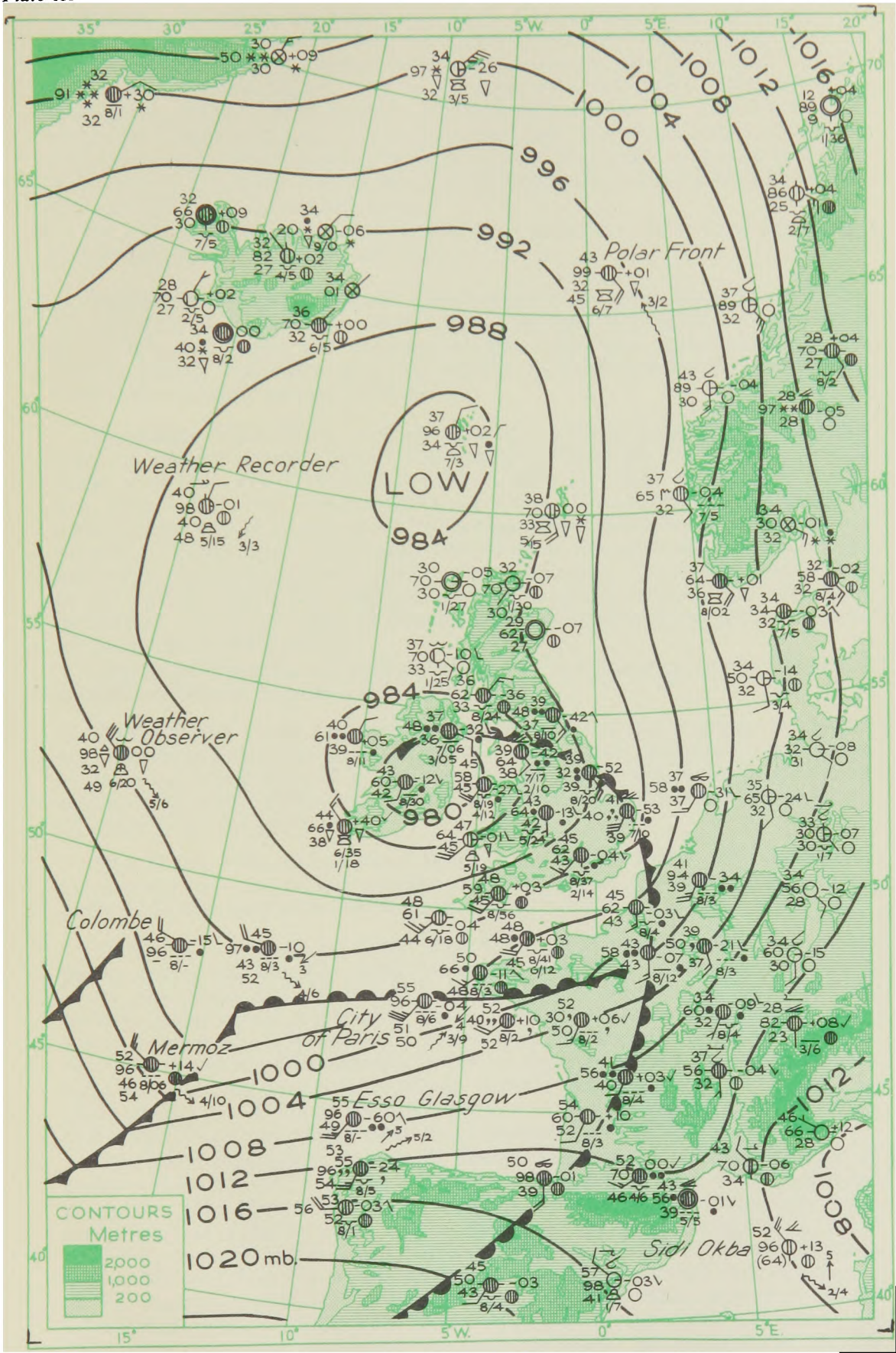


FIG. 17.

It may be pointed out that at times, depressions appear on the weather map which seem to have formed entirely within polar air, and it may be necessary to return to a modified form of the older local heating theory. It would seem to follow, therefore, that depressions not only differ amongst themselves but also differ in their origin.

The life of a depression is very varied and may extend from one or two to five or more days. When a low pressure system appears to maintain its existence for a long period it frequently happens that it is reinforced from time to time by combining with associated SECONDARY DEPRESSIONS which have developed on its southern side. (See Plate III).



FEBRUARY 8, 1951, 0600 G.M.T.  
DEPRESSION



**Desert.**—A region in which the high temperature and small rainfall cause the evaporation to exceed the precipitation, and consequently there is insufficient moisture to support vegetation. Deserts may be caused by any of the following conditions: (1) the presence of a persistent anticyclone, an example due to this cause occurs in northern Africa where the Sahara coincides with the average position of the sub-tropical belt of high pressure; (2) a cold current on the western coast of a large mass of land such as occurs in Peru; and (3) a configuration of ground which shuts out the moisture-bearing winds, for example, Gobi, in central Asia.

For a formula used by Köppen and Geiger for the limit of rainfall which constitutes a desert climate, see ARID.

**Desiccation.**—The permanent disappearance of water from an area due to a change of climate and especially a decrease of rainfall. Large areas in central Asia, Africa and western America have been desiccated since the Glacial period, but there does not appear to have been much progressive desiccation during the past 2,000 years.

**Deviation.**—The difference of an observation from the mean value of the series of which it forms a part. For example, the mean January pressure at Kew, over the period 1901–30 is 1016·7 mb., the mean in January, 1938, was 1012·3 mb., and the deviation  $-4\cdot4$  mb. The deviations of a series of observations can be summarised by finding either the *mean deviation* or the STANDARD DEVIATION. The mean deviation is the arithmetic mean of the individual deviations taken without regard to sign; the standard deviation is the square root of the arithmetic mean of the squares of the individual deviations. In most series of observations the standard deviation is about  $1\frac{1}{4}$  times the mean deviation.

The angle between the surface WIND and the direction of the isobars is sometimes termed the deviation of the wind.

**Dew.**—Water drops deposited by condensation of water vapour from the air, mainly on horizontal surfaces cooled by nocturnal radiation. In the case of grass and the foliage of plants the greater part of the water drops which appear after a cold night were proved by Aitken to be the result of exudation of water from the plant.

**Dew Point.**—The temperature to which air can be cooled without causing CONDENSATION. It is the temperature for which the saturation vapour pressure is identical with the pressure of the vapour in the air.

**Dewpond.**—A pond on high ground on chalk downs which retains its water during all but the most prolonged droughts, after ponds at lower levels are dried up. A dewpond is artificially constructed, a watertight bottom being made of about 9 in. of puddled chalk or clay treated with lime; a layer of chalk rubble is placed over the bottom to protect it from the feet of cattle. Sometimes a layer of straw is placed below the watertight bottom, sometimes it is placed above—between the bottom and the chalk rubble; in a few ponds there are two or three alternate layers of straw and puddled clay, in others there is no layer of straw at all.

The chief interest in dewponds lies in the mystery of their supply of water; they do not dry up in hot summer weather in spite of the watering of cattle. The idea that gave the ponds their name was that they were replenished at night by dew, the theory being that the non-conducting layer of straw prevented the outward radiation from the heated earth from reaching the water, and that the water, therefore, was kept cool and dew condensed on it. Careful experiment, however, seems to show that only very rarely in the short summer night does the temperature of the water fall below the dew-point. Another suggestion was that the water was replenished by the heavy night mists which enshroud the higher part of the downs during hot summer weather, the mist condensing on surrounding shrubs and dripping



into the pond or being deposited mechanically by turbulence. In any case by far the greater part of the supply of water must come from rain, which is greater at high levels than in the plains, the wide shelving margins of the ponds serving as GATHERING GROUNDS.

**Diathermancy—Diathermanous.**—(Based on B. Stewart. "Treatise on Heat." 2nd Ed., pp. 183–5.) The discovery, by Melloni, that rock salt is a body which transmits heat freely, sufficiently indicates that most substances which are transparent for light are not so with regard to heat. This is expressed by saying that most substances are "athermanous" and that rock salt is almost the only "diathermanous" solid, these two words corresponding to the terms opaque and transparent in the science of optics. Tyndall found that a solution of iodine in bisulphide of carbon has the property of completely stopping the light rays, while it allows dark heat to pass in great quantity. He found that a fluid lens formed of this solution and enclosed in rock salt will stop all the light from an electric lamp but permit the dark rays to pass in abundance.

Oxygen and nitrogen are diathermanous, water vapour and carbon dioxide absorb heat rays of certain wave-lengths so that atmospheric air is only partially diathermanous.

**Diffraction.**—Ordinary experience with light suggests that it always passes through the air in straight lines, and that it cannot go round an obstacle. This is an apparent contrast with sound; for we hear without difficulty round a corner. There are, however, numerous phenomena which indicate that light can be diverted from the straight course by obstacles. These phenomena are grouped under the name of diffraction. They can be explained by the wave theory of light. According to this theory the contrast between the behaviour of light and sound is a matter of scale, the wave-lengths of light being very small in comparison with those of sound.

Light is diffracted by waterdrops to produce CORONAE, as well as other colour effects observed on clouds. A rarer phenomenon, BISHOP'S RING, is explained by diffraction by dust particles in the upper atmosphere. The blue of the sky is due to the scattering of light by the molecules of which the air is constituted. Scattering of this type is regarded by some authors as covered by the term diffraction.

**Diffusion.**—The term diffusion is used in meteorology to indicate either molecular diffusion or else eddy diffusion.

Molecular diffusion is the process by which contiguous fluids mix slowly even in spite of differences in their density. The process of molecular diffusion follows certain definite laws which are similar to those for the diffusion of heat by thermal conduction. This process is so slow, however, that in practice the effects due to it are usually negligible compared with those produced by eddy diffusion.

Sir G. I. Taylor has shown that eddy diffusion, or mixing in the atmosphere by turbulent motion (see TURBULENCE) follows the same type of law as molecular diffusion in certain respects. More recent work, particularly that of L. F. Richardson, has shown that this similarity or analogy extends only up to a point. The laws relating to eddy diffusion appear to be more complex than those for the better-known type of diffusion. This difference is due, at least partially, to the fact that the eddies which cause the diffusion vary over a wide range of size.

**Discontinuity.**—As a rule the fundamental atmospheric variables, pressure, wind velocity, temperature and humidity, are continuous functions of space and time. Occasionally, however, their variation in a small distance (or in a short time at a fixed point) is so much above normal that their distribution is regarded as discontinuous. For example, a fall of 10° F. in temperature,

usually spread over some hours at least, may take place in a few minutes and this indicates what may be regarded as a discontinuity in the atmosphere. See also SURFACE OF DISCONTINUITY.

**Disturbance.**—Sometimes used instead of DEPRESSION, especially in broadcast general inferences.

**Diurnal Variation.**—This term is used to indicate the changes in the course of an average day of the magnitude of a meteorological element. If we have a series of hourly values of the element for a large number of days, and if we determine the average values for those days of the element at 1h., 2h., . . . . 24h., it will be found that the averages show steady and regular variations during the course of the twenty-four hours, and that irregular fluctuations which may appear on any of the days are eliminated from the averages provided the number of days taken is large enough. Thus the characteristic feature of the diurnal variation of atmospheric pressure is a 12-hourly oscillation which has its maxima at the same local time all over the intertropical and temperate zones. In the polar regions the oscillation has its maxima at the same absolute time along a circle of latitude. The amplitudes of those waves are greatest at the equator and diminish towards the poles. This double wave of pressure may be seen occurring with great regularity each day on the traces from a self-recording barometer in the tropics, the maxima occurring approximately at 10h. and 22h. and the minima at 4h. and 16h. In the British Isles non-periodic changes in pressure, due to the passage of cyclones and anticyclones, are as a rule so relatively large that they obliterate the 12-hourly oscillations, but the latter may be recognised in periods of quiet settled weather, and are evident when averages are taken of hourly values as explained above. Other elements showing conspicuous diurnal variations, especially during the warmer months of the year, are air temperature and relative humidity. Diagrams showing the diurnal variation in each month of air temperature, based on data for 25 years at Aberdeen, Kew Observatory, Valentia Observatory and Falmouth are given in "Temperature Tables of the British Isles" (M.O. 154, 1902). Temperature is normally at a maximum about two hours (in winter) to three hours (in summer) after local mean noon and at a minimum about sunrise. Relative humidity depends not only on the amount of moisture which the air contains, but on the temperature of the air, and on days when the temperature range is large relative humidity also exhibits large variations; it is normally at a minimum in the afternoon about the time of occurrence of maximum temperature, and at a maximum in the early morning about the time of occurrence of minimum temperature. The *Observatories' Year Book*, a serial publication of the Meteorological Office, contains many data relating to the diurnal variations of meteorological and geophysical elements.

**Divergence.**—Divergence is the opposite of CONVERGENCE, the article on which should be consulted. If the winds are such that more air flows out of a given area than flows into it there is said to be divergence. The deficiency of air must be made good by a downward current from the upper layers. Such a downward current is termed SUBSIDENCE. The chief effects are absence of precipitation and the frequent development of INVERSIONS with dry air above them. Since the lower layers of the atmosphere hold most moisture, divergence tends to cause a steady decrease in the total water content in the column of air over a given area. No appreciable divergence can take place with a system of geostrophic winds (see GRADIENT WIND). The two chief causes are, first, surface friction, which causes a flow of air near the ground from high to low pressure, with divergence from an anticyclone or ridge of high pressure. Secondly, there is divergence from a region of rising barometer, owing to lack of perfect balance between wind and pressure gradient. This effect is smaller near the ground than the frictional divergence from an anticyclone, but it extends much higher and is probably often more important.

**Doctor.**—See HARMATTAN.

**Doldrums.**—The equatorial oceanic regions of calms and light variable winds accompanied by heavy rains, thunderstorms and squalls. These belts are variable in position and extent, and as a whole move north and south with the annual changes of the sun's declination. The movement is considerably less than that of the sun and is of the order of  $5^{\circ}$  on either side of the mean position, with a lag of from one to two months behind the sun.

**Drainage Area.**—The area whose surface directs water towards a stream above a given point on that stream. See also CATCHMENT AREA and GATHERING GROUND.

**Drizzle.**—Precipitation in which the drops are very small. If the drops are of appreciable size although the rain is small in amount the term adopted is "slight rain."

**Drops.**—See RAINDROPS.

**Drosometer.**—An instrument for measuring the quantity of dew deposited. A self-recording type ("drosograph") used in Italy consists of a light horizontal pan to receive the dew the weight of which is made to actuate the recording pen, through a system of levers.

**Drought.**—Dryness due to lack of rain. Certain definitions have been adopted in order to obtain comparable statistical information on the subject of droughts. Thus an *absolute drought* is a period of at least 15 consecutive days, to none of which is credited 0.01 in. of rain or more. A *partial drought* is a period of at least 29 consecutive days, the mean daily rainfall of which does not exceed 0.01 in. A *dry spell* is a period of at least 15 consecutive days to none of which is credited 0.04 in. of rain or more. During the 62 years 1858–1919 there were 69 absolute droughts and 163 dry spells at Camden Square, London. The definitions of absolute drought and partial drought were introduced in *British Rainfall*, 1887, p. 21, while that of dry spell was first used in *British Rainfall*, 1919, p. 15. A chapter is devoted to the subject in each volume of *British Rainfall*.

**Dry Air.**—When a meteorologist speaks of "dry air" he does not normally mean air that contains no AQUEOUS VAPOUR, although a chemist or physicist, speaking of laboratory experiments, would generally use the words in that sense: the atmosphere, even in the driest parts of the world, always contains some aqueous vapour, but in the laboratory air can be made perfectly dry, hence the distinction. In meteorology we may take it that air referred to as "dry" has at least a sufficiently low RELATIVE HUMIDITY for EVAPORATION to be taking place actively from earth, rock, etc., as well as from vegetation. In the BEAUFORT NOTATION a more precise meaning has been attached to the words, which are applied only to air with a relative humidity of less than 60 per cent.; the Beaufort letter for such air is "y."

**Dry- and Wet-Bulb Hygrometer.**—See PSYCHROMETER.

**Dry Season.**—A period of a month or more with little or no rain, which recurs regularly every year. Thus on the north coast of Africa summer is the dry season, while on the coast of West Africa the dry season occurs in winter of the northern hemisphere. See also CLIMATIC ZONES.

**Dry Spell.**—See DROUGHT.

**Duration of Sunshine.**—The number of hours in any period (e.g. a day, month or year), estimated according to long-established practice from the records of a SUNSHINE RECORDER, during which the sun was sufficiently intense to scorch the standard card when concentrated by the standard glass sphere. Normal values of mean daily and monthly duration of sunshine for numerous stations are given in "Averages of Bright Sunshine for the British Isles".



**Dusk.**—The time when civil twilight ends, the darker stage of twilight or the interval between the time of ending of civil twilight and the onset of complete darkness. See TWILIGHT.

**Dust.**—The atmosphere carries in suspension, often for long distances, solid particles of varying character and size. The chief sources of these particles are volcanic eruptions, meteors, sand raised by storms of wind over deserts and, in the neighbourhood of towns, industrial and domestic smoke. This atmospheric dust is of considerable importance meteorologically. If present in sufficient quantity it weakens the sunlight, this usually occurs in calm weather in large cities.

Volcanic eruptions of an explosive type, such as that of Krakatoa in 1883, project into the higher levels of the atmosphere enormous quantities of very fine dust, so fine that it takes more than a year to settle. The volume of dust from Krakatoa has been estimated as 18 cubic kilometres. This dust interferes with the passage of the sun's radiation through the atmosphere, and the measurements made at the Smithsonian Astrophysical Observatory on Mount Wilson after the eruption of Mt. Katmai, Alaska, in 1912, showed a decrease of 20 per cent. Terrestrial radiation to space is also intercepted and partly returned to the earth, but W. J. Humphreys has shown that this process is less effective than the interception of solar radiation, so that volcanic dust lowers the temperature. Humphreys suggests that in this way it may be one of the causes of ICE AGES. Another effect of volcanic dust is the unequal diffraction of light rays, producing brilliant sunsets. See SUNRISE AND SUNSET COLOURS.

Whether ordinary dust particles act as nuclei for the condensation of water vapour in the air is not clearly understood. There are present in the atmosphere, as well, particles of hygroscopic substances such as common salt, sulphuric acid, etc.; these are known as "hygroscopic nuclei," and molecules of water will condense on them when the air is only 75 per cent. saturated.

The amount of dust present in the air can be measured by a DUST COUNTER.

**Dust Counter.**—An instrument for counting the dust particles in a known volume of air. In Aitken's dust counter condensation of water is made to occur on the nuclei present and the number of drops is ascertained. Hygroscopic nuclei as well as true dust particles are, therefore, recorded. In Owens' dust counter a jet of damp air is forced through a narrow slit in front of a microscope cover glass. The fall of pressure due to expansion of the air after passing the slit causes the formation of a film of moisture on the glass, to which the dust adheres, forming a record which can be studied under a microscope.

**Dust Devil.**—A whirlwind, formed by strong convection over a dry sandy region, which carries up the dust into the air with it. Dust devils have been observed to rotate both in clockwise and counter-clockwise directions. Their estimated heights vary considerably, in some cases they are said to reach as high as 2,000 or 3,000 ft. The speed with which they move also varies very much, it may be under 5 miles an hour, or it may exceed 30 miles an hour.

**Duststorm.**—Duststorms occur when a very turbulent wind passes over dry sandy or dusty soil. The winds associated with them may be relatively strong but not necessarily very strong, their most pronounced characteristic being their turbulent nature rather than their strength. Their arrival is usually marked by the advance of a "wall of dust," towering upwards for several thousand feet and sometimes extending up to over 10,000 ft. In advance of this wall the wind is light and the weather oppressively warm, while behind it, in the duststorm, the wind rises and visibility is reduced to low limits by the flying dust and debris raised from the ground. These storms

are frequent in such arid desert regions as are to be found in the middle of north Africa and in the plains of Iraq, north-west India and the United States.

For the development of a duststorm there are three essentials: (1) an ample supply of fine dust or dry silt, (2) relatively strong winds to stir it up and (3) a steep lapse rate of temperature in the dust-carrying air. The last two conditions are frequently associated with the thundery squall which blows outwards in front of an advancing thunderstorm. For this reason duststorms are particularly liable to occur in thundery weather in desert regions. In such regions the air is frequently so dry that the rain associated with the thunderstorms evaporates before it reaches the ground, but when the rain does reach the ground the dust is washed down with it and the duststorm is usually short-lived and patchy.

There is a marked distinction between duststorms and sandstorms. See SANDSTORM.

**Dynamic Cooling.**—The fall of temperature produced by expansion due to diminished pressure. See ADIABATIC.

**Dyne.**—The C.G.S. unit of force. It is the force which, applied to a mass of one gramme during one second will produce a velocity of one centimetre per second.

**Earth Currents.**—The existence of electric currents flowing in the earth's crust and the association of abnormally high values of such currents with magnetic storms and notable auroral displays have been known since the early days of telegraphy. Apart from observations of the current in ordinary telegraphic lines, systematic information is obtained by recording continuously the potential difference between a pair of similar electrodes buried in the earth, under as nearly as possible like conditions, and separated by a convenient distance which should not be much less than a mile. In order to obtain data as to the resultant current, or potential difference, it is desirable to have two pairs of electrodes situated respectively in and perpendicular to the meridian. Because of lack, until recently, of reliable data as to the conductivity of the earth's crust in the neighbourhood of recording stations, it is customary to express the observational results not in terms of current density but in terms of potential gradient between the pairs of electrodes. Owing to various inherent difficulties (electrode effects, local peculiarities, etc.), there is considerable uncertainty as to average values and resultant direction of the earth potential gradient. It appears that in normally quiet times the average potential gradient may be as high as 0.2 or 0.3 volt/Km., although the values found in several places are very considerably less than this; while at times of disturbance values of at least 1 volt/Km. have been observed. Data as to the general direction of flow of earth currents are somewhat confusing, for example, 17° E. of N. at Haparanda, 59° at Lund, 19° at Houlton, 25° at Wyand, 31° at New York, 70° at Tucson, 79° at Chesterfield, 63° at Fairbanks (Alaska) and 80° at Watheroo (Western Australia). It is considered that the distribution of land and water exerts an important influence on the whole system of superficial currents.

**Diurnal Variation.**—The earth potential gradient undergoes regular solar and lunar diurnal variations, the lunar variation having about one-fifth the range of the solar.

Considerable differences in type and amplitude are found between the solar variations at different stations. At most places two maxima and minima exist, the chief minimum of the north component occurring near noon in the northern hemisphere, but at Huancayo (Peru) the variation is a simple oscillation centred at noon. The variation at Watheroo is similar in form but opposite in sign to that in the northern hemisphere. Except at Tucson, Arizona (where the variations are parallel) the eastward component varies similarly to the northward, but is opposite in phase. The range of the solar diurnal variation is least in winter and greatest in spring and summer.

*Connexion with Terrestrial Magnetism.*—Part, at least, of the electric field in the earth's crust is connected with that associated with the magnetic field. The primary electric current system considered as existing in the ionosphere produces during magnetic storms a secondary field in the earth (at a depth of some 250 Km. according to Chapman), with currents also in the surface strata; in such cases and only in such cases is there a close parallelism between recorded earth currents and magnetic variations. In magnetically quieter conditions there is similarity between the east component of the earth current and the horizontal component of magnetic force, but a pronounced difference between the north component of the earth current and the east component of magnetic force.

**Earthquake.**—Any rapid movement of the ground may be called an earthquake. The term is usually restricted, however, to movements which originate naturally and below the surface. There is an enormous range in the intensity of earthquakes. In a destructive earthquake the range of oscillation of the ground may be as much as four inches, and the maximum acceleration of the movement may be comparable with the acceleration due to gravity. Permanent changes of level may occur. Such a great earthquake may be felt by sensitive persons 1,000 miles from the central area.

The initial displacement which results in an earthquake usually occurs at some considerable depth below the surface. The place where this initial displacement occurs is called the focus or hypocentre. The spot on the ground vertically above the focus called the epicentre. The depth of the focus is only a mile or so for volcanic earthquakes. The small earthquakes experienced in the British Isles (e.g., Hereford and Jersey, 1926) have focal depths of less than 6 miles.\* For greater earthquakes the depth is generally comparable with 30 miles, but in certain regions, notably round the Pacific Ocean, there are "deep focus earthquakes" which originate at depths from 100 to 350 miles.†

Each year there are on the average about 5,000 earthquakes large enough to be felt.‡ Of these about 100 are more or less destructive. The number of earthquakes the waves from which are registered by seismographs in England is about 300. Nearly half of these have their origins under the sea.

The larger earthquakes are all to be attributed to the yielding of the rocks under the influence of such forces as produce the folding of strata and the growth of mountains. Probably the fracture usually occurs along an existing fault, one part of the rock shearing over another. In some cases the shearing movement extends to the surface; the amount of the displacement may be as much as 20 ft., vertically or horizontally. The dislocation which takes place in a single earthquake may not relieve the strain entirely. A great earthquake is usually followed by a series of after-shocks.

To the question whether the frequency of earthquakes depends on the influence of the moon or on the weather no very definite answer can be given except that such influences are by no means dominant.

The waves which are propagated from an earthquake and are recorded by seismographs pass through the body of the earth or round the crust. The first to reach a distant station are body-waves of compression and expansion, these are followed by body-waves of distortion and these again by the surface waves. Thus when the distance from the epicentre is one-quarter of the earth's circumference the times of passage are approximately 13 min. 16 sec., 24 min. 14 sec. and 43 min. 30 sec. for the three types of wave. The superficial waves are generally much larger than the body-waves, which together constitute the "preliminary tremors," but deep focus earthquakes produce comparatively small superficial waves. The discussion of the behaviour of the different waves has thrown much light on the constitution of the interior of the earth.

\* Jeffreys, H.: *London, Mon. Not. R. astr. Soc., geophys. Suppl.*, Vol. I, No. 9.

† Turner, H. H.: *London, Mon. Not. R. astr. Soc., geophys. Suppl.*, Vol. I, No.

‡ A. Sieberg: "Erdbebenkunde," Gustav Fischer, Jena, 1923.

**Earth Temperature.**—The temperature of the interior of the earth is very high, and in consequence heat flows by conduction from the interior towards the cooler surface. If the temperature of the surface layer were constant the flow of heat would be constant, and a steady gradient of temperature would be established right up to the surface. In these circumstances, the temperature differences at different depths would be approximately proportional to the differences between the depths and temperature would always increase as the depth increased.

This simple régime is profoundly affected by the fact that the temperature of the surface layers of the earth is subject to large changes, some of which are periodic and some irregular. By far the largest variations are increases due to solar radiation and decreases due to terrestrial radiation, but conduction of heat from the superincumbent air also plays an important part. The two principal types of periodic variation are (1) seasonal and (2) diurnal.

If the surface layer is subjected to a steadily increasing temperature the gradient of temperature in the first few inches of the soil is reversed, and heat commences to flow downwards from the surface towards the layer of minimum temperature. Below that layer the flow remains upwards from the heated interior. The establishment of a flow of heat downwards takes time but, on the other hand, when the flow is once established it will persist after the increase of temperature at the surface has disappeared. If now the temperature of the surface layer is steadily reduced the temperature gradient in the first few inches becomes such that heat again flows upwards, and we have a peculiar arrangement in which temperature downwards increases at first, reaches a maximum, then diminishes, reaches a minimum and finally increases again steadily towards the interior. Every variation of temperature at the surface leads to a corresponding propagation of heat upwards or downwards, but the rapid variations have not time to extend very far down. The diurnal variation disappears at a depth of less than 3 ft. as a rule, but the seasonal variation has time to spread down much further, to about 30 or 40 ft. At some such depth the temperature is sensibly constant and below that depth there is a steady increase of temperature downwards, the conditions being now unaffected by surface fluctuations of temperature.

The following average values of temperature in the soil at Oxford illustrate some of the above statements: at six inches, earth temperature is lowest ( $38\cdot5^{\circ}$  F.) in December and highest ( $69\cdot4^{\circ}$  F.) in August; at ten feet, earth temperature is lowest in April ( $47\cdot5^{\circ}$  F.) and highest in September ( $57\cdot5^{\circ}$  F.). In April and also in September there is not much difference between earth temperature at six inches and at ten feet, but at five feet earth temperature in April is less than at six inches or ten feet, while in September it is greater. In the summer months the temperature at six inches is much in excess of that at ten feet, while in the winter months temperature steadily rises from six inches to ten feet.

The variations of earth temperature produced by periodic variations of the temperature of the surface layers have been studied mathematically, and the results of the investigations have been verified by observation.

**Earth Thermometer.**—A thermometer for ascertaining the temperature of the soil at a known depth. The commonest form (Symons's) consists of a mercurial thermometer with its bulb embedded in paraffin wax, suspended in a steel tube at depths of one foot or four feet. For depths of a few inches only a mercurial thermometer with its stem bent at right angles, for convenience in reading, is employed.

**Eclipse Weather.**—The influence which the eclipse exercises on solar radiation received depends on a number of factors, but broadly speaking the radiation at any time is proportional to the extent of the unobscured sun. Light diminution is very gradual in the early partial phases, and very

rapid just before totality. During the total phase light is received from two sources, the solar appendages, chiefly the corona, and the partially illuminated atmosphere lying at the moment just outside the umbral shadow. Of those the former is by far the largest contributor, but the illumination from both causes varies with the circumstances of individual eclipses.

The fall of temperature is one of the most clearly defined phenomena, but is influenced by many factors. A table compiled by H. H. Clayton of 12 total eclipses from 1878 to 1905, after correction for diurnal variation, shows maximum falls varying from  $1.5^{\circ}$  F. to  $8.1^{\circ}$  F. The amount of fall varies with the character of the station, being for the eclipses cited  $1.5^{\circ}$  F. over the open ocean,  $3.2^{\circ}$  F. on a small tropical island, and  $5.5^{\circ}$  to  $8.1^{\circ}$  F. over large land areas. Over land areas the fall shows a latitude effect with a minimum in high latitudes and a maximum at the equator. The recovery of normal values appears to take place simultaneously with the end of the eclipse, in the upper air, over the ocean and on small islands, but is delayed from 1 to  $2\frac{1}{2}$  hours after the end of the eclipse in continental situations. The temperature normally begins to fall 20 minutes after first contact, and the minimum occurs from 2 to 20 minutes after totality. Kite meteorograph observations from the "Otaria" in 1905 gave a fall of only  $1^{\circ}$  F. at 300m. above the Atlantic Ocean. Temperature variation is, therefore, probably confined to a very shallow layer not exceeding 300m. or 400m. above the earth's surface. At hill stations the fall is usually less than at low-level stations, but comparisons are not always consistent.

Changes of vapour pressure are more difficult to distinguish, but there appears to be an increase of vapour pressure up to a time 30 to 50 minutes, preceding totality, a minimum pressure at totality, and a second maximum about 30 minutes afterwards. This is characteristic only of stations in or near the total belt, but applies both on the ground and at 300m. The decrease is as large over the ocean as over large land areas. Relative humidity is acted on by opposing factors, the decrease in vapour pressure and the decrease in temperature. Over land areas the relative humidity usually rises to a maximum at the time of minimum temperature through preponderance of the second factor. Dew is often formed on the ground near the time of mid-eclipse. Cloud changes which appear to be definitely associated with the eclipse and also the formation of fog have been noted.

The variation of atmospheric pressure is not conspicuous with ordinary instruments, but observations with these and with microbarographs have produced considerable but not conclusive evidence to show that the eclipse curve has two minima and three chief maxima, the latter occurring at totality and about 75 minutes before and after it. The fluctuation is of the order of 0.2 mb.

A diminution in wind velocity is a feature almost as marked as the temperature fall. The minimum usually agrees closely with the time of minimum temperature. There are also strong evidences of maxima represented by gusts of increased velocity occurring 30 to 50 minutes before and 40 to 60 minutes after totality.

The production of winds with definite cyclonic circulation has been observed on some occasions but not on others. The resultant eclipse wind, however, frequently shows a definite succession of changes, with a reversal of direction before and after totality; it can never be large as the temperature gradient produced by the shadow is comparatively small.

The optical phenomena are of considerable interest; the colours of sky, clouds and landscape are usually very striking and subject to rapid changes about the time of totality. While the sun is completely obscured the light is of very peculiar quality, and appears to justify adjectives such as "livid" and "unnatural," by which it is usually described. Vitiation of distance estimates is a noticeable feature at this time. The approaching umbral shadow is indigo or blackish, and may be seen, from an elevated position,

to pass points at known distances. As it reaches the observer definite pulsations, probably diffraction phenomena, may be observed. The best known of eclipse optical phenomena are the "shadow-bands." These are observed about 5 minutes before totality, and therefore definitely before the umbral shadow has reached the observer, and again after it has left him. The shadow-bands thus have no connexion with the pulsation of the shadow edge. The phenomenon consists of undulating dark bands, separated by light spaces, following one another in a direction usually normal to the tangent to the crests. The bands are visible on the ground, but are best seen if a sheet is laid down, or on snow, or on the walls of white houses. The bands appear to flicker and, while sometimes of considerable regularity, are often very vague and confused. Their speed is also inconstant, varying from about 3 to 25 m.p.h., and, therefore, very much slower than the speed of the moon's shadow. This is one of several facts which have disproved the theory that the bands are diffraction fringes bordering the moon's shadow. The bands were photographed for the first time in 1925 in the United States, and they have been observed up to a height of 3,800m. on sheets hung below manned balloons. The general inference is that they are caused by the diminishing crescent of light penetrating air strata differing in their thermal and hygro-metrical conditions and, therefore, in their refractive power.

**Eddy.**—A name given to the deviation from steady motion which occurs in any viscous fluid which flows past any obstacle, or in which neighbouring streams flow past or over each other. Certain types of eddies, such as those formed in water at the side of a moving vessel, and those which sometimes form at street corners, are of the nature of whirls, but in meteorology the restriction of the use of the name eddy to whirling motions is not justifiable. See TURBULENCE.

**Eddy Viscosity.**—According to the kinetic theory of gases, the viscosity of a fluid is due to the motion of molecules in a field where a velocity gradient exists, resulting in the transfer of momentum from one layer of the fluid to another. For the simplest molecular model, the coefficient of viscosity is given by  $\mu = \frac{1}{3}\rho cl$ , where  $\rho$  is the fluid density,  $c$  is the average molecular velocity and  $l$  is the length of the free path. This concept of the transfer of momentum by secondary motion perpendicular to the mean flow has been applied to explain phenomena in turbulent medium, taking the eddies to be carriers of momentum (Prandtl) or vorticity (Taylor). The quantity corresponding to the coefficient of viscosity is now  $A = \rho w l$ , where  $w$  is the eddy velocity in the direction of transfer (usually the vertical), and  $l$  is a length termed the "mixing path" (*Mischungsweg*), and somewhat loosely defined as the distance traversed by an eddy before mixing with the surrounding fluid. With this definition the eddy shearing stress is  $\tau = A \partial \bar{u} / \partial z$ , where  $\bar{u}$  is the mean velocity, and  $z$  is the transverse co-ordinate. Unlike the molecular coefficient, the quantity  $A$ , which in continental literature is termed the "interchange coefficient" (*Austauschkoeffizient*) is, in general, a function of position. In English meteorological writings, the quantity  $K = A/\rho$ , is used, and is generally termed the "eddy viscosity."

In 1915, G. I. Taylor, by considering two dimensional motion and making use of the conservation of vorticity of a moving element, was able to apply these ideas with considerable success to the atmosphere. Taking  $K$  independent of height, the approach of the actual wind to the geostrophic wind can be calculated and compared with pilot balloon observations. The results, on the whole, reproduce reasonably well the main features of wind structure from about 100 ft. to 2,000 ft. Taylor found that  $K$  was of the order of  $10^4$  cm.<sup>2</sup>/sec., a value in reasonable agreement with that found for the eddy conductivity of heat. The scale of eddy transfer of momentum is thus vastly greater than that of molecular transfer.

For heights below 100 ft. or so, the assumption that the eddy viscosity is independent of height leads to expressions for the wind profiles which are

not in agreement with observations. It is found that the wind structure in these regions may be represented as a power of the height, or better, as a linear function of the logarithm of the height. The index in the power law and the parameters in the logarithmic law are functions of the roughness of the surface and of the degree of atmospheric stability. It thus follows that, near the ground, the eddy viscosity itself varies considerably with height, the nature of the surface and the degree of atmospheric stability.

**Effective Height of an Anemometer.**—The height at which a given anemometer would register a mean velocity equal to that actually observed, if there were no obstructions such as buildings or trees in its vicinity. When there are obstructions around the site of an anemometer it is the practice to raise its vane to such a height above ground that the effective height is equal to the standard height in an unobstructed situation, namely 10 metres or 33 ft. In these circumstances the recorded mean velocity can be converted to wind force on the Beaufort Scale by means of the ordinary table of velocity equivalents. (See "Observers Handbook".)

**Electrical Units.**—The definitions of the absolute electrical and magnetic units will be found in treatises on electricity. We note here that the fundamental relation for the electrostatic group is the definition of a unit of charge, viz., the repulsion between two unit charges of electricity at unit distance is unit force, whilst the fundamental relation for the electromagnetic group is the definition of the unit magnetic pole, viz., the repulsion between two unit magnetic poles at unit distance is unit force.

The number of electrostatic units in an electromagnetic unit is  $v^n$  where  $v$  is the number which represents the velocity of light (which number is  $3 \times 10^{10}$ , or more precisely  $2.997 \times 10^{10}$ , in the C.G.S. system) and the index  $n$  is 0,  $\pm 1$  or  $\pm 2$ .

The practical electrical units are defined by their relations to the corresponding C.G.S. electromagnetic units. The relations to the electrostatic units are also shown in the following list.

	$n$	Practical unit	Electromagnetic C.G.S.	Electrostatic C.G.S.
Quantity of Electricity ..	1	Coulomb ..	} $10^{-1}$	$3 \times 10^9$
Electric current ..	1	Ampere ..		
Potential ..	-1	Volt ..	} $10^8$	1/300
Resistance ..	-2	Ohm ..		
Induction ..	-2	Henry ..	} $10^9$	$1/(9 \times 10^{11})$
Energy ..	0	Joule ..		
Power ..	0	Watt ..	} $10^7$	$10^7$
Capacity ..	2	Farad ..		
			$10^{-9}$	$9 \times 10^{11}$

The C.G.S. unit of magnetic force is the Oersted. It is such that unit magnetic pole in a field of 1 oersted experiences a force of 1 dyne and is connected with the electrical units by the relation that it is the force produced at a distance of 1 cm. from an infinitely long straight wire carrying a current of 5 amperes. The C.G.S. unit of magnetic induction is the Gauss. The practical unit in geomagnetism is the Gamma, which is  $10^{-5}$  C.G.S. units. In free air the numerical values of magnetic force and magnetic induction are the same; thus at Eskdalemuir in 1936

$$\begin{aligned}
 \text{the average total magnetic force} &= 47849\gamma \\
 &= 0.47849 \text{ oersted} \\
 \text{" " " " " induction} &= 0.47849 \text{ gauss}
 \end{aligned}$$

In atmospheric electricity the relation between potential gradient and induced charge is frequently required. This relation is

$$F = 4 \pi \zeta \sigma$$

where  $\sigma$  the density of the charge is measured in coulombs per square centimetre,  $F$  the strength of the field is measured in volts per centimetre, and  $\zeta$  is equal to  $9 \times 10^{11}$ .

A convenient symbolism for the C.G.S. units has been introduced by Prof. H. Benndorf. Noting that  $c$  is the initial letter of coulomb, the practical unit of electric charge, he writes cem and ces for the units of charge in the electromagnetic and electrostatic systems. Similarly aem and aes are units of current and so on. The indivisible quantity of electricity, the electronic charge, is equal to  $4.8 \times 10^{-10}$  ces and therefore to  $1.59 \times 10^{-19}$  coulomb.

**Electricity.**—See ATMOSPHERIC ELECTRICITY.

**Electricity of Precipitation.**—Precipitation, both solid and liquid, is nearly always electrically charged when it reaches the ground. The charge may be positive or negative and drops with charges of either sign may fall simultaneously. The average charge per cubic centimetre of rain is of the order of one electrostatic unit ( $1/3 \times 10^{-9}$  coulomb) but charges of about 20 e.s.u. per cm.<sup>3</sup> have been observed and, in the case of individual drops, the intensity of electrification may be as high as 200 e.s.u. per cm.<sup>3</sup> Snow is usually more highly charged than rain. Since the charges vary over such a wide range it is necessary to carry out a long series of observations in order to ascertain the net charge carried down by precipitation at any particular place. It is well established that much more rain is charged positively than negatively (the ratio being roughly 3 : 1), but the excess of positive charge carried to earth is not proportionately large since the intensity of electrification is generally considerably greater when the precipitation is negatively charged than when it is positively charged. Of the types of rain that are prevalent in western Europe it is the showery type that is responsible for most of the high negative charges whilst thunderstorm rain is usually associated with excess of positive charge, the heavier rain at the commencement of a storm being positively charged and the more moderate rain of later stages tending to be negatively charged; ordinary continuous rain nearly always carries a small positive charge\*. During positively charged rain the potential gradient at the ground is much more often negative than positive, but during negatively charged rain there is no marked tendency for the gradient to be of one sign rather than the other although there may be violent fluctuations in sign.

The results of measurements of the electricity of rain throw considerable light on the causes of the electrical phenomena associated with disturbed weather conditions; on the other hand they add to the difficulty of explaining the phenomena in terms of a simple theory. It appears that there must be at least two distinct physical processes by which the electrification of precipitation is produced.† In the upper parts of clouds where the temperature is usually well below freezing point it is probable that the impact of ice crystals is the main process by which a separation of electricity takes place, the ice becoming negatively charged and the air positively charged. Precipitation originating as ice crystals will tend to carry down negative charge leaving the upper part of the cloud positively charged, but it does not necessarily follow that all precipitation originating in this manner will be negatively charged since the smaller ice crystals which sink less rapidly will tend to collect the positive charge accumulating at the top of the cloud. A second process of separation of electricity comes into play in well-developed thunderstorms in which the strong vertical air currents are able to break up large water drops into smaller drops, the water becoming positively charged and air negatively charged.‡ Localised regions of positive charge thus develop, generally at the base near the front of a thundercloud, and the heavy rain which falls from such a region nearly always carries a high positive charge.

\* Scrase, F. J.; *London, Geophys. Mem.*, No. 75, 1938.

† Simpson, G. C. and Scrase, F. J.; *London, Proc. roy. Soc.*, A. 161, 1937, pp. 309–52.

‡ Simpson, G. C.; *London, Proc. roy. Soc.*, A. 114, 1927, pp. 376–401.



There is a third process of electrification which may become effective in the lowest layers of a cloud or between cloud and ground where the precipitation is in the liquid stage; this is the influence process\* by which water drops falling sufficiently fast in an electric field, tend, on account of the induced charges on their upper and lower halves, to attract ions of opposite sign to that of the field. This mechanism suggests that the electrification of rain is the result rather than the cause of disturbed potential gradient, whereas in actual fact it is not until a cloud turns to rain that the potential gradient is appreciably disturbed.

The net transfer of positive electricity from the atmosphere to the earth by precipitation constitutes a current which is on the whole in the same direction as the fine weather conduction current and this fact only adds, therefore, to the difficulty in explaining how the earth's electric charge is maintained.

**Electrometer.**—An instrument for measuring electromotive force or potential difference. Its function is, therefore, similar to that of a voltmeter, but electrometers are distinguished by the fact that their action depends on electrostatic force, whereas ordinary voltmeters depend for their action on the magnetic or heating effects of an electric current. The indications of an electrometer do not involve the passage of a current through the instrument, and they can, therefore, be used for such purposes as the determination of the electrical potential of a point in the atmosphere.

The instrument generally used for absolute measurements of potential gradient is the Wulf bifilar electrometer. For continuous records a quadrant electrometer is generally used, the registration being photographic. Autographic records can also be obtained with the Benndorf quadrant electrometer, which is provided with a guillotine to depress the "needle" at regular intervals and so produce marks on paper. For recording photographically rapid changes of potential, a Dolezalek quadrant electrometer can be used with the period reduced to about a second. Measurements of potentials such as a fraction of a volt can conveniently be made with a Lindemann electrometer, as for instance in observations of conductivity.

**Electroscope.**—An instrument for indicating the presence of electrification, usually by some simple action, such as the mutual repulsion of two strips of foil.

**Element.**—In meteorology one of the components which determines the state of the atmosphere at any given time and place. The chief meteorological elements are temperature, pressure, wind, precipitation, humidity, cloudiness. Atmospheric electricity and atmospheric pollution are sometimes included.

**Energy.**—Used frequently in meteorology in the general sense of vigour or activity. Thus, a cyclone is said to develop greater energy when its character, as exhibited by a low barometer, steep gradients and strong winds, becomes more pronounced. But there is a technical dynamical sense of the word, the use of which is sometimes required in meteorology, and which must become more general when the physical explanation of the phenomena of weather is studied, because all the phenomena of weather are examples of the "transformations of energy" in the physical sense.

The most important conception with regard to energy is its division into two kinds, kinetic energy and potential energy, which are mutually convertible. A clock weight gives a good idea of potential energy. When the clock is wound up the weight has potential energy in virtue of its position; it will utilise that energy in driving the clock until it is "run down" and can go no further. Potential energy must be restored to it by winding up before it can do any more driving. The potential energy in this case is measured by the amount

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\* Wilson, C. T. R.; *Philadelphia, J. Franklin Inst.*, 208, 1929, pp. 1-12.

of the weight and the vertical distance through which it is wound up. In dynamical measure the potential energy of the raised weight is  $mgh$ , where  $m$  is the mass of the clock weight,  $h$  the vertical distance through which it is wound up,  $g$  the acceleration of gravity. It is to the mysterious action of gravity that the energy is due :—hence the necessity for taking gravity into account in measuring the energy.

Using the simple product  $mgh$  as a measure of the potential energy of gravitation, by a simple formula for bodies falling freely under the action of gravity, we have

$$mgh = \frac{1}{2}mv^2$$

where  $v$  is the velocity acquired by a body falling through a height  $h$ , or, speaking in terms of energy, by losing the potential energy of the height  $h$ . It thus obtains a certain amount of motion which represents kinetic energy, in exchange for its potential energy. The kinetic energy is expressed by the apparently artificial formula  $\frac{1}{2}mv^2$ . In virtue of its motion it has the power of doing "work": if it were not for unavoidable friction the mass could get itself uphill again through the height  $h$  by the use of its motion, and thus sacrifice its kinetic energy in favour of an equivalent amount of potential energy.

The exchange of potential and kinetic energy can be seen going on in a high degree of perfection in a swinging pendulum. At the top of the swing the energy is all potential, at the bottom all kinetic. The swings get gradually smaller because in every swing a little of the energy is wasted in bending the cord or in overcoming the resistance of the air.

What we get in return for the loss of energy in friction is a little HEAT, and one of the great conclusions of physical science in the middle of the nineteenth century was to show that heat is also a form of energy, but a very special form, that is to say, its transformation is subject to peculiar laws. Heat is often measured by rise of temperature of water (or its equivalent in some other substance). Calling this form of energy thermal energy and measuring it by the product of the "water equivalent,"  $M$ , and the rise of temperature  $\theta - \theta_0$  produced therein, we have three forms of energy all convertible under certain laws, viz. :—

Potential energy	..	..	$mgh$ .
Kinetic energy	..	..	$\frac{1}{2}mv^2$ .
Thermal energy	..	..	$M(\theta - \theta_0)$ .

We have mentioned only a lifted clock weight as an example of potential energy, but there are many others, a coiled spring that will fly back when it is let go, compressed gas in a cylinder that will drive an engine when it is turned on, every combination, in fact, that is dormant until it is set going and then becomes active.

From the dynamical point of view, the study of nature is simply the study of transformations of energy.

In meteorology kinetic energy is represented by the winds; potential energy by the distribution of pressure at any level, by the electrical potential of the air and by the varying distribution of density in the atmosphere, causing convection; thermal energy by the changes of temperature due to the effect of the sun or other causes. It is the study of the interchange of these forms of energy which constitutes the science of dynamical meteorology.

**Entropy.**—A term introduced by R. Clausius to be used with TEMPERATURE to identify the thermal condition of a substance with regard to a transformation of its HEAT into some other form of ENERGY. It involves one of the most difficult conceptions in the theory of heat, about which some confusion has arisen.

The transformation of heat into other forms of energy, in other words the use of heat to do work, is necessarily connected with the expansion of the working substance under its own pressure, as in the cylinder of a gas engine, and the condition of a given quantity of the substance at any stage

of its operations is completely specified by its volume and its pressure. Generally speaking (for example, in the atmosphere), changes of volume and pressure go on simultaneously, but for simplifying ideas and leading on to calculation it is useful to suppose the stages to be kept separate, so that when the substance is expanding the pressure is maintained constant by supplying, in fact, the necessary quantity of heat to keep it so, and, on the other hand, when the pressure is being varied the volume is kept constant; this again by the addition or subtraction of a suitable quantity of heat. While the change of pressure is in progress, and generally also while the change of volume is going on, the temperature is changing, and heat is passing into or out of the substance. The question arises whether the condition of the substance cannot be specified by the amount of heat that it has in store and the temperature that has been acquired just as completely as by the pressure and volume.

To realise that idea it is necessary to regard the processes of supplying or removing heat and changing the temperature as separate and independent, and it is this step that makes the conception useful and at the same time difficult.

For we are accustomed to associate the warming of a substance, i.e. the raising of its temperature, with supplying it with heat. If we wish to warm anything we put it near a fire and let it get warmer by taking in heat, but in thermodynamics we separate the change of temperature from the supply of heat altogether by supposing the substance is "working." Thus, when heat is supplied the temperature must not rise; the substance must do a suitable amount of work instead; and if heat is to be removed the temperature must be kept up by working upon the substance. The temperature can thus be kept constant while heat is supplied or removed. And, on the other hand, if the temperature is to be changed it must be changed dynamically not thermally, that is to say, by work done or received, not by heat communicated or removed.

So we get two aspects of the process of the transformation of heat into another form of energy by working, first, alterations of pressure and volume, each independently, the adjustments being made by adding or removing heat as may be required, and secondly, alterations of heat and temperature independently, the adjustments being made by work done or received. Both represent the process of using heat to perform mechanical work or vice versa.

We could, therefore, specify the condition of a given quantity by  $H$  and  $T$ , its store of heat and its temperature. Further consideration will show, however, that the quantity  $H$  is not very suitable for the purpose. When a substance expands adiabatically it is doing work, and since it is receiving no heat from an outside source it must draw upon its own effective internal supply of heat. Hence the latter diminishes in direct ratio to the decrease of absolute temperature and the value which remains constant is not  $H$  but the ratio  $H/T$ . We call this ratio the entropy, an adiabatic line which conditions thermal isolation and therefore equality of entropy is called an isentropic. If a new quantity of heat  $h$  is added at a temperature  $T$  the entropy is increased by  $h/T$ . If it is taken away again at a lower temperature  $T'$  the entropy is reduced by  $h/T'$ .

In the technical language of thermodynamics the mechanical work for an elementary cycle of changes is  $\delta p \cdot \delta v$ , and the element of heat  $\delta T \cdot \delta \phi$ . The conversion of heat into some other form of energy by working is expressed by the equation

$$\delta T \cdot \delta \phi = \delta p \cdot \delta v$$

when heat is measured in dynamical units.

Entropy is a relative term; it is also an abstraction and cannot be measured directly. Its importance lies in the assistance which it gives in deriving thermodynamic relationships. Problems of dynamical meteorology seem to be more closely associated with these strange ideas than those which

we regard as common. For example, it may seem natural to suppose that if we could succeed in completely churning the atmosphere up to, say, 10 kilometres (6 miles) we should have got it uniform in temperature or isothermal throughout. That seems reasonable, because if we want to get a bath of liquid uniform in temperature throughout we stir it up; but it is not true. In the case of the atmosphere there is the difference in pressure to deal with, and, in consequence of that, complete mixing up would result not in equality, but in a difference of temperature of about  $100^{\circ}\text{C.}$  between top and bottom, supposing the whole atmosphere dry. The resulting state would not, in fact, be isothermal; the temperature at any point would depend upon its level and there would be a temperature difference of  $1^{\circ}\text{C.}$  for every hundred metres. But it would be perfectly isentropic. The entropy would be the same everywhere throughout the whole mass. And its state would be very peculiar, for if you increased the entropy of any part of it by warming it slightly the warmed portion would go tight to the top of the isentropic mass. It would find itself a little warmer, and, therefore, a little lighter specifically than its environment, all the way up. In this respect we may contrast the properties of an isentropic and an isothermal atmosphere. In an isentropic atmosphere each unit mass has the same entropy at all levels, but the temperatures are lower in the upper levels. In an isothermal atmosphere the temperature is the same at all levels, but the entropy is greater at the higher levels.

An isothermal atmosphere represents great stability as regards vertical movements, any portion which is carried upward mechanically becomes colder than its surroundings and must sink again to its own place, but an isentropic atmosphere is in the curious state of neutral equilibrium which is called "labile." So long as it is not warmed or cooled it is immaterial to a particular specimen where it finds itself, but if it is warmed, ever so little, it must go to the top, or if cooled, ever so little, to the bottom.

In the actual atmosphere above the level of ten kilometres (more or less) the state is isothermal; below that level, in consequence of convection, it tends towards the isentropic state, but stops short of reaching it by a variable amount in different levels. The condition is completely defined at any level by the statement of its entropy and its temperature, together with its composition which depends on the amount of water vapour contained in it.

Speaking in general terms the entropy increases, but only slightly, as we go upward from the surface through the TROPOSPHERE until the STRATOSPHERE is reached, and from the boundary upwards the entropy increases rapidly.

If the atmosphere were free from the complications arising from the condensation of water vapour the definition of the state of a sample of air at any time by its temperature and entropy would be comparatively simple. High entropy and high level go together; stability depends upon the air with the largest stock of entropy having found its level. In so far as the atmosphere approaches the isentropic state, results due to CONVECTION may be expected, but in so far as it approaches the isothermal state, and stability supervenes, convection becomes unlikely.

**Equation of Time.**—See TIME.

**Equatorial Air.**—See TROPICAL AIR.

**Equiangular Spiral.**—A spiral is the locus of the extremity of a line (or radius vector) which varies in length as it revolves about a fixed point. The equiangular spiral is such that as the vector angle increases arithmetically the radius vector increases geometrically. Another definition is that the tangent makes a constant angle  $\alpha$  with the radius vector. The equation in polar co-ordinates is  $r = ae^{\theta \cot \alpha}$ .

The study of turbulence led Hesselberg and Sverdrup to a theoretical result involving this type of spiral, namely that if the wind at successive levels above the ground is represented by a series of vectors drawn from the point at which

the wind is measured, the extremities of the vectors lie on an equiangular spiral with its pole at the end of the vector representing the geostrophic wind. See WIND.

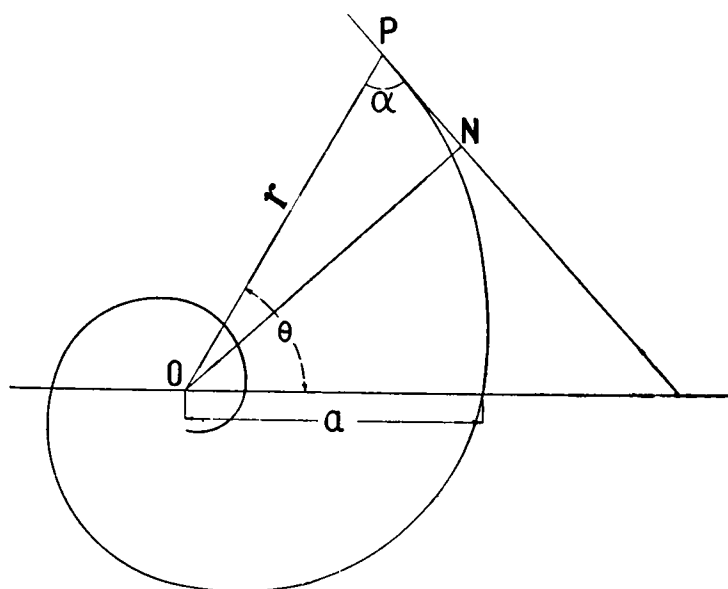


FIG. 18.

**Equinox.**—The time of the year when the astronomical day and night are equal, each lasting twelve hours. At the equinox the sun is “on the equator” or is “crossing the line.” It is on the horizon in the morning exactly in the east, and exactly in the west in the evening all over the world. Sunrise occurs at the same time all along a meridian. The sun is visible by refraction for a little longer than the duration of the astronomical day.

There are two equinoxes. The spring or vernal equinox about March 21, and the autumnal equinox about September 22.

**Equivalent Constant Wind.**—A particular type of average wind of great importance in BALLISTICS. It may be defined as that wind, constant in speed and direction, which would produce the same displacement of a shell in flight as the actual varying winds which the shell meets during its flight.

**Equivalent Potential Temperature.**—See ROSSBY DIAGRAM.

**Equivalent Temperature.**—Equivalent temperature may be defined as the temperature of absolutely dry air which has the same wet-bulb temperature as the actual air.

**Error.**—In any observation other than the counting of discrete units, such as the number of balls in a basket, the repetition of the observation does not usually yield precisely the same result. This is particularly the case when an instrument is used to yield a measurement to the greatest possible number of significant figures. Successive measurements will then frequently give varying values for the last significant figure. It follows that no single observation can be regarded as strictly correct. The difference between the observed value and the true value is called the “error” of the observation.

In the discussion of errors of observation it is usually assumed that the observations have been carried out with the greatest possible care. Just as an observer may make a mistake in counting the number of balls in a basket, so he may commit a mistake of  $5^\circ$  in reading a thermometer. Such a mistake should be classified as a “blunder” and not as an “error.” But even when all possible care has been taken to avoid blunders there still remain errors which cause individual observations in a series to differ from one another and from the true value of the quantity to be measured. These residual errors are due to the peculiarities of the observer, of the instrument, or of the external conditions.

The observer may have individual peculiarities, particularly in measuring positions of moving bodies, or estimating the instantaneous magnitude of a changing length. A good observer tends always to make the same error in observing, whereas an inexperienced observer is more erratic, both as to the magnitude and sign of his error. The personal error or "personal equation" of an observer can in some cases be estimated by comparison with a standard observer, or by means of specially designed laboratory experiments.

The instrument may have errors of construction or of graduation. These can generally be eliminated by comparison with a standard instrument. They may be constant errors, always of the same sign and magnitude, as in the case of a barometer whose scale has been displaced vertically from its correct position; or they may be systematic, bearing a fixed relation to one or more of the conditions of observation. For example, if a thermometer be constructed by graduating a degree scale upon a glass tube at equal intervals, any inequalities in the bore of the tube will lead to systematic errors which can be eliminated by comparison with a standard instrument.

Changing external conditions may also lead to errors in observation. By external conditions we mean such of the conditions of observation as are beyond the observer's control, as for example the vibration of a theodolite by the wind. It is seldom possible to make a correction for such conditions. All that can be done is to select such times of observation as shall be as little as possible subject to uncontrollable external conditions, when such selection is possible.

To obtain accurate observations with an instrument we therefore require to know its constant or systematic error. If the observer has a personal error, an effort should be made to estimate it, and allow for it. When these constant or systematic errors have all been allowed for as far as possible, it will generally be found that the individual observations in a series still differ from one another. The residual error which causes this difference is called the "accidental" error of the observation. The word "accidental" is here used in a special sense, to denote the sum total of all the errors whose source is unknown. They may be due for example to changes in the observer, as when an observer, becoming tired, makes errors of varying magnitude and sign in different observations; or to unsuspected temperature changes in the instrument; or to irregular effects of wind upon the instrument or upon the object observed. They may also be due partly to failure to realise the nature of some of the factors affecting the quantity measured, or even to defects in the theory on which the reduction of the observations is based. The endeavour of the observer should be to take account of all changing conditions as far as possible, and so to remove as much of the errors of observation as he can into the class of constant or systematic error.

Some judgment is, however, necessary in the application of these principles in meteorology. In climatological observations, for example, it is a waste of time to measure the air temperature to  $\cdot 01^{\circ}$  C., since the fluctuating changes of temperature at a given place from one minute to the next generally exceed this value. Reading to  $\cdot 1^{\circ}$  C. is, however, readily possible.

See also PROBABILITY, PROBABLE ERROR, NORMAL LAW.

**Evaporation.**—The process of conversion of water or ice into aqueous vapour. The atmosphere is very rarely completely saturated, so that evaporation is nearly always going on, and in general the greater the difference between the amount of water vapour which the air holds and the amount which would saturate it at the existing temperature, the more rapid is the rate, but other factors such as the nature of the water surface from which evaporation is taking place, and wind, influence the rate.

Some figures for the average depth of water evaporated in various places are given below.

*Evaporation from the Surface of Water*

	35-year average. London, Camden Square.		1937 Great Britain, mean of 14 stations.		South Africa, Bulawayo. 20° 2' S., 28° 58' E.		Egypt, Wadi Haifa. 21° 55' N., 31° 20' E.		Australia, Cue, W.A. 27° 27' S., 117° 52' E.		Tasmania, Hobart. 42° 53' S. 147° 20' E.	
	in.	mm.	in.	mm.	in.	mm.	in.	mm.	in.	mm.	in.	mm.
January ..	·10	2·5	·20	5·1	8·94	227	11·10	282	21·46	545	5·87	149
February ..	·25	6·4	·22	5·6	7·40	188	12·64	321	17·13	435	4·21	107
March ..	·66	16·8	·47	11·9	8·74	222	17·96	456	16·78	426	3·03	77
April ..	1·51	38·4	1·21	30·7	8·90	226	21·85	555	11·22	285	1·97	50
May ..	2·43	61·7	2·44	62·0	9·02	229	25·52	648	7·48	190	1·22	31
June ..	2·91	73·9	3·00	76·2	7·99	203	25·28	642	4·84	123	0·67	17
July ..	2·97	75·4	2·65	67·3	8·07	205	23·82	605	5·35	136	0·83	21
August ..	2·33	59·2	2·52	64·0	12·84	326	22·84	580	6·26	159	1·30	33
September ..	1·38	35·1	1·64	41·7	14·73	374	22·92	582	9·13	232	1·77	45
October ..	·62	15·7	·81	20·6	14·96	380	20·08	510	13·39	340	3·07	78
November ..	·25	6·4	·34	8·6	10·79	274	15·12	384	18·00	457	4·02	102
December ..	·09	2·3	·27	6·9	9·84	250	10·75	273	22·37	568	4·88	124
Year ..	15·50	393·8	15·77	400·6	122·22	3,104	229·88	5,838	153·41	3,896	32·84	834

For any area where the percolation is small the amount of evaporation is given by the difference between the rainfall and run-off. Statistics of run-off and rainfall for a number of areas are published by the Ministry of Health in the annual volumes of the "Surface Water Year Book."

**Evaporimeter.**—An instrument for determining the rate of evaporation of water into the atmosphere. Evaporimeters fall into two classes, (a) those employing a free water surface, (b) those in which evaporation takes place from a continuously wetted porous surface of blotting paper, fabric or ceramic material. Class (a) is exemplified by the Symons evaporation tank commonly used in this country. It consists of a galvanized iron tank usually 6 ft. square and 2 ft. deep, nearly filled with water and sunk into the ground with its rim projecting about 1½ in. The evaporation, expressed as depth in inches, is deduced from daily readings of level made with a micrometer gauge, allowance being made for rainfall. Evaporimeters of class (b) have been designed by Piché, Livingston, Owens and others but they have not come into general use in this country as meteorological instruments.

**Expansion.**—The increase in the size of a sample of material, which may be due to heat or to the release of mechanical strain, or the absorption of moisture or some other physical or chemical change.

The size may be taken as the length or volume, sometimes as the area. In the science of heat the fractional increase of length or volume for one degree of temperature is called the coefficient of thermal expansion. Thus the coefficient of "linear" expansion with heat of the brass used for barometer scales is 0·0000102 per degree Fahrenheit, which means that for 1° F. the length of the scale increases by 102 ten-millionth parts of its length at the standard temperature (62° F.). The coefficient of "cubical" expansion of mercury is ·0001010, which means that the volume of a quantity of mercury increases by 1·01 ten-thousandth of its bulk at the standard temperature (32° F.) for 1° F. The corresponding expansions and coefficients for 1° C. or 1° A. are larger in the ratio of 18 to 10.

Expansion of volume alters the density of a substance, and changes of density are therefore numerically related to expansion.

The expansion of a gas may be caused either by reduction of pressure or by increase of temperature. So in order to see the effect of temperature alone we must keep the pressure constant. In these circumstances the coefficient of expansion is ·00366 for 1° A. referred to 273° A. as standard, or ·002 for 1° F. referred to 41° F. as standard.

**Exposure.**—In meteorology, the method of presentation of an instrument to that element which it is destined to measure or record, or the situation of the station with regard to the phenomenon or phenomena there to be observed.

If meteorological observations are to be of full value attention must be paid to the manner of the exposure of the instruments. Details are to be found in the "Observer's Handbook." Uniformity of exposure is of the greatest importance, and for that reason the pattern of the thermometer screen has been standardised in most countries, while in these Islands a standard height of one foot above ground for the rain-gauge has been fixed. It is important, too, that the sites of the thermometer screen and rain-gauge should not be unduly shut in; on the other hand, a very open exposure, as on a bare moor, is undesirable for a rain-gauge, as is also a position on a slope, a roof, or near a steep bank. In these cases the catch is reduced by the effect of wind eddies due to the obstruction of the gauge itself. A SUNSHINE RECORDER demands an entirely unobstructed horizon near sunrise and sunset at all seasons of the year. The question of the exposure of ANEMOMETERS is one of great difficulty. The effect of the ground on a uniform current of air blowing above it is to reduce the velocity, the amount of reduction increasing as the ground is approached, and, at the same time, to introduce unsteadiness into the motion which is manifested by the creation of eddies in the air. The motion is then said to be turbulent (see TURBULENCE). A recording tube anemometer erected in a turbulent wind shows a large number of gusts and lulls corresponding with various parts of the eddy-motion. Hence the extent of the gustiness of the wind as recorded by the anemometer (see GUST) is a fair index of the excellence of the exposure. The ideal exposure for an anemometer is at the top of a pole 30 or 40 ft. high, erected on a flat treeless plain. Trees and buildings introduce much turbulence into air motion, and where these occur in the vicinity of an anemometer the head of the instrument is raised with a view to making the EFFECTIVE HEIGHT equivalent to the standard value (10 m. or 33 ft.).

**Exsiccation.**—Drying by the draining away or driving away of moisture. The term implies some change, frequently the result of human agency which decreases the quantity of moisture available without any appreciable change in the average rainfall. It is used in contrast with DESICCATION, which implies an actual drying up due to a change of climate. Examples of exsiccation are the washing away of the soil due to the cutting down of forests, with the consequent conversion of a fertile region into the semblance of a desert, the advance of sand dunes across cultivated ground, and the draining of swampy ground.

**Extremes.**—The highest and lowest values of meteorological elements. Standard climatological tables give the highest and lowest temperatures recorded at an observing station in the day, month and year. The mean daily maximum temperature is the average of the maxima for each day, similarly for the mean daily minimum. The monthly maximum and minimum temperatures are the highest and lowest temperatures recorded during the month. The highest and lowest temperatures during the whole period of the observations are called the absolute extremes.

The absolute extremes of temperature are:—For the British Isles: highest,  $100\cdot5^{\circ}$  F. at Tonbridge, July 22, 1868; lowest,  $-17^{\circ}$  F. at Braemar, February 11, 1895. For the surface of the globe: highest,  $136^{\circ}$  F. at Azizia (Uzzizia), Tripoli, September 13, 1922; lowest,  $-90\cdot0^{\circ}$  F. at Verkhoyansk, Siberia, February 5 and 7, 1892. In the upper air: lowest,  $-133\cdot4^{\circ}$  F. at a height of  $16\frac{1}{2}$  Km. over Agra, India on October 4, 1928.

The highest known pressures corrected to M.S.L. are: British Isles, 1055 mb., in Scotland on January 31, 1902; World, about 1079 mb., in Siberia, January 23, 1900. The lowest pressures are: British Isles, 926 mb., in Ochertyre on January 26, 1884; World, 887 mb., in the Pacific Ocean on August 18, 1927.

The extreme annual or seasonal totals of rainfall are important in agricultural countries, and maximum values of rainfall in a short period are of interest to engineers. The extreme annual total in the British Isles is 247 in., at Llyn Llydaw, Snowdon, in 1909.



The heaviest known rainfalls in 24 consecutive hours are : British Isles, 9.56 in., at Bruton, Somerset on June 28, 1917 ; World, 45.99 in., in the Philippine Isles on July 14-5, 1911.

The maximum wind velocities in gusts, as shown by pressure-tube anemographs, are also important to engineers. The extreme GUST recorded for the British Isles is 113 m.p.h. at St. Ann's Head on January 18, 1945. The highest hourly wind velocity is 78 m.p.h. (34.9 m./sec.), at Fleetwood on December 22, 1894, recorded by a Robinson cup anemometer.

**Eye of Storm.**—The central calm area of a tropical cyclone. The most noticeable feature of this area is the sudden drop in wind from hurricane force to light unsteady breezes or even to a complete calm, with more or less cloudless sky and absence of rain. The interior margin of the storm appears to be symmetrical around the calm centre. Over the ocean the sea in the eye of the storm is usually very high and turbulent.

**Eye of Wind.**—A nautical expression indicating the direction from which the wind blows.

**Fahrenheit, Gabriel Daniel.**—The improver of the thermometer and barometer, born 1686 at Danzig. He used mercury instead of spirit for thermometers and marked the freezing point of water at 32°, and the boiling point of water at 212°.

The Fahrenheit scale is still extensively used in English-speaking countries. The size of the degree is convenient and the range of the scale, 0° F. to 100° F., is a serviceable one for the climates of the temperate zone, where temperatures below 0° F. at the earth's surface are of rare occurrence.

**Fall.**—"The fall of the leaf," a term in common use in America for autumn.

**Falling Time, of Barometer.**—When a mercurial barometer is raised quickly from an inclined position to the vertical, the mercury will not fall immediately to the equilibrium position appropriate to the pressure of the surrounding air. The rate at which the mercury falls is for a particular barometer proportional to  $h$ , where  $h$  is the height of the mercury above the equilibrium position, and this rate is a measure of the sensitivity of that barometer. In marine barometers the sensitivity is reduced, by constricting the tube, to minimise PUMPING and it is specified that the falling time between heights corresponding with pressures 50 and 18 mb. above the true pressure of the surrounding air must lie between 4 and 5 minutes. The falling time so measured is equal to the "lagging time"  $L$ , and when pressure is changing at a steady rate for a period of many minutes the error due to lag is eliminated by reading the barometer  $L$  minutes after the time at which the pressure is required.

**False Cirrus.**—A name previously used for cirrus nothus. See CLOUDS, CIRRUS.

**Fata Morgana.**—A complicated form of MIRAGE in which multiple images of an object are produced ; these images are frequently elongated. It is produced by several layers of air of different refractive indices.

**Firn.**—A German word meaning old snow which is in the process of being transformed into glacier ice. The word is also used to denote the accumulation area of old snow above a glacier and is synonymous with the French word *névé*. There is no corresponding word in English. G. Seligman suggests that in English writings the term "firn snow" be used for the snow particles which are in the process of transformation into ice, and "névé" to indicate the accumulation area above a glacier. The changes which take place in the newly fallen snowflake before it becomes glacier ice are described by G. Seligman in "Snow Structure and Ski Fields" (Macmillan, London, 1936), where a detailed nomenclature of the different snow forms is also given.

**Floe.**—An area of ice other than fast ice whose limits are within sight. Floes up to 2 ft. in thickness may for convenience of description be termed "light floes" ; floes thicker than this, "heavy floes." Fast ice is sea ice

remaining in the position of growth and is only met along coasts where it is attached to the shore or over shoals where it may be held in position by islands or stranded icebergs.

**Fog.**—Fog is defined as obscurity in the surface layers of the atmosphere caused by particles of condensed moisture or of smoke held in suspension in the air. In international meteorological practice the term “fog” is limited to a condition of atmospheric obscurity in which objects at a distance of one kilometre are not visible. When visibility exceeds this limit, but is less than two kilometres, the obscuration is called “mist” or “haze” according to whether it is produced by condensed water particles or by foreign solid matter such as dust or smoke.

If the accumulation of dust or smoke in the atmosphere is so great as to reduce visibility below one kilometre, a pure dust fog or smoke fog occurs. Smoke fogs are characteristic of large towns and industrial areas where there is a continuous output of smoke and other impurities from factory chimneys, etc. The worst type of fog in such areas occurs when conditions are also favourable for condensation and a mixture of the two kinds of fog produces considerable obscurity.

Dust fogs are associated with the desert regions of the globe. They occur, for example, off the west coast of Africa during the season of the HARMATTAN which carries clouds of dust from the Sahara.

The following scale of fog intensity is used in meteorological work :—

Symbol		Description	Limit of visibility. Objects not visible at a distance of	
			m.	yd.
F	..	Dense fog .. ..	40	44
		Thick fog .. ..	200	220
f	..	Fog .. ..	400	440
m or z	..	Moderate fog .. ..	1,000	1,100
		Mist or haze .. ..	2,000	2,200

Condensation of water vapour in the surface layers of the atmosphere is brought about most frequently by the direct cooling of the air below its dew point. The cooling can occur either by lowering of the temperature of the surface of the ground, which is subsequently communicated to the air above it, or by the drift of air over a surface which is colder than itself. In both cases an inversion of the temperature lapse rate is formed in the lower layers of air, and condensation is produced by the turbulent mixing of the air within these layers (see TURBULENCE). For the effective formation of fog, the wind must be light, in order to allow the air in contact with the ground to become sufficiently cooled. When fog has formed in the manner outlined above, radiation from its upper surface produces further cooling and so leads to an intensification of the fog.

Fogs over land occur chiefly in autumn and winter. They are formed most frequently on the calm, clear nights which are associated with anti-cyclonic conditions. They reach their maximum intensity, normally in the early morning, between one and two hours after sunrise, and usually disperse before midday. In winter, however, such fogs occasionally cover a wide area and persist for some days. Fogs may also be formed by the passage of warm air over cold ground or by the mixing of two currents of air of different temperatures. A peculiarity of the London area is the formation of fog, due to condensation together with an accumulation of smoke, in a layer of air above the surface. Such fogs, which are usually of brief duration, may cause darkness in the middle of the day equal to that of night.

Fogs at sea, unlike land fogs, are characteristic of spring and summer, and are usually formed by the passage of a current of air from a large land mass, or from tropical or sub-tropical regions, over the relatively cold sea.

High-level country experiences fog at all seasons due to drifting low cloud which envelops the high ground. High ground near the sea suffers the most in this respect.

The height to which an ordinary fog extends varies considerably. It is usually less than 1,000 ft. and frequently less than 500 ft. Sea fogs are sometimes so shallow that the mast-heads of ships protrude above them. In certain conditions a fog has no clearly defined upper boundary but merges into cloud which may extend to a considerable height.

The following table shows the percentage frequencies of fog and mist at different seasons at stations in the British Isles. The figures are based on observations at 7h., 13h. and 18h. G.M.T. during six years, the frequencies at each of these three hours being averaged to give the frequencies of whole days of fog.

Station	Height above M.S.L. in feet	Number of days per 100							
		Visibilities less than 1,000 m.				Visibilities less than 2,000 m.			
		Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
Valentia .. ..	30	0.1	0.3	0.1	0.0	0.1	0.5	0.4	0.2
Malin Head .. ..	51	0.6	0.6	0.6	0.4	0.8	1.2	1.0	1.0
Stornoway .. ..	30	0.5	0.1	0.9	0.1	1.1	1.4	1.5	0.6
Wick .. ..	81	1.6	3.2	0.5	0.2	2.2	3.7	0.9	0.4
Donaghadee .. ..	40	0.9	1.3	0.8	0.8	1.8	2.5	1.8	1.6
Mount Batten (Plymouth) .. ..	82	0.7	1.3	1.5	0.7	1.0	2.4	2.5	2.0
Portland Bill .. ..	32	1.8	1.8	0.9	0.8	2.5	2.8	1.6	1.7
Holyhead .. ..	26	1.2	2.1	0.7	0.6	2.0	3.6	1.8	2.0
Lerwick .. ..	54	1.4	3.2	2.9	0.4	1.9	4.0	3.4	0.8
Leuchars .. ..	40	1.9	0.8	1.5	1.0	3.2	1.4	2.7	3.4
Falmouth .. ..	200	2.1	2.7	2.2	0.7	3.1	3.4	3.0	1.6
Dungeness .. ..	20	1.2	1.3	2.4	3.5	2.1	1.9	4.0	5.5
Calshot (Southampton)	10	1.2	0.4	2.4	3.1	2.6	1.2	4.7	5.5
Inchkeith .. ..	190	2.4	2.1	2.8	2.1	3.8	2.9	3.5	4.4
Gorleston .. ..	14	1.6	1.2	2.9	5.9	1.9	1.5	5.0	8.6
Roches Point .. ..	22	1.9	2.6	1.8	1.5	3.8	4.4	4.5	4.9
Felixstowe .. ..	15	0.8	0.5	2.3	5.2	2.1	1.3	5.0	9.9
Scilly .. ..	165	3.0	4.9	4.5	2.0	3.7	5.7	5.6	3.0
Clacton .. ..	54	0.7	0.4	2.9	5.4	2.2	0.9	6.4	9.8
Aberdeen .. ..	46	2.2	1.6	2.0	1.7	5.3	3.1	4.9	6.4
Andover .. ..	295	2.5	0.9	3.3	6.5	3.7	1.7	5.9	9.4
Pembroke .. ..	150	4.6	4.8	2.7	4.1	5.6	6.0	3.6	5.2
Spurn Head .. ..	29	1.9	2.3	4.1	7.1	3.6	3.3	6.1	11.3
Cranwell .. ..	236	1.8	1.6	5.1	9.1	2.7	2.1	7.9	13.6
Shoeburyness .. ..	11	1.1	0.4	6.2	8.3	2.7	0.8	10.1	13.5
Ross on Wye .. ..	223	1.7	1.2	7.6	5.1	3.7	2.2	13.5	10.0
Birr Castle .. ..	173	1.6	1.0	5.4	5.1	5.8	2.7	9.2	14.2
Lympne .. ..	350	2.7	2.1	4.6	10.0	5.0	3.6	8.6	16.2
Tynemouth .. ..	67	3.3	4.2	5.0	6.2	6.3	5.9	9.7	12.0
Farnborough .. ..	230	3.2	0.7	8.1	7.3	5.5	1.3	14.3	12.6
Biggin Hill .. ..	597	3.5	1.4	6.8	10.6	7.9	3.2	12.2	17.3
Croydon .. ..	244	2.7	0.7	7.2	7.3	7.1	2.0	16.5	17.6
Liverpool .. ..	189	4.8	1.0	7.3	5.6	14.5	4.0	15.2	14.5
Sealand (Chester) .. ..	16	2.8	0.8	10.0	8.3	10.0	3.5	20.4	17.9
Kew .. ..	18	3.5	0.8	11.4	11.3	8.6	2.2	20.3	21.3
Renfrew .. ..	36	2.9	0.7	10.5	9.2	11.3	4.5	18.8	20.4
Birmingham .. ..	535	5.1	1.8	10.1	12.9	12.9	4.9	19.4	24.1
Beachy Head .. ..	525	10.1	9.5	8.2	17.1	15.1	13.4	18.2	24.6

**Fog Bow.**—A white rainbow of about  $40^\circ$  radius seen opposite the sun in fog. Its outer margin has a reddish and its inner a bluish tinge but the middle of the band is quite white. A supernumerary bow is sometimes seen inside the first and with the colours reversed. The bows are produced in the same way as the ordinary rainbow but owing to the smallness of the drops, the diameter of which is about 0.05 mm., the colours overlap and the bow appears white.

**Föhn.**—A warm, dry wind which blows down the slopes on the leeward side of a ridge of mountains. The name originated in the Alps where the föhn is very prevalent, especially on the northern slopes in the inner valleys; the wind also occurs on the eastern side of the Rocky Mountains where it is known as the CHINOOK. Owing to its warmth and dryness it melts the snow very quickly and causes a considerable rise in temperature. It is frequently accompanied by lenticular clouds.

The föhn occurs in the Alps mostly with a southerly wind. The air when coming against the ridge of mountains ascends and dynamic cooling takes place with condensation and precipitation. The temperature of the air falls at the adiabatic rate for wet air, that is at about  $1^\circ\text{C.}$  for every 200 m. of ascent. When the air descends the slopes on the other side of the mountain, having lost its moisture it is dynamically warmed at the "dry adiabatic" rate of  $1^\circ\text{C.}$  for every 100 m. and reaches the valleys as a warm, dry wind.

The föhn is likely to occur wherever cyclonic systems pass over mountainous regions; for example it frequently occurs on the coast of Greenland where it has a considerable influence on the winter climate.

**Foot-pound-second System.**—A system of units based upon the foot, the pound and the second as fundamental units. Seldom used in meteorology or the pure sciences, but forms the basis of the units used by engineers. On this system the unit of force is the "poundal," which is the force required to give a mass of 1 pound an acceleration of 1 foot per second per second. The unit of work, the "foot-pound," is the work done in raising a weight of 1 pound through a vertical distance of 1 foot against gravity.

The foot-pound-second system is the counterpart of the C.G.S. system, in which the fundamental units are the centimetre, gram and second.

**Forecast.**—The first use in this country of synoptic charts for forecasting the weather anticipated in the near future was made by Admiral Fitzroy in 1860, and it was he who invented the special meaning of the term "forecast" to avoid the somewhat unfortunate connotations attaching to such terms as "prognostic" and "prophecy."

In practice, a forecast as issued, for 12, 24 or 36 hours, includes:—

(1) A statement of the anticipated direction and force of the surface wind and the changes therein which are expected during the period of the forecast.

(2) A statement of the anticipated state of the sky (as regards clouds), precipitation (rain, hail, snow or sleet) and temperature, whether it is likely to be greater than, equal to or less than, the normal for the time of year, or higher or lower than at the time of making the forecast.

(3) A note as to the probability of such occurrences as night frost, fog or thunder.

Forecasts issued for special purposes contain special matter, additional to that already specified. For aviation, for example, the anticipated winds at selected or demanded heights are included together with a statement concerning the visibility and any anticipated changes in it. Again, for seamen, statements may be included concerning visibility and the state of the sea.

To derive the forecasts, the forecaster depends upon a close study of the current synoptic charts, especially with regard to anticipated changes in the distribution of pressure, and with constant appeal to physics and to precedent.

The period covered by the forecasts issued by the Meteorological Office does not exceed, as a rule, 24 to 36 hours, but usually a statement under the heading FURTHER OUTLOOK is added, giving the conditions likely to be experienced in the 24 hours or more following the period covered by the actual forecast. Attempts to find means to forecast the coming of weather changes at a greater distance ahead are described under LONG-RANGE FORECAST. See also SINGLE OBSERVER FORECASTING.

**Fortin Barometer.**—A portable form of mercurial BAROMETER in which the zero of the scale is fixed by a pointer, inside the cistern. By making the cistern partly of leather and providing an adjusting screw, the level of mercury in the cistern can be brought up to the scale zero before each reading is taken.

**Fourier Series.**—A representation of any periodic function of an independent variable in terms of sines and cosines of multiples of that variable is called a Fourier Series. It was first developed by Fourier in his treatise "Théorie de la Chaleur" (Paris, 1822). In symbols,

$$f(x) = A_0 + A_1 \sin x + A_2 \sin 2x + \dots \\ + B_1 \cos x + B_2 \cos 2x + \dots$$

See HARMONIC ANALYSIS.

**Fracto.**—An adjective used in cloud nomenclature to denote a ragged broken structure (fractocumulus, fractostratus, fractonimbus).

**Frazil Ice.**—Ice which forms in spicules or small plates in rapidly flowing rivers, the movement of the water preventing the ice crystals from forming a solid sheet of ice. The formation has been best observed in the rivers of Canada, and the name is a French-Canadian word, from a French word for cinders, the frazil crystals being supposed to resemble forge-cinders.

**Freeze, Freezing.**—With reference to the weather, "freezing" is used when the temperature of the air is below the freezing point of water. In America, freezing conditions sufficiently persistent to produce what we should call "a FROST" are usually described as "a freeze."

**Frequency.**—The number of times that a particular phenomenon of weather has happened in the course of a given period of time, generally a

*Frequency Table.*—Number of Spells of Wind of Specified Duration from NE., E. or SE., during the nine years 1904–12 inclusive. South-east England and northern France.

Duration of Spell	January	February	March	April	May	June	July	August	September	October	November	December
Days	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
1	12	7	13	15	15	19	13	13	11	12	13	11
2	7	3	3	3	10	7	6	5	8	4	4	2
3	2	5	4	3	3	3	4	—	3	7	1	2
4	3	—	3	1	1	1	4	2	6	1	2	—
5	—	1	—	2	4	—	—	—	1	1	1	—
6	1	—	—	2	1	2	—	2	—	—	1	1
7	—	—	1	1	—	1	—	—	—	—	—	1
8	1	—	—	1	—	—	—	—	1	2	—	1
9	—	—	—	—	—	—	—	—	—	1	—	—
10	—	—	—	—	—	—	—	—	—	—	1	—
11	—	1	—	—	—	—	—	—	—	—	—	—
12	—	—	—	—	—	—	—	1	—	—	—	—
13	—	—	1	—	—	—	—	—	—	—	—	—
Total number of days of E. wind.	58	44	63	71	74	65	53	55	76	75	53	42
Total number of days of observations.	279	255	279	270	279	270	279	279	270	279	270	279

number of years. Here, for example, is a summary of the spells of wind from the easterly quarter, according to the direction of the isobars, over south-east England and northern France in nine years. Taking January, for instance, the nine years supply a total of 279 days, of which 58 were days of E. wind. These consisted of one sequence of eight consecutive days of E. wind, one sequence of six days, three sequences of four, two sequences of three and seven sequences of two days, with finally twelve isolated days of E. wind.

In this case the number of years over which the observations extend is given, quite an arbitrary number, and thus the numbers for frequency of occurrence have to be considered with reference to the number of years selected. It is, however, usual to reduce frequency figures to a yearly average.

In view of the awkwardness of having to bear in mind the possible number of occurrences, while considering the actual or average number, it is convenient to use the percentage frequency instead of the actual frequency. This plan is often adopted for giving the results of observations at sea, which are made six times a day, or every four hours.

It is often convenient to represent the results of observation by means of a *frequency curve*. An example is shown giving the distribution of frequencies of deviations from normal of monthly mean pressures at Edinburgh for the period 1770-1869. (Fig. 19.) This curve approximates to the "normal frequency curve" given by the NORMAL LAW (OF ERRORS).

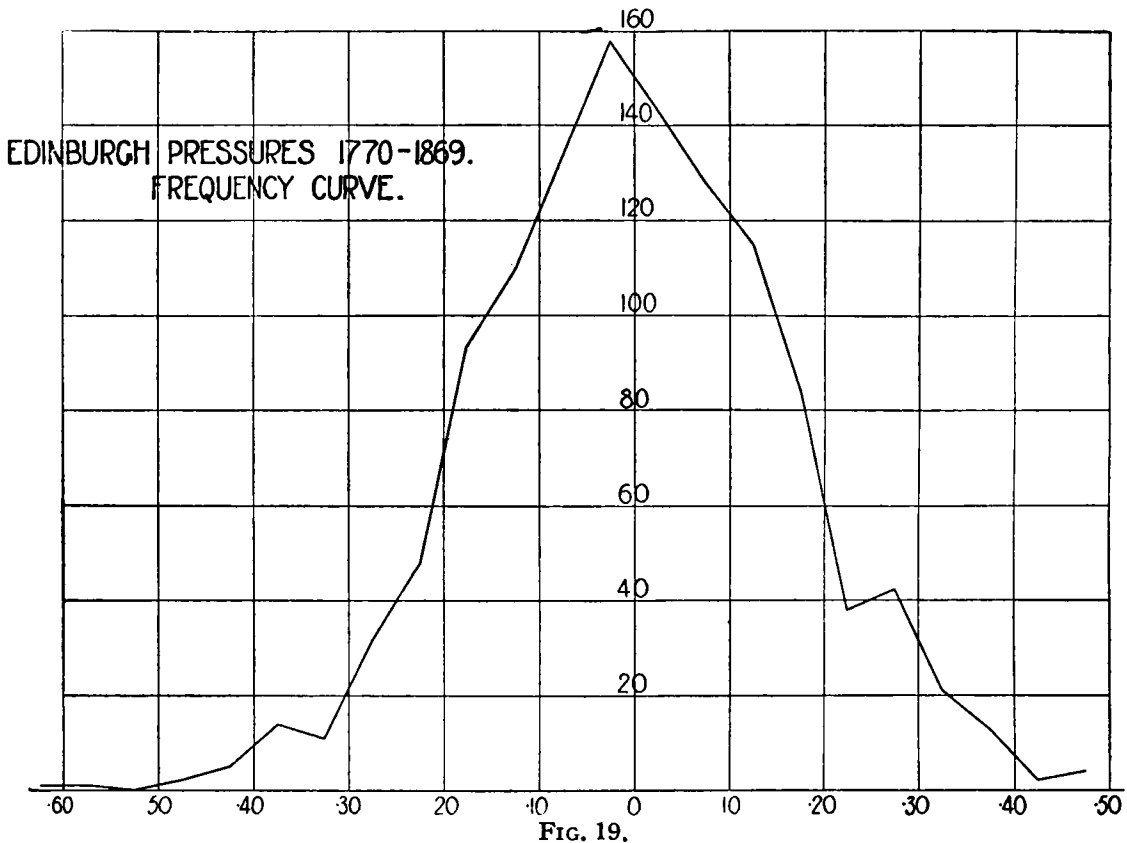


FIG. 19.

**Friction.**—A word used somewhat vaguely in meteorological writings in dealing with the effect of the surface of the sea or of the land, with its obstacles in the form of irregularity of surface, hills, buildings, or trees upon the flow of air in the lower layers of the atmosphere. The effect of the irregularities of surface is to produce **TURBULENCE** in the lowest layer which gradually spreads upwards, if the wind goes on blowing, and consists of irregular eddies approaching to regularity in the case of a cliff eddy which can be noticed when a strong wind blows directly on to a cliff and produces an eddy with a horizontal axis. An account of the eddies caused by the eastern face of the rock of Gibraltar is given in *Geophysical Memoirs*, Vol. VII, No. 59, 1933.

The general effect of this so-called friction is to reduce the flow of air past an anemometer so that the recorded wind velocity is below that which would be experienced if the anemometer were high enough to be out of the reach of the surface effect. Numerical values for this effect are of great practical importance, because they are concerned with the change of velocity in the immediate neighbourhood of the ground. But it is not easy to obtain them, because every exposure near land or sea is more or less affected and therefore no proper standard of reference can be obtained by direct observation. Recourse is, therefore, had to the computation of the wind from the distribution of pressure, the so-called "geostrophic" or GRADIENT WIND.

From the comparison of a long series of geostrophic and observed winds we conclude that over the open sea, or on an exposed spit of flat sand like Spurn Head, the wind loses one-third of its velocity from "friction," and at other well-exposed stations the loss is, on the average, as much as 60 per cent., but for any particular anemometer it is different for winds from different quarters because the exposure seaward or landward is different. Information on this point for a number of Meteorological Office stations is given in a memoir by Mr. J. Fairgrieve (*Geophysical Memoirs*, Vol. 1, No. 9, p. 189).

The consequence of this effect can sometimes be seen in weather maps. On one occasion when the whole of the British Isles was covered with parallel isobars running nearly west and east, all the stations on the western side gave the wind as force 8 (42 m.p.h.), while those on the eastern side gave force 5 (21 m.p.h.), so that the velocity was reduced by one-half in consequence of the "friction" of the land. If the velocity at the exposed western stations be taken at two-thirds the velocity of the wind free from friction, we get the following interesting result which is probably correct enough for practical use:—One-third of the velocity is lost by the sea friction on the western side, and one-third more by the land friction of the country between west and east.

**Front.**—The term introduced by the Norwegian meteorologists to denote the line of separation between cold and warm masses of air. The more important fronts are due primarily to the large-scale horizontal movements, which bring masses of air of widely different origin into juxtaposition. The actual boundary is sometimes diffuse, and only becomes sharp when there is pronounced CONVERGENCE (see FRONTOGENESIS). Sharp fronts are often made diffuse by SUBSIDENCE in the cold air, provided that there is little precipitation, the cold air behind the front descending and being warmed by compression so that it becomes difficult to distinguish it from the warm air which it is displacing. From the line of the front on the ground, a SURFACE OF DISCONTINUITY or frontal surface slopes upward over the cold air. The contrast of temperature, and therefore of density, affects the pressure and wind distribution, and it can be shown that a front must in general lie along a trough of low pressure (though a rounded trough is not necessarily a front). It may, however, be parallel to the isobars, in which case the steeper pressure gradient is on the side of the higher pressure. In consequence, surface friction normally causes some convergence and rainfall along a front, but large amounts of rain can only occur when there is convergence extending up to some thousands of feet, which results in the warm current rising *en masse* up the sloping frontal surface. See also DEPRESSION, POLAR FRONT, COLD FRONT, WARM FRONT, AIR MASS.

**Frontogenesis.**—The development or marked intensification of a FRONT. The process is really a development from a zone of transition between AIR MASSES, indicated by a steep horizontal gradient of temperature, to a real DISCONTINUITY. The drawing together of the isotherms is accompanied by the removal of the intermediate air, either horizontally (deformation) or vertically; the latter involves CONVERGENCE and is the most potent factor. Suitable surface conditions, such as coast lines, snow or ice boundaries, or abnormal gradients of sea temperature, favour frontogenesis.



**Frontolysis.**—The disappearance or marked weakening of a FRONT. The opposite of FRONTOGENESIS. SUBSIDENCE is the most important factor in causing frontolysis.

**Frost.**—Frost occurs when the temperature of the air is below the freezing point of water. It may be transient and local, as is usual in the case of frosts due to the cooling of comparatively mild air of oceanic origin at night under a clear sky, or it may continue night and day over a large area. When persistent frost occurs over a large proportion of the British Isles, it is always initiated by the arrival of dry cold air from the continent or the Arctic Regions. A persistent anticyclone to the north-west, north or north-east of the British Isles in the winter half of the year, may cause such an influx of cold dry air, generally with northerly or easterly winds. If these bring heavy snow, the spell of frost is apt to be severe, because snow absorbs only a small proportion of the solar radiation that falls upon it, while emitting radiation of longer wave-lengths very readily; and because its thermal conductivity is so low compared with that of the ground that the normal winter flow of heat from the deep earth to the surface is checked. It is with snow-covered ground that temperatures below zero Fahrenheit are liable to occur even in the south of England. The exceptional frosts of February, 1895, were preceded by heavy snow. The expression "degrees of frost" denotes the number of degrees that the temperature falls below the freezing point.

**Frost Day.**—A frost day is defined as a period of 24 hours ending at 9 h. G.M.T. or at 21 h. where observations are made at 21 h. on which the screen minimum temperature is 32° F. or less.

**Frost, Protection against.**—The use of orchard heaters for the purpose of protecting fruit crops from destruction by frost during the blossoming season has obtained a considerable vogue in the United States of America. In this country severe frost during the period of maximum susceptibility is relatively rare, but the American methods of orchard heating have been adopted by some growers. Accurate data are scanty, but it appears that it is practicable, without a prohibitive expenditure of fuel, to maintain the orchard temperature above the lethal point, on "radiation nights" when there is no general air movement and frost is the result of nocturnal radiation from the ground and plants. In these circumstances the heating effect is applied to the cold surface layers of air beneath the inversion, and an appreciable rise of temperature may be produced. In a "wind frost," on the other hand, when a lethal temperature is due to a definite flow of cold air of great vertical extent, no process of heating could ever be effective. Some American growers have also used large fans rotated about an inclined axis by powerful motors supported on towers thirty or forty feet high. The aim is to draw down warm air from higher levels to displace the cold surface layers of air, and a high standard of efficiency is claimed by the makers of the installations.

**Funnel Cloud.**—The cloud formed at the core of a WATERSPOUT or TORNADO, sometimes extending right down to the earth's surface, attributed to the reduction of pressure at the centre of the vortex.

**Further Outlook.**—A statement in brief and general terms appended to a detailed forecast and giving the conditions likely to be experienced in the 24 hours or more following the period covered by the actual forecast.

**Gale.**—As ordinarily understood a gale simply means a high wind. For technical purposes however it is necessary to have a more definite specification, and it is now the practice in the London Meteorological Office to limit the term gale to winds of force 8 or above on the BEAUFORT SCALE, although Admiral Beaufort himself described force 7 as a moderate gale. As the result of international agreement it has been decided that the equivalent velocity of force 8 on the Beaufort scale extends from 15·3 to 18·2 metres per second for an anemometer exposed at a height of 6 metres over a level surface, this corresponds to velocities between 17·2 and 20·7 metres per second for an exposure 10 metres above the ground, which is the normal exposure of

the anemometers used at British stations. Great difficulty is encountered in comparing the frequency with which gales occur at different places. If the observations to be compared are all made by estimates according to the Beaufort scale, the comparison is made difficult because of the different exposure to the wind at the place of observation. Observations made within a sheltered harbour will obviously give fewer gales than observations made on a nearby headland. Similar difficulties as regards the exposure occur with records obtained by anemometers; but in addition there are difficulties due to the varying height of the anemometers above the ground and also due to the method of reading the anemometer trace. The velocity equivalent of 17.2 m./sec. was determined from records each extending over an hour during which the velocity was frequently above this value and also frequently below. Thus it is not correct to report a gale whenever an anemometer trace reaches 17.2 m./sec. From this it is clear that it is essential to state exactly how statistics of frequency of gales have been obtained, and to take into account when discussing the statistics the "exposure" at the observing stations.

The table headed "Average occurrence of gales during the 20 years 1916-35" that is appended to this article is based on as homogeneous a set of statistics as it is possible to obtain. The majority of the observations are "Beaufort estimates," which were made on lightships and lighthouses in exposed situations and coastguard stations, 1916-35. The table shows that the south-west of England is the most subject to gales and the east of Scotland the least subject.

*Average occurrence of gales during the 20 years 1916-35*

Districts	January	February	March	April	May	June	July	August	September	October	November	December	Year
Scotland :—													
North-east .. ..	5.9	4.1	2.3	1.7	0.5	0.5	0.1	0.3	1.5	3.3	3.5	4.8	28.4
East .. ..	2.9	1.8	0.7	0.6	0.3	0.3	0.1	0.1	0.5	1.3	1.4	1.9	11.9
North-west .. ..	5.5	3.6	2.4	1.1	0.5	0.5	0.2	0.6	1.7	3.6	3.7	4.1	27.4
West and North Channel.	4.8	2.9	1.9	1.3	0.4	0.5	0.2	0.3	1.2	3.7	3.6	4.2	24.9
Ireland :—													
North .. ..	6.1	3.8	1.9	1.5	0.5	0.6	0.3	0.3	1.9	3.5	3.7	3.9	28.3
South .. ..	4.7	3.0	2.1	1.7	0.3	0.4	0.3	0.8	1.5	3.7	3.9	4.4	26.8
Irish Sea .. ..	4.5	2.6	2.1	1.5	0.6	0.7	0.3	0.5	1.9	3.9	3.0	4.1	25.5
St. George's Channel..	4.7	2.5	1.7	1.3	0.4	0.4	0.3	0.7	1.7	3.5	3.6	4.0	24.7
Bristol Channel ..	5.1	3.3	2.4	1.6	0.9	0.7	0.6	1.1	1.7	4.7	4.7	4.9	31.5
England :—													
South-west .. ..	5.3	3.5	3.1	2.3	0.8	0.7	0.5	0.9	2.0	4.4	4.9	6.1	34.5
South .. ..	4.1	2.5	1.7	1.5	0.3	0.2	0.5	0.7	1.4	3.9	3.7	4.1	24.5
South-east .. ..	3.7	2.5	1.7	1.6	0.5	0.4	0.7	0.7	1.3	4.1	3.3	4.1	24.7
East .. ..	3.1	2.7	1.8	1.6	0.5	0.4	0.5	0.8	1.5	3.9	3.1	3.2	23.1
North-east .. ..	2.3	2.1	1.2	0.7	0.1	0.1	0.1	0.3	0.7	1.7	1.9	2.1	13.5

**Gale, Day of.**—In British climatology a day of gale is defined as a day on which a wind of force 8 or more (BEAUFORT SCALE) has lasted for at least 10 minutes at any time during the 24 hours ending at midnight G.M.T.

**Gale Warning.**—The Meteorological Office issues notice of the probability of gales on or near the coasts of the British Isles by broadcast warnings and by telegram to ports and fishing stations recommended by responsible local authorities, and the fact that one of these notices has been received at any station is made known by hoisting a cone, 3 ft. high and 3 ft. wide at base, and painted black.

Two cones are used (*a*) the south cone (point downwards) and (*b*) the north cone (point upwards). For the significance of these cones reference should be made to the instructions issued to all gale-warning stations.

The issue of a warning indicates that an atmospheric disturbance is moving or developing in such a way as probably to cause a gale in exposed situations or in the open sea in the district to which the warning is sent, i.e. within a distance of 50 to 100 miles of the place where the cone is hoisted. The meaning of the warning is simply "Look out for high winds or gales."

It needs to be noted that, in connexion with the gale warning service, the term "gale" is used for winds of force 8 and above on the BEAUFORT SCALE OF WIND FORCE.

**Gas.**—The name used for any kind of fluid which has unlimited capacity for expansion under diminishing pressure. It is to be distinguished from a liquid which has only a limited capacity for expansion under reduced pressure.

A liquid may occupy only the lower part of a vessel like a bottle; it will flow to the bottom of the vessel and leave a "free" surface. But a gas cannot be located in that way; its volume is determined not by the amount of material but by the size of the vessel which contains it and by the pressure upon its boundaries.

In scientific practice gas means any substance which obeys approximately the gaseous laws; these laws are two, viz. :—

(1) When the temperature is kept constant the pressure of a given mass of gas is inversely proportional to the volume which it occupies, or the density is directly proportional to the pressure.

(2) When the volume is kept constant the pressure is proportional to the ABSOLUTE TEMPERATURE, or when the pressure is kept constant the volume is proportional to the absolute temperature.

**Gathering Ground.**—An area from which water is obtained by way of rainfall, drainage or percolation. See also CATCHMENT AREA and DRAINAGE AREA.

**Gauss.**—See ELECTRICAL UNITS.

**General Inference.**—The term "General Inference" is used in weather forecasting for a description of the general pressure distribution and the changes of pressure in progress together with a statement of the type of weather likely to be experienced through such changes. It usually precedes a series of more detailed forecasts for individual districts and gives the foundations or framework on which these forecasts are formed.

**General Rainfall.**—The mean value of the depth of rainfall for a given period over an area of substantial extent.

**Geophysics.**—Physics is a comprehensive name for the branches of science which deal with those natural phenomena which are not biological and not merely descriptive. Geophysics is the name for those parts of physics which are concerned with the earth and its atmosphere. Meteorology, seismology, terrestrial magnetism, atmospheric electricity and hydrology (including the theory of the tides) all rank as geophysical subjects. Geology and geography are concerned largely with matters which do not come within the range of geophysics, but there is no definite limitation.

**Geopotential.**—Potential energy is the general name given to ENERGY which is available for conversion to kinetic energy. Thus we may talk of the potential energy of a coiled-up spring. In many cases the potential energy is acquired by a change of position in a field of force and in such cases potential is defined as the potential acquired by the appropriate unit of quantity. When dealing with matter in the gravitational field of the earth, potential, or more specifically geopotential is the potential energy of unit mass. The zero of potential is taken as at sea level.

Since the gravitational attraction of the earth is greater near the poles than near the equator more energy is required to raise a body to a given height near the poles, and therefore the geopotential increases more rapidly as we ascend in high latitudes than in low. Conversely the height at which a given potential is reached is less in high latitudes than in low. Points

with the same geopotential may be said to be at the same level. By using geopotential rather than height for specifying the position of parts of the atmosphere, the consideration of the air movements is simplified, and for this reason the practice of publishing the results of balloon soundings in terms of geopotential has been advocated and indeed adopted by the international organization.

The natural unit of geopotential is the potential acquired when a mass is raised through the unit distance in a field of force of unit strength. Thus, in the C.G.S. system the unit would be  $1 \text{ cm.} \times 1 \text{ cm./sec.}^2$ . The unit proposed by V. Bjerknes was  $10^6$  times greater and is known as the dynamic metre; the unit of geopotential used in upper air observations is the geopotential metre which is 0.98 dynamic metre.

**Geostrophic.**—See GRADIENT WIND.

**Glacier Breeze.**—A cold breeze, blowing down the course of a glacier, which owes its origin to the cooling of the air in contact with the ice. See KATABATIC.

**Glaisher Stand.**—A form of stand devised by James Glaisher for the exposure of thermometers. The stand consists of a vertical portion, partially roofed, on which the thermometers are mounted, with a doubly roofed sloping rear portion designed to prevent the front portion becoming heated from the rear. The whole is capable of rotation about a vertical axis so that direct sunshine may be prevented from affecting the thermometers at all times. The stand has been superseded at nearly all important stations by the STEVENSON SCREEN.

**Glazed Frost.**—When rain falls with the air temperature below the freezing point a layer of smooth ice, which may attain considerable thickness, is formed upon all objects exposed to it. This is known as glazed frost. The accumulation of ice is frequently sufficient to bring down telegraph wires. In these Islands the phenomenon is one of comparative rarity. It occurred on the morning of December 21, 1927, in London, and in many other parts of England, and caused several thousand street accidents. Glazed frost also occurs when a warm damp wind supervenes upon severe cold, the moisture condensing on still freezing surfaces and thus producing a coating of ice.

A phenomenon similar to glazed frost may also result if sleet, formed by the passage of snow through an upper stratum of air above the freezing-point, occurs during frost. Instances of this occurred in London during the winter of 1916-7, and road traffic, in some cases even rail locomotion, was rendered difficult or impossible.

**Glory.**—The system of coloured rings surrounding the shadow of the observer's head on a bank of cloud or mist. A typical series of colours in a well developed glory is the following:—A whitish yellow field bounded by dull red; bluish green, reddish violet; blue, green, red; green, red.

When light passes through circular holes in an opaque screen, colours are produced by DIFFRACTION. If little mirrors all facing the sun could be substituted for the droplets in a cloud, the light from each mirror would behave as if it came through a hole from the reflection of the sun and similar diffraction colours would occur. The action of the drops is probably analogous. The mathematical theory developed by Ray is on these lines. Earlier writers had supposed that the phenomena were produced by the diffraction, by particles comparatively near the surface, of light reflected from deeper portions of the fog or cloud.

A glory may be surrounded by a FOG BOW.

**Gold Slide.**—When a mercurial barometer is used at sea level in lat.  $45^\circ$  the correction to be applied to its readings in order to reduce them to standard conditions is directly proportional to the difference between its STANDARD TEMPERATURE and the actual temperature. To simplify the application of this correction, it is clearly possible to graduate the attached thermometer

directly in millibars, the zero corresponding with the standard temperature. If the height of the barometer cistern is changed by an amount not exceeding 100 ft. the consequent correction is merely equivalent (to a first approximation) to a change in the zero of the correction scale. The same statement applies to a change of latitude.

In the Gold slide, devised by E. Gold, F.R.S., this principle is applied in a practical form for use on marine barometers. The "ATTACHED THERMOMETER" is mounted in a brass stock and the "barometer correction scale" of millibars is mounted on a vertical slide actuated by rack and pinion. Scales are provided whereby the necessary adjustments for index error, height and latitude are readily made and the total correction is read off on the sliding scale opposite the end of the thermometric column, thus avoiding calculation or reference to tables.

**Gradient.**—The word gradient is used in surveying and in common practice to indicate the slope of a hill, that is the change in height per unit horizontal distance. The word has been adopted in meteorology to indicate the change in certain elements, for example pressure and temperature, per unit horizontal distance and its use has further been extended to the change of elements in the vertical, though this use seems hardly justified. Thus, when temperature gradient is referred to, it is generally the change of temperature with height in the atmosphere which is meant and not the change along the earth's surface between one place and another. More recently the term LAPSE rate has been used to replace gradient in the vertical direction; thus, if the temperature falls at the rate of  $5^{\circ}$  per 1,000 ft. height in the atmosphere, this is referred to as a lapse rate of  $5^{\circ}$  per 1,000 ft.

Of the several connexions in which the word gradient is used in meteorology that in which it indicates the rate of change of pressure along the earth's surface is the most important, pressure gradient being one of the fundamental quantities with which the meteorologist has to deal. This is mainly due to the fact that the wind at a short distance above the earth's surface is so closely related to the pressure gradient that in many cases a better estimate can be formed of the general wind from the run of the isobars than by any other means. The pressure gradient is the change of pressure per unit distance measured perpendicular to the isobars, that is in the direction in which pressure changes most rapidly. Instead of measuring the pressure difference in a given distance such as 100 miles, it is in practice found more convenient to measure the distance between two consecutive isobars and deduce the gradient by dividing the pressure difference between the two isobars by this distance. The measurement of pressure gradient is a simple matter when the isobars are straight or only slightly curved, are parallel to one another, and are uniformly spaced. When the pressure distribution is irregular and the isobars sinuous, the measurement of the pressure gradient becomes more difficult and it is necessary to study the individual pressure readings in addition to the run of the isobars to determine the gradient in any region.

**Gradient Wind.**—The flow of air which is necessary to balance the pressure-gradient. The direction of the gradient wind is along the isobars, and the velocity is so adjusted that there is equilibrium between the force pressing the air inwards, towards the low pressure, and the centrifugal action to which the moving air is subject in consequence of its motion.

In the case of the atmosphere the centrifugal action may be due to two separate causes; the first is the tendency of moving air to deviate from a GREAT CIRCLE in consequence of the rotation of the earth; the deviation is towards the right of the air as it moves in the northern hemisphere, and towards the left in the southern. The second is the centrifugal force of rotation in a circle round a central point according to the well-known formula for any spinning body. In this case we regard the air as spinning round an axis through the centre of curvature of its path. This part of the centrifugal action is due to the curvature of the path on the earth's surface. Both components of the centrifugal action are in the line of the pressure gradient:

the part due to the rotation of the earth is always tending to the right in the northern hemisphere, the part due to the curvature of the path goes against the gradient from low to high when the curvature is cyclonic, and with the gradient when it is anticyclonic, so that in the one case we have the gradient balancing the sum of the components due to the earth's rotation and the spin, and in the other case the gradient and the spin-component balance the action due to the earth's rotation.

The formal reasoning which leads up to this result is given at the end of this article. The two components have been named by Sir Napier Shaw—that due to the rotation of the earth being called the *geostrophic* component and that due to the curvature of the path, the *cyclostrophic* component.

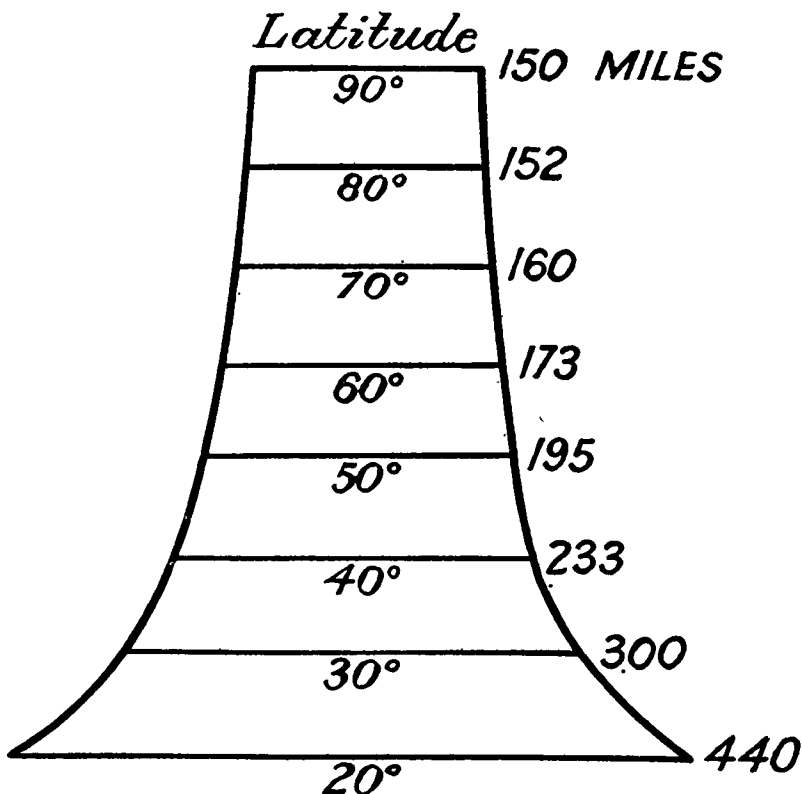
Consider the relative magnitude of these components under different conditions. It will be noticed that the geostrophic component depends upon latitude, the cyclostrophic component does not, so, other things being equal, their relative importance will depend upon the latitude; so we will take three cases, one near the equator at latitude  $10^\circ$  within the equatorial belt of low pressure, one near the pole latitude  $80^\circ$  of undetermined meteorological character, and one, half-way between, in latitude  $45^\circ$ , a region of highs and lows travelling eastward.

Using  $V$  to denote the wind velocity, when the radius of the path is 120 nautical miles the cyclostrophic component is equal to the geostrophic—

- in latitude  $10^\circ$  when  $V$  is 5.6 metres per second;
- in latitude  $45^\circ$  when  $V$  is 22.9 metres per second;
- in latitude  $80^\circ$  when  $V$  is 31.9 metres per second.

It will be seen that in the equatorial region the cyclostrophic component is dominant as soon as the wind reaches a very moderate velocity.

For practical application in deducing the geostrophic component of the gradient winds from isobaric charts a graduated scale is used, the graduations being selected to correspond with the average latitude and average surface conditions to which it is to be applied. If the distance between the isobars for a definite value  $V$  of the geostrophic component is  $D$  for latitude  $90^\circ$



then the distances between the isobars for any other latitude  $\lambda$  for the same value  $V$  of the wind is  $D \operatorname{cosec} \lambda$ . If the isobars are drawn for intervals of 2 mb. and  $V$  is 10 m.p.h. then the value of  $D$  is 150 miles. The diagram on p. 99 drawn to scale gives the actual distances apart of 2 mb. isobars on a map scale  $1 : 10^7$  for different latitudes. The distances given are for air of standard density, i.e.  $0.001226 \text{ gm./cm.}^3$ . They are the actual lengths of the horizontal line drawn at each latitude. The distances in miles are given at the right of the diagram. (For other distances or densities, speeds are inversely proportional, i.e. the simple rule is that halving the distance or the density doubles the speed.)

#### EQUATION FOR GEOSTROPHIC WIND.

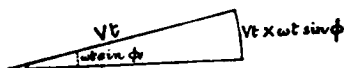
*The Relation between the Earth's Rotation and the Pressure Distribution for Great-Circle-Motion of Air.*

The rotation  $\omega$  of the earth about the polar axis can be resolved into  $\omega \sin \phi$  about the vertical at the place where latitude is  $\phi$  and  $\omega \cos \phi$  about a line through the earth's centre parallel to the tangent line.

The latter produces no effect in deviating an air current any more than the polar rotation does on a current at the equator.

The former corresponds with the rotation of the earth's surface counter-clockwise in the northern hemisphere and clockwise in the southern hemisphere under the moving air with an angular velocity  $\omega \sin \phi$ . We therefore regard the surface over which the wind is moving as a flat disc rotating with an angular velocity  $\omega \sin \phi$ .

By the end of an interval  $t$  the air will have travelled  $Vt$ , where  $V$  is the wind velocity, and the earth underneath its new position will be at a distance  $Vt \times \omega t \sin \phi$ , measured along a small circle,



from its position at the beginning of the time  $t$ .

Taking it to be at right angles to the path, in the limit when  $t$  is small, the distance the air will appear to have become displaced to the right, over the earth, is  $V \omega t^2 \sin \phi$ .

This displacement on the " $\frac{1}{2} g t^2$ " law (since initially there was no transverse velocity) is what would be produced by a transverse acceleration

$$2\omega V \sin \phi.$$

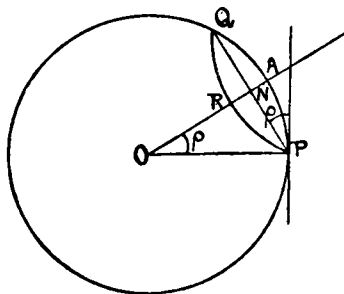
Hence the effect of the earth's rotation is equivalent to an acceleration  $2\omega V \sin \phi$ , at right angles to the path directed to the right in the northern hemisphere, and to the left in the southern hemisphere.

In order to keep the air on the great circle, a force corresponding with an equal but oppositely directed acceleration is necessary. This force is supplied by the pressure distribution.

#### EQUATION FOR CYCLOSTROPHIC WIND

*Force necessary to balance the Acceleration of Air moving uniformly in a small circle, assuming the earth is not rotating*

Let  $A$  be the pole of circle  $PRQ$ . Join  $PQ$ , cutting the radius  $OA$  in  $N$ . Acceleration of particle moving uniformly along the small circle with velocity  $V$  is  $V^2/PN$  along  $PN = V^2/R \sin \rho$  where  $R$  = radius of earth; and  $\rho$  is the angular radius of the small circle representing the path.





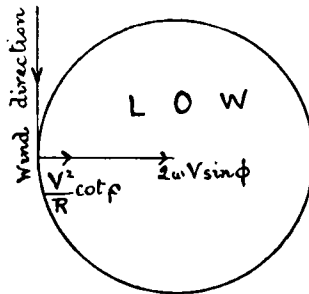
The horizontal component of this acceleration, that is, the component along the tangent at  $P$ , is  $V^2 \cos \rho / R \sin \rho = V^2 \cot \rho / R$ .

GENERAL EQUATION CONNECTING PRESSURE GRADIENT, EARTH'S ROTATION, CURVATURE OF PATH OF AIR AND WIND VELOCITY

I. *Cyclonic motion*.—The force required to keep the air moving on a great circle in spite of the rotation of the earth must be such as to give an acceleration  $2\omega V \sin \phi$  directed over the path to the left in the northern hemisphere. It must also compensate an acceleration due to the curvature of the path,  $V^2 \cot \rho / R$ , by a force directed towards the low pressure side of the isobar.

For steady motion these two combined are equivalent to the acceleration due to the gradient of pressure, i.e.  $\frac{\gamma}{D}$  where  $D$  is the density of the air, and  $\gamma$  the pressure gradient, directed towards the low pressure side,

$$\therefore \frac{\gamma}{D} = 2\omega V \sin \phi + \frac{V^2}{R} \cot \rho.$$



II. *Anticyclonic motion*.—In this case  $2\omega V \sin \phi$  and  $\gamma/D$  are directed outwards from the region of high pressure, and the equation becomes

$$\frac{\gamma}{D} = 2\omega V \sin \phi - \frac{V^2}{R} \cot \rho.$$

The cyclostrophic component does not represent the whole of the acceleration, there is also the acceleration along the path of the air, which is generally of the same order of magnitude as the acceleration at right angles to the path.

**Gram**.—The unit of mass in the C.G.S. system. It is one-thousandth part of the standard kilogram which was originally supposed to represent the weight of a cubic decimetre of pure water at  $4^\circ \text{C}$ .; but subsequent research has shown that the relationship was not exact. A gram = 15.4 grains, or rather more than  $\frac{1}{30}$  ounce.

**Gram-Calorie**.—See CALORIE.

**Grass Minimum Temperature**.—The minimum temperature indicated by a thermometer freely exposed in an open situation at night with its bulb in contact with the tips of the grass blades on an area covered with short turf. If under these conditions the minimum reading is  $30.4^\circ \text{F}$ . or lower, a GROUND FROST is said to occur.

**Graupel**.—The German word for SOFT HAIL.

**Gravity.**—The attraction between material bodies. The law of universal gravitation is that every mass attracts every other mass with a force which varies directly as the product of the attracting masses and inversely as the square of the distance between them. It is convenient to regard the attracted body as of unit mass. The law then implies that the force exerted is independent of the temperature and of the velocity of the attracting body. Both these conclusions have been attacked of late years, but it is not questioned that they are sufficiently exact for meteorological purposes.

It was shown by Newton that a sphere whose density varies only with the distance from the centre attracts an external body exactly as if the whole mass were collected at the centre, and that a similarly constituted spherical shell—i.e. a mass bounded by two concentric spherical surfaces—while attracting an external body as if its mass were collected at the centre, exerts no attraction at any internal point. Let us apply this to a point in the atmosphere at height  $h$  above the ground, regarding the earth as a perfect sphere of radius  $R$ , and assuming the density, whether of the earth or the atmosphere, to vary only with the radial distance. The atmosphere outside the spherical surface of radius  $R + h$  exerts no attraction, while the earth's mass plus that of the atmosphere ( $M + M'$ ) within the surface of radius  $R + h$  attract as if collected at the centre. Thus the attractive force is  $G (M + M')/(R + h)^2$ , where  $G$  is a constant. This becomes  $g_0 (1 + M'/M) (1 + h/R)^{-2}$ , where  $g_0 = GM/R^2$  is the corresponding force at the earth's surface, i.e. wholly within the atmosphere. Counted in kilograms  $M'$  is large, but even if we went to the confines of the atmosphere  $M'/M$  would be less than one millionth. Thus the attraction of the atmosphere may be neglected, at least for meteorological purposes. The variation with height of the earth's own attraction is much more important. At all heights attained by balloons we may neglect  $h^3/R^3$ , and so replace  $(1 + h/R)^{-2}$  by  $(1 - 2h/R + 3h^2/R^2)$ . But at a height of 10 miles this represents a reduction of one part in 200 in gravity.

Although the astronomical definition of gravity relates only to the universal attraction between masses, in geophysics the value of the gravitational acceleration  $g$  is taken to represent the total vertical acceleration and therefore to include the centrifugal acceleration.

In reality the earth is not a sphere but approaches to a spheroid whose equatorial radius is 10·7 k. longer than its polar radius. The earth's surface is also irregular in outline, and the density variable, at least near the surface. Thus the formulae actually advanced to show the variation of gravity at different parts of the earth's surface are complicated.

The theoretical value of  $g$  at mean sea level in lat.  $\vartheta$  is

$$g = 980\cdot616 (1 - 0\cdot0026373 \cos 2\vartheta + 0\cdot0000059 \cos^2 2\vartheta) \quad \dots (1)$$

in C.G.S. units.

The local value of the acceleration of gravity at a given land station on a uniform plateau flat for over 150 Km. from the station at a height  $H$  metres above mean sea level is obtained by subtracting  $0\cdot0003086 H$  from the value given by formula (1).

In the free air at an altitude  $Z$  metres above mean sea level the value of gravity above a wide plateau is obtained by subtracting the free air term  $\{(0\cdot00030855 + 0\cdot000000227 \cos 2\vartheta)Z - (0\cdot00007254 + 0\cdot00000010 \cos 2\vartheta)(Z/1000)^2\}$ .

For details of the corrections to be applied to the values obtained from these formulae to take account of variation with height of the surface round the station, or below it for a free air station, reference should be made to Technical Regulations, World Meteorological Organization, Volume I, Annex II.

It will be noted that the reference to a value of  $g$  at latitude  $45^\circ$  has ceased to be basic.

The determination of  $g$  absolutely at any spot with the precision which the formulae suggest is extremely difficult, but relative values of  $g$ , or differences between its values at different places, can be determined with very high precision by means of pendulum observations.

If  $t$  and  $t'$  be the times of oscillation of a certain pendulum at two stations, the corresponding values  $g$  and  $g'$  of gravity are connected by the relation  $g'/g = (t/t')^2$ .

This enables gravity at any station to be determined in terms of gravity at a base station. For accurate work corrections have to be applied to the observed times of swing to allow for departures of temperature and pressure from their standard values, also for chronometer-rate and flexure of the pendulum-stand. When all the known corrections are carefully made a very high degree of accuracy is obtainable. For instance, taking  $981\cdot200$  as the value of  $g$  at Kew Observatory, this being the value accepted for the purposes of the Trigonometrical Survey of India, the last two comparisons instituted between Greenwich and Kew, the one made by the United States Coast and Geodetic Survey, the other by the Trigonometrical Survey of India—using two different sets of half-second pendulums, gave for  $g$  at Greenwich the respective values  $981\cdot188$  and  $981\cdot186$ .

Pendulum and other geodetic observations have led to a theory of *isostasy* which has received strong support of late years, especially in the United States. According to this theory if we start at about 100 Km. below sea level we find between there and the free surface an approximately uniform quantity of matter irrespective of whether the free surface is mountainous or not. A lesser density under lofty mountains and a higher density under deep seas act as compensations.

While the mass of a body is independent of its position, its weight, i.e. the gravitational attraction exerted on it, varies with  $g$  and so increases as we pass from the equator towards either pole. Denoting by  $g_\phi$  the value of  $g$  in lat.  $\phi$  we obtain from the formula

$$g_{90} = 983\cdot208, \quad g_0 = 978\cdot035.$$

In other words, gravity at the poles exceeds gravity at the equator by 1 part in 189.

**Green Flash.**—The “green flash” is a phenomenon which is observed fairly often at sunset, more rarely (because seldom looked for) at sunrise. At sunset the last glimpse of the sun which is seen is a brilliant green. The colour lasts but two or three seconds. The explanation is that the rays from the sun are refracted in their passage through the atmosphere, the blue and green more than the yellow and red so that when the sun is so low that no red light from it can reach the observer, green light from the upper limb can. The blue light is generally absorbed or diffracted by the atmosphere. The phenomenon requires a clear atmosphere; whether unusual refractive power is also necessary has not been settled.

**Gregale.**—A strong NE. wind occurring chiefly in the cool season in the south-central Mediterranean. The name has been applied to strong NE. winds in other localities of the Mediterranean; it is used, for example, on the south coast of France (*grégale*) and in the Tyrrhenian Sea (*grecale*). In the neighbourhood of Malta *gregale* occurs most often, when pressure is high over central Europe and the Balkans and relatively low to the south over Libya; with this type there is little or no rain, visibility is good apart from spray and temperature is not much below normal. *Gregale* also sets in with the passage of the cold front of a depression moving south-eastwards across the Ionian

Sea or Greece ; with this type heavy showers of rain may occur, with low temperature. A third type of gregale at Malta is due to depressions passing to the south, the atmosphere is usually thick, rain may or may not fall. Gregale also blows at times with small local depressions.

**Ground Frost.**—As injury to the tissues of growing plants is not caused until the temperature has fallen appreciably below the freezing point of water (32° F.) a "ground frost" is regarded as having occurred when the thermometer on the grass has fallen to 30° F. or below. If the thermometer is read to tenths of a degree the limit is 30.4° F.

**Ground, State of.**—Observations of the state of the ground are made regularly at a number of stations in this country in connexion with the operations of aircraft and of agriculture. The code provides for 10 different conditions of the ground in the vicinity of a station, such as dry, moist, wet (standing water in pools etc.), frozen, covered with glazed frost without snow, wholly or partly covered with ice, snow, loose dry snow, dust, or sand. The current Code, which replaces an earlier one, was approved for general use by the Conference of Directors, Washington, 1947. An amplified code is used at CROP WEATHER stations.

**Gulf Stream.**—The Gulf Stream is one of the strongest and most constant ocean currents. Originating in the eastern area of the Gulf of Mexico it flows through the Straits of Florida and up the eastern coasts of the United States. The Gulf Stream does not flow inshore, but generally speaking follows the edge of the continental shelf. It is continued by a weaker and broader current, often called the Gulf Stream, but more accurately the North Atlantic Drift, right across the Atlantic Ocean, leaving the coast of America in about latitude 40° N. and reaching the British Isles in about latitude 50° N. Like all ocean currents it is subject to variability and even to reverse sets. Recent research shows that up the American coast the Gulf Stream is strongest in spring and summer, when it flows with a mean strength of 30 miles per day. The transatlantic current has a mean strength of 3–5 miles per day. In the autumn the Bahama current flowing to the eastward of the Bahamas joins the Gulf Stream in about latitude 30° N., at other seasons it is partial and interrupted. It is popularly supposed that the temperate climate of the British Isles is due to the warmth conveyed by the Gulf Stream, but the real state of affairs is that our climate is due to the prevailing westerly and south-westerly winds, which also cause the extension of the Gulf Stream across the Atlantic. For a discussion of the effects of the Gulf Stream on the weather of western Europe see *London, Geophysical Memoirs*, No. 34, 1926, and *London, Meteorological Magazine*, 63, 1928, p. 61.

**Gust.**—The word was used originally for any transient blast of wind, but is now limited to the comparatively rapid fluctuations in the strength of the wind, which are characteristic of winds near the surface of the earth and are mainly due to the turbulence or eddy motion arising from the friction offered by the ground to the flow of the current of air.

An investigation regarding the nature of gusts, as indicated by a tube-anemograph, was carried out by the Advisory Committee for Aeronautics and the results are contained in several reports on wind structure published in the annual reports of the Committee. The number and extent of the fluctuations are very irregular ; the range between gusts and lulls is dependent on the mean velocity of the wind and the exposure of the anemometer. Other factors also play their part, and winds from certain quarters tend to be more gusty than those from others. Expressing the fluctuations as a percentage of the mean velocity the following results were obtained for various anemometers (*Report of the Advisory Committee for Aeronautics*, 1909–10, pp. 103–4).

Anemometer						Range of fluctuation as a percentage of the mean velocity
Southport (Marshside)	..	..	..	..	..	30
Scilly (St. Mary's)	..	..	..	..	..	50
Shoeburyness, ENE. wind	..	..	..	..	..	30
" " W. wind	..	..	..	..	..	80
Holyhead (Salt Island)	..	..	..	..	..	50
Falmouth (Pendennis), S. wind	..	..	..	..	..	25
" " W. wind	..	..	..	..	..	50
Aberdeen	..	..	..	..	..	100
Alnwick	..	..	..	..	..	80
Kew	..	..	..	..	..	100

In this table a fluctuation of 100 per cent. means that a wind with a mean velocity of, say, 30 m.p.h. fluctuates over a range of 30 m.p.h., between about 15 m.p.h. and 45 m.p.h., in consequence of the gustiness.

Gusts are to be distinguished from squalls. A squall is a blast of wind, occurring suddenly, lasting for some minutes, and dying away as suddenly. Gusts are the result of mechanical interference with the steady flow of air, whereas squalls are attributable to meteorological causes.

The strongest gusts recorded on anemographs of the Meteorological Office in recent years are :—

			m./sec.	m.p.h.	kt.
1922	..	Pendennis Castle	46.0	103	89
1927	..	Tiree	48.3	108	94
	..	Paisley	46.5	104	90
1929	..	Scilly Is., St. Mary's	49.6	111	96
	..	Pendennis Castle	46.0	103	89
1930	..	Pendennis Castle	45.6	102	89
1935	..	Bell Rock Lighthouse	45.2	101	88
	..	Butt of Lewis	44.7	100	87
1936	..	St. Ann's Head	44.7	100	87
	..	Tiree	46.5	104	90
1937	..	Holyhead	47.8	107	93
	..	St. Ann's Head	48.3	108	94
1938	..	Liverpool (Bidston)	45.2	101	88
	..	Kirkwall	44.7	100	87
1940	..	St. Ann's Head	46.0	103	89
1945	..	St. Ann's Head	>50.5	>113	>98
1946	..	Scilly Is., St. Mary's	44.7	100	87
1950	..	Pendennis Castle	46.5	104	90
1951	..	Millport	48.3	108	94
	..	Bell Rock Lighthouse	44.7	100	87
1952	..	Cranwell	49.6	111	96
	..	Stornoway	48.3	108	94
	..	Lerwick	46.0	103	89
1953	..	Aberdeen (Dyce)	45.2	101	88
	..	Kete	48.7	109	95
1954	..	Scilly Is., St. Mary's	46.9	105	91
	..	Stornoway	45.2	101	88

**Haar.**—A local name in eastern Scotland and parts of eastern England for a kind of wet sea fog which at times invades coastal districts. Haars occur most frequently in summer months.

**Haboob.**—The name is derived from the Arabic "habb" meaning to blow and is used generally to imply the passage of a dense mass of whirling dust which is usually accompanied by a sudden increase in the strength of the wind with a change of direction, by a sharp fall of temperature and by very low visibility on account of the dust raised, while often it is followed

by heavy rain and sometimes by thunderstorms. Haboobs occur in north and north-eastern Sudan and are most frequent near Khartoum. At Khartoum they are chiefly experienced from May to September, though they may occur at any time; they have a pronounced diurnal frequency being rare between 4 a.m. and 2 p.m. and most common in the afternoon and evening. Most haboobs appear to be due to a current of relatively cold air undercutting warm air; occasionally the cold air is due to the passage of a shallow depression across northern Sudan. See L. J. Sutton, *London, Quart. J.R. met. Soc.*, **57**, 1931, pp. 143–61.

**Hail.**—The term properly denotes the hard pellets of ice of various shapes and sizes and more or less transparent, which fall from cumulonimbus clouds and are often associated with thunderstorms.

Hailstones may attain a great size, stones as large as grape-fruit have been observed and the recorded weights range up to a kilogram (over 2 lbs.).

An important characteristic of a cumulonimbus cloud is the rapid ascent into it of a moist current of air, which is quickly cooled by reason of the reduced pressure which it encounters aloft. As the process continues cloud particles, and finally rain-drops, are formed, but if the ascensional velocity of the air exceeds 8 m./sec. all the condensed water is retained in the cloud (see RAIN-DROPS). At a level not usually exceeding 4 Km. in this country the temperature has already fallen below freezing point. There is much evidence for believing that, at least in many cases, ice crystals are not immediately formed as soon as the temperature falls below freezing point, but that water-drops are still produced. These are in the supercooled condition, and they are carried upwards into the higher part of the cloud. Near the top of this cloud, however, ice crystals will appear and these will grow into pellets of small hail by a process of condensation direct from vapour to ice. When the weight of a pellet is sufficient to overcome the resistance of the upward air current it will commence to fall.

During the downward journey the pellet will fall through upward-moving air containing supercooled water-drops and its size will increase by the deposition upon it of the water so encountered, provided that freezing occurs when the water unites with the hailstone. The growth of the hailstone therefore depends upon (a) the liquid water content of the air, (b) its upward velocity and (c) the heat exchanges between the hailstone, the air and the supercooled water. Schumann has shown that the growth of spherical hailstones to diameters of the order of 8 cm. will occur on reasonable assumptions as to the magnitude of these quantities.

The international symbol for hail is ▲. Two other varieties, *soft hail* (*Reifgraupeln* ✕) and *small hail* (*Frostgraupeln* △) are recognised. See Fig. 30 p. 212.

*Soft hail* consists of white opaque grains 2 to 5 mm. in diameter having a snow-like structure; it occurs mainly at temperatures about the freezing point and mostly on land, often before or together with ordinary snow.

*Small hail* consists of semitransparent, round (occasionally conical) grains of frozen water, 2 to 5 mm. in diameter. They generally have a nucleus of soft hail, covered by a very thin layer of clear ice, and occur in association with rain rather than with snow. They generally fall from cumulonimbus clouds.

**Halo Phenomena.**—The term halo, which might be applied to any circle of light round a luminous body, is restricted by meteorologists to a circle produced by refraction through ice crystals; in contrast to coronae which are produced by diffraction. All the optical phenomena produced by reflection and refraction of light by ice crystals are sometimes grouped together as halo phenomena.

The most common halo is a luminous ring of  $22^\circ$  radius surrounding the sun or moon, the space within the ring appearing less bright than that just outside. The ring, if faint, is white; if more strongly developed the inner edge is a pure red, outside which yellow may be detected. The halo of  $22^\circ$  is very common. In England it can be seen by an assiduous observer about one day in three.\*

The angle of  $22^\circ$  is the angle of minimum deviation for light passing through a prism of ice (index of refraction 1.31) with faces inclined at  $60^\circ$ . Thus the occurrence of the halo of  $22^\circ$  radius indicates the presence of ice crystals with faces inclined at  $60^\circ$ . Alternate faces of a hexagonal prism are inclined at this angle, and as hexagonal prisms are frequently found amongst ice crystals the halo is probably due to the refraction of light through such prisms.

A halo of  $46^\circ$  is to be seen occasionally, though seldom complete. This halo requires crystals with faces at right angles.

The halo of  $22^\circ$  is sometimes within a circumscribed nearly elliptical halo the points of contact being at the highest and lowest points. The complete circumscribed halo is only seen when the elevation of the sun is  $40^\circ$  or more. With lower elevations separate tangent arcs are seen. These phenomena are explained by the presence of prismatic ice crystals floating with their axes horizontal.

Another group of phenomena requires prismatic crystals with their axes vertical. In this group are parhelia, or MOCK SUNS (patches of light at the same elevation as the sun) and the circumzenithal arc (a horizontal circle rather more than  $46^\circ$  above the sun).

In weather lore halos are often spoken of as presaging storms. In modern meteorology the cirrostratus cloud in which halos are likely to be observed is regarded as a feature of a WARM FRONT. Halos are too common, however, to be good signs of exceptional weather.

**Harmattan.**—A dry wind blowing from a north-east or sometimes easterly direction over north-west Africa. Its average southern limit is about  $5^\circ$  N. latitude in January and  $18^\circ$  N. in July. Beyond its surface limit it continues southwards as an upper current above the south-west monsoon. Being both dry and relatively cool, it forms a welcome relief from the steady damp heat of the tropics, and from its health-giving powers it is known locally as THE DOCTOR, in spite of the fact that it carries with it from the desert great quantities of impalpable dust, which penetrates into houses by every crack. This dust is often carried in sufficient quantity to form a thick haze, which impedes navigation on the rivers.

**Harmonic Analysis.**—There are many meteorological phenomena which recur with some approach to regularity day by day. If the changes of such a variable as temperature are represented by a curve, then the portions corresponding to successive days bear a strong likeness to one another. If for the actual record for each day the record for the average day were substituted, the variation for a long period would be represented by a curve in which the part corresponding with each day was like its fellows. The simplest curve possessing this property of continuous repetition is a curve of sines. As an example the variation of temperature at Kew Observatory, Richmond, in July, may be cited. The sequence of change throughout the average day is shown in the lower part of Fig. 20. The representative curve is not unlike a curve of sines, but it is not quite symmetrical. The rise which commences at sunrise and lasts until after 15 h. is more steady than the drop which is rapid in the evening and slow after midnight. A good approximation to the temperature on the average day is given, however, by the expression  $289.9 + 3.7 \sin (15t + 224\frac{1}{2}^\circ)$  where  $t$  is the time in hours reckoned from midnight. It will be seen that the lowest value is reached at the time given

\* At the Radcliffe Observatory, Oxford, the average number of days per year on which solar halos were observed was 152, while the average number of nights per year with lunar halo was 38.



by  $15t + 224\frac{1}{2}^\circ = 270^\circ$ , i.e. at 3h. 6m. and the maximum comes 12 hours later at 15h. 6m. The substitution of a sine curve for the curve based on the observations would make the minimum too early by an hour, but would not affect the maximum so much.

The curve showing the diurnal variation of temperature in March (in the upper part of the figure) is not so near to a sine curve as that for July. The rise in temperature from minimum to maximum takes little more than six hours. The best sine curve for representing the variation is given by the formula

$$\theta = 278.74 + 2.47 \sin (15t + 222^\circ)$$

and is shown by the broken line in the figure. It will be seen that the agreement is by no means close. To obtain a more accurate expression for the temperature, an additional sine term with a period of 12 hours may be introduced. The best formula containing such a term is

$$\theta = 278.74 + 2.47 \sin (15t + 222^\circ) + 0.63 \sin (30t + 39^\circ)$$

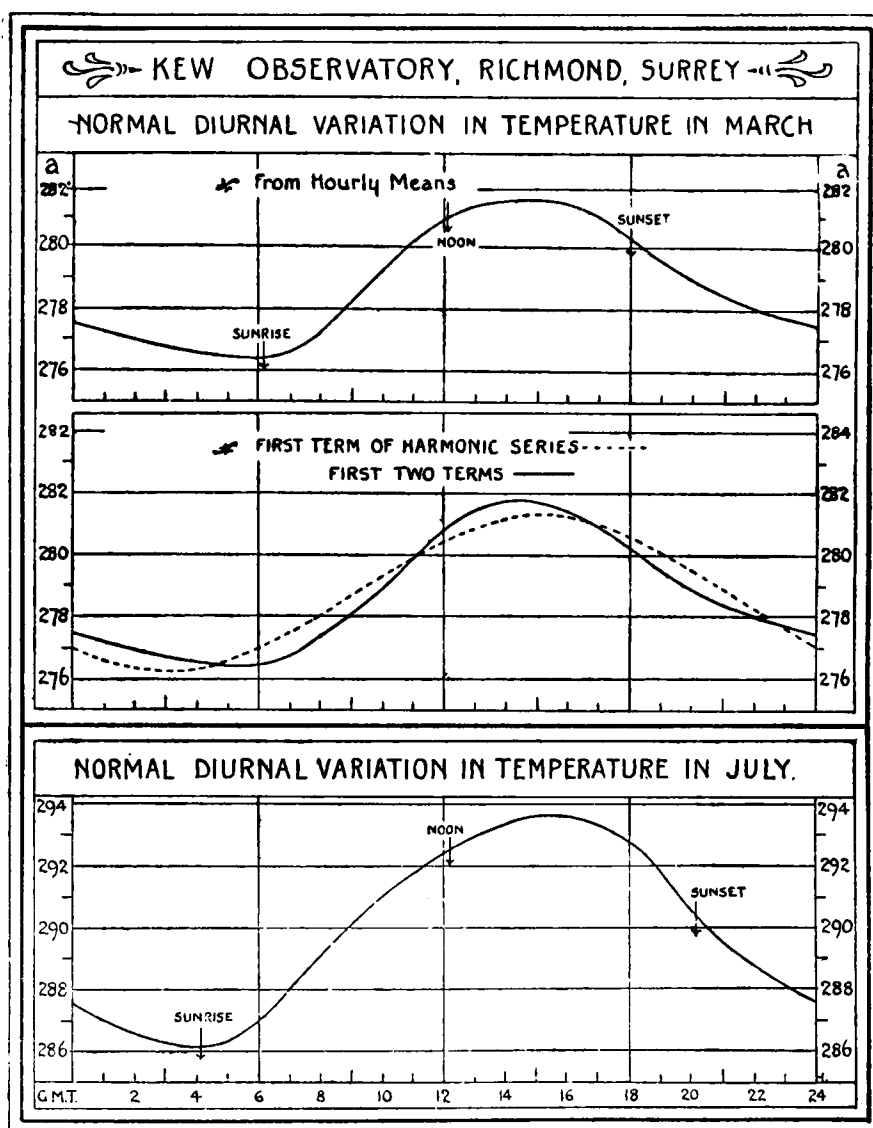


FIG. 20.

The new term  $0.63 \sin (30t + 39^\circ)$  is positive in the early morning and in the early afternoon, so that it delays the drop to the minimum and makes the maximum earlier. In the upper part of Fig. 20, the continuous curve which

corresponds with the proposed formula crosses the simple sine curve at intervals of six hours. The resemblance to the curve based on the observations is greatly improved. A closer resemblance would be obtained if additional terms

$$0.08 \sin (45t + 330^\circ) + 0.12 \sin (60t + 190^\circ)$$

were included in the formula.

The harmonic representation of a diurnal inequality may be expressed in either of the alternative forms—

$$\begin{aligned} & a_1 \cos (15^\circ \times t) + a_2 \cos (30^\circ \times t) + a_3 \cos (45^\circ \times t) \\ & \quad + a_4 \cos (60^\circ \times t) + \dots \\ & + b_1 \sin (15^\circ \times t) + b_2 \sin (30^\circ \times t) + b_3 \sin (45^\circ \times t) \\ & \quad + b_4 \sin (60^\circ \times t) + \dots \\ & P_1 \sin (15^\circ \times t + A_1) + P_2 \sin (30^\circ \times t + A_2) + \\ & P_3 \sin (45^\circ \times t + A_3) + P_4 \sin (60^\circ \times t + A_4) + \dots \end{aligned}$$

where  $t$  denotes the time in hours counting from some fixed hour, usually midnight. The latter is the form which has been adopted in the previous part of this note, as it best exhibits the physical significance of the results, but the first form is that employed for the actual numerical calculation of the harmonic coefficients. We first calculate the  $a$ ,  $b$  coefficients and then derive the  $P$ ,  $A$  coefficients from the relations

$$\begin{aligned} \tan A_n &= a_n/b_n; \quad P_n = a_n/\sin A_n = b_n/\cos A_n; \\ P_n^2 &= a_n^2 + b_n^2 \end{aligned}$$

where  $n$  may be 1, 2, 3, 4, etc.

Details of the methods adopted for practical computation of the coefficients will be found in the "Handbook of Statistical Methods in Meteorology."

The process of finding the trigonometric series to give the best representation of a periodic function is known as harmonic analysis. The reverse process, determining the value of the function at any time when the components are known, is harmonic synthesis. Both processes can be carried out by suitable machines, and also by arithmetical computation from given data. The latter process is the more usual except in the case of the prediction of tides.

In any term  $P \sin (nt + A)$  the coefficient  $P$  which determines the range is called the amplitude and  $nt + A$  is called the phase angle,  $A$  being the phase angle for midnight. It may be mentioned that the alternative form  $P \cos n(t - t_0)$  where  $t_0$  is the time of the maximum, has certain advantages; it was adopted by General Strachey for the discussion of harmonic analysis of temperature in the British Isles.

By comparison of the amplitudes and phase angles for different places and different seasons, climates may be classified. For example, the amplitude of the whole-day term for temperature in July at Falmouth is  $2.1^\circ \text{ A.}$ , and the phase angle for local apparent midnight is  $250^\circ$ . In comparison with Kew, the amplitude is small and the maximum occurs early. This difference in phase is typical of the difference in conditions on the coast and inland. It may be stated, however, that as regards temperature, harmonic analysis has not yielded information which cannot be obtained more readily from the curves showing the daily variation. With pressure more important results have been discovered.

For temperature, the first or all-day term in the expansion in trigonometric series is by far the most important. With pressure the second term is comparable in size with the first, and at most stations there are two maxima and two minima in the course of 24 hours. The first term is found to depend on the situation of the station, whether near the coast or inland, in a valley or on a mountain-side, whereas the second or twelve-hour term depends principally on the latitude. The daily changes represented by the first term are clearly understood, they are the effects of local heating of the air.

The daily variation of pressure at Cairo in July is represented graphically by Fig. 21.

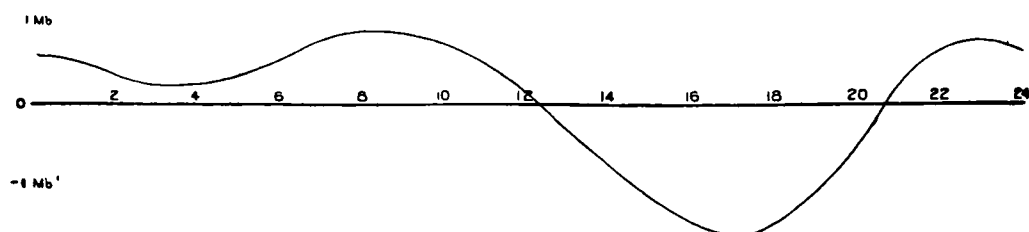


FIG. 21.—Daily variation of the Barometer at Cairo (Abbassia Observatory) in July.

The departure of the pressure from the mean for the day is given in millibars by the expression

$$\begin{aligned} & \cdot 92 \sin (15t + 17^\circ) + \cdot 66 \sin (30t + 140^\circ) \\ & + \cdot 12 \sin (45t + 348^\circ) + \cdot 05 \sin (60t + 250^\circ). \end{aligned}$$

The first term represents an oscillation with the maximum and minimum at about 5h. and 17h. respectively. It indicates that as the air is warmed in the daytime it expands and overflows from the Nile valley over the surrounding high ground and over the neighbouring seas.

The second term represents an oscillation with maxima at 10h. 20m. and 22h. 20m. These hours are almost the same all over the globe. The amplitude depends on the latitude and to a certain extent on the time of the year. The mean value for the year at Cairo is 0.8 mb. It is about 1.3 mb. at the equator, 0.5 in latitude 45°, 0.35 in London and 0.1 mb. in latitude 60°.

The third term is interesting as it changes its phase by 180° at the equinoxes. The first maximum occurs at 2h. in summer, the first minimum at the same hour in winter.

It has been mentioned that the all-day term depends largely on local conditions. An interesting contrast is offered by the British observatories. At Richmond, Surrey, the amplitude of this term in July is about 0.3 mb., and it has about the same value at Valentia, but the phases are opposite; at Richmond the maximum occurs at 5h., whereas at Valentia it is the minimum which occurs in the morning (at 7h.).

Harmonic analysis may be extended to the investigation of changes which are caused by forces having different periods. The classical instance is that of the tides. The tides being caused by the attraction of the sun and the moon show as periods the solar and also the lunar day. The process by which the heights and the times of tides are foretold in practice depends on harmonic analysis and synthesis.

**Haze.**—See Fog.

**Heat.**—The name used for the immediate cause of the sensation of warmth, a primary sensation which is easily recognised and needs no explanation. As used in relation to the weather, heat and cold are familiar words for opposite extremes of temperature of the air. What the American writers call a heat wave is a spell of hot weather in which the maximum temperatures reach 90° or 100° F. (above 305°A.), and a cold wave is a spell of the opposite character during which temperatures in the neighbourhood of the Fahrenheit zero, or 32 degrees of frost may be experienced. In continental climates, during the passage of severe cyclonic depressions, the transitions from heat to cold are sometimes extremely abrupt and far-reaching; a difference of temperature of 50° F. in a few hours is not unknown. We have visitations of similar character in this country, but they are less intense. A few days in succession with a temperature over 80° F. would suffice for a heat wave, and a few days with 10° of frost would certainly be called a cold wave. One of the most noticeable features of our climate is the succession of cold spells which interrupt the genial weather of late spring and early summer. They are not very intense, but a drop in the mean temperature of the day from 55° F. to 45° F., which roughly defines them, produces a very distinct impression.

As used in connexion with the study of the atmosphere, heat has another sense which must not be overlooked. It denotes the physical quantity, the reception of which makes things warmer, and its departure makes them colder. If you wish to make water hot, you supply heat to it from a fire or a gas-burner or, in modern days, by an electric heater, a very convenient contrivance for getting heat exactly where you want it. On the other hand, if you want water to become cooler, you leave it where its heat can escape, by CONDUCTION, aided by CONVECTION or by RADIATION. You can also warm water by adding some hot water to it, or cool it by adding cold water to it. Either process suggests the idea of having the same quantity of heat to deal with altogether, but distributing it, or diluting it, by mixing.

The idea of having a definite quantity of heat to deal with, and passing it from one body to another is so easily appreciated and so generally applicable, that the older philosophers used to talk confidently of heat as a substance which they called Caloric, and which might be transferred from one body to another without losing its identity. They measured heat, as we do still, by noting by how much it would raise the temperature of a measured quantity of water. For students of physics the unit of heat is still a *gram-calorie*, the heat which will raise a gram of water through one degree centigrade. To raise  $m$  grams from  $t_1^\circ \text{C.}$  to  $t_2^\circ \text{C.}$ ,  $m(t_2 - t_1)$  gram-calories are required. The amount can be recovered, if none has been lost meanwhile, by cooling the water. If we wish to be very precise, a small correction is required on account of the variation in what is called the capacity for heat of water at different temperatures, but that need not detain us.

For students of engineering, the unit called the British Thermal Unit, is a pound-Fahrenheit unit instead of the gram-centigrade unit, and the heat required to raise  $m$  pounds of water from  $t_1^\circ \text{F.}$  to  $t_2^\circ \text{F.}$  is  $m(t_2 - t_1)$  B.Th.U.

It is in many ways a misfortune that students of physics and engineering do not use the same unit. It is no doubt a good mental exercise to learn to use either indiscriminately without confusion, but it takes time.

From measurements of heat we get the idea that with different substances the same change of temperature requires different quantities of heat; the substances have different capacities for heat. We define *capacity for heat* as the heat required to raise a unit of the substance (1 gram or 1 lb.) through 1 degree.

It is a remarkable fact that of all common substances water has the greatest capacity for heat. It takes one unit to raise the temperature of a unit mass of water one degree, it takes less than a unit, sometimes only a small fraction of a unit, to raise the temperature of the same amount of another substance through one degree. We give the name *specific heat* to the ratio of the capacity for heat of any substance to the capacity for heat of water. Numerically, specific heat is the same as the capacity for heat in calories per gram.

The specific heat of water is 1, the specific heat of any other common substance is less than 1. The specific heat of copper is only  $1/11$ . So the heat which will raise the temperature of a pound of copper  $1^\circ$  will only raise the temperature of a pound of water  $1/11^\circ$ , or the heat which will raise the temperature of a mass of water  $1^\circ$  will raise the temperature of the same mass of copper  $11^\circ$ .

This peculiar property of water makes it very useful for storing heat and carrying it about. From that point of view it is the best of all substances for cooling the condenser of an engine, for distributing heat at a moderate temperature in a circulating system, and for many other economic purposes.

In meteorology its influence is very wide. Large masses of water, of which the ocean is a magnificent example, are huge storehouses which take up immense quantities of heat from the air when it is warm and give it out again when the air is cold, with very little change in its own temperature, so that a large lake, and still more the ocean, has a great influence in reducing the extremes of temperature of summer and winter, and of day and night, in the countries which border it.

There is another remarkable storage of heat in which water takes a predominant share that is dealt with in physical science under the name of *latent heat*.

Water at 288°A. (59° F.) cannot be evaporated into water vapour unless every gram of it is supplied with 589 calories of heat, which produce no effect at all upon the temperature. The water is at 288°A. to start with, and the water vapour is at exactly the same temperature and yet 589 calories of heat have gone. They are *latent* in the water vapour but produce no effect on the thermometer. You can get them back again easily enough if you condense the vapour back again into water, but you must manage somehow to take away the heat while the condensation is taking place. The separation of the "waters that are above the firmament from the waters that are below the firmament," or in modern language, the evaporation of water from the sea or a lake or the wet earth and its condensation in the form of clouds and rain, implies the transference of enormous quantities of heat from the surface to the upper air, the dynamical effect of which belongs to another chapter of the romantic story of heat which deserves more than the few words which we can afford for it. Readers can find an interesting account in Tyndall's "Heat, a Mode of Motion."

The idea of heat as an indestructible substance, caloric, which could be transferred from one body to another without loss, became untenable when it was found that when air was allowed to expand in a cylinder it cooled spontaneously to an extent that corresponded exactly, so far as could be ascertained with the means then available, with the amount of mechanical work that the cylinder was allowed to do. It was the last step in the process of reasoning by which men had come to the conclusion that, when *mechanical work* was devoted to churning water or some other frictional process, heat was actually produced, not brought from some other substance but created by the frictional process.

It took many years for men to reconcile themselves to so novel an idea, and a good deal of ingenuity was devoted to trying to evade it, but it has now become the foundation stone of physical science. Heat is not an unalterable indestructible substance but a form of *energy*. It can do mechanical work in a steam-engine or a gas-engine or an oil-engine, but for every foot-pound\* of work that is done a corresponding amount of heat must disappear, and in place of it a corresponding amount of some other form of energy is produced. A good deal of heat, besides, may be wasted in the process so far as practical purposes are concerned. In a steam-engine, of the whole amount of heat used, only one-tenth may be transformed, the rest wasted, as we have said; but it is still there raising the temperature of the water of the condenser or performing some other unproductive but necessary duty.

There is, therefore, a numerical equivalent between heat and other forms of energy.

We give the relation :—

$$\begin{aligned} 1 \text{ B.Th.U. is equivalent to } 777 \text{ foot-pounds of energy.} \\ 1 \text{ gram-calorie} &= 42,640 \text{ gram-centimetres.} \\ &= 41,830,000 \text{ ergs.} \end{aligned}$$

We have led up to this statement in order to point out how extraordinarily powerful heat can be in producing mechanical energy.

If, in the operations of nature, one single cubic metre of air gets its temperature reduced by 1° C. in such a way that the heat is converted into work by being made to move air, the equivalent of energy would be a cubic metre of air moving with a velocity of nearly 45 m./sec. (101 m.p.h.).

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\* A *foot-pound* of work is the work done in lifting one pound through a distance of one foot. A *gram-centimetre* is the work done lifting one gram through one centimetre. An *erg* is the absolute unit of work on the C.G.S. system; 1 gram-centimetre = 981 ergs.

So familiar have we become with heat as a form of energy that we measure the heat of sunlight in joules\* and the intensity of sunshine in watts per square centimetre, i.e. the number of joules falling on one square centimetre per second.

*The specific heat of air.*—The foregoing statement is necessary to lead up to a matter of fundamental importance in the physics of the atmosphere, namely the heat that is required or used to alter the temperature of air in the processes of weather; in technical language this is the capacity for heat of air or the specific heat of air.

We have explained that when air is allowed to do work on its environment, in expanding, heat disappears, or more strictly is transformed. So the amount of heat required to warm air through a certain number of degrees depends upon how much expansion is allowed during the process. The most economical way of warming air from the thermal point of view is to prevent its expanding at all; it then has "constant volume" and its specific heat is 0.1715 calories per gram per degree at 273°A. It is remarkable, but true, that if you have a bottle full of air, it will take more heat to raise the temperature of each gram of it by a degree if you take the stopper out while the warming is going on, than if you keep it tight. The difference between warming a bottle of air with the stopper in and with it out, simple as it may seem, has got in it the whole principle of heat as a form of energy. The effect of leaving the stopper out is that the pressure of the air inside the bottle is the atmospheric pressure for the time being and is therefore practically constant throughout the brief operation. The specific heat of air at constant pressure is 0.2417 gram-calories or 1.010 joules per gram per degree Centigrade. The specific heat of air at constant volume is 0.72 joules per gram per degree Centigrade. The difference of the two represents the heat equivalent of the work used in expanding unit mass of the gas against atmospheric pressure.

**Helm Wind.**—A strong, often violent north-easterly wind blowing down the western slope of the Crossfell Range in Westmorland and Cumberland, which on account of its origin is in general decidedly cold. It may occur at all seasons of the year provided that the general direction of the surface wind is between NNE. and E. As a rule, therefore, it is most common in late winter and spring. When the "helm wind" is blowing, a heavy bank of cloud (the "Helm") rests along or just above the Crossfell Range, and at a distance of one to four miles from the foot of the Fell, a slender, nearly stationary roll of whirling cloud (the "Helm Bar") appears in mid-air and parallel with the "helm" cloud. The cold wind blows strongly down the steep fell sides until it comes nearly under the Bar, when it suddenly ceases; approaching this point it is characteristically very gusty and may cause structural damage. To the west of this calm at the surface, a slight westerly wind may be experienced for a short distance. In dry weather the space between the Helm and the Bar is usually quite clear although the rest of the sky may be cloudy, and the strong wind has a marked desiccating effect; in rainy weather, very little rain falls in the region where the strong wind is experienced. When the uninterrupted depth of the north-easterly surface current up to the summit level of the clouds is greater than about 6,000 ft., the bar with its underlying reverse current at ground level is no longer found. North-easterly wind with cloud is not uncommonly referred to as "helm wind" elsewhere, e.g. in the Lake District but the full development is confined to the strip of country east of the River Eden, particularly near Crossfell itself.

**High.**—Sometimes used to indicate an area of high barometric pressure for which the technical term ANTICYCLONE was coined by Sir Francis Galton. The central region of an anticyclone on a weather chart is frequently indicated by the word "high."

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\* A *joule* is a more convenient unit than the small unit, the erg; one joule=ten million ergs ( $10^7$  ergs) and one calorie=4.18 joules.

The *watt* is a unit of power, that is, rate of doing work: a power of one watt does one joule of work per second.

**Hoar-Frost.**—Thin ice crystals in the form of scales, needles, feathers or fans deposited on surfaces cooled by radiation. The deposit is frequently composed in part of drops of dew frozen after deposition and in part of ice formed directly from water vapour at a temperature below the freezing point.

**Horizon.**—The “sensible or visible horizon” which is visible from a ship at sea, the line where sea and sky apparently join, is a circle surrounding the observer a little below the plane of the horizon in consequence of the level of the earth’s surface being curved and not flat. The depth of the “sensible horizon” below the “rational horizon” or horizontal plane is approximately the same as the elevation of the point from which the “sensible horizon” is viewed. Apart from any influence of the atmosphere the distance of the visible horizon for an elevation of 100 feet (30 metres) is about 12 miles. The actual distance is about 2 miles greater on account of refraction. It varies as the square root of the height, so that it would require a height of 400 feet to give a horizon 24 miles off. A level canopy of clouds 10,000 feet high is visible from a point on the earth’s surface for a distance of about 125 miles, or the visible canopy has a width of 250 miles.

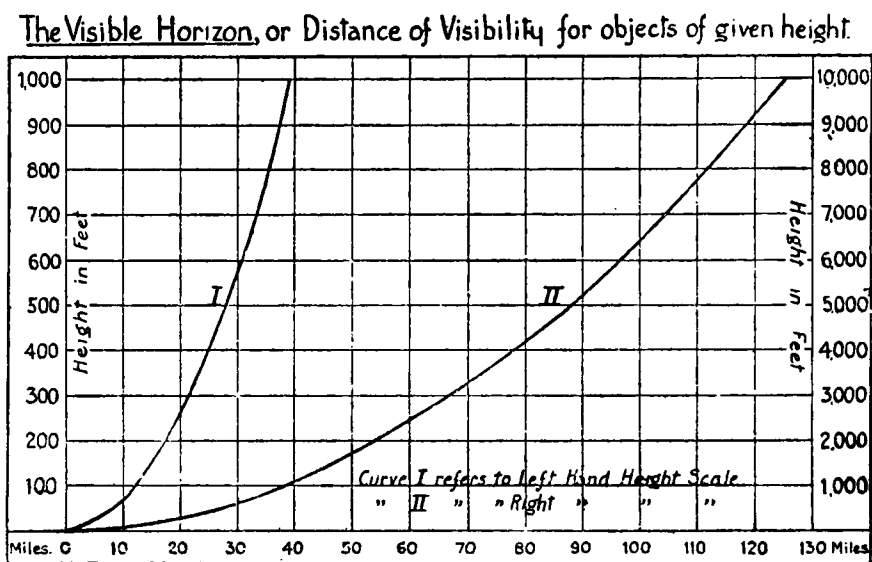


FIG. 22.—Diagram showing the relation between the height of an observation point in feet and the distance of the visible horizon in miles (neglecting refraction), or the height in feet of a cloud or other distant object and the distance in miles at which it is visible on the horizon.

**Horse Latitudes.**—The belts of calms, light winds and fine, clear weather between the TRADE WIND belts and the prevailing westerly winds of higher latitudes. The belts move north and south after the sun in a similar way to the DOLDRUMS. The name arose from the old practice of throwing overboard horses which were being transported to America or the West Indies when the ship’s passage was unduly prolonged.

**Humidity.**—The condition of the atmosphere in respect to water vapour. Air may be described as “humid” when it has a high moisture content, but when the word “humidity” is employed without a qualifying adjective the RELATIVE HUMIDITY is usually meant. See AQUEOUS VAPOUR.

**Humidity-mixing-ratio.**—The relative proportions by weight of water vapour and dry air, in a given specimen of damp air. It is usually denoted by the symbol  $x$ . Thus  $x$  is the number of grams of water vapour mixed with 1 gram of dry air. If  $e$  is the vapour pressure,  $p$  the total pressure, and  $\epsilon$  the ratio of the densities of water vapour and dry air, ( $\epsilon = 0.622$ )

$$x = \frac{\epsilon e}{p - e}$$

The humidity-mixing-ratio, as usually defined, is, as stated above, the number of grams of water vapour mixed with one gram of dry air, but in practice,



particularly in the use of the tephigram, it is more convenient to define it as the number of grams of water vapour mixed with one kilogram of dry air. This avoids the use of many places of decimals.

The term "Mixing ratio", without the word "Humidity", was introduced by W. von Bezold in one of his earlier papers "On the thermo-dynamics of the atmosphere", of which a translation is in the "Mechanics of the earth's atmosphere" by C. Abbe (Smithson. misc. Coll., Washington, Vol. XXXIV, 1893), but the first reference to the term "Humidity-mixing ratio" is believed to be by C. W. B. Normand in "Wet-bulb temperatures and the thermo-dynamics of the air" (Indian met. Mem., Calcutta, Vol. XXIII, No. 1, 1921).

**Hurricane.**—A name (of Spanish or Portuguese origin) given primarily to the violent wind storms of the West Indies and Gulf of Mexico, which are CYCLONES with diameters of from 50 to 1,000 miles, wherein the winds reach hurricane force near a central calm space; the whole system advances in a straight or curved track. Similar tropical revolving storms off the coasts of Queensland are also known as hurricanes.

In the BEAUFORT SCALE OF WIND FORCE the name hurricane is given to a wind of force 12, and its velocity equivalent is put at a mean velocity exceeding 34 m./sec. or 75 m.p.h., but from the remarks under GUSTINESS it will be understood that at ordinary exposures a wind with a mean velocity of 75 m.p.h. will include gusts of considerably higher velocity, reaching 100 m.p.h. or more. Hurricane winds in this sense are occasionally experienced in this country.

**Hydrometeor.**—A generic term for weather phenomena such as rain, cloud, fog, etc., which mostly depend upon modifications in the condition of the aqueous vapour in the atmosphere.

**Hydrometer.**—An instrument for measuring the density of liquids. In marine meteorology hydrometers are used for determining the density of sea water.

**Hyetograph.**—A pattern of self-recording RAIN-GAUGE in which the recording pen is actuated by a series of stops attached to a vertical float rod.

**Hygrodeik.**—A dry- and wet-bulb PSYCHROMETER mounted on a frame, graduated and furnished with an index for determining quickly the relative humidity, dew-point, etc., by a graphical method.

**Hygrograph.**—An instrument for recording continuously the humidity of the atmosphere. See HYGROMETER.

**Hygrometer.**—An instrument for determining the humidity of the air. The dew-point hygrometer, developed by Daniell, Regnault and others, aims at determining the dew-point by artificially cooling, until dew is deposited, a polished surface whose temperature can be measured. Since dew-point hygrometers depend only on the measurements of a temperature and involve no assumption as to the properties of the materials or the laws of evaporation from a wet surface, they may be classed as "absolute" instruments. To the same class belong chemical hygrometers in which the quantity of moisture in a given mass of air is determined by direct weighing. Unfortunately, neither dew-point nor chemical hygrometers are suitable for routine use in meteorology, and it is therefore necessary to use methods depending on (a) the change of length of hairs with varying relative humidity, or (b) the lowering of temperature due to evaporation.

In the hair hygrometer, of which Lambrecht's polymeter and Richard's hair hygrograph are applications, use is made of the fact that human hair expands with increasing relative humidity. Hair hygrometers are incapable of high precision, but they possess the advantage that they operate equally well above or below the freezing point. Wet- and dry-bulb hygrometers (or "psychrometers") are ordinarily used for routine observations. They depend on the accurate determination of the depression of the wet bulb reading below the dry bulb and give sufficient precision for ordinary needs.

Their accuracy is considerably increased if arrangements are made, as in the Assmann PSYCHROMETER, for "aspirating" the air at a known speed.

Prof. G. M. B. Dobson and Dr. A. W. Brewer have recently devised a hygrometer for use in air at a temperature below 32° F. on aircraft making meteorological ascents. It measures the frost point of the air by the deposition of ice from a jet of air upon the cooled surface of an aluminium thimble. The flow of cooling liquid inside the thimble is controlled by the observer so that the ice deposit remains constant. The temperature of the thimble is then measured by an electrical resistance thermometer. It was by means of this instrument that the extreme dryness of the lower STRATOSPHERE was discovered by A. W. Brewer. See STRATOSPHERE.

**Hygroscope.**—An instrument for showing whether the air is dry or damp, usually by the change in appearance or dimensions of some substance. Hygroscopes are frequently sold in the form of weather predictors, e.g. "weather houses" in which the appearance of the "old man" or the "old woman" is determined by the twisting and untwisting of a piece of catgut in response to changes of humidity.

**Hypsometer.**—Literally, an instrument for measuring height (Gr. *Hypsos*). The term is, however, applied exclusively to an instrument in which water is boiled under conditions which make it permissible to assume that the temperature within the vessel is, accurately, the boiling point of water. The boiling point of water depends on the atmospheric pressure in accordance with the following table:—

Boiling point	Pressure	
Degrees absolute	Millimetres of mercury at 0° C., sea level, latitude 45°	Millibars
374	787·67	1050·12
373	760·00	1013·23
372	733·16	977·45
371	707·13	942·74
370	681·88	909·08
369	657·40	876·44
368	633·66	844·79
367	610·64	814·10
366	588·33	784·36
365	566·71	755·54
364	545·77	727·62

Consequently, a measurement taken by means of a thermometer placed in the hypsometer serves to determine the pressure. If the measurement is made on a mountain and the pressure has been determined at some lower level, the height of the station can be calculated. Everything depends upon the accuracy of the thermometers. To obtain the height to within ten feet it must be possible to measure temperature to within one-hundredth of a degree. This requires very accurate thermometers combined with skilful manipulation. Nevertheless, the compactness of a hypsometer gives the instrument an advantage over the fragile and cumbersome mercurial barometer in journeys of exploration.

If the atmospheric pressure is known from the reading of a good barometer, a hypsometer may be used to determine the error at the boiling point of a thermometer, provided of course, that the boiling point lies within the range of the thermometer.

**Ice.**—Owing to the large amount of heat absorbed in melting (80 CALORIES for one gramme melted) a mass of ice represents a powerful reservoir of cold. Masses of ice or snow can attain to such dimensions in nature that the heat absorbed during melting is of climatological importance. An excellent example is furnished by the icebergs observed by Antarctic explorers. The largest of these appear to be portions of the great Ice Barrier that have

broken away during the summer months. They are generally several hundred feet thick and may exceed 20 miles in length. The amount of heat required to melt one 20 miles long, 5 miles broad and 600 feet thick would be sufficient to raise the temperature of the air over the whole British Isles from the ground up to a height of 1 kilometre (3,281 feet) by over  $40^{\circ}\text{C}$ .

When ice forms upon a pond during frosty weather the cooled water at the surface is continually replaced by warmer water from below until the whole mass has fallen to  $277^{\circ}\text{A}$ . ( $39^{\circ}\text{F}$ .), which is the temperature at which water has its greatest density. The surface can then cool undisturbed until the freezing point is reached and ice begins to form. The formation of ice in rivers is a more complicated question; in cold countries three kinds of ice are produced (1) sheet ice which forms on the surface of the water, first of all near the banks extending gradually towards the centre (2) FRAZIL ICE and (3) ground ice, both of which form in the rapidly-moving stream in the centre of the river in very cold weather. Ground ice (or anchor ice) forms at the bottom, adhering to rocks and other substances in the river bed. It often rises to the surface dragging with it masses of rock; it can be very destructive to river structures.

When the sea freezes the crystals formed contain no salt but cannot easily be separated from the brine which is mixed up with them, consequently the water obtained by melting genuine sea ice is salt. When, however, this ice forms hummocks under the action of pressure the brine drains out and leaves pure ice. Newly-formed sea ice has a surprising degree of flexibility, due to the fact that the crystals are separated by layers of brine or salt, and even when it is several inches thick the surface can be moved up and down unbroken by a swell. As the thickness increases this can no longer happen, and the sheet is broken up into pieces, which grind together and soon form the beautiful "pancake ice" familiar to polar explorers.

Some beautiful illustrations of ice forms have been given by Wright and Priestley in their book on the British Antarctic Expedition.\*

A. Maurstad in "Atlas of sea ice"† has suggested a terminology for use in describing the various forms of sea ice. This atlas was adopted by the International Meteorological Committee at Warsaw in 1935 for international use.

The properties of ice depend very largely on its mode of formation. H. T. Barnes‡ gives the mean value of the DENSITY of ice formed from boiled water as  $\cdot 91676$ , but the density of natural ice appears to be about  $\cdot 9170$  decreasing slightly with age. ICEBERGS, owing to the amount of included air, may have a much lower density. The coefficient of linear expansion of ice at  $-10^{\circ}$  to  $0^{\circ}\text{C}$ . lies between  $\cdot 000050$  and  $\cdot 000054$ ; its specific heat at  $0^{\circ}\text{C}$ . is about  $\cdot 5$ .

The great ice masses of the Arctic Ocean and the Greenland Seas exercise an appreciable influence on the weather of north-west Europe.§ The most important effect for the British Isles is the tendency for much ice in spring and early summer to be followed by stormy weather in late autumn and winter.

**Ice Age.**—A geological period in which great glaciers and ice sheets cover large parts of the continents, reaching the sea in places and lowering the temperature of the oceans. The latest began early in the Quaternary Period, when the ice covered much of Europe and North America; the present ice sheets of Greenland and the Antarctic are relics of this Ice Age. Other great Ice Ages occurred in the Permo-Carboniferous, when the ice sheets developed principally within the present tropics, in South America, Africa, India and Australia; and in the earliest known geological period, the Archæan.

\* Wright, C. S. and Priestley, R. E.; "British (Terra Nova) Antarctic Expedition 1910-13. Glaciology." London, 1922.

† Oslo, *Geophys. Publ.*, 10, No. 11, 1935

‡ Ottawa, *Trans. roy. Soc. Can. Series 3*, 3, 1909, pp. 4-6.

§ Brooks, C. E. P. and Quennell, W. A.; London, *Geophys. Mem.*, No. 41, 1928.

**Iceberg.**—A mass of land ice broken from a glacier or a barrier and floating in the sea. The glacier bergs are greenish in colour, irregular in shape and may be broken by crevasses. The bergs which are broken off from an ice barrier are white, rectangular in shape and often very large; they are usually described as "tabular" and are characteristic of the Antarctic. Another type of berg which is not a true iceberg is composed, at least above sea level, of névé or compacted snow; these bergs have much the appearance of tabular bergs, but float with a greater proportion above the sea surface than true icebergs.

With favourable winds and currents, icebergs drift into latitudes of 40–50°. Icebergs decrease in size by melting, erosion and calving. Calving often disturbs the equilibrium and causes the iceberg to roll over. Melting takes place most rapidly on the water line, and in warm water from below when the iceberg calves frequently. Erosion is caused mostly by the waves and the swell, but also by the rain. H. T. Barnes' experiments show that iceberg ice is as pure as distilled water, containing only 4 parts of solid per million. Icebergs also contain a considerable quantity of air, ranging in various specimens examined from 7 to 20 or 30 per cent.

**Iceblink.**—The whitish glare in the sky over ice which is too far away to be visible.

**Ice Day.**—An ice day is defined as a period of 24 hours beginning normally at 9 h. G.M.T. on which the maximum temperature is 32° F. or less.

**Ice, formation on aeroplanes.**—In certain conditions ice may form on the wings, propellers and other parts of an aircraft in flight and so affect its aerodynamic characteristics that continued flight is either seriously impeded or has to be abandoned. The four main types of ice formation may be summarised in order of increasing danger (a) a white semicrystalline coating of ice which has little effect on flying. It generally forms in clear air when a cold aircraft enters warmer and damper air during a rapid descent and is due to condensation of water vapour direct into ice crystals (see HOARFROST); (b) a light white opaque deposit which forms when flying in filmy clouds consisting of small supercooled water drops (see RIME); (c) a transparent or translucent coating of ice having a glassy surface appearance which forms within dense clouds consisting of large supercooled water drops; and (d) a heavy coating of clear ice which forms when rain falls on an aircraft whilst flying in a layer of the atmosphere whose temperature is below freezing point (see GLAZED FROST).

The physics of ice formation indicate that when a supercooled water drop impinges on an aircraft, part of the drop freezes immediately at the leading edge whilst the remaining part of the drop freezes subsequently. In the case of a small drop the final freezing occurs quickly giving opaque ice on and near the leading edge. For a large drop the final freezing is not quite so rapid and the drop has opportunity to spread over the wing. This leads to the more dangerous type of clear ice which not only builds up outwards from the leading edge but also spreads back over the wings. For ice accumulation to become dangerous it is necessary that there should be abundance of large water drops at air temperatures below the freezing point. These conditions are met with only in clouds, rain, sleet, or rain and hail.

Observations made in England show that ice formation may occur in any type of cloud, except members of the cirrus group which are composed of very small ice crystals, provided the temperature in the cloud lies within the range 10° F. to 32° F. It is occasionally experienced at temperatures below 10° F. but is usually not then heavy. The cloud in which it is most frequently encountered in winter is stratocumulus but the heaviest deposits occur in cumulus and cumulonimbus. Stratocumulus is a "layer" type of cloud from which rain does not normally fall and it is usually possible to fly in clear air either above or beneath it. Cumulus and cumulonimbus are "heap" clouds and as a rule there is no difficulty in avoiding them. Cumulonimbus is often associated with heavy showers with thunder and lightning. Ice formation is comparatively rare in altostratus clouds probably because they are frequently composed of ice crystals.

The worst type of ice formation, **GLAZED FROST**, is associated with the passage of fronts, chiefly warm fronts, in winter. It is comparatively rare in this country but more frequent on the continent and in North America. The average height of the freezing point level in the British Isles varies from about 1,800 ft. in winter to 10,000 ft., in summer and represents the average lowest levels where ice formation may be expected. On a few occasions during every winter the ice zone extends down to ground level, and even in the warmest part of the summer it has been known to extend below 5,000 ft.

**Ice Saints.**—St. Mamertius on May 11, St. Pancras on May 12 and St. Gervais on May 13 are known on the continent as the "cold Saints' Days." It is said in France that these three days do not pass without a frost. From observations at selected stations in Scotland from 1857–66 Buchan found a cold period from May 9–14. For further information see *London, Meteorological Magazine*, 57, 1922, p. 177 and 63, 1928, p. 93.

**Ice Sheet.**—A large area of land ice, with a dome-shaped, almost level surface, which almost completely covers the land on which it rests, so that precipitation of snow takes place directly on the surface of the ice. The best known and largest ice sheets at present existing are those of the Antarctic and Greenland.

**Index.**—The pointer or other feature in an instrument whose position with regard to the scale determines the reading. The term is also sometimes applied to the fixed mark which constitutes the zero, e.g. in the term "index-error." See **ERROR**.

**Index Correction.**—The quantity which (with proper sign) has to be added to an instrumental reading to correct for index error (see **ERROR**). It is of the same magnitude as the index error, but of the opposite sign.

**Index Error.**—See **ERROR**.

**Indian Summer.**—A warm, calm spell of weather occurring in autumn, especially in October and November. The earliest record of the use of the term is at the end of the eighteenth century, in America, and it was introduced into this country at the beginning of the nineteenth century. There is no statistical evidence to show that such a warm spell does tend to recur each year.

**Insolation.**—A term applied to the solar radiation received by terrestrial or planetary objects (Willis Moore).

The amount of solar radiation which reaches any particular part of the earth's surface in any one day depends upon (1) the **SOLAR CONSTANT**, (2) the area of the intercepting surface and its inclination to the sun's rays, (3) the transparency of the atmosphere, and (4) the position of the earth in its orbit. The following table compiled from Angot\* assumes the atmosphere to be perfectly transparent.

*Calculated Insolation reaching the Earth.*

Latitude	January	February	March	April	May	June	July	August	September	October	November	December	Year
N.													
90° ..	0.0	0.0	1.9	17.5	31.5	36.4	32.9	21.1	4.6	0.0	0.0	0.0	145.4
80° ..	0.0	0.1	5.0	17.5	30.5	35.8	32.4	20.9	7.4	0.6	0.0	0.0	150.2
60° ..	3.0	7.4	14.8	23.2	30.2	33.2	31.1	24.9	16.7	9.0	3.8	1.9	199.2
40° ..	12.5	17.0	23.1	28.6	32.4	33.8	32.8	29.4	24.3	18.4	13.4	11.1	276.8
20° ..	22.0	25.1	28.6	30.9	31.8	32.0	31.8	30.9	28.9	25.8	22.5	20.9	331.2
Equator	29.4	30.4	30.6	29.6	28.0	27.1	27.6	28.6	30.1	30.2	29.5	28.9	350.3
S.													
20° ..	33.8	32.2	29.0	24.9	21.2	19.6	20.5	23.7	27.7	31.1	33.3	34.1	331.2
40° ..	34.8	30.4	23.9	17.4	12.5	10.4	11.6	15.8	21.9	28.5	33.6	36.0	276.8
60° ..	33.0	25.3	16.0	8.1	3.3	1.7	2.7	6.5	13.6	22.6	31.1	35.3	199.2
80° ..	34.2	20.5	6.3	0.3	0.0	0.0	0.0	0.0	3.8	16.0	31.0	38.1	150.2
90° ..	34.7	20.7	3.2	0.0	0.0	0.0	0.0	0.0	1.0	15.6	31.5	38.7	145.4

\* "La distribution de la chaleur à la surface du globe." *Ann. Bur. mét., Paris*, 1883.

The unit is the amount of energy that would be received on unit area at the equator in one day, at the equinox, with the sun at mean distance, if the atmosphere were completely transparent. The solar constant being taken as  $1.94 \text{ cal./cm.}^2/\text{min.}$ , Angot's unit is found to be  $889 \text{ cal./cm.}$  (The numerical factor which is introduced is  $24 \times 60/\pi$ .)

**Instability.**—Any system can remain in equilibrium when the forces acting upon it balance each other. If further, when the system is disturbed from its equilibrium position and then left to itself, it returns to its original state, it is said to be in stable equilibrium. If when disturbed and left to itself it stays in the disturbed position it is said to be in indifferent equilibrium. If when disturbed and left to itself, it goes still further from its original state, it is said to be in unstable equilibrium. Stability and instability thus have to be defined in terms of the effects of small disturbances. A pencil standing on end is stable, since it is not upset by small disturbances, though it falls down when disturbed through a not very large finite angle.

In meteorology we are mainly concerned with the vertical stability of air masses, and the customary treatment of the question lays down the condition of stability as the possession of a LAPSE rate not exceeding the ADIABATIC. When the LAPSE rate grows to a value exceeding the adiabatic, convection begins, the convection tending to reduce the lapse rate to the adiabatic value once more. It is not unusual however to find in practice lapse rates exceeding 10 or even 20 times the adiabatic for a short distance from the ground upwards in strong sunshine. It thus appears that the phenomena are likely to be more complicated than the assumptions usually made in discussing this topic.

The discussion above refers to statical equilibrium. When a system in motion is slightly disturbed, if the result is to produce small oscillations superimposed on the original motion, the system is dynamically stable. If the result is to cause an increasing departure from the original motion the system is said to be dynamically unstable.

**Instability Shower.**—See SHOWER.

**Interpolation.**—When a varying quantity has been observed at certain intervals of time, or of some other independent variable, the evaluation of values appropriate to intermediate stages of the independent variable is called interpolation. When a curve can be drawn to represent the observations with reasonable accuracy, the values for intermediate values of the independent variable can be read off from the curve. Numerous formulae have also been developed for the same purpose. These might be used for example in deducing the intermediate values of a function from values tabulated for definite intervals. On account of its utility in such cases, interpolation has been described as “reading between the lines of a mathematical table.”

**Intertropical front.**—The surface of separation between the wind circulations proper to the northern and southern hemispheres. Over the Atlantic and Pacific Oceans, where it is closely related to the DOLDRUMS, it is the boundary between the north-east and south-east TRADE WINDS. Over the continents it is replaced by the boundary between other wind systems with components directed towards the equator, e.g. in Africa between the HARMATTAN and the south-west MONSOON. The FRONT moves northward in the northern summer and southward in the southern summer, but its average position is north of the equator. Over the oceans the range of movement is small, but over the continents it may be very large.

**Inversion.**—An abbreviation for “inversion of temperature-gradient” (see GRADIENT). The temperature of the air generally gets lower with increasing height but occasionally the reverse is the case, and when the temperature increases with height there is said to be an “inversion.”

There is an inversion at the top of a fog layer, and generally at the top of other clouds of the stratus type. Inversions are shown in the diagram of variation of temperature with height in the upper air, Fig. 26, by the slope of the lines upwards towards the right instead of towards the left,

which is the usual slope. In the TROPOSPHERE inversions do not generally extend over any great range of height; the fall of temperature recovers its march until the lower boundary of the STRATOSPHERE is reached. At that layer there is generally a slight inversion beyond which the region is isothermal, so far as height is concerned. For that reason the lower boundary of the stratosphere is often called the "upper inversion." In some soundings with balloons-sondes from Batavia the inversion has been found to extend upwards for several kilometres from the commencement of the stratosphere.

It is usual, at least in temperate latitudes, to find an inversion somewhere between the ground and a height of about a hundred metres at night, when the sky has been clear for several hours and the wind has not been very strong. During anticyclonic weather in winter this surface inversion may grow until it extends to a considerable height and it may then persist for several days. The dense fogs which characterise some cities in winter usually originate from such an inversion. Alternatively, the accumulation of smoke overhead may produce almost complete darkness at midday in a city if the inversion is sufficient to prevent the smoke from dispersing. Fogs on land nearly always imply the existence of an inversion. An inversion invariably means thermal stability of the atmosphere and the absence of turbulence.

The term "counter-lapse" has been suggested as an alternative to inversion.

**Ion.**—The name selected by Faraday for the component parts into which a chemical molecule is resolved in a solution. Of the two components one carries a positive charge the other an equal negative charge. The laws of electrolysis indicate that these charges are of the same magnitude for ions of all substances. Electric force causes the free ions charged with positive electricity to move in one direction whilst those charged with negative electricity move in the opposite direction. These movements constitute the electric current through the solution.

Similarly a gas may conduct electricity by virtue of the presence of free ions. The ions may be produced by combustion, by the action of radio-active substances (like radium), by ultra-violet light, or by cosmic radiation. The conduction of electricity through the atmosphere is now attributed to the free ions which exist in it. (See ATMOSPHERIC ELECTRICITY.)

It is supposed that all matter is built up of units which have positive or negative charges. The positively charged units are called protons, the negatively charged ones electrons. In neutral matter the positive and negative charges just balance, according to this hypothesis. A negative ion is matter to which an extra electron is attached, a positive ion is matter which has lost an electron. The ionic charge is always a multiple of the charge of an electron, the value of which as determined by Millikan is  $15.9 \times 10^{-20}$  coulomb.

**Iridescence or Irisation.**—Words formed from the name of Iris, the rainbow goddess, to indicate rainbow-like colours. In its more technical usage iridescence refers to tinted patches generally of a delicate red or green, sometimes blue and yellow, occasionally seen on high clouds. A brilliant iridescent cloud of considerable area is "one of the most beautiful of sky phenomena." The boundaries of the tints are not circles with the sun as centre but tend to follow the outlines of the cloud. The iridescence is probably due to diffraction by small waterdrops and the colours seen are determined partly by distance from the sun, partly by the size of the drops, whereas in the production of the corona the variations between the drops are of little importance and the same tint is to be seen at the same distance from the sun in any direction. The drops responsible for iridescence are very small and probably supercooled well below the freezing point. Just as a HALO is evidence for the presence of ice crystals so iridescence is evidence for the presence of supercooled waterdrops.

In Norway, Prof. Størmer has had photographs of iridescent clouds taken with cameras at a considerable distance apart and has found the height of the clouds to be about 20 Km., more than twice the height of ordinary cirrus clouds.

**Isallobar.**—Isallobars are lines drawn upon a chart through places at which equal changes of pressure have occurred in some period of time. They are formed by plotting the changes in barometric pressure which have taken place between two sets of observations. Lines of equal change, or isallobars, are drawn to enclose regions of rising and of falling pressure.

Generally the areas of rise or fall in an isallobaric chart are regular in forms. Dr. Nils Ekholm,\* by whom this method of plotting the pressure differences was introduced, claimed that when successive charts of isallobars were drawn the movements of the various groups of isallobars were on the whole more regular than those of the isobaric groups. E. G. Bilham,† however, points out, when the pressure distribution is accurately known at the beginning and end of a time interval, that

“in the case of small depressions uncomplicated by other systems the isallobars are merely a sort of composite picture of the two sets of isobars and no additional information is imparted by them. . . . When the distribution is complex, however, the isallobaric chart is of value since it performs the function of separating the active from the quiescent features of the pressure distribution.”

**Isallobaric Wind.**—A component wind due to changing pressure gradients.

It is only on occasions when the pressure distribution is not varying that the use of the gradient wind equation is strictly justified. The mathematical expression for the wind in a changing pressure system includes, in addition to the “GRADIENT WIND,” a component directed at right angles to the ISALLOBARS and proportional to the gradient of the isallobars, this component being known as the isallobaric wind, and a term representing a harmonic oscillation of the wind. The last mentioned term would be difficult to detect because it should be damped out rather rapidly by surface frictional effects, but important discrepancies which have on occasions been found when attempts have been made to relate upper wind measurements to the pressure gradient and the isallobaric gradient are of an order quite compatible with the temporary existence of the initial oscillation.

The isallobaric component is relatively small, rarely exceeding 5 m./sec.; but is dynamically important in problems of convergence and rainfall.

**Isanomaly.**—This word is a combination of the prefix ISO and the word ANOMALY, and is used of lines joining all points on a map or chart having equal anomalies, or differences from normal, of a particular meteorological element.

**Isentropic.**—Without change of ENTROPY, generally equivalent in meaning to ADIABATIC. Isentropic surfaces in the atmosphere are surfaces of constant POTENTIAL TEMPERATURE.

**Isentropic Analysis.**—An analysis, used particularly in the United States, of the physical and dynamical processes taking place in the free atmosphere on the basis of the location and configuration of the various isentropic surfaces and distribution of atmospheric properties (e.g. HUMIDITY-MIXING-RATIO) and motion on them. ISENTROPIC CHARTS are the main tool in this work.

**Isentropic charts.**—Synoptic charts of atmospheric properties on specified isentropic surfaces.

**Iso.**—A prefix meaning equal, extensively used in meteorological work, in conjunction with another word, to denote lines drawn on a map or chart to display the geographical distribution of any element, each line being drawn

\* “Wetterkarten der Luftdruckschwankungen.” *Met. Z., Braunschweig*, 21, 1904, p. 345.

† “Isallobars of moving circular depressions.” *Geogr. Ann., Stockholm*, 1921, H.4, p. 356.



through the points at which the element has the same value. The words having this prefix are generally self-evident in meaning and can be interpreted without any difficulty.

In 1889 the tentative use of the word *isogram* was suggested by Sir Francis Galton as a generic term for all lines of this type. The name *isopleth* is literally applicable for this purpose and is so used by many writers. The use of *isogram*, however, seems advisable, in order to avoid confusion, as *isopleth* is often used with a more specific meaning, viz., a line showing the variation of an element with regard to two co-ordinates, such as the time of year (month) and the time of day (hour).

Some of the more important examples of the use of iso are set out below.

*Isobars* :—Lines on a chart joining places of equal barometric pressure.

*Isotherms* :—Lines showing equal temperatures.

*Isohyets* :—Lines showing equal amounts of rainfall.

*Isohels* :—Lines showing equal duration of sunshine.

*Isonephhs* :—Lines showing equal amounts of cloudiness.

*Isotach* :—Lines showing equal wind speeds.

**Isobar.**—The distribution of atmospheric pressure is indicated on a weather map by means of isobars—these being lines of equal pressure or lines along which the pressure is constant.

The atmospheric pressure at any given place is readily obtained by means of a mercury barometer, but in order that the barometric readings from different places may be comparable one with another it is necessary that they be reduced to a common standard. Corrections are, therefore, applied to reduce the readings to mean sea level (see REDUCTION TO SEA LEVEL). On the charts used at the Meteorological Office in connexion with weather forecasting, it is customary to plot the barometric readings to the nearest tenth of a millibar and to draw the isobars for every two millibars, the isobars being those of even number, i.e. 1000 mb., 1002 mb., 1004 mb., etc. It seldom happens that an exact even millibar reading occurs at any station at one of the fixed observation times, and in consequence it is necessary to find the position of the even millibar readings by means of interpolation. When there is a close network of stations and the pressure variations from place to place are not too great, this is quite a simple matter, if it be assumed that the barometer falls uniformly between two stations. By repeating this process a series of positions for any given value is obtained and by drawing a curve connecting these points the isobar for this value is formed. Isobars even in complicated pressure systems can be drawn readily after some practice.

It will be seen that when travelling along an isobar pressure remains continually higher on one side of the isobar than on the other, and that an isobar must come back again to the place from whence it starts if a large enough area be considered. This may be simply stated by saying that an isobar must form a closed curve.

After the pressure readings have been plotted on a map and the isobars drawn, it will be seen that the isobars are analogous to contour lines, the areas of high pressure corresponding with the hills and those of low pressure with the valleys.

Examples of different systems of isobars will be found in the illustrations which accompany the articles on ANTICYCLONE, COL, DEPRESSION, SECONDARY, TROUGH and WEDGE.

**Isomeric Values.**—The values obtained when the average monthly rainfall amounts for any station are expressed as percentages of the annual average. When the percentage values for a number of stations for any month are plotted on an outline map an isomeric chart is obtained for the month, and the lines drawn on such a chart to represent the distribution of the values are termed "isomers" or lines of equal proportion. Isomeric charts of the British Isles showing the proportion of the annual average rainfall falling in each month of the year were published in *London, Quart. J. R. met. Soc.*, 41, 1915, pp. 1-44 and *British Rainfall*, 1914, pp. 25-44.

**Isopycnic.**—Relating to field of mass. Term for surface of equal density. See BAROCLINIC. Isopycnic charts of the globe for different heights in the atmosphere are given in *London, Quart. J. R. met. Soc.*, 50, 1924, pp. 37–41.

**Isosteric.**—Relating to field of mass. Term for surface of equal specific volume. See BAROCLINIC.

**Isotherm.**—A line joining places along which the temperature of the air or of the sea is the same. When the places are at different altitudes a correction may be necessary on account of the general upward decrease of temperature (see REDUCTION TO SEA LEVEL). The first isotherms were constructed by A. von Humboldt in 1817. Isotherms of mean daily maximum and mean daily minimum temperature for the year and each month, together with isotherms of absolute maximum and minimum temperature are given in the "Climatological Atlas of the British Isles". Isotherms for the globe for each month and the year are contained in the "Manual of Meteorology," Vol. 2, by Sir Napier Shaw (Cambridge University Press, 2nd Edition, 1926).

**Isothermal**—of equal TEMPERATURE. An isothermal line is a line of equal temperature, and, therefore, is the same as isotherm.

Isothermal is frequently used in meteorological writings on the upper air for the so-called "isothermal layer" by which is meant the layer indicated in the records of all sounding balloons, of sufficient altitude, by the sudden cessation of fall of temperature with height and generally by a slight INVERSION (see also GRADIENT) followed by practical uniformity of temperature.

The layer is not really isothermal, since it has a horizontal temperature gradient. The word STRATOSPHERE was therefore coined by M. Teisserenc de Bort, who was instrumental in discovering this region, while he gave the name of TROPOSPHERE to the region below. These names have now been generally adopted.

**Jet Stream.**—A jet stream is a more or less horizontal, flattened tubular current in the vicinity of the tropopause, with its axis on a line of maximum wind speed and characterized by high wind speeds and strong transverse wind shears.

Generally speaking a jet stream is a few thousand kilometres in length, a few hundred kilometres in width and a few kilometres in depth; the wind speed is at least 60 kt. at every point on its axis; the vertical wind shear is approximately 10 to 20 kt. per Km. and the horizontal wind shear is of the same order of magnitude as the Coriolis parameter, that is to say of the order of 20 kt. per 100 Km. in middle latitudes and 10 kt. per 100 Km. in low latitudes.

**Joule.**—The unit of energy associated with the practical system of ELECTRICAL UNITS.

1 joule = 1 watt-second = the energy converted to heat when a current of one ampere flows through a resistance of one ohm for one second.

The joule is approximately the energy required to lift one kilogramme through 10 centimetres; it is equal to  $10^7$  ergs.

The 20° calorie, the heat required to raise the temperature of one gram of water by 1° C. from 19½° C. to 20½° C. is equivalent to 4.18 joules.

**Katabatic.**—See WIND.

**Kew Pattern Barometer.**—A portable marine BAROMETER designed by P. Adie in 1854 for the Kew Committee of the British Association. The scale is graduated to take account of changes in the level in the steel cistern so that it is only necessary to read the top of the mercury column. The tube is constricted to minimise PUMPING when the barometer is used at sea. Similar barometers, known as "station" barometers, but without the constriction, were subsequently adopted for use on land, and are regularly employed at most British and Colonial meteorological stations.

**Khamsin.**—A southerly wind blowing over Egypt in front of depressions passing eastward along the Mediterranean or north Africa, while the pressure is high to the east of the Nile. As this wind blows from the interior of the continent it is hot and dry, and it often carries a considerable quantity of dust. It is supposed to be most prevalent for about 50 days from April to June.

Gales from S. or SW. in the Red Sea are also known as khamsin.

**Kilowatt-hour.**—The unit by which electrical energy is sold. This unit has sometimes been referred to as a Board of Trade Unit but that name is not to be recommended as confusion may arise with the "British Thermal Unit" the heat required to raise the temperature of a pound of water by 1° F.

$$\begin{aligned} 1 \text{ kilowatt-hour} &= 3.6 \times 10^{13} \text{ ergs.} \\ &= 8.6 \times 10^5 \text{ calories.} \end{aligned}$$

**Kite.**—An appliance which ascends into the air in virtue of the pressure of a relative wind upon an inclined surface. The kite is held captive by means of a cord or wire. It consists of a framework of wood or light metal, covered with fabric, or other suitable material. The general form used for scientific work is the box kite, invented by Hargrave; this form consists of a light wooden framework, usually rectangular in cross section, covered with fabric at either end for about one quarter of the length, the middle portion being left free, thus forming rectangular cells. Kites were frequently flown in tandem, and heights of over 20,000 ft. have been reached. A box kite of lozenge shape was used by W. H. Dines, a special form of meteorograph being designed for use with it.

There are many forms of kites, from the Malay kite, with the attached tail, to the large man-lifting kites used by Cody and others. Kites were known to the Chinese at a very early date, and were flown upon festive occasions.

High-altitude kite-flying necessitates the use of a thin steel wire.

**Kite Balloon.**—A captive balloon, elongated in form, and fitted with fins or air ballonets at the rear end. The kite balloon is so rigged, that when moored, it flies with the forward end tilted to the wind, thus, the underside of the gas bag acts as a plane surface, tending to lift the balloon in the manner of a kite.

The fins or ballonets are connected with an opening facing the wind, by which they are kept inflated.

The observer's basket is suspended from the gas bag by means of cords. Small kite balloons have been designed for carrying meteorographs. Unless special precautions are taken, the steel cable constitutes a danger to aircraft, as in the case of the kite. See BALLOON, KITE.

**Kuro-Shiwo.**—Variously translated "blue salt" stream or "black" stream, a warm-water current of a characteristic dark blue colour the main branch of which flows north-eastward along the south coast of Japan, and continuing on this course gradually merges in the general eastward drift of the North Pacific. This current is analogous to the Gulf Stream of the Atlantic, carrying warmth to higher latitudes; between it and the east coast of Japan flows a cold current from the Bering Sea, analogous to the Labrador current. The strength of the Kuro-Shiwo varies with the wind, increasing in the (summer) season of the south-west monsoon and decreasing in the (winter) season of the north-east monsoon. A branch of the Kuro-Shiwo sets into the Japan Sea.

**Labile.**—A term sometimes used to denote unstable or neutral equilibrium in the atmosphere, i.e. LAPSE RATE equal to or exceeding the ADIABATIC. In German the word is used to denote unstable equilibrium only.

**Lag.**—The delay between a change in the conditions and its indication by an instrument. It is the aim of instrument makers to reduce this interval as much as possible, but a limit is often set by practical considerations such as the need for robust construction. In marine barometers lag is introduced

deliberately to minimise "pumping." In Symons's earth thermometers lag is introduced by immersing the bulb in paraffin wax, a poor conductor of heat, so that the reading does not change perceptibly when the thermometer is drawn up for reading into surroundings at a different temperature.

**Land and Sea Breezes.**—These are caused by the unequal heating and cooling of land and water under the influence of solar radiation by day and radiation to the sky at night, which produce a gradient of pressure near the coast. During the day time the land is warmer than the sea and a breeze, the sea breeze, blows onshore; at night and in the early morning the land is cooler than the sea and the land breeze blows offshore. The breezes are most developed when the general pressure gradient is slight and the skies are clear. In such circumstances the sea breeze usually sets in during the forenoon and continues until early evening, reaching its maximum strength during the afternoon; the land breeze may set in about midnight or not until the early morning. The land and sea breezes are much influenced by topography and vary considerably from one part of the coast to another. In the British Isles the pure sea breeze rarely exceeds force 3, but in lower latitudes it may reach force 4 or 5. The land breeze is usually less developed than the sea breeze. The sea breeze does not usually extend more than 15–20 miles on either side of the coast line, and often its extent is considerably less. The depth of the current is shallow at its commencement, but in favourable circumstances it may exceed 2,000 feet, at the time of its maximum development.

**Lapse.**—The term lapse was proposed by Sir Napier Shaw to denote the decrease of temperature of the atmosphere with height. The **lapse rate** is the fall of temperature in unit height, and is taken positive when the temperature decreases with height.

When the temperature at different heights is represented diagrammatically, height being conveniently measured along the vertical co-ordinate and temperature along the horizontal axis, the condition of the atmosphere is represented by a curve which is sometimes called the "lapse line." Average conditions in the atmosphere are represented by a straight line whose slope corresponds to a lapse rate of about 0·6° C. per 100 metres.

The lapse rate of temperature is of fundamental importance in determining the vertical stability of the atmosphere (see ADIABATIC, INSTABILITY and ENTROPY). When the lapse rate is negative the temperature increases with height (see INVERSION). In the TROPOSPHERE this only occurs through limited intervals of height.

**Latent Heat.**—The quantity of heat absorbed or emitted without change of temperature during a change of state of unit mass of a material. The latent heat of fusion of one gram of ice is 79·77 gram calories. The latent heat of condensation of 1 gram of water vapour varies from 597 gram calories at 0° C. to 539 gram calories at 100° C.

**Latent Instability.**—See INSTABILITY.

**Latitude.**—The geographical latitude is defined as the angular elevation of the celestial pole above the surface tangential to the spheroid which represents the earth. It is also equal to the angle between the normal to this surface and the plane of the equator. The geographical latitude  $\phi$  at any point differs only slightly from the geocentric latitude  $\phi'$ , the latter being the angle between the radius of the earth passing through the point and the plane of the equator. The relation of  $\phi$  and  $\phi'$  is approximately represented by the equation  $\phi - \phi' = 68\cdot8'' \sin 2\phi$ . Geocentric latitude is found to be more useful than geographical latitude in seismology as the calculation of distance from place to place is facilitated.

Astronomical latitude is defined as the elevation of the celestial pole above the level of a mercury surface, or in other words as the angle between the plumb line and the plane of the equator.

**Law of Storms.**—A nautical expression denoting the mariners' rules for minimising the dangers of tropical cyclones, and especially for avoiding the so-called "dangerous half" of the cyclone. These rules as used at the present time were drawn up by Dr. C. Meldrum and Captain Wales.

**Least Squares, Law of.**—A law, based on the theory of errors, which states that the best estimate of any quantity, observations of which are distributed according to the normal law of errors, is that for which the sum of the squares of the residuals of these observations is least. It may be applied to pairs of related values  $x_1 \dots x_n$  and  $y_1 \dots y_n$  to obtain the constants of the function  $y = f(x)$  which best expresses the relation between  $x$  and  $y$ , i.e. that for which the sum of the squares of the differences between the observed and computed values of  $y$  is a minimum.

**Lenticular.**—In shape like a lens or lentil. The shape is characteristic of a type of cloud most often seen over hills or mountains, formed in a damp layer at the crest of a stationary or slow-moving wave. The cloud is formed by a large mass of clustered cloudlets and is apparently disposed horizontally. It has well defined edges, a pointed end and a broad middle or base. The cloud is usually of smooth appearance, but the cloudlets are often visible, streaming through the cloud. Sometimes the side of the cloud has an appearance not unlike that of stratified rocks. The lenticular clouds are frequently associated with *фöhn*. Clouds of rather similar structure are the caps on cumulus clouds, and the flat patches sometimes visible near cumulonimbus, often appearing dark against a white background.

**Leste.**—A hot, dry, S. wind occurring in Madeira and northern Africa in front of an advancing depression.

**Levanter.**—An easterly wind in the Straits of Gibraltar. It is most frequent from July to October and in March. At Gibraltar it causes complex and dangerous eddies in the lee of the Rock. With moderate winds a banner cloud stretches out from the summit of the Rock a mile or more to leeward; when the wind reaches force 7 or over the cloud lifts and disappears. Levanter is usually associated with high pressure over western Europe and low pressure to the south-west of Gibraltar over the Atlantic or to the south over Morocco.

**Leveche.**—A hot, dry, southerly wind which blows on the south-east coast of Spain in front of an advancing depression. It frequently carries much dust and sand, and its approach is indicated by a strip of brownish cloud on the southern horizon.

**Level.**—A surface is level, if it is everywhere at right angles to the direction of the force of gravity, which is indicated by the plumb-line. The word is also used to indicate the height of a level surface above a standard such as MEAN SEA LEVEL.

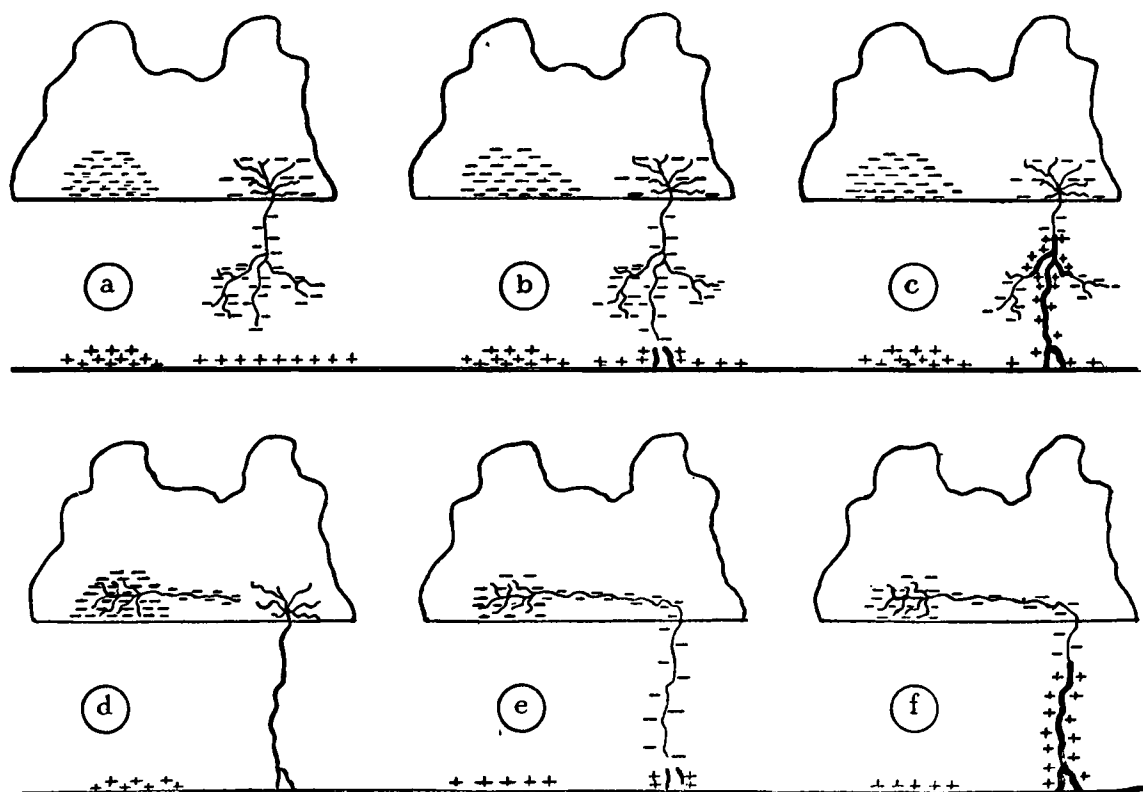
**Lightning.**—The flash of a discharge of electricity between two clouds or between a cloud and the earth. A distinction is drawn between "forked" lightning, in which the path of the actual discharge is visible, and "sheet" lightning, in which all that is seen is the flash of illuminated clouds and which is attributed to the light of a discharge of which the actual path is not visible.

Since the introduction of photography many photographs of lightning have been obtained, and in general character they cannot be distinguished from photographs of electric discharges of six inches or more in length which are obtained in a laboratory, but the varieties of form of lightning discharges are very numerous. Frequently a flash shows many branches, especially the upper part of a flash between the clouds and the earth. Among a collection of photographs thrown upon a lantern screen, W. J. S. Lockyer once interpolated a photograph of the River Amazon and its tributaries, taken from a map, and the photograph was accepted without comment as a picture of lightning.

The quantity of electricity which is discharged by a lightning flash has been shown by C. T. R. Wilson\* to be of the order 20 coulombs. A. Matthias, who utilised an oscillograph with a very open time scale, 10 cm. to a second, found at Wannsdorf near Berlin that a single lightning flash usually involved about five partial discharges. The duration of a partial discharge was between  $\cdot 0005$  second and  $\cdot 01$  second. The maximum interval between consecutive partial discharges was  $0\cdot 37$  second. The same observations indicate that the theory that the lightning discharge is oscillatory cannot be upheld.

The development of a lightning flash has been studied in South Africa by Prof. B. F. J. Schonland and his colleagues with the aid of the camera invented by Sir Charles Vernon Boys. This camera had two lenses which were turned rapidly about a common axis. (See BOYS CAMERA.) Two photographs are taken simultaneously and, by comparison of the photographs, it is possible to determine the sequence of events. It is found that a flash begins with a faint light travelling down from the cloud in a jerky way and leaving a fainter trail. At intervals the trail branches, the light travelling simultaneously along different tracks. Eventually one of the branches approaches the earth. Then a vigorous, much brighter, luminosity travels rapidly up this branch, and the other branches light up in succession. Subsequent strokes are not branched, but they have the same double character, leader and return stroke. The time taken by the leader to reach the ground is comparable with  $\cdot 01$  sec.; the return stroke covers the same distance in about  $\cdot 0001$  sec. This interpretation of the Boys photographs is in agreement with results obtained in the study of the "atmospherics" which are heard on the wireless and which are evidence that electric waves produced by lightning can travel right round the globe.

The sign of the electricity brought down by a lightning stroke which hits an electric power line has been determined occasionally. There is a great preponderance of negative strokes. Laboratory experiments by Alibone



Reproduced by permission from London, *Proc. roy. Soc., A*, 164, 1938, p. 134.  
FIG. 23.—The development of a flash of lightning.

\* London, *Philos. Trans., A*, 221, 1920, p. 73.

indicate that this is probably because negative lightning is strongly attracted by elevated structures which are apt to carry streamers of St. Elmo's fire. There is no such attraction for positive lightning which is more likely to go straight to earth.

**Line-Squall.**—Squalls may occur simultaneously along a line, sometimes 300 or 400 miles in length, advancing across the country, and to such phenomena the name "line-squall" is applied.

The passage of a line-squall at a ground station in a country like the British Isles is marked by characteristic happenings which include all or some of the following :—

An arch or line of low black cloud of definite straightness.

A sudden or rapid rise of wind velocity.

A sudden or rapid change of wind direction.

A sudden or rapid drop in temperature.

A rapid rise in barometric pressure.

Heavy rain or hail (occasionally snow).

Thunder and lightning.

It is the first and second of these characteristic happenings that, combined, have given the special name. In the upper air the passage of the squall is marked by dense cloud and very violent vertical disturbances.

The fundamental physical fact underlying the phenomena is that suddenly a distinctly colder body of air replaces a warmer current, and this sudden replacement is brought about when the COLD FRONT of a depression passes. The advancing cold current pushes itself wedge-wise under the warmer air and causes that warmer air to rise up an oblique plane ; this ascent is sufficient to produce the cloud and precipitation mentioned, whilst the rise in pressure and the drop in temperature are the results of the following cold air.

In the British Isles the warm current in front of the squall is usually from a southerly or south-westerly point and moist. In some parts of the world it is dry and in these latter cases the squall may pass without rain or even without cloud ; the dryness means that a great ascent has to be carried out before saturation, and hence cloud formation, is attained and sufficient ascent may not occur.

Line-squalls usually cross the British Isles in an easterly direction. Their speed of advance can be forecast with considerable certainty for in active systems any given part of a cold front advances with a velocity which is approximately equal to the component, perpendicular to the front, of the gradient wind in the cold (polar) air in its rear.

The life of a line-squall is often 24 hours or more.

**Local Time.**—Time reckoned from the epoch noon which at any place is the time of transit of either the true sun or mean sun (according as local apparent or local mean time is being used) across the meridian. A sundial and a sunshine recorder both indicate local apparent time (see TIME).

**Longitude.**—The intersection of a plane through the axis of rotation of the earth with the earth's surface is called a meridian. The longitude of any place is the angle between the meridian through that place, and a standard meridian. The standard meridian is usually taken to be the meridian of Greenwich.

**Long-range Forecast.**—A forecast for a period of a week or more ; a forecast for three or more months is, however, generally called a "seasonal forecast." A wide variety of methods for long-range and seasonal forecasting have been tried in different parts of the world, including :—

- (1) Influence of variations of solar radiation on subsequent weather.
- (2) Relations between weather in successive seasons in the same or different parts of the world.
- (3) Periodicities.
- (4) Methods based on the generalised weather situation over a period of time.

*Variations of solar radiation* have been used by C. G. Abbot and H. H. Clayton as the basis of forecasts for a week or more in North and South America. The data are the daily measurements of the SOLAR CONSTANT by the Smithsonian Institution, but there is some doubt as to the significance of these values.

*Relations between weather in different seasons.*—This method was first adopted in India for forecasting the MONSOON rainfall and has been developed by Sir Gilbert Walker as a basis for seasonal forecasting (or “foreshadowing”) in other parts of the tropics. He formed series of data for places in all parts of the world, mostly means for three-monthly seasons, and correlated each of these with all the others for the same season and for three and six months before and after. From these CORRELATION coefficients he is able to derive regression equations, connecting the element to be forecast with preceding conditions in the same or other parts of the world.

In the United States sea temperatures in the North Pacific are used as the basis for seasonal forecasts of rainfall in California, and the effect of the temperature of the Gulf Stream on the weather of the eastern coasts is being studied.

*Periodicities* in weather have frequently been used as the basis for forecasts over extended periods, but have generally proved untrustworthy. Weather cycles are not true periodicities in the mathematical sense, but are subject to variations of phase, amplitude and length, or may appear and disappear suddenly. Cycles appear to be more regular in tropical than in temperate regions and have been used to forecast the seasonal rainfall of Java with moderate success.

*The generalised weather situation* is that given by weather maps representing average conditions over a period of time, from 10 days to a month. This smooths out temporary features such as rapidly moving secondary depressions and emphasises persistent or structural features such as slow-moving anticyclones and centres of cyclonic activity.

**Looming.**—A nautical expression for an indistinct enlarged appearance of any object, particularly during the prevalence of slight fog. The expression is not used for unusual visibility by reason of which distinct objects appear nearer. The term is also used for the optical phenomenon in which objects normally below and beyond the horizon become visible.

**Low.**—Used to denote a region of low pressure, or a DEPRESSION, in the same way as “high” is used for a region of high pressure or anticyclone. On weather charts the central part of a depression is usually indicated by the word “low.”

**Lowitz, Arcs of.**—On rare occasions arcs slightly concave towards the sun extend obliquely downwards and inwards from the parhelia of the 22° halo. They are formed by refraction through ice crystals oscillating about the vertical.

**Luminous Night Clouds.**—See NOCTILUCENT CLOUDS.

**Lunar.**—Dependent upon *luna*, the moon; thus a lunar rainbow is a rainbow formed by the rays of the moon, a lunar cycle a cycle dependent upon the moon’s motion. A month is really, from its name, a lunar cycle, but the introduction of a calendar month makes it necessary to draw a distinction between it and the lunar month, which is the period from new moon to new moon. In astronomy it is called the synodic month, and is equal to 29·5306 days on the average. See CALENDAR.

**Lustrum.**—A period of five years, which is commonly used for grouping meteorological statistics which extend over a long period of years. In the Latin original the word meant a purifactory ceremony performed after the quinquennial census (Oxford Dictionary).



**Mackerel Sky.**—A sky covered with CIRROCUMULUS or ALTOCUMULUS clouds arranged in somewhat regular waves and showing blue sky in the gaps.

**Maestro.**—A NW. wind in the Adriatic. It is most frequent on the western shore and in summer; it is strongest on the west sides of depressions. NW. winds in other parts of the Mediterranean, notably in the Ionian Sea, and on the coasts of Sardinia and Corsica are also known as Maestro.

**Magnetic Character.**—It has been the practice for many years at magnetic observatories to divide days into three classes, "0," "1" and "2," according to the degree of disturbance; "0" representing the days with a fairly normal diurnal variation of magnetic force (see TERRESTRIAL MAGNETISM) and most free from irregular movements, and "2" representing the days most disturbed. The classifications so made are communicated quarterly to the Royal Netherlands Meteorological Institute at De Bilt, where the data are employed in accordance with an international agreement, in making an official selection from each month of five of the quietest and five of the most disturbed days.

**Magnetic Storm.**—A state of large irregular disturbance or fluctuation, world-wide in extent, of the earth's magnetic field, the normal quiet-day diurnal changes being largely or entirely masked and replaced by others with special characteristics. The duration may vary from a few hours to a few days. Some storms begin abruptly (a "sudden commencement") and apparently simultaneously, at least to within the limits of accuracy of measurement of the autographic records, at all places. The intensity of disturbance is greater in high than in low latitudes; in middle latitudes the absolute range of variation in a force component of the earth's field amounts to a very few per cent. of the normal value of the component. A conspicuous feature of most storms is the depression in the value of horizontal magnetic force after the early stages of the storm. Storms may occur at any time of the year and at any phase of the solar cycle; but the frequency of occurrence of highly disturbed conditions is greater near the equinoxes than near the solstices, and greater in years of sunspot maximum than in years of sunspot minimum. There is a marked tendency for magnetically disturbed conditions to recur at intervals of about 27 days (the solar rotation period), although a large disturbance may not be followed by another, or even by any noteworthy disturbance, 27 days later. Other conditions being favourable, AURORA is usually observed from places in comparatively low latitudes on occasions of magnetic storms. On such occasions large and irregularly varying earth currents cause interference with telegraphic communication. Definite effects in radio-wave propagation have been observed during magnetic disturbances, and it has recently been established that bright eruptions in the solar chromosphere cause simultaneous radio fade-outs and distinct terrestrial magnetic effects. See also TERRESTRIAL MAGNETISM.

**Magnetogram.**—The record from a MAGNETOGRAPH.

**Magnetograph.**—An instrument for obtaining continuous records of the variations of the earth's magnetic field. The usual type includes three magnets, delicately suspended with their axes horizontal. One, with its axis in the magnetic meridian, records the changes of DECLINATION (D); a second is perpendicular to the meridian and shows the fluctuations of horizontal force (H); the third can move in the vertical plane and records the variations of vertical force (V). Some forms are modified to give the geographical horizontal components (N. and W.).

To each magnet a mirror is attached which reflects light from a fixed lamp on to a rotating cylinder covered with photographic sensitised paper, the cylinder normally rotating once in 24 hours, although in the "Quick Run" type the period is much less.

In the "la Cour" instrument a system of prisms is incorporated in the optical system in such a way that if the primary light spot moves off the paper during a severe magnetic storm another spot comes on about 10 cm. from the original. Very large variations can be recorded with this form of instrument.

A fixed mirror is added below each magnet and light reflected from this provides a straight line on the MAGNETOGRAM from which the curves can be measured to obtain absolute values of the magnetic elements. The value equivalent to the position of the base line is obtained by comparison of the magnetogram with determinations from an absolute MAGNETOMETER.

**Magnetometer.**—An instrument for obtaining absolute measurements of the earth's magnetic field. The elements usually measured are D, H and I (the dip of a freely suspended magnet); other components are calculated from these. For details of construction and principles involved in the use of magnetometers, see "Dictionary of Applied Physics", Vol. II, pp. 528-40.

**Mammatus.**—The lower surface of certain cloud sheets sometimes has an udder-like or mammillated appearance. This structure is distinguished by the adjective "mammatus" or the prefix *mammato*, e.g. *mammatocumulus*.

**Manometer.**—An instrument for measuring differences of pressure. Ordinarily the weight of a column of liquid is balanced against the pressure to be measured. The mercurial BAROMETER is, therefore, a form of manometer.

**Mares' Tails.**—The popular name for tufted CIRRUS clouds.

**Maritime Polar Air.**—See POLAR AIR.

**Marsden Square.**—Mainly used for identifying the geographical position of meteorological data over the oceans. System devised by Marsden in 1831 who divided a Mercator chart of the world into squares of 10° LATITUDE by 10° of LONGITUDE. Each square is arbitrarily numbered, and is again subdivided into 100 one-degree squares which are numbered from 00 to 99 so that given the position of the square the first figure of the sub-square denotes the latitude and the second figure the longitude.

**Maximum.**—The highest value reached by any element in a given period. For example, the highest temperature recorded during the 24 hours is the maximum temperature for that period. See EXTREMES.

**Mean.**—The mean value of a set of numerical quantities is the average value determined by adding them together and dividing the result by the number of quantities. In some cases there may be an ambiguity unless the context makes it clear as to how the numerical quantities are classified. For example, the mean temperature of the atmosphere extending above a certain place might indicate the arithmetical mean of the temperatures taken at equal intervals of height or at equal intervals of pressure going upwards. See also NORMAL, AVERAGE.

**Mean Sea Level (M.S.L.).**—Is defined as the average level of the sea as calculated from a long series of observations obtained at equal intervals of time. On Ordnance Survey maps of the British Isles the heights of places are given above Ordnance Survey Datum, which was formerly taken as mean sea level at Liverpool; of recent years mean sea level at Newlyn, Cornwall, has been taken as this standard.

**Median.**—When a series of observations is arranged in order of magnitude, the central value (if the number of observations is odd) or the mean of the two central values (if the number is even) is termed the "median". If any observation is taken at random, there is an even chance that it will be above or below the median. It may differ appreciably from the MEAN, in which case the FREQUENCY distribution is said to be *skew*.

**Megadyne.**—One million dynes. A pressure of a megadyne per square centimetre is equal to one bar or 1,000 millibars. See DYNE.

**Meniscus.**—The curved upper surface of liquid in a tube. In the case of water, the meniscus, when viewed horizontally against the light, appears as a dark belt. The upper edge represents the highest point to which the water is drawn up against the glass, and the lower edge the lower part of the surface out in the middle of the tube. When the tube is broad like the measuring glass of a rain-gauge, the bottom edge should be used in reading. Mercury has a convex upper surface and in the case of the barometer the index is adjusted to the top of the meniscus.

**Mercator's Projection.**—See PROJECTION.

**Mercury.**—Mercury is a metallic element of great value in the construction of meteorological instruments. In the mercurial barometer its great density enables the length of the instrument to be made moderate, while the low pressure of its vapour at ordinary temperatures makes possible a nearly perfect vacuum in the space above the top of the barometric column. In the mercury thermometer there is no risk of condensation in the upper end of the stem, as in the case of the spirit thermometer.

Specific gravity = 13.5951 at 0° C.

Specific heat = 0.0335 at 273° A.

Vapour pressure = 0.00021 mb. at 0° C.

= 0.00343 mb. at 30° C.

Freezing point = 234.2° A.

Coefficient of expansion = .0001818 per ° C.

**Meteor.**—A meteor or shooting star is a fragment of solid material entering the upper regions of the atmosphere from outer space and visible by its own luminosity. The luminosity is attributed to incandescence due to the compression of the air in front of the meteor. A large meteor may have a luminous trail that persists for half an hour or longer. The majority of meteors are exceedingly small, comparable with grains of sand, but large bodies—meteorites, aerolites or siderites—fall to the ground occasionally. There is no generally accepted theory of the origin of meteors.

Accurate determinations of the track of the meteor by reference to the constellations by observers in different parts of the country may enable the height of the track to be determined. Usually a meteor becomes luminous between 150 and 100 Km. above ground and disappears at about 80 Km. It is remarkable that very few disappear at heights between 70 and 50 Km.

According to the theory of meteors worked out by Lindemann and Dobson\* the density of the air and therefore its temperature can be estimated from the records of the velocity of meteors, their brilliance and their points of appearance and disappearance. The theory indicates that at 60 Km. and perhaps lower the atmosphere is at a high temperature, at least as high as that near the ground. See AUDIBILITY; OZONE.

Lindemann and Dobson\* accept the explanation that "the meteor appears when a cosmic particle of matter, moving at a sufficiently high speed relative to the earth, becomes heated by atmospheric friction to such a temperature that it evaporates". The friction acts, however, not so much by the rubbing of the air streaming past the meteorite as by building up of a cap of air heated by compression. The temperature of the particle cannot exceed, but must be somewhat lower than the temperature of this heated cap but the cap itself does not seem to be incandescent.

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\* LINDEMANN, F.A. AND DOBSON, G.M.B.; A theory of meteors, and the density and temperature of the outer atmosphere to which it leads. *Proc. roy. Soc., London*, A, **102**, 1923, p.411.

The appearance of a large meteor is followed occasionally by sounds usually known as "detonations." The sounds are probably due to the waves created by the meteor making its way through the air, not to the explosive breaking up of the meteor. The sounds can be heard occasionally at a distance of 50 miles from any part of the visible path of the meteor. In some cases a zone of silence and an outer zone of audibility have been found.

To explain the breaking up of a meteor it has been suggested that the air pressure acting on a surface which is probably quite irregular causes the meteor to spin. The meteor is not strong enough to withstand the centrifugal force generated by very rapid rotation and therefore breaks into fragments.

The name meteor was originally used for any phenomenon occurring in the atmosphere. Thus the aqueous meteors included precipitation of all forms as well as clouds, mist, etc.; luminous meteors comprised aurora, rainbow, halos and mirages. Only within the last 100 years has the meaning become restricted to "shooting star."

**Meteorograph.**—A self-recording instrument which gives an automatic record of two or more of the ordinary meteorological elements. Of late the term has been more generally applied to the instruments that are attached to kites or small balloons and sent up to ascertain the pressure, temperature and humidity of the upper atmosphere. See BAROTHERMOGRAPH.

**Meteorology.**—The science of the atmosphere; from the Greek *μετεωρος*, lofty or elevated (*τα μετεωρα*, atmospheric phenomena) and *λογος*, discourse. Modern meteorology includes the study of the physical processes which occur in the atmosphere, and of the connected processes of the lithosphere and hydrosphere.

**Metre.**—The unit of length in the METRIC SYSTEM. It was intended to be equal to one forty-millionth of the Paris meridian, but errors entered into the calculation and it must now be considered as an arbitrary length. It is the distance, at the melting point of ice, between two lines engraved upon a platinum iridium bar kept in Paris and equals 1,553,164.1 wave-lengths of the Cadmium red ray in dry air at 15° C. (H scale) and 760 mm. pressure.

1 metre = 10 decimetres = 100 centimetres = 1,000 millimetres.

The Order in Council of 1898 defines the inch as 25.400 millimetres, from which it may be deduced that the metre is 39.370113 inches.

**Micro-**—A prefix meaning small from the Greek *μικρος*, for example, microbarograph, microseism. Micro is sometimes used in the sense of one millionth, for example, microfarad.

**Microbarograph.**—An instrument designed for recording small and rapid variations of atmospheric pressure. It consists of an air-tight reservoir of ample size containing air, and the difference of the external atmospheric pressure and the internal pressure in the reservoir is made to leave a record on a drum driven by clockwork. The reservoir is well protected from changes of temperature by a thick covering of felt or other non-conducting material, and it is also provided with a small leak, the magnitude of which can be adjusted. If the external pressure changes slowly the leak allows the internal pressure to follow it closely, but as the leak is small, the internal pressure cannot adjust itself rapidly to any sudden changes in the external pressure, and consequently a record of such changes is obtained.

**Microclimate.**—A modification of the general climate produced by the immediate environment. Thus while the climate of an area such as the county of Hertfordshire may be broadly described in general terms, important differences are found over relatively short distances, due to ground contours, geological factors, plant cover, etc. In general, valley bottoms experience a larger diurnal range of temperature than the adjacent hills, together with an intensification of phenomena such as frost and morning fog associated with nocturnal radiation. Important differences are also found between the climates of cities and those of adjacent rural districts. In ecological studies a distinction

is sometimes drawn between the "local climate" (i.e. the climate of the habitat) and the "microclimate" (i.e. the climate of the immediate surroundings of the subject of study). In agriculture the term "microclimate" has been applied to the meteorological conditions within the crop; for example, among the ears and stems in a cornfield.

**Microseisms.**—Seismographs are designed to record the tremors which pass through the ground from distant earthquakes but these instruments reveal also the fact that the ground is nearly always oscillating. The continuous oscillations are known as microseisms. The amplitude of microseismic disturbances is conveniently expressed in terms of the unit denoted by  $\mu$ ; this unit is the millionth part of a metre. In the British Isles the average amplitude of the microseismic oscillations recorded by a seismograph varies from about  $0.3\mu$  in July to about  $2.6\mu$  in January. The average period is about 6 seconds. The oscillations are always fluctuating, however. During one half minute the amplitude may increase; during the next half minute the oscillations die out as if there were interference between waves from different origins.

Microseisms are most vigorous at times when there are strong winds over not too distant seas. The theory put forward by the German seismologist, E. Wiechert, that microseisms are produced by the sea waves beating on steep rocky coasts is supported by some observations but is not accepted by all seismologists. An alternative explanation is that the variations in pressure on the surface of the sea set up the microseismic oscillations.

**Mile.**—The *statute mile* is defined as 1,760 yds. or 5,280 ft. The *geographical mile* is the length of an arc of one minute of latitude, and varies with latitude, being equal to  $(6076.8 - 31.1 \cos 2\phi)$  ft. or  $(1852.2 - 9.5 \cos 2\phi)$  m. in latitude  $\phi$ . The *nautical mile*, as used in hydrographic surveying is identical with the geographical mile, but in general practice the nautical mile is taken as 6,080 ft., the approximate value of the geographical mile in lat.  $50^\circ$ .

**Millibar.**—The thousandth part of a BAR, which is the meteorological unit of atmospheric pressure on the C.G.S. system. Since the bar is equal to a pressure of one megadyne per square centimetre, i.e. to 1,000,000 dynes per square centimetre, a millibar is equivalent to 1,000 dynes per square centimetre.\* The millibar has been in general use in the Meteorological Office since May 1, 1914. The principal advantage of using a unit of this type is that a statement of atmospheric pressure as a certain number of millibars is perfectly definite. According to the older practice a separate unit had to be used for length in reading the height of the mercury in the barometer, generally the inch or the millimetre, but this length is not a measure of the atmospheric pressure until the density of the mercury, the temperature of the scale and the value of gravity at the place are allowed for. The "millibar" on the other hand can only be used for pressure.

One thousand millibars are equivalent to the pressure of a column of mercury, 750.1 mm. (29.531 in.) high at  $0^\circ$  C. ( $273^\circ$  A.) in latitude  $45^\circ$ .

**Minimum.**—The lowest value reached by an element in a given period. See EXTREMES.

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\* It should be explained here that a megadyne is a measure of force. The dyne is the unit force of the C.G.S. system of units, and stands for the force which produces unit acceleration in one gram. As the force of gravity is the most familiarly known of all forces, we may say that the force of one dyne differs but little from the weight of a milligram, and a megadyne stands in the same relation to the weight of a kilogram. The precise numerical relation is dependent upon locality, because the weight of a body, that is, the force which gravity exerts on it, depends upon latitude and the distance from the earth's centre. At sea level, in latitude  $45^\circ$ , the gram weighs 980.6 dynes, the kilogram 0.9806 megadynes.

**Mirage.**—The term mirage is used for certain appearances produced by the refraction of light by the atmosphere; these appearances include the illusion of a sheet of water in the desert as well as cases in which definite distant objects can be seen in duplicate.

Over a heated desert the air very close to the ground is less dense than that above it so that the velocity of light is greatest close to the ground. Rays coming down from the sky at a gentle inclination may be bent up again to the observer, to whom the rays appear to come from a bright water surface. The banks, reeds, etc., are the images of various objects distorted by being viewed through layers of air of varying density so that a dark stone appears as though it were an upright stake. Hills situated a short distance away may appear as detached masses floating on this lake-like surface, their lower portions being invisible under the conditions prevailing. Mirages may often be seen over smooth road surfaces on calm hot days in England, especially over tarred roads.

These are all cases of inferior mirage. "Superior" mirage in which the light rays are bent downwards from a warm stratum of air resting on a colder is seen most frequently in polar regions. The distances involved are greater so that the details can hardly be observed without telescopic aid. With such assistance a distant ship may sometimes be seen in triplicate, one of the images being inverted. As the stratification which produces superior mirage is stable, the images are clear and well defined in contrast to the shimmering images of the inferior mirage.

The images produced by superior mirage are not always exactly in the same vertical. The separation is explained by a slight departure of the strata of equal density from horizontal planes. Lateral refraction of this kind is to be distinguished from the phenomenon which can be observed sometimes near a heated wall when objects appear to be reflected in the wall.

**Mist.**—See FOG.

**Mistral.**—A north-westerly or northerly wind which blows off-shore along the north coast of the Mediterranean from the Ebro to Genoa. In the region of its chief development its characteristics are its frequency, its strength, and dry coldness. It is most intense on the coasts of Languedoc and Provence especially in and off the Rhône delta. On the coast the speeds experienced are about 45 mi./hr. but in the Rhône valley over 85 mi./hr. has been reached.

**Mock Moon.**—See PARASELENÆ.

**Mock Sun.**—See PARHELION.

**Mock Sun Ring or Parhelic Circle.**—The circle passing through the sun parallel to the horizon. The whole of this circle may be bright but colourless. The phenomenon is explained by the presence of ice crystals with vertical facets from which the light is reflected. See HALO PHENOMENA.

**Mode.**—In a series of values, the value of most frequent occurrence. An approximate rule, when there is only one mode, is

$$\text{mode} = \text{median} - 3(\text{mean} - \text{median}).$$

**Monsoon.**—The name is derived from an Arabic word for "season," and originally referred to the winds of the Arabian sea, which blow for about six months from the NE., and six months from the SW. It has been extended to include certain other winds which blow with great persistence and regularity at definite seasons of the year. The primary cause of these winds is the seasonal difference of temperature between land and sea areas. The winds are analogous to land and sea breezes, but their period is a year, instead of a day, and they blow over vast areas, instead of over a limited region.

Near the equator the seasonal changes of temperature are in general too small to cause the development of monsoons; in the higher latitudes of the prevailing westerlies and in the polar regions the wind components due to contrast of temperature between land and sea are at most sufficient only to modify slightly the "planetary" wind circulation, so that the regions most favourable to the development of monsoon conditions are in middle latitudes, near the tropics.

The moisture content (determined by the length of sea track pursued) of the landward-blowing winds and the topography of the land on to which the moisture-carrying winds blow have great influence on the amount of rainfall associated with the landward monsoon. Owing to a suitable combination of the various factors monsoon conditions reach their greatest development over eastern and southern Asia, in most of which regions a rainy summer monsoon from the SW. is the outstanding feature of the climate. In the countries of its occurrence the term "the monsoon" is popularly used to denote the rains, without reference to the winds.

Monsoon conditions occur also, but to a much less extent in north Australia, parts of western, southern and eastern Africa, and parts of North America and Chile.

**Month.**—See LUNAR, CALENDAR.

**Moon.**—The only satellite revolving round the earth. Its *sidereal* period of revolution (i.e. with respect to the so-called "fixed" stars) averages about  $27\frac{1}{4}$  days, but varies as much as three hours from this value on account of the eccentricity of its orbit, and its "perturbations." The *synodic* period of revolution (i.e. the interval from new moon to new moon) has a mean value of about 29·53 days, but varies about 13 hours on account of the eccentricities of the orbits of the moon and the earth.

The brilliance of the moon is due solely to sunlight falling upon it. The fallacy that the moon's rays are injurious to plants arises from the fact that nights of ground frost are clear nights, on which the moon will be visible if suitably placed.

**Moon, Phases of.**—The appearance of the moon, by custom restricted to the particular phases of *new moon* when nothing is visible, *first quarter* when a semicircle is visible with the bow on the west, *full moon* when a full circle is visible, and *last quarter* when a semicircle is visible with the bow on the east. The changes of phase are due to the changes in relative position of earth, moon and sun. The moon rotates on its axis once in each orbital revolution, and so the same face of the moon is always turned towards the earth. The popular belief in the association of weather changes with the phases of the moon is not confirmed by meteorological investigations, though S. Chapman\* has shown that there is a very minute lunar tide in the atmosphere, giving a variation of pressure of only a small fraction of a millibar.

**Mother of Pearl Clouds.**—These were first noted and so named by Mohn; they were seen by Störmer in 1890 and seen and photographed in Scandinavia in 1932. Their somewhat rare appearances have been during winter months on occasions when an extensive and deep depression lies over northern Scandinavia. The clouds are somewhat lenticular in form, very delicate in structure, and show very brilliant irisation at angular distances up to  $40^\circ$  from the sun's position. The colouring endures for some considerable time after sunset. The mean height of these clouds according to Störmer's calculations is 24 Km. and thus they lie well within the stratosphere; the diameter of the cloud particles has been computed as not exceeding 0·0025 mm.

**Mountain Breeze.**—A breeze which blows at night down valleys and mountain slopes. At night the mountain slopes become cooled by radiation, the air in contact with them is also cooled and its consequent increase in density causes it to flow downwards. See KATABATIC.

**Nephoscope.**—An instrument for determining the direction of motion of a cloud and its angular velocity about a point on the ground vertically below it. The types most commonly employed are the Fineman reflecting nephoscope and the Besson comb nephoscope, descriptions of which will be found in the "Observer's Handbook." A camera obscura arranged to project a view of the clouds near the zenith on to a graduated board may be used as a nephoscope.

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\* London, *Proc. roy. Soc.*, A 151, 1935, pp. 105–17.

**Neutral Point.**—See POLARIZATION.

**Night Sky, Light of.**—See AURORA PERMANENT.

**Nimbostratus (Ns.).**—*A low, amorphous and rainy layer, of a dark grey colour and nearly uniform; feebly illuminated seemingly from inside. When it gives precipitation it is in the form of continuous rain or snow.*

*But precipitation alone is not a sufficient criterion to distinguish the cloud which should be called nimbostratus even when no rain or snow falls from it.*

*There is often precipitation which does not reach the ground; in this case the base of the cloud is always diffuse and looks "wet" on account of the general trailing precipitation, virga, so that it is not possible to determine the limit of its lower surface.*

**Nimbus (Nb.).**—A term formerly used for a dense layer of dark shapeless cloud with ragged edges from which steady rain or snow usually falls. In 1933 this name was combined with other names of clouds, e.g. nimbostratus, fractonimbus and is now no longer used alone.

**Noctilucent Clouds.**—These have been seen several times in both hemispheres and always in the summer months at the place of observation and during the midnight hours. They appear most frequently just after the solstices. In appearance they resemble cirrus but have a bluish-white to yellowish colour. Photogrammetric measurements assign to them a mean height of 82 Km. They usually move from north-east with velocities of from 100 to 300 miles per hour, but may also move from other directions at lower speeds. Nothing is known as to their composition.

**Normal.**—The name given to the average value over a period of years of any meteorological element such as pressure, temperature, rainfall or duration of sunshine. Owing to the fact that the average of any finite number of observations of a variable quantity is subject to a "standard error" depending upon the variability of the observations, it follows that the normals available to meteorologists must be subject to uncertainty. The uncertainty can be reduced by increasing the number of observations, and it is an advantage therefore to use as long a period as possible in calculating meteorological normals, provided the observations are known to be homogeneous. The degree of uncertainty associated with averages for relatively short periods may be illustrated by the following data for Oxford (Radcliffe Observatory).

Period	January	February	March	April	May	June	July	August	September	October	November	December	Year
(a) Rainfall (in.)													
10 years, 1921–30 ..	2.55	1.90	1.28	1.97	1.90	1.36	2.50	2.41	2.36	2.40	2.89	2.69	26.21
35 " 1881–1915	1.81	1.64	1.65	1.60	1.87	2.24	2.37	2.28	1.71	2.89	2.30	2.46	24.82
30 " 1901–30 ..	2.16	1.71	1.88	1.93	1.98	2.03	2.52	2.34	1.86	2.74	2.28	2.78	26.21
121 " 1815–1935	1.97	1.63	1.59	1.78	1.94	2.17	2.45	2.38	2.39	2.73	2.30	2.20	25.53
(b) Temperature( ° F.)													
10 " 1921–30 ..	40.7	39.7	42.7	46.0	52.9	57.7	62.2	60.1	56.4	50.2	42.5	40.3	49.3
35 " 1881–1915	38.4	39.7	42.1	47.0	52.8	58.5	61.9	60.9	56.6	49.4	43.5	39.9	49.2
30 " 1901–30 ..	40.0	40.2	42.9	46.8	53.7	57.9	61.8	60.8	56.7	50.5	43.1	40.7	49.6
121 " 1815–1935	38.4	39.5	41.9	46.5	52.6	58.5	61.3	60.5	56.1	49.5	43.1	39.9	49.0

In practice it is difficult to maintain complete uniformity in the conditions of observation over long periods. Also, it is clearly desirable for purposes of comparing the climates of different places that the adopted normals should refer to similar periods. For these reasons it is the practice to select a standard period for the computation of normals for routine use, notwithstanding the fact that at certain stations the observations have extended over longer



periods. In the British Isles the present standard period for rainfall normals is the 35 years 1881–1915. For sunshine and temperature, normals are calculated for 30-year periods and are revised every five years. The period 1901–30 was adopted by the International Meteorological Organization at Warsaw in 1935 as a standard period for climatological normals.

Charts of the normal distribution of various climatic elements are available for many areas in the form of climatological atlases. For the British Isles monthly and annual charts of pressure, wind, temperature, rainfall, snow, thunder, sunshine, fog and cloud are given in the "Climatological atlas of the British Isles" (London, H.M.S.O., 1952). World charts for various elements are included in Shaw and Austin's "Manual of Meteorology" Vol. II, Cambridge, 1936.

**Normal Law (of Errors).**—When the error to which an observation is subject may be regarded as made up of a large number of small independent errors, each as likely to be positive as negative, it can be shown that the probability that one observation should yield a result having an error between  $x$  and  $x + dx$  is

$$\frac{h}{\sqrt{\pi}} e^{-h^2 x^2} dx.$$

where  $h$  is a parameter. If a large number  $n$  of observations be made we should therefore expect a number

$$\frac{nh}{\sqrt{\pi}} e^{-h^2 x^2} dx.$$

to lie between the limits  $x$  and  $x + dx$ . The observations are then said to satisfy the "normal law of errors." It will be noted that the FREQUENCY is the same for  $+x$  as for  $-x$ , so that the frequency curve is symmetrical about the axis of  $y$ . Many proofs of the normal law are to be found in text books on "least squares," but no proof is altogether satisfactory. Further it must be noted that distributions of observations are frequently met, especially in biological and allied sciences, which are not symmetrical.

The parameter  $h$  is related to the STANDARD DEVIATION  $\sigma$  by  $h\sigma = .7071$ .

**Norte, Norther.**—A strong, cold, northerly wind which blows mainly in winter on the shores of the Gulf of Mexico. Here it is sometimes humid and accompanied by precipitation. The northers reach the Gulf of Tehuantepec as cold, dry winds, where they often set in suddenly and quickly raise a heavy sea.

**Observer.**—In meteorology, a person who undertakes, in co-operation with others at a réseau of stations, to make regular and simultaneous records of the weather upon an organised plan. Good observing requires punctuality and accuracy, and therefore skill in reading and setting instruments, and intelligence in noting occurrences which are worth recording, though they are not in the prescribed routine. The best observer is one who is personally interested in scientific work on a co-operative basis.

**Occlusion.**—A newly developed DEPRESSION has in accordance with the Bjerknes theory a WARM SECTOR running out from the centre which contains warm or tropical air, the rest of the depression at the earth's surface being occupied by cold or polar air. The front of the warm sector is the WARM FRONT of the depression while the back of it is the COLD FRONT, these fronts marking the chief regions of cloud and rain in the depression. Owing chiefly to the inertia of the cold air ahead of the WARM FRONT the cold front closes on the warm front. The warm sector is then reduced to a line called the line of occlusion and subsequently is lifted from the surface of the earth. It is still present, however, in the upper layers and the cloud and rain associated with the fronts are therefore to be found along a line of occlusion for some time

after the warm air has left the earth's surface. There is also often a difference between the two cold air masses which enables the occlusion to persist as a front. The majority of depressions which reach Europe from the Atlantic are occluded by the time they reach the seaboard, and lines of occlusion are thus much more frequent upon European weather charts than warm and cold fronts.

**Ocean Current.**—See CURRENT, OCEAN.

**Okta.**—Unit, equal to area of one eighth of the sky, used in specifying cloud amount.

**Ombrometer.**—Another name for RAIN-GAUGE.

**Optical Phenomena.**—The optical phenomena of interest to meteorologists are numerous. They include the BLUE OF THE SKY, SUNRISE AND SUNSET COLOURS, the production of RAINBOWS, CORONAE and HALOS, the fading of daylight and the twinkling of the stars. These matters are very fully dealt with in the great treatise of the Austrian meteorologist Pernter, the second edition of which was prepared by his pupil and collaborator F. M. Exner.\* The best account in English is to be found in Humphreys's "Physics of the Air."†

**Orientation.**—From *Oriens* (Lat.), the rising of the sun—the east. The direction of an object referred to the points of the compass.

**Orographic Rain.**—Rain caused by the interference of rising land in the path of moisture-laden wind. A horizontal air current striking a mountain slope is deflected upwards, and the consequent dynamical cooling associated with the expansion of the air produces rain if the air contains sufficient aqueous vapour. Mountain ranges at right angles to the direction of the wind offer greater obstruction to the wind and therefore are more likely to produce rain than mountain ranges which lie in the direction of the wind. In the case of isolated mountain peaks, the wind is often able to go round and the amount of rain produced may be trifling. The prevailing wind of these Islands is from the SW. and as this damp wind passes across the country the aqueous content decreases. A mountain range of a given height along the west coast would therefore produce a greater rainfall than a range of similar height and position relative to the wind in the east. Orographic rains are typically persistent and usually widespread. Their great importance lies in the fact that the main controlling factor, the rising ground, is always operative, and naturally, always in the same place. Thus a station on a hill is not only usually wetter year by year than a neighbouring station in a valley, but the proportion remains fairly constant. Some valleys, if they are surrounded by mountains on all sides, receive nearly as large a rainfall as the surrounding mountains since air is generally rising as it passes over these valleys. See CONVECTIONAL RAIN, CYCLONIC RAIN.

**Oscillation.**—A periodic movement to and fro, or up and down, or a periodic variation of a quantity above and below its mean value. The simplest dynamical illustration is the simple pendulum, which swings first to one side of the vertical then to the other. The term oscillation is used in meteorology in connexion with a wide variety of phenomena, such as the diurnal variation of pressure, the annual variation of temperature, the gusts and lulls of wind, etc.

**Overcast Day.**—Since January 1, 1949 defined in Great Britain as a day on which the average CLOUDINESS at the hours of observation is more than 6 OKTAS of the sky. Before 1949 it was defined as a day on which the average CLOUDINESS at the hours of observation was more than 8 tenths of the sky‡.

\* Pernter, J. M., and Exner F. M. "Meteorologische Optik." Wien and Leipzig, 1922.

† 3rd Edition, New York, 1940.

‡ Codex of Resolutions adopted at International Meteorological Meetings, 1872–1907 London, 1909.

**Ozone.**—An allotropic form of oxygen for which the chemical symbol is  $O_3$ . It is produced by passing electrical sparks through oxygen or by the action of cathode or ultra-violet rays. The amount of ozone in the atmosphere is best determined by spectroscopic observations, as ozone absorbs ultra-violet light of certain wave-lengths. By this test it can be shown that there is very little ozone in the atmosphere near the ground. There is, however, a region in the upper atmosphere where ozone is comparatively plentiful.\* The quantity of ozone can be determined by the analysis of sunlight, and is found to be such that if it could be brought down to the ground it would form a layer about 3 mm. thick. The most reliable method of determining the height at which the ozone occurs is by examination of the ultra-violet light from the zenith sky at different times of day. The bottom of the region in which ozone occurs is about 20 Km. above the ground. The amount shows considerable variations. The zone absorbs ultra-violet light coming from the sun and it is believed that the energy derived from this ultra-violet light maintains a very high temperature in the upper atmosphere. See METEORS and AUDIBILITY.

**Ozone, Measurement of.**—Measurements of absorption by ozone have been made by means of a spectrograph incorporating a quartz Féry prism and an optical wedge, scattered light of wave-lengths outside the region used being absorbed by a mixture of the chlorine and bromine vapour†. An instrument employing a photo-electric cell and amplifier has also been designed, by which a direct comparison of the intensity of two wave-lengths in sunlight or in skylight can be made.‡

**Pack Ice.**—Sea ice which has drifted from its original position. It is termed "close pack" if the floes are mainly in contact and "open pack" if the floes for the most part do not touch.

**Pallium.**—Occasionally used in the past for NIMBOSTRATUS.

**Pampero.**—A name given in the Argentine and Uruguay to a severe storm of wind, sometimes accompanied by rain, thunder and lightning. It is a LINE-SQUALL, with the typical arched cloud along its front. It heralds a cool south-westerly wind in the rear of a DEPRESSION; there is a great drop of temperature as the storm passes.

**Parallax** is an apparent change in the position of an object caused by a change in the position of the observer. In connexion with the reading of meteorological instruments an *error of parallax* may arise whenever the indicator of the instrument (e.g. end of column of mercury or water, pointer, etc.), and the scale against which the indicator is to be read are at a distance from one another which is comparable with the length of the smallest readable scale division; for in such a case a movement of the observer's head may cause his line of vision to the indicator, to intersect the scale at different points and so give rise to different readings. The error is eliminated by ensuring that the line of vision to the indicator is at right angles to the scale when the reading is made.

Parallax is unfortunately almost universal among meteorological instruments. Thus the distance of the scale of the ordinary Kew-pattern barometer from the top of the mercury meniscus is about half an inch, and as an accuracy of .001 in. in the scale reading is usually required, the error of parallax may in this case be very serious. Barometers are, however, designed to ensure that errors of parallax can be completely eliminated when reading. An error of parallax of  $\frac{1}{2}^\circ$  F. may easily be made in reading a thermometer in a Stevenson screen; to avoid such errors, care must be taken to see that imaginary lines drawn towards the observer at right angles to the scale at all points, at which readings may be taken, are not obstructed by part of

\* *London, Quart. J.R. met. Soc.*, 51, 1925, p. 367 and *London, Proc. roy. Soc.*, 120, 1928, p. 255.

† *London, Quart. J.R. met. Soc.*, 51, 1925, p. 367 and *London, Proc. roy. Soc.*, 110, 1926, pp. 660–93, and 120, 1928, p. 255.

‡ *London, Proc. Phys. Soc.*, 43, 1931, pp. 324–39.

the screen itself, or by other thermometers placed in the screen. Errors of parallax in reading a rain measure are also important, and they occur whenever an observer places his eye either above or below the level of the water surface in the rain measure.

**Parameter.**—A quantity related to one or more variables in such a way that it remains constant for any specified set of values of the variable or variables, e.g. in STATISTICS, MEAN, STANDARD DEVIATION.

**Paranthelia.**—A mock sun at the same elevation as the sun and in an azimuth greater than  $90^\circ$  from the sun may be called a paranthelion. White paranthelia at  $120^\circ$  from the sun are fairly common. Paranthelia at about  $140^\circ$  from the sun have been recorded on rare occasions.

**Paraselenae** or mock moons, analogous to mock suns, have been observed occasionally. No measurements are available but it may be presumed that mock moons will be at the same elevation as the moon and that the angular distance will vary like that between sun and mock sun, being  $22^\circ$  when the luminary is on the horizon and  $25^\circ$  when the luminary is at an elevation of  $30^\circ$ .

**Parhelia.**—Images of the sun, coloured or white. The mock suns seen most frequently are at the same elevation as the sun and coloured with red nearest the sun. When the sun is near the horizon the distance is equal to the radius of the ordinary halo, i.e.  $22^\circ$ . When the sun is higher the distance is greater so that if halo and mock sun are both seen the mock sun is outside the halo. White mock suns are to be seen in the azimuth  $120^\circ$  from the sun. Bright patches seen at the top and bottom of the halo of  $22^\circ$  at the points of contact of the tangent arcs, are sometimes referred to as mock suns.

**Pentad.**—A period of five days. Five-day means are frequently used in meteorological work, as five days form an exact sub division ( $\frac{1}{3}$ rd) of the ordinary year, an advantage not possessed by the week.

**Percolation.**—The downward passage of surface water through the soil. Part of the rain which falls on the land surface re-evaporates, part runs off into streams and rivers to the sea, while part percolates through the soil. Measurements of the amount of rain water which percolates through certain depths of soil have been published in the annual volumes of *British Rainfall*. Usually the gauge consists of a cubic yard of natural earth inserted in a metal container and sunk in the hole formed by removing this earth. The rain water which percolates through is drained off and measured daily at 9h., access to the receiver being obtained by means of a trap door at the side of the gauge. The results are usually published as a depth in hundredths or thousandths of an inch of water. See EVAPORATION.

**Periodical.**—Recurring at regular intervals, like the position of the bob of a simple pendulum. The most obvious periodical variations in the atmosphere are associated with the alternation of night and day, and the alternation of winter and summer, corresponding respectively with the day and the year. Strictly speaking a variation is not to be called periodical unless the interval between successive maxima and successive minima is constant, and so the sunspot variation should not strictly be described as periodical, since the interval between successive maxima or minima varies from about 8 years to about 16 years.

**Periodicity.**—A periodical variation. A vast amount of labour has been devoted by meteorologists to the search for periodical variations other than those whose periods are the day or the year, by the use, at some stage or other of the work, of the methods of HARMONIC ANALYSIS. It is thus implied that a periodicity as normally treated, shall be at least approximately of the nature of a harmonic oscillation, capable of being represented by a simple sine curve. A periodicity requires for its complete determination the length

of the period, the amplitude (i.e. half the total range) of the variation, and the time of occurrence of the maximum. If a periodicity is to be of value in forecasting, the square of its amplitude must be an appreciable fraction of the square of the STANDARD DEVIATION of the original observations.

**Periodogram.**—A diagram used in a method devised by Schuster for the investigation of hidden periodicities. In meteorological phenomena, the variations from day to day or from month to month are so irregular that usually the existence of any period other than the yearly one is masked. Schuster's method of finding the lengths and amplitudes of periods which are thus masked by apparently casual variations consists in taking different trial periods  $T$ , and evaluating the amplitude  $R$  for each trial period. A graph is drawn with  $R^2$  as ordinate and  $T$  as abscissa. Usually the diagram thus obtained shows a number of peaks which stand out above the general level of the curve. The values of  $T$  corresponding with these peaks are taken to be the most likely periods. There is no special advantage in graphing  $R^2$  and  $T$  rather than  $R$  and  $T$ , since the same peaks stand out in the graph of  $R$  and  $T$ . If the original  $n$  observations formed a random distribution, with standard deviation  $\sigma$ , the expectation (or mean value) of  $R^2$  would be  $4\sigma^2/(n-1)$ . Schuster has shown that the probability that any particular value of  $R^2$  should exceed  $K$  times  $4\sigma^2/(n-1)$  is  $e^{-K}$ . This expression is frequently used to test the reality of periods revealed by the periodogram, but the process requires considerable care.

**Persistence.**—In meteorology, the tendency for abnormal conditions of the same type to continue over a longer period than usual; thus we speak of a persistent anticyclone. E. V. Newnham\* has shown that the tendency for the persistence of wet or fine weather increases with the length of the period through which similar conditions have already persisted. Thus at Greenwich after one day without rain, the probability that the next day will be rainless is .57, but after ten successive fine days, the probability has risen to .80. Similarly, after one rain-day, the probability of a rain-day is .59, but after ten successive rain-days it is .70.

**Personal Equation.**—An expression used to denote the correction which might or should be applied to an observer's readings of an instrument, in consequence of an unconscious tendency on his part to read too high or too low. The tendency is usually nearly constant for any given observer reading a given instrument. A familiar example is that of reading the rain-measure. The observer is directed to hold the measure so that the meniscus is level with the eye, but it is difficult for an observer to judge when this condition is correctly secured. Some observers hold the glass always too high, resulting in readings which are too low, others possess the opposite tendency.

**Phenology.**—The study of the sequence of seasonal changes in nature. All natural phenomena are included, seed-time, harvest, flowering, ripening, migration, and so on, but often in practice the observations are limited to the time at which certain trees and flowering plants come into leaf and flower each year, and to the dates of the first and last appearances of birds and insects.

A "bioclimatic law" has been proposed by Dr. Andrew Hopkins of the United States Weather Bureau. It was determined from phenological observations made in the eastern United States, and states that a progression or regression (according to season) of plant life occurs there, which is at the rate of four days for each degree in latitude or five degrees of longitude, or for 400 ft. of altitude. The law appears to hold approximately for the British Isles in so far as changes of latitude and altitude are concerned.

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\* "The persistence of wet and dry weather." *London, Quart. J.R. met. Soc.*, 42, 1916, p. 153.

**Phenomenon.**—"That of which the mind or senses directly takes note." The word is generally used in meteorology, however, to denote either (1) an unusual intensity of some occurrence, e.g. "ugly" sky, high rainfall, low temperature, high pressure, gale; or (2) occurrences which are only occasionally noted, e.g. thunder, halo, fog, glazed frost.

**Phosphorescence.**—The phosphorescence of the sea is one of the most remarkable of natural phenomena and various explanations of it have been attempted in the past. One theory held that sea water absorbed sunlight by day and emitted it by night. In 1749–50, however, a small animalcule giving a blue light was discovered by Vianuelli and Guixellani in the Mediterranean and subsequent investigation has shown that animal life is the origin of marine phosphorescence. Light production is due to a great variety of organisms, from microscopic ones up to many forms of deep sea fish, and the peculiarity of the light is that it is generated without heat, a process never yet achieved in the laboratory. Different types of light have been analysed and the colour is also found to vary through white, silver, green blue and lilac to red. The method of production has been shown to be some form of slow oxidation which is entirely automatic in the lower forms of life but is in some measure under control in the higher forms. Recent research has shown that while phosphorescence may occur anywhere it is most frequent in the warmer tropical seas and in particular in the Arabian Sea, where it exhibits a definite maximum in August. In the North Atlantic ocean some regions show summer maxima, while others have spring maxima. It also appears that phosphorescence is more frequent in coastal regions than in mid-ocean. One remarkable type of phosphorescence is the diffused "milky sea" which may give light enough to read by and to illuminate clouds. This type has often been reported as exerting a calming effect upon the sea surface. More elaborate phenomena occur which have not yet been satisfactorily explained, such as phosphorescent bands and the great rotating phosphorescent wheels.

**Photographs, Meteorological.**—Whenever unusual meteorological phenomena occur an attempt should be made to photograph them, if possible. Notes accompanying photographs should give the date, time and geographical position of the occurrence of the phenomenon, the direction from which the photograph is taken, and the weather conditions prevailing at the time and the relative sizes of the photograph and the original or the focal length of the lens.

For photographing clouds, Cave\* finds that panchromatic plates and colour screens give the most satisfactory results; he advises a moderately deep yellow screen for all clouds except cirrus, and for cirrus a red screen. For persons unfamiliar with panchromatic plates and colour screens, Clarke† recommends very slow plates and hydroquinone developer.

**Pilot Balloon.**—A small free rubber balloon, filled with hydrogen for obtaining the direction and velocity of the upper wind. The balloons commonly employed have circumferences 40, 70, 90 and 150 in. when fully inflated, and are usually specified by reference to these circumferences. They are normally filled with hydrogen so as to have a known theoretical rate of ascent, based upon the following formula:—

$$V = q L^{\frac{1}{2}} / (L + W)^{\frac{1}{2}}$$

where  $V$  is the upward velocity,  $W$  the weight of the balloon (and any attachment), and  $L$  the free lift. If  $L$  and  $W$  are expressed in grams and  $V$  in feet per minute,  $q$  is about 275. If  $V$  is in metres per minute the value of  $q$  is 84 (83·8). Assuming a known rate of ascent, the balloon may be kept in sight by means of a single theodolite of special construction, and the direction and velocity of the wind in the interval between two readings of

\* The forms of clouds. *London, Quart. J.R. met. Soc.*, 43, 1917, pp. 61–82.

† Instructions for the taking of photographs of clouds. Paris, Commission Internationale des Nuages et Office National Météorologique de France.

the theodolite computed, using either graphical methods or a special pilot-balloon slide-rule. At high altitudes owing to the balloon developing minute holes and becoming porous, the balloon no longer rises at the assumed rate and errors occur in this method of observation.

A more accurate method of observation involves the use of two theodolites, one at each end of a measured base line, and the attendance of several observers. By observing the balloon through the two theodolites the actual height of the balloon can be calculated in addition to other factors. A third method of observation is to attach a tail of known length to the balloon, and measure the angle subtended between the end of the tail and the centre of the balloon, by means of a graticule or divided scale in the eye-piece of the theodolite. This method is useful, but occasionally a swinging tail is apt to lead to incorrect values. For use at night an ordinary balloon is employed with a light attached. Commonly, the light consists of a small Chinese lantern, but in some countries an electric bulb lit by a small dry battery is used.

**Pitot Tube.**—An instrument for determining the velocity of a stream of fluid by measuring the increase of pressure above the “static” or undisturbed pressure, in an open tube facing the stream. The velocity is computed from the relationship  $p = \frac{1}{2} \rho v^2$  (where  $p$  is pressure,  $\rho$  density and  $v$  velocity). Suitably mounted, a pitot tube may be used as an ANEMOMETER.

**Pleion.**—A term introduced by H. Arctowski to signify an area over which some meteorological element, for example, temperature, is above normal. Areas where the element is below normal are termed antipleions. Arctowski drew his pleions by constructing overlapping twelve-monthly departures from average, and he found a tendency for the pleions and antipleions obtained in this way to persist for a considerable time, moving slowly across the country.

**Pluviograph.**—A self-recording RAIN-GAUGE; the rise of the water in the gauge is recorded by means of a pen attached to a float. Some form of device by which the gauge automatically empties itself when the water reaches a certain height is often employed. See HYETOGRAPH.

**Pluviometer.**—A RAIN-GAUGE.

**Pocky Clouds.**—See MAMMATUS.

**Polar Air.**—Air originating in high latitudes. Air which arrives directly from the ice-bound areas of the arctic is now usually known as ARCTIC AIR. Polar air in present-day synoptic meteorology has usually an adjective attached to it, most frequently “maritime,” occasionally “continental.” Polar maritime air is often (in winter usually) of arctic origin, but it may have originated over cold parts of the oceans, and its general feature (so far as the British Isles are concerned) is that the surface layers have gained heat from those parts of the Atlantic which are kept warm by the Gulf Stream. Its surface temperature is generally below that of the sea, and its LAPSE-RATE of temperature is high at least for some thousands of feet. In both arctic and polar maritime air INSTABILITY SHOWERS are frequent, and there is sometimes thunder (chiefly near the coasts in winter and over land in summer), but this requires cold air to an adequate height, which exists most frequently in depressions, at a sufficient distance from the warm sector (if any). Polar air has a marked tendency to subside and this results in stability, except sometimes in the lowest few thousand feet. See SUBSIDENCE, AIR MASS.

Sometimes polar maritime air travels far to south and then returns, and so begins to lose heat at the surface. This is the only type of polar air which has a high dew point.

Polar continental air is very cold in the winter, but in summer it gives sunny and comparatively warm weather.

Currents consisting of polar air are called polar currents.

**Polar Front.**—The line of discontinuity, which is developed in suitable conditions between air originating in polar regions and air from low latitudes, on which the majority of the DEPRESSIONS of temperate latitudes develop. It can sometimes be traced as a continuous wavy line thousands of miles in length, but it is interrupted when polar air breaks through to feed the trade winds, and is often replaced by a very complex series of FRONTS, or by continuous gradients of temperature.

**Polarimeter.**—A polariscope provided with circles or other equipment for making quantitative observations upon the state of polarization.

**Polarization.**—Waves may be made to run along a taut rope by shaking one end. The wave motion may be confined to one plane ; or it may be chiefly in one plane ; or it may take place equally in all directions round the rope. Similarly, the waves which run along a ray of light must belong to one of these classes and the ray is accordingly said to be completely polarized, partially polarized or unpolarized as the case may be. The plane of polarization is defined as the plane in which the wave motion is a minimum, or, in terms of the electromagnetic theory of light, the plane in which the electric vector is a minimum.

Light reflected from the surface of water or glass is (in general) partially polarized in the plane containing the incident and reflected parts of the ray. That is to say, the excess motion occurs parallel to the surface of the water or the glass. Light coming from the blue sky is also partially polarized. This discovery was made by Arago in 1809. The polarization is most marked in the light which comes from a region in the solar vertical at  $90^\circ$  from the sun. In this case some two-thirds of the wave motion is confined to the plane containing the sun, the observed point and the observer ; or, in terms of the electromagnetic theory, the electric vector in the wave front is at right angles to this plane. In or near to the solar vertical are three neutral points, or small regions, the light from which is unpolarized. They are named after Arago, Babinet, and Brewster, and their approximate positions are respectively,  $160^\circ$  from the sun (i.e.  $20^\circ$  above the anti-solar point),  $20^\circ$  above and  $20^\circ$  below the sun. So-called neutral lines pass through points in which the plane of polarization is inclined at  $45^\circ$  to the vertical and also through the neutral points mentioned. When the sun's altitude exceeds  $20^\circ$  the plane of polarization of light received from regions (excluding the vicinity of neutral points) not within  $30^\circ$  of the sun does not usually differ greatly from the plane containing the sun, observer and observed point. The degree of polarization and the position of the neutral points depend on the sun's altitude, on the wave-length of the light examined, on the degree of turbidity of the atmosphere, and in consequence of the last factor, on the weather conditions. Factors promoting an increase of the amount of light reflected through the atmosphere (e.g. a layer of snow on the ground) decrease the percentage of polarization. Light from the clear sky at night is only very feebly polarized.

The phenomena of polarization of sky light are to be attributed to the scattering of light. It was demonstrated theoretically by Rayleigh (third Baron) that the light scattered, by air molecules or other particles small in comparison with the wave-length of light, in a direction perpendicular to the sun's rays should be completely polarized in a plane containing the incident and scattered rays ; polarization should be less complete in other directions and non-existent in either direction along the incident rays. Rayleigh (fourth Baron) and others have shown experimentally that polarized light is scattered from a beam of ordinary light traversing dust-free air ; polarization is in the sense indicated by theory and is a maximum, about 96 per cent., in a direction perpendicular to the primary beam. Although theory and experiment thus account satisfactorily for the orientation of the plane of polarization of the sky light, they fail to explain the degree of the polarization, which is found to be much less than we should expect. Moreover, the occurrence of neutral points and other phenomena remains unaccounted



for. A point of the sky is illuminated not only by the sun but also by light from other parts of the sky. According to Soret, Ahlgrimm, and others, the light due to secondary scattering by the air molecules and small suspended particles is partly unpolarized and partly polarized in the horizontal plane, i.e., perpendicularly to the polarization due to primary scattering. This theory, which is not universally accepted, indicates why there is incomplete polarization even in the skylight received perpendicularly to the sun's rays; and also that the two polarization effects cancel to produce unpolarized light at certain points, the neutral points, on the sun's vertical.

**Pollution.**—See ATMOSPHERIC POLLUTION.

**Polymeter (Lambrecht's).**—An instrument combining a thermometer and a direct reading hair hygrometer. The hairs, which hang vertically, operate a pointer which indicates directly the relative humidity and the depression of the dew-point below the air temperature. The thermometer gives the air temperature and the dew-point can thus be readily ascertained from the readings of the two instruments.

**Ponente.**—A westerly wind which blows in the Mediterranean.

**Poorga (Purga).**—See BURAN.

**Potential** as applied to energy indicates the ENERGY which is due to the position of a body. In considering the total amount of energy available in any case we must consider not only the position but the quantity of working substance that is collected there. If we wish to consider the influence of the position alone we must limit our ideas to a particular amount of the working substance. We naturally choose the unit measure as the amount for this purpose, and the potential energy of unit quantity is called the *potential at the point*. Thus, the electrical potential at any point in the atmosphere is the amount of energy which one unit of electricity possesses in virtue of its position at the point. Similarly, the gravitational potential or GEOPOTENTIAL at any point above the earth's surface is the potential energy of a unit quantity of material, a gram or a pound, placed there.

**Potential Temperature.**—The temperature which a specimen of air would acquire if it were brought to standard pressure under ADIABATIC conditions. If the absolute temperature and the pressure of the air be  $T$  and  $p$  respectively and the standard pressure be  $P$ , the potential temperature  $\theta$  is given by the relation

$$\theta = T \left( \frac{P}{p} \right)^{0.29}$$

Potential temperature is related to the entropy  $\phi$  by the relation :—

$$\phi = c_p \log_e \theta + \text{constant}$$

where  $c_p$  is the specific heat at constant pressure.

**Precipitable Water.**—Precipitable water is a term defining the quantity of water vapour in a section of either the total atmospheric shell or an outer section of that shell. It is the depth of water that would be obtained if all the water vapour in a vertical column of 1 sq. cm. cross section were condensed on to a horizontal plane of area 1 sq. cm., placed at the lower limit of the section of atmosphere in question. Simpson (*London, Mem. R. met. Soc.*, 3, No. 21, 1928) has used the term in connexion with the amount of water vapour in the stratosphere, basing his calculations on the expression: precipitable water  $m$  (in millimetres) equals  $1,000 p/g$  where  $p$  is pressure in millibars of saturated water vapour at the temperature of the base of the stratosphere,

**Precipitation.**—Used in meteorology to denote any aqueous deposit, in liquid or solid form, derived from the atmosphere. Thus the figure representing the precipitation at a given station during a given period includes not only the RAINFALL, but also DEW and the water equivalent of any solid deposits (SNOW, HAIL or HOAR-FROST) received in the RAIN-GAUGE. This aggregate figure appears in British statistical publications under the single heading RAINFALL.

**Pressure.**—Pressure is the force per unit area exerted against a surface by the liquid or gas in contact with it, and since the force on a unit area of a surface at any particular point in a fluid is independent of the orientation of the unit surface in the fluid, it follows that no specification of direction is necessary in speaking of the pressure at any given point in the fluid. The pressure of the atmosphere which is measured by the barometer, is produced by the weight of the overlying air. The pressure exerted by the wind is very small in comparison with that of the atmosphere; a wind of force 6 on the BEAUFORT SCALE exerts approximately one thousandth part of the pressure of the atmosphere. See ATMOSPHERIC PRESSURE, EXTREMES, MILLIBAR.

**Probability.**—If in a large number  $N$  of trials, an event occurs  $n$  times and fails to occur  $N - n$  times, the fraction  $n/N$  is called the probability of occurrence of the event. If a coin is tossed, the ratio of heads to the number of trials will have a general tendency to approach more and more closely to  $\frac{1}{2}$  as the number of trials is increased. Strictly speaking, probability can only be discussed in dealing with a large number of trials. If a coin is tossed 6 times, we cannot assume that the result will be 3 heads and 3 tails, though if we were so placed that we had to adopt some definite figure, we should assume 3 heads and 3 tails as the likeliest distribution. If the probability of occurrence of an event is  $1/10$ , then we could not say that the event should occur 10 times in 100 trials, nor even that it should occur 1,000 times in 10,000 trials, though the figure 1,000 could be accepted as being relatively more reliable than the figure 10 in the first case.

In some cases we can resolve a complex event into a number of simpler events, and it is important in that case to know how to evaluate the probability of the complex event from the separate probabilities of the simpler events. Let the complex case be the simultaneous occurrence of two events A and B, the probability of occurrence of A being  $a$  and the probability of occurrence of B being  $b$ . Then the probability of the occurrence of both A and B is  $ab$ , if, and only if, the events A and B are absolutely independent. Unless the events are independent, this simple rule of multiplication of probabilities is invalid. But, provided the events are all independent, the rule can be extended to any number of events.

When we come to the problem of determining the probability of an event solely from statistics relating to the frequency of its occurrence, since we cannot make  $N$  indefinitely large, we have to be content with taking the ratio of the observed frequency of occurrence to a finite number of trials  $N$ , as the probability  $p$ .

If the probability of the occurrence of an event is  $p$ , the probability of its non-occurrence is  $1 - p$ . In a large number of trials, say  $N$ , the event will occur  $Np$  times on the average, but for any series of  $N$  trials the actual number of occurrences may differ from  $Np$ . It is useful to have some guidance as to the extent of the variability to be expected in the result. The PROBABLE ERROR of the result  $Np$  is  $\cdot 6745 \sqrt{Np(1-p)}$  or  $\frac{1}{2} \sqrt{Np(1-p)}$  with sufficient accuracy. An example may help to make clear the utility of this relation. The ratio of the number of male children born to the number of female children born is said to be  $1.05 : 1$ . If in a particular community 51,400 out of 100,000 children born were male, could we deduce from this any abnormality in the community? The expected

number of male children is  $100,000 \times \frac{1.05}{2.05}$  or 51,220. The probable error

is  $\cdot 6745 \sqrt{\frac{100,000 \times 1.05 \times 1.0}{(2.05)^2}}$  or 107. The deviation from the expected

result is 180, and is therefore, less than twice the probable error. If, on the other hand, the number had been 51,800 males out of 100,000 births, the deviation would have been about six times the probable error, and we should be justified in regarding this as greater than would be produced by chance and, therefore, as indicating some abnormality in the community concerned.

A common way of expressing probability is to state it in the form of "odds against" or "odds on" the occurrence of the event. If the probability of an event is  $1/10$ , the event fails nine times for each time it succeeds, and this may be expressed by saying that the odds are 9 to 1 against the event. See also NORMAL LAW.

**Probable Error.**—A quantity, usually denoted by  $r$ , such that the error of a single observation is as likely to be within as without the limits  $\pm r$ . In other words, there is an even chance that the error of a single observation shall not exceed  $r$ . The probable error, therefore, gives a measure of the closeness with which the observations are clustered about their mean value. If  $x_1, x_2, \dots, x_n$  are  $n$  observations normally distributed whose mean value is  $\bar{x}$ , the probable error  $r$  is given by

$$r = 0.6745 \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}}$$

It is usually sufficiently accurate to replace  $n - 1$  by  $n$  in the denominator. If the observations are distributed in accordance with the NORMAL LAW OF ERRORS the probability of the occurrence of an error as great as  $2r$  is  $\cdot 177$ , of an error as great as  $3r$ ,  $\cdot 043$ , of an error as great as  $4r$ ,  $\cdot 007$ , of an error as great as  $5r$ ,  $\cdot 001$ , and of an error as great as  $6r$ , about  $\cdot 00005$ .

**Prognostics.**—See WEATHER MAXIM.

**Projection.**—This term is used in connexion with maps in a sense wider than that of geometrical perspective. It denotes any relationship establishing a correspondence between a domain of the earth's surface and a domain of a plane surface, the map, such that to each point of one corresponds one and only one point of the other. The projection is completely represented by constructing, on the plane surface, a graticule formed by two intersecting systems of lines, corresponding respectively to parallels of latitude and meridians of longitude on the earth. The position on the map of any features on the earth's surface is then determined by reference to this graticule.

The scale of the map is the ratio of the distance between two neighbouring points on the map to the corresponding distance on the earth. A perfect map in which the scale is uniform throughout is not possible. A class of projections termed "orthomorphic" or "conformal" have the property that, at any point, the scale in all directions is the same, though varying from point to point. This is equivalent to the property that the angle of intersection of any two lines on the earth (such as an isobar and a meridian) is preserved unchanged on the map, or the shape of any small area is preserved. Orthomorphic projections are not much used generally, but owing to the above properties, they enter into meteorological practice as base maps for the representation of meteorological elements. They are recommended for this purpose by a resolution of the International Meteorological Committee, Salzburg, 1937. Three orthomorphic projections are recommended for the purposes of synoptic meteorology:—

(a) the stereographic projection for the polar regions on a plane cutting the sphere at  $60^\circ$ ;

(b) the Lambert orthomorphic conic projection for middle latitudes, the cone cutting the sphere at  $30^\circ$  and  $60^\circ$ ;

(c) Mercator's projection for the equatorial regions with true scale at  $22\frac{1}{2}^\circ$ .

The projection recommended in (a) is a special case of conical orthomorphic projection in which the meridians converge at their true angle and in which the scale is correct on any one chosen parallel. It is particularly suitable for the polar regions.

The projection recommended in (b) is very suitable, especially for middle latitudes, and is used for the majority of the working charts of the Meteorological Office. The meridians are straight lines converging to the pole and

the parallels of latitude are circles centred at the pole. The scale is correct at all points along two chosen parallels and any two meridians converge at an angle which is a fraction of the angle between them on the earth, the fraction depending solely on the choice of standard parallels. The spacing of the other parallels is then uniquely determinate to secure the orthomorphic property. The scale is somewhat too low between the standard parallels and increases rather rapidly outside them.

The projection recommended in (c) is another special type of orthomorphic projection in which the angle between the meridians is zero. The meridians are equally spaced parallel straight lines and the parallels of latitude are straight lines at right angles to the meridians and spaced so as to secure the orthomorphic property. This projection is most suitable for the equatorial zone.

Conical and zenithal projections can be made with other than orthomorphic properties, by suitably altering the spacing of the parallels. Preservation of areas may be secured or a compromise between the equal area and orthomorphic properties.

The latter is the case in Clarke's zenithal projection used in the *Daily Weather Report* (British Section) of the Meteorological Office.

There are, in addition, many other projections, each to serve a special purpose. Of these Mollweide's "Equal-Area Projection" is often useful when a world map is required. The whole globe is represented within an ellipse whose major axis is twice the minor axis.

(For further information see "Map Projections," by A. R. Hinks, Camb. Univ. Press. The mathematical properties of orthomorphic projections are to be found under "conformal representation" in books on the theory of functions of a complex variable.)

**Psychrometer.**—An alternative name for the dry- and wet-bulb hygrometer. Two similar thermometers are employed, one, the "dry" bulb, reading the air temperature, while the other, the "wet" bulb, whose bulb is covered with muslin wetted with pure water, gives the "temperature of evaporation." For a given value of the temperature, the wet bulb reads lower than the dry bulb by an amount depending on the humidity and the rate of flow of air over the bulbs. The connexion in the simplest form may be written

$$x = f - Ap(t - t')$$

where  $x$  = vapour pressure under the conditions of observation,

$f$  = saturation vapour pressure at the temperature ( $t'$ ) of the wet bulb,

$p$  = the pressure of the air,

$t$  = the temperature of the dry bulb,

$t'$  = the temperature of the wet bulb,

$A$  = a "constant".

In the "Hygrometric Tables" issued by the Meteorological Office for use with "light airs" the constant  $A$  is given the value 0.444, for wet-bulb temperatures above 32° F. and 0.400 below that temperature. In the edition published in 1927 (reprinted 1956) the saturation vapour pressure over water is taken as the standard at all temperatures, even below 32° F. A number of other tables have been published for the purpose of ascertaining the relative humidity, dew-point, etc., from the readings of the two thermometers under various conditions.

In the Assmann psychrometer, a definite rate of ventilation is secured by drawing the air over the bulbs by the agency of a fan driven by clockwork. The thermometers are mounted in a plated metal frame designed to secure immunity from errors due to solar radiation. In the sling or "whirling" psychrometer (see SLING THERMOMETER), a similar degree of ventilation is secured by whirling the thermometers which are mounted in a frame resembling a "policeman's rattle." For use on aircraft psychrometers have been designed to utilise the motion of the aeroplane itself for ventilation purposes.

**Pumping.**—Unsteadiness of the mercury in the barometer caused by fluctuations of the air pressure produced by a gusty wind, or due to the oscillation of a ship.

**Purple Light.**—Shortly after the sun has set below the western horizon a brighter patch appears on the darkening sky about  $25^\circ$  directly above the position where the sun has disappeared. This patch appears brighter as the sky darkens and takes on a purple tone. The patch expands into a disc and when the sun is about  $4^\circ$  below the horizon it reaches its maximum brilliancy, when it may be so bright that white buildings in the east which are lit up by it, glow with a purple colour which corresponds to the afterglow seen on the peaks of snow-covered mountains. The disc of purple light sinks downwards at twice the rate at which the sun sinks while at the same time its radius expands and its light becomes less intense. It finally sets behind the bright segment of the twilight arch. Occasionally when the first purple light has passed below the horizon, the phenomenon repeats itself with less intensity. The second patch of light appears at a slightly less altitude than the first but otherwise follows the same course.

Another coloured band is to be seen in the east at sunset immediately above the SHADOW OF THE EARTH. This band called the counter or anti-twilight is golden when the shadow is on the horizon. As the shadow rises the band acquires a reddish tint passing through reddish grey, purple violet, purple into red and orange yellow and, finally, green, rapidly increasing in breadth and brightness as it does so. The upper boundary is quite indefinite. The band reaches its maximum height and brightness about the time when the sun is  $2-3^\circ$  below the horizon and the western purple light is just becoming visible. After this the anti-twilight disappears and it usually ceases to be recognisable when the sun is  $4^\circ$  below the horizon.

Sometimes there is a marked blue band at the base of the anti-twilight. In contrast to the western purple light the brightness of the anti-twilight increases with the height of the observer.

**Pyranometer.**—See PYRHELIOMETER.

**Pyrgeometer.**—See PYRHELIOMETER.

**Pyrheliometer.**—An instrument for measuring the rate at which radiant heat is received from the sun. In Ångström's form the rate of absorption of heat by a thin strip of blackened platinum, when exposed normally to the sun's rays, is ascertained by measuring the electric current necessary to heat a similar strip to the same temperature. The rate of generation of heat in the strip in the electrical circuit is then equal to the rate of absorption of heat by the strip exposed to the sun. In Abbot's "silver disc" pyrheliometer, the rise of temperature in a silvered disc exposed to the sun's rays is measured directly and the intensity of the radiation is determined therefrom by reference to the calibration data of the instrument. The PYRANOMETER, devised by Abbot and Aldrich, measures outgoing radiation (nocturnal radiation) as well as sky radiation. The nocturnal radiation can also be measured by Ångström's PYRGEOMETER, in which use is made of the fact that the radiation from a gilded strip of manganin is less than that from a blackened strip.

**Radiation.**—*Units.*—The intensity of radiation is measured by the energy which crosses a certain area in a given time. In physics the unit adopted is generally one erg per  $\text{cm}^2$  per sec. For meteorological purposes a larger unit is required and one milliwatt per  $\text{cm}^2$  is found appropriate. The relation between these units is simple. Moreover, the latter unit can be brought into relation with the engineers' unit of power, the kilowatt, by adopting the

square decametre as unit of area. In most meteorological work the energy is expressed in terms of the gram-calorie (see CALORIE), the energy required to raise the temperature of a gram of water by one degree centigrade. Theoretically this is not a good unit as it can only be made definite by specifying the actual range of temperature. The capacity for heat of water varies from 4.219 joules per gram per degree at 0° C. to 4.173 at 35° C. In meteorology the 15° calorie and the 20° calorie have both been used. The equivalents are 4.184 joules and 4.180 joules respectively. Fortunately the difference is of little practical importance. The relations between the units of radiation are :—

$$\begin{aligned} 1 \frac{\text{mw.}}{\text{cm.}^2} &= 1 \frac{\text{Kw.}}{\text{dm.}^2} = 10^4 \frac{\text{ergs}}{\text{cm.}^2 \text{ sec.}} \\ 1 \frac{\text{gm. cal.}}{\text{cm.}^2 \text{ min.}} &= 69.7 \frac{\text{mw.}}{\text{cm.}^2} \\ 1 \frac{\text{gm. cal.}}{\text{cm.}^2 \text{ day}} &= \frac{1}{1440} \frac{\text{gm. cal.}}{\text{cm.}^2 \text{ min.}} = .0484 \frac{\text{mw.}}{\text{cm.}^2} \end{aligned}$$

These units are suitable for the measurement of the total radiation received by a surface from the sun or from the whole sky. For the measurement of the radiation from a part of the sky W. H. Dines adopted the convenient practice of giving the radiation which would be received on a flat surface from the whole sky if the intensity were uniform. When the intensity is uniform, the radiation per unit of solid angle is equal to  $(2/\pi) \times$  (the radiation received on a flat surface).

*Black-body radiation.*—The colours attributed to solid objects depend on their appearance when daylight falls on them. A white surface scatters a large proportion of the daylight: a dull black surface absorbs the daylight. Little light is absorbed by a bright metallic surface.

According to the theory of exchanges all solids give out radiant heat. When a solid is hotter than its surroundings it gives out more heat than it absorbs. The radiation from a burnished metal is much less than that from a dull surface at the same temperature, and experiment indicates that at moderate temperatures the strongest radiation is given out by a black surface.

When solids are heated so that they become red hot or even white hot there are still differences between the amounts of radiation which they emit. In general the solid which is black at ordinary temperatures continues to give out most radiation at higher temperatures. Experiment suggests that there is an upper limit to the radiation which can be emitted by a surface of specified area at any given temperature. The ideal substance which would at every temperature emit the greatest possible amount of radiant energy is known as a "perfect radiator" or "perfectly black" substance.

It has been demonstrated that the radiation which passes out through the narrow mouth of a cavity in a solid at uniform temperature is equivalent to that from a perfect radiator at that temperature. The radiant energy emitted by an element  $dS$  of the surface of a perfect radiator is given by a simple formula, found empirically by Stefan and afterwards demonstrated theoretically by Boltzmann. The formula is

$$\text{total radiation} = \sigma T^4 dS$$

$T$  being the absolute temperature and  $\sigma$  a constant. If  $T$  is measured in centigrade degrees from  $-273.1^\circ \text{C.}$  the value of  $\sigma$  is

$$5.709 \times 10^{-5} \text{ ergs per cm.}^2 \text{ per sec.}$$

This is equivalent to  $5.709 \times 10^{-12}$  watts per  $\text{cm.}^2$  and to  $82 \times 10^{-13}$  gram-calories per  $\text{cm.}^2$  per min. The same formula serves to give the flux of radiation passing directly or obliquely across an area  $dS$  parallel to the radiating surface and a small distance from it.

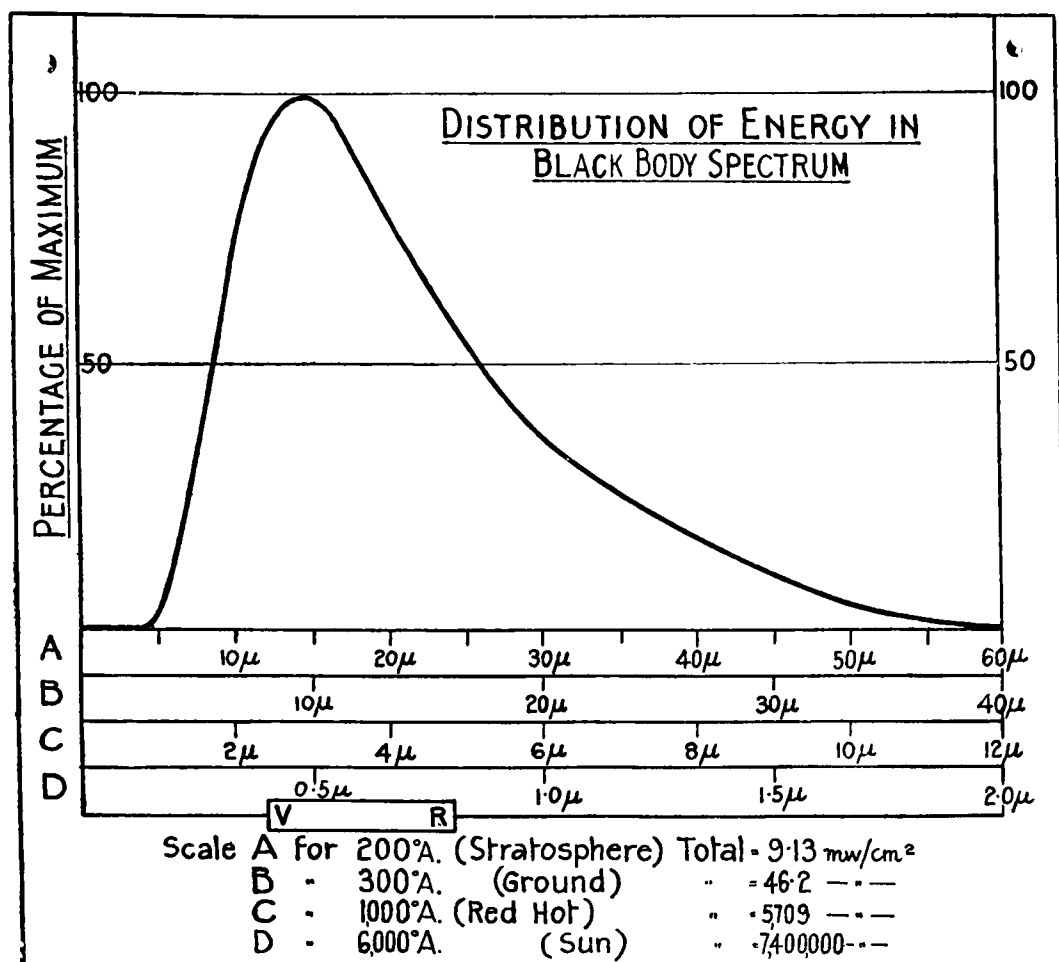


FIG. 24.

*The distribution of energy in the spectrum.*—The familiar fact that a piece of metal changes colour as it is heated in a furnace is an indication that the distribution of radiant energy in the spectrum is changing. *Wien's displacement law* tells us that the graph showing the relation of energy to wave-length for a perfect radiator at one temperature will serve to give the relation at any other temperature. The wave-length scale has to be changed in the inverse ratio of the temperatures, whilst the energy scale is changed by the fifth power of this inverse ratio.

*Planck's radiation formula.*—The laws of Stefan and Wien can be deduced from the classical laws of thermodynamics. The actual distribution of energy in the black-body spectrum cannot be deduced from these laws. The specification of this distribution was given by Planck. In doing so he made one of the most important and difficult steps in the advance of science, by propounding the "Quantum Theory."

Planck's distribution law is illustrated in Fig. 24 for a black body at 6,000°A. The distribution of energy is comparable with that in solar radiation. The visible spectrum occupies the range from 0.4 $\mu$  (violet) to 0.77 $\mu$  (red) or in Ångström units from 4,000Å to 7,000Å.

Other scales in the diagram illustrate the distribution of infra-red radiation from cold surfaces and from a red-hot surface. Note that nearly all the energy emitted from the red-hot surface is in the infra-red. The curve ordinate corresponding with 0.75 $\mu$  on scale C should be only 0.06 per cent. of the maximum ordinate which corresponds with 3 $\mu$ .

*Radiation and the atmosphere.*—The principal gases of the atmosphere, oxygen and nitrogen, are transparent to nearly all the radiation of the solar spectrum and also to the long-wave radiation such as is given out by a body

at the temperature of the ground. Carbon dioxide absorbs long-wave radiation with wave-length in the neighbourhood of  $15\mu$ . The most important absorbent in the atmosphere is, however, water vapour. The water vapour absorbs some of the solar radiation in the visible spectrum (so giving rise to "rain-bands" in the spectroscop) and much of the infra-red radiation. Most long-wave radiation is absorbed by water vapour but there is a short range of wave-lengths between  $8\mu$  and  $12\mu$  for which the vapour is transparent.

Since gases emit and absorb radiation of the same wave-lengths, the radiation which is returned by the atmosphere to the ground comes mostly from the water vapour and it is found by observation that the strength of the radiation from the sky after dark depends on the amount of water vapour present as well as on its temperature.

Thus the absorbing power of water vapour plays an important part in the meteorology of the lower atmosphere. It is believed to be equally important in the meteorology of the upper atmosphere as it is mostly through the absorption of long-wave radiation that the temperature of the stratosphere is maintained.

The part played by water in the form of clouds in regulating the temperature of the globe has not been fully realized until recently. Clouds have a high reflecting power and it is estimated that the light reflected from the clouds together with light reflected from the sea and from the air accounts for half of the radiation received by the planet from the sun. This half passes out into space as short-wave radiation. The other half is absorbed by the planet; the equivalent energy passes out again eventually as long-wave radiation. The value of this fraction depends on the average amount of cloud over the globe. Simpson\* has pointed out that an increase in radiation from the sun would lead to an increase in the amount of cloud and, therefore, to an increase in the proportion of light and heat reflected. There is almost an automatic control of the temperature of the globe. It is instructive to notice that Venus, which is nearer to the sun than is the earth, is continually mantled in clouds whilst Mars, which is further away, is devoid of cloud. Only the earth enjoys such conditions that the cloud-thermostat can be effective.

*Terrestrial radiation.*—The cooling of the ground at night is mainly due to the excess of the outward radiation above the radiation which comes down from the sky. The radiation from the ground is practically the same as would be given out by a perfect radiator at the same temperature. (See BLACK-BODY RADIATION.) It is convenient to regard it as divided into three parts: (a) radiation in wave-lengths between  $5.5\mu$  and  $7\mu$  and all radiation of longer wave-length than  $14\mu$ . To radiation of this sort water vapour is opaque; (b) radiation in wave-lengths between  $8\frac{1}{2}\mu$  and  $11\mu$ : to such radiation water vapour is transparent; (c) radiation in intermediate wave-lengths. To this water vapour is semi-transparent.

The radiation of the (a) type is caught quite close to the ground. There is always enough water vapour to send back a full measure of this radiation so that the inward and outward flows of radiant energy balance. The radiation of the (b) type passes (if the air is clear and there are no clouds) right through the atmosphere to outer space. There is no compensating inward radiation. The proportion of (c) radiation absorbed by the atmosphere depends on the quantity of water vapour in the atmosphere and the strength of the return radiation is affected in the same way.

According to the observations made by A. Ångström in Algeria and California the ratio of the incoming radiation from the sky to that emitted by a black body at air temperature varies between 62 per cent. for a vapour pressure of 4 mb. and 74 per cent. for a vapour pressure of 16 mb.

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\* "Further studies in terrestrial radiation." *London. Mem. R. met. Soc.*, 3, No. 21, 1928.



If the ground were at the same temperature as the air and the vapour pressure 10 mb. the resultant outward flow from the ground would be 32 per cent. of black-body radiation. Actually the ground is cooled below air temperature and there is a corresponding reduction in the radiation given out. Thus with the ground  $5^{\circ}\text{C}$ . below air temperature the radiation emitted from the ground is reduced to about 93 per cent. of that of a black body at air temperature and the resultant outflow of radiation is reduced from 32 per cent. to 25 per cent.

The conditions favourable for cooling of the ground at night are :—

(1) A cloudless sky. When the sky is covered with clouds at moderate heights the radiation from the clouds in types (b) and (c) is almost equivalent to the radiation of the same types from the ground.

(2) Dry air—so that the return radiation of type (c) may be slight.

(3) Absence of wind. The effect of wind is to bring more air into contact with the ground. The air gives heat to the ground and so prevents it from cooling so much. On the other hand the cooling of the lowest layers of the air produces stratification and reduces turbulence so that the wind can continue at considerable heights and glide over the quiet air near the ground. Thus it is equally true that the air is calm because the ground is cold and that the ground is cold because the air is calm.

(4) Low conductivity of the ground. The heat conducted from below tends to keep up the temperature of the surface. In this connexion it may be noticed that snow being a bad conductor the surface of snow can attain very low temperatures.

The most conspicuous signs of effective terrestrial radiation are the deposit of DEW and HOAR-FROST.

*Terrestrial-radiation thermometer.*—The “grass minimum thermometer” is sometimes referred to as a “terrestrial-radiation thermometer.” Low readings of such a thermometer are a sign that terrestrial radiation has been effective but there is no rule for deriving from the thermometer readings a numerical estimate of the strength of the radiation. The thermometer is placed above the grass so that its temperature is not affected by conduction from the ground. It is to be expected that the thermometer will be a little cooler than the grass blades near by.

*Ultra-violet radiation.*—When a spectrum is photographed it is found that the limits of the photograph are by no means the same as the visible limits of the spectrum. Probably the red end of the spectrum is cut off in the photograph. On the other hand the photograph extends considerably beyond the violet. The photographic paper is said to have been affected by ultra-violet radiation. The prolongation of the solar spectrum beyond the violet was first noticed by Sir John Herschel in throwing the spectrum on turmeric paper. The prolongation was yellow. Herschel's experiment was an example of how certain substances become “fluorescent” when illuminated by ultra-violet light.

The wave-lengths of ultra-violet light are shorter than those of visible light, the limit of which is about  $0.4\mu$ . On the other hand there is no ultra-violet of very short wave-length in the light which reaches us from the sun. The solar spectrum is cut off at about  $0.3\mu$ . It is believed that the ultra-violet of shorter wave-length is absorbed by ozone some 30 kilometres or more above the ground.

One of the effects of ultra-violet light is the ionization of gases. It is probable that the high electrical conductivity of the “Heaviside layer” in the upper atmosphere is produced in part by ultra-violet light from the sun.

**Radio-meteorograph.**—See RADIO-SONDES.

**Radio-sondages (Radio-soundings).**—The first successful attempt to transmit radio signals from apparatus carried by a small balloon was made by P. Idrac and R. Bureau in March, 1927. Since that date many forms of apparatus

designed to regulate such signals and report the temperature, pressure and humidity of the upper atmosphere, have been invented. Most designers have worked on Olland's principle in which the interval of time between two pulses indicates pressure, the one between the next two, temperature and so on. The next fundamental development was the use of the thermometric element to vary the frequency of the radio signal by controlling the capacity of a condenser as was done by Duckert in Germany and by Väissälä in Finland in 1932.

There are however objections to varying the radio-frequency of a transmitter, and in designing the first English radio-sonde in 1937, Dr. H. A. Thomas incorporated a continuous wave transmission modulated by two audio-frequency notes of frequencies varying with the pressure and temperature respectively. Variations of the pressure and temperature elements controlled the self-inductance of the modulating circuit. These notes were separated and their frequencies measured at the receiving station and converted from previous calibrations to pressure and temperature readings. Later the Kew radio-sonde was developed from the Thomas sonde, and has been in general British use for several years. The Kew radio-sonde measures pressure, temperature and humidity, and transmits the readings by means of the modulated continuous wave technique. The circuits controlled by each element are switched in alternately so that at any moment only one circuit is modulating the transmission. As in the case of the Thomas sonde, the frequencies are measured at the observing station and converted from previous calibrations.

Certain wave-bands are allocated by international agreement for radio-soundings.

**Radio-sondes.**—These are specially designed instruments carried by free balloons which transmit by radio the instantaneous values of pressure, temperature and, usually, humidity in the atmosphere.

The outstanding importance of this method is that it enables the values of pressure, temperature and humidity at different heights in the atmosphere to be obtained in all conditions of weather, and at altitudes far greater than can be reached by other means. The normal height to which it is possible to obtain information by radio-sonde is about 60,000 ft. In favourable conditions values can be obtained up to 80,000 ft.

**Rain.**—"Condensed moisture of atmosphere falling visibly in separate drops" (Concise Oxford Dictionary). The distinction between rain and DRIZZLE, though readily recognizable, is not easy to express in a precise form. It has been suggested that the term rain should be limited to liquid precipitation in which the diameter of the drops exceeds 0.5 mm. but this figure has not been internationally agreed and it is almost certainly too high.

**Rain-band.**—A dark band in the solar spectrum on the red side of the sodium D lines, due to absorption by water vapour in the earth's atmosphere. The band may be best seen when the spectroscope is pointed at the sky rather than directly at the sun. The band is strengthened with increase of water vapour and also when the altitude of the sun is low and its light has to shine through a greater thickness of air. Taken alone the rain-band is of doubtful value as a prognostic of rain. Accurate measurements of the absorption may be utilized however to determine the quantity of moisture in the atmosphere whereas ordinary meteorological observations merely give the quantity of vapour near the ground.

**Rainbow.**—A rainbow is seen when the sun shines upon raindrops. The drops may be at any distance from the observer from a few yards to several miles. When sunlight falls upon a drop of water some of the light enters the drop, is reflected from the far side and emerges from the near side. The light which is reflected in this way does not come out in all directions but only in directions lying within about  $42^\circ$  from the direction of the sun. The reflected light is most intense near the limit. Accordingly an observer looking towards the raindrops receives a certain amount of light from all directions within  $42^\circ$  from the shadow of his head but most light along rays which make about  $42^\circ$  with the central line. The limiting angle depends on the colour

of the light and in so much as white light is compounded of light of different spectral colours the observer sees a number of concentric arches of different colours.

Some of the light falling on a drop does not emerge until after it has been reflected twice. None of the twice reflected light which reaches an observer makes an angle of less than  $50^\circ$  with the line to the centre of his shadow. The colours of the outer bow formed in this way are in the reverse order to those of the inner bow. The space between the inner and outer bows appears darker than the space inside the inner or beyond the outer bow.

It is a common mistake to assume that the colours of all rainbows are the same. The colouration depends on the size of the drops. Drops larger than 1 mm. in diameter yield brilliant bows about  $2^\circ$  in width, the limiting colour is distinctly red. With drops about 0.3 mm. in diameter the limiting colour is orange and inside the violet there are bands in which pink predominates. With smaller drops supernumerary bows appear to be separate from the primary bow. With still smaller drops about 0.05 mm. in diameter the rainbow degenerates into a white fog bow with faint traces of colour at the edges.

The wave theory of light has provided in the hands of Airy and Pernter a satisfactory explanation of all the variations in the colour of rainbows.

Rainbows are not infrequently observed by moonlight but as the human eye cannot distinguish colour with faint lights the lunar rainbow appears to be white.

**Rain Day.**—A period of 24 hours, commencing normally at 9h. G.M.T., on which 0.01 in. or 0.2 mm. or more of rain is recorded. The following papers deal with average numbers of rain days in the British Isles :—

(1) The distribution over the British Isles in time and space of the annual number of days with rain. *British Rainfall*, 1926, p. 260–79.

(2) The distribution over the British Isles of the average number of days with rain during each month of the year. *London, Quart. J. R. met. Soc.*, 54, 1928, p. 89–101. See also WET DAY.

**Raindrops.**—*Size and rate of fall of raindrops.*—The size of raindrops can be measured, if, for example, a shallow tray containing dry plaster of Paris is exposed for a few seconds during rain. Each drop which falls into the tray will make a plaster cast of itself which can easily be measured. A better method is to collect the drops upon thick blotting paper. If, while still wet, the paper is dusted over with a dye powder a permanent record will be obtained consisting of circular spots whose diameter is a measure of the size of the drops. By comparing the diameters of the discs produced by raindrops with those produced by drops of water of known size, the amount of water contained in the former can be found. The following table contains some results obtained by P. Lenard\* in this way at nine different times :—

Drops			Number of drops per square metre per second								
Diameter	Volume										
mm.	in.	mm. <sup>3</sup>	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
0.5	.019	0.066	1,000	1,600	129	60	0	100	514	679	7
1.0	.039	0.523	200	120	100	280	50	1,300	423	524	233
1.5	.059	1.77	140	60	73	160	50	500	359	347	113
2.0	.079	4.19	140	200	100	20	150	200	138	295	46
2.5	.098	8.19	0	0	29	20	0	0	156	205	7
3.0	.118	14.2	0	0	57	0	200	0	138	81	0
3.5	.138	22.5	0	0	0	0	0	0	0	28	32
4.0	.157	33.5	0	0	0	0	50	0	0	20	39
4.5	.177	47.8	0	0	0	0	0	200	101	0	0
5.0	.196	65.5	0	0	0	0	0	0	0	0	25
Total number ..			1,480	1,980	486	540	500	2,300	1,840	2,190	500
Rate of rainfall .. (mm./min.)			0.09	0.06	0.11	0.05	0.32	0.72	0.57	0.34	0.26

\* "Über Regen." *Met. Z., Braunschweig*, 21, 1904, pp. 249–62.

(1) and (2) refer to a rain 'looking very ordinary' which was general over the north of Switzerland. The wind had freshened between (1) and (2).

(3) Rain with breaks during which the sun shone.

(4) Beginning of a short fall like a thunder shower. Distant thunder.

(5) Sudden rain from a small cloud. Calm; sultry before.

(6) Violent rain like a cloud-burst, with some hail.

(7), (8) and (9) are for the heaviest period, a less heavy period and the period of stopping of a continuous fall which at times took the form of a cloudburst.

Probably the best method of measuring the sizes of small raindrops is that of Nolan and Enright (*Sci. Proc. R. Dublin Soc.*, 17, 1922, p. 3). Glass microscope slides are prepared by spreading on each of them a layer of thick dark oil of density 0.9. When one of these slides is exposed to rain the drops falling on it pass into the oil layer and are there suspended in the form of perfect spheres, sinking very slowly. The rate of movement through the oil is so slow that the smallest drops do not reach the bottom of the layer until after 48 hours. The diameters of the drops are easily and accurately measured under a low-power microscope.

It is apparent from the table that by far the greater number of drops have a diameter of 2 mm. or less. In short showers, especially those occurring during thunderstorms, the frequency of large drops is much greater. In such showers the diameter of the largest drops appears to be about 5 mm. We shall see later that it is impossible for a drop, whose diameter exceeds 5.5 mm. or rather less than a quarter of an inch, to fall intact.

The rate at which a raindrop, or any other object, can fall through still air depends upon its size. When let fall its speed will increase until the air resistance is exactly equal to the weight, when it will continue to move at steady speed. The manner in which this "terminal velocity," as it is called, varies with the size of the raindrops is shown in Fig. 25 on which some of the actual observations made by Lenard have been plotted.

We may consider this diagram in another way. The frictional resistance offered by the air to the passage of a drop depends upon the relative motion of the two, and it is of no consequence whether the drop is moving and the air still, or the air moving and the drop still, or both air and drop moving if they have different velocities. The velocities given in the tables are those with which the air in a vertical current must rise in order just to keep the drops floating, without rising or falling. The above results were, in fact, actually determined by Lenard in this way, by means of experiments with vertical air currents on drops of known size. We see that beyond a certain point the terminal velocity does not increase with the size of the drops but tends to decrease. This is due to the fact that the drops become deformed, spreading out horizontally, with the result that the air resistance is increased. For drops greater than 5.5 mm. diameter, the deformation is sufficient to make the drops break up before the terminal velocity is reached.

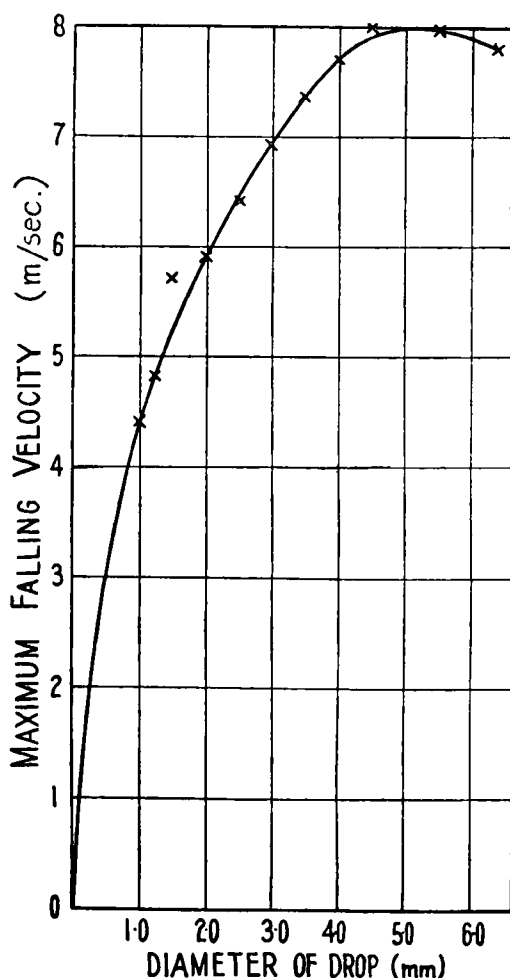


FIG. 25

An important consequence of Lenard's results is that no rain can fall through an ascending current of air whose vertical velocity is greater than 8 m./sec. In such a current the drops will be carried upwards, either intact or after breaking up into droplets. There is good reason for believing that vertical currents exceeding this velocity frequently occur in nature.

On account of their inability to fall in an air current which is rising faster than their limiting velocity, raindrops formed in these currents will have ample opportunity to increase in size. These large drops can reach earth in two ways: either by being carried along in the outflow of air above the region of most active convection, or by the sudden cessation of or a lull in the vertical current. The violence of the precipitation under the latter conditions may be particularly disastrous. See also CLOUDBURST AND HAIL.

**Rainfall.**—The total product of PRECIPITATION OR CONDENSATION from the atmosphere as received and measured in a RAIN-GAUGE. Ultimately all rainfall is due to condensation of AQUEOUS VAPOUR. Condensation occurring at a considerable height above ground gives rise initially to CLOUDS, and finally, under conditions which are still not completely understood, to aggregates of water droplets or ice particles of sufficient size to fall with appreciable speed and to survive the loss by EVAPORATION during the journey to the ground. RAIN, SNOW and HAIL precipitated in this manner make up by far the greater part of the total rainfall, but there are also small additions due to the deposition of DEW, HOAR-FROST OR RIME on to the collecting surface of the rain-gauge.

Three types of rainfall are recognized, depending upon the process by which the dynamical cooling leading to cloud formation is brought about.

The types are OROGRAPHIC, CYCLONIC and CONVECTIONAL and these are discussed under their separate headings. While orographic and cyclonic rains are often very persistent and widespread, convectional rains are typically intense and of short duration. Both orographic and cyclonic rains are rather more frequent in winter, while convectional rains are more common in summer.

*The average annual rainfall* at any station is the mean annual fall over a long period, often the 35 years, 1881–1915. Annual averages are included for many stations in the annual volumes of *British Rainfall*. The monthly and annual averages at some 570 stations are set out in Section V of the "Book of Normals of Meteorological Elements for the British Isles." Over the British Isles the average annual rainfall varies from 20 in. along the Thames estuary to over 150 in. in the English Lake District, Snowdonia and parts of the Western Highlands of Scotland. Maps showing the average distribution in the year and the individual months have been included in the "Rainfall Atlas of the British Isles," published by the Royal Meteorological Society in 1926. Details of the largest averages are given in a note under the title of the "Wettest places in the British Isles" in the *Meteorological Magazine*, 72, 1937, pp. 142–4. The average monthly rainfall 1881–1915 for each month of the year of the larger divisions and of the British Isles is set out below.

	England	Wales	England and Wales	Scotland	Ireland	British Isles
	in.	in.	in.	in.	in.	in.
January .. ..	2·69	4·72	2·99	4·90	4·07	3·78
February .. ..	2·34	3·94	2·57	4·18	3·53	3·26
March .. ..	2·47	3·82	2·67	4·05	3·36	3·22
April .. ..	1·98	2·96	2·12	2·99	2·75	2·52
May .. ..	2·19	2·95	2·30	3·01	2·75	2·61
June .. ..	2·33	3·05	2·44	2·83	2·82	2·64
July .. ..	2·75	3·60	2·87	3·78	3·37	3·25
August .. ..	3·11	4·71	3·35	4·51	4·20	3·88
September .. ..	2·37	3·51	2·54	4·00	3·13	3·09
October .. ..	3·69	5·63	3·97	4·90	4·08	4·25
November .. ..	3·19	5·25	3·49	5·29	4·28	4·19
December .. ..	3·56	6·00	3·92	5·88	4·96	4·72
Year .. ..	32·67	50·14	35·23	50·32	43·30	41·41

It will be noticed that over the British Isles as a whole December is the wettest month and April the driest. The three months October, November and December receive nearly twice as much rain on the average as the three months April, May and June. There is also a subsidiary maximum in August, making that month the fourth wettest of the year. The seasonal distribution in the various divisions of the British Isles is very similar. In July and August the rainfall is actually greater in the east of England than many earlier months of the year, and in some places those months are the rainiest in the year on account of the frequency of summer thunderstorms. Over the east and south of England generally the rainiest month is October, while for the west and north of Great Britain it is December or January.

*Extremes of rainfall* can be conveniently considered for the various units of time, e.g. the year, month, day and even for shorter periods. In the case of the month and year, the distribution of the extreme values is largely controlled by the configuration of the land, while for shorter periods the largest values on record occur in the drier regions of central and eastern England, where convectional rains are more common. (a) The wettest year over the British Isles as a whole was 1872, and the driest year 1887. The wettest and driest years on record have not been the same, however, in all parts of the British Isles, and maps showing the wettest and driest years in all parts of the country have been published (see *London, Quart. J. R. met. Soc.*, 52, 1926, pp. 237-48). Annual totals exceeding 240 in. were recorded at The Styne, at the head of Borrowdale in Cumberland, in 1872 and 1923, at Ben Nevis Observatory, in Inverness, in 1898, and at Llyn Llydaw on Snowdon in 1909. The rainfall in 1921 in the south-east of England was by far the smallest on record, as little as 10 in. being recorded at Margate. (b) The wettest month over the British Isles as a whole was December, 1876, and the driest months February, 1891; June, 1925; March, 1929; February, 1932 and April, 1938. The largest actual values at individual stations are set out below:—

Station	County	Month	Amount
Snowdon (Llyn Llydaw) .. ..	Carnarvon ..	October, 1909 ..	in. 56.54
Borrowdale (The Styne) .. ..	Cumberland ..	January, 1872 ..	50.05
Ben Nevis Observatory .. ..	Inverness ..	December, 1900 ..	48.34

Several stations recorded no rain in February, 1891; April, 1893; September, 1894; February, 1895; July, 1911; April, 1912; June, 1921; June, 1925; March, 1929; March, 1931; February, 1932; February, 1934 and April, 1938. The stations with no rain were mainly in south-eastern England. In February, 1891, some 270 stations situated in central and south-east England measured no rain for the month, while in June, 1925, no rain was recorded over an area of 6,410 square miles, or an area equal to about 85 per cent. of the total area of Wales.

The distribution of the extreme annual values is very largely controlled by the configuration of the land, the largest values occurring in the mountainous regions and the smallest on the plains. The distribution of the monthly extremes reveals a second factor, viz., that the south-east of England is more liable to periods of little or no rain, while in the north-west rain falls more frequently. Thus, at Eallabus, in Islay, on the west coast of Scotland, rain fell every day from August 12 to November 8, 1923, a period of 89 days, or nearly three months, the average annual rainfall at Eallabus being only about 50 in. a year. This second factor is shown very clearly in monthly and annual maps of the number of days with rain. They indicate that in general there is a steady increase in the number of days with rain from the south-east to north-west, even at stations with the same annual fall. The least number of days recorded in any year was in 1921, when there were less than 100 days of rain over a well marked area in the neighbourhood of the Thames Estuary. In 1923 the north-west of Ireland had more than 300 days with rain and Ballynahinch Castle, in Connemara, recorded 309 rain days in the same year.

A map of the average annual number of rain days was published in *British Rainfall*, 1926, p. 264, and maps of the average number in each month in *London, Quart. J. R. met. Soc.*, 54, 1928, pp. 90-101.

The longest periods on record in these Islands with no rain occurred in 1893, during the famous spring drought, when some 20 stations in the south-east of England, mostly in Kent and Sussex, recorded no rain for a period of 50 days or more. Locally in this district there was a two months' drought from March 17 to May 16. The year 1893 was unprecedented for periods of little or no rain.

The largest falls on record for one day (9h. to 9h.) are set out below :—

County	Station	Amount	Date
		in.	
Somerset .. ..	Bruton (Sexey's School) .. ..	9·56	June 28, 1917.
" .. ..	Cannington (Brymore House) .. ..	9·40	August 18, 1924.
" .. ..	Bruton (King's School) .. ..	8·48	June 28, 1917.
" .. ..	Aisholt (Timberscombe) .. ..	8·39	June 28, 1917.
Glamorgan .. ..	Rhondda (Pont Lluest Wen) .. ..	8·31	November 11 1929.
Inverness .. ..	Loch Quoich (Kinlochquoich) .. ..	8·20	October 11, 1916.
Cumberland .. ..	Borrowdale (Seathwaite) .. ..	8·03	November 12, 1897.

The average annual rainfall for the first four stations is 30 to 35 in. while that for the sixth and seventh stations exceeds 100 in. ; so that with the short interval of the day the influence of configuration over the distribution of extreme values has practically disappeared.

The most widespread heavy rain on record occurred in East Anglia on August 25 and 26, 1912, when 1,939 square miles received more than 4 in., corresponding with a volume of rainfall of 154,133 million gallons.

Details of heavy falls on rainfall days, 1865 to 1934, are given in *British Rainfall*, 1934, pp. 266-83.

Of the list of heavy falls in short periods, it is only possible to quote a few examples. The fall of 1·25 in. in five minutes reported at Preston in Lancashire, on August 10, 1893, gives the largest rate on record, viz., 15 in. per hour. The largest fall in half an hour is 2·90 in. recorded at Cowbridge in Glamorganshire on July 22, 1880, and in one hour that of 3·63 in. at Maidenhead on July 2, 1913. The heavy rain of 4·65 in. in two and a half hours on June 16, 1917, at Campden Hill in Kensington, is worthy of mention, since this amount is the largest on record for London for a rainfall day. It has been estimated that during the unprecedented storm at Cannington, near Bridgwater, on August 18, 1924, as much as 8 in. of rain (and hail) fell in 5 hours.

Intense falls are classified in *British Rainfall* as " noteworthy," " remarkable " and " very rare." A revised classification and other details are given in *British Rainfall*, 1935, pp. 262-80.

*Variations of annual rainfall.*—In the " Rainfall Atlas," to which reference has already been made, maps are given showing the fall of each of the 56 years in the series 1868 to 1923, as a percentage of the average. Similar maps are published in the recent volumes of *British Rainfall* and the whole series gives a history of the rainfall fluctuations over the country during the last 70 years.

While the variations of rainfall from point to point in any one year or at the same point in successive years can be shown clearly on maps the variations from year to year of the total annual rainfall for any large area as a whole are shown more effectively by figures. The following table is taken from the *Meteorological Magazine* for June, 1923, and brought up to date by reference to the recent volumes of *British Rainfall*.

*Annual rainfall for each year, 1868 to 1937, expressed as a percentage of the average of the 35 years, 1881 to 1915*

Year	England and Wales	Scotland	Ireland	British Isles	Year	England and Wales	Scotland	Ireland	British Isles
1868	99	113	104	104	1903	128	129	124	127
1869	105	100	98	102	1904	89	93	101	93
1870	82	80	95	84	1905	86	97	89	89
1871	97	92	98	96	1906	101	111	93	101
1872	144	134	128	137	1907	99	104	99	100
1873	89	105	94	94	1908	91	99	96	94
1874	95	108	98	99	1909	105	101	93	101
1875	114	99	99	107	1910	113	105	109	110
1876	117	114	104	113	1911	94	99	96	96
1877	126	131	123	127	1912	125	108	108	116
1878	110	92	96	102	1913	98	93	106	99
1879	109	91	96	100	1914	108	103	108	107
1880	113	86	95	102	1915	110	96	102	105
1881	109	95	100	103	1916	114	117	114	115
1882	127	113	113	120	1917	98	97	99	97
1883	107	106	110	108	1918	107	106	111	108
1884	88	104	98	94	1919	105	93	91	98
1885	101	91	92	96	1920	109	105	111	109
1886	117	94	109	110	1921	70	99	88	82
1887	74	80	77	77	1922	105	94	92	100
1888	98	93	98	97	1923	113	120	110	114
1889	94	85	93	92	1924	120	105	122	117
1890	90	103	97	95	1925	106	100	99	104
1891	111	100	98	105	1926	102	111	100	103
1892	94	96	98	95	1927	123	114	108	118
1893	83	97	82	86	1928	115	123	126	118
1894	108	102	104	105	1929	100	101	106	101
1895	96	95	96	95	1930	117	109	116	115
1896	93	99	94	95	1931	109	104	111	109
1897	101	95	114	103	1932	103	108	95	102
1898	87	109	98	95	1933	81	80	77	80
1899	94	106	102	99	1934	95	110	105	100
1900	109	119	115	113	1935	113	108	98	109
1901	88	94	96	92	1936	109	94	105	105
1902	84	86	92	87	1937	110	91	103	104

In this table the average rainfall for the 35 years 1881 to 1915 for each district dealt with is taken as 100, and the general rainfall for each year of the series is stated as a percentage of that amount. The table shows that for the British Isles as a whole, wet and dry years have alternated irregularly. There was a run of nine consecutive wet years from 1875 to 1883. Then, commencing in 1891, there was a remarkable series of one wet year followed by two dry, repeated five times in regular succession. During the 19 years, 1884 to 1902, only five had a rainfall above the average. Subsequently a definite wet period set in and during the 29 years, 1909 to 1937, only six years can be regarded as dry. It is interesting to note that one of the driest years on record, namely 1887, occurred in the run of generally dry years, while the other dry years, 1921 and 1933, occurred in a definite wet period.

**Rain-gauge.**—An instrument for measuring rainfall. In the "Snowdon," "Meteorological Office" and allied patterns, a funnel, usually 5 in. or 8 in. in diameter, is used to collect the rain. A brass tube of fairly narrow bore, to minimise evaporation, conducts the collected water into the collecting vessel which may be a bottle or a copper can. The funnel is supported by means of an outer can preferably of sheet copper. The rim is of stout brass with a sharp bevelled edge and the funnel is deep, with vertical sides to minimise errors due to splashing and to retain snow. The gauge is mounted in an open situation with its rim 12 in. above ground level.



In self-recording gauges, such as the **HYETOGRAPH**, the collected rainfall is usually made to raise a float to which is attached a pen writing on a chart wrapped round a clock-driven drum. Various methods, involving much ingenuity, have been adopted to secure sensitiveness and to return the pen to the zero line after a definite amount of rain has fallen.

**Rain Shadow.**—An area with a relatively small average rainfall due to sheltering by a range of hills from the prevailing rain-bearing winds. The phenomenon is noticeable in rainfall maps for months in which unusually strong W. winds have predominated, e.g. to the east of Wales.

**Rain Spell.**—A period of at least 15 consecutive days to each of which is credited .01 in. of rain or more; thus the definition of the term "rain spell" is analogous to that of the term "absolute drought." (See **DROUGHT**.) During the 62 years, 1858–1919, there were seven rain spells at Camden Square (London). See also **WET SPELL**.

**Réaumur.**—René Antoine Ferchault de, died 1757, whose name is given to a scale of temperature now almost obsolete. On it the freezing point of water is zero, and the boiling point 80°.

**Recurvature of Storm.**—This expression refers to the recurvature of the track of a tropical **CYCLONE**, which is a typical feature of the great majority of these phenomena. It is also known as the "recurve." In the northern hemisphere a tropical cyclone after proceeding in a more or less westerly direction recurves and normally takes a north-easterly direction; in the southern hemisphere the final direction is normally south-easterly. The tracks are often described as "parabolic," though in the majority of cases "hyperbolic" would be more accurate. The point of recurve is of great importance for the forecasting of the subsequent path. This point is often the seat of the maximum energy of the disturbance.

**Reduction**, as applied to meteorological observations, generally means the substitution for the values directly observed of others which are computed therefrom. The process of reduction generally eliminates the influence of one or more factors that are not at the moment a subject of study. An illustration of the process is given under **REDUCTION TO SEA LEVEL**.

**Reduction to Sea Level.**—Both temperature and pressure are "reduced to sea level" before they are plotted on charts. To reduce mean temperature to sea level 1° F. is added for each 300 ft. in the elevation of the station; 1° A. for 165 m.; other rates are used for maximum temperature and minimum temperature (see "Computer's Handbook", Introduction, p. 13). This reduction is regarded as necessary in forming maps of **ISOTHERMS** of regions with a considerable range of level, otherwise the isotherms simply reproduce the contours; but it reduces the practical utility of the maps because the addition of ten or twelve degrees to the temperature actually observed gives an entirely false idea of the actual state of things in the locality represented.

The same objection does not apply to the reduction of pressure to sea level because the human organism has no such separate perception of pressure as it has of temperature.

The reduction of pressure to sea level is carried out in accordance with the general rule for the relation of difference of pressure to difference of height. This goes according to the equation

$$h - h_0 = k T (\log_{10} p_0 - \log_{10} p)$$

where  $h$ ,  $p$ ,  $h_0$ ,  $p_0$  are corresponding values of height and pressure,  $T$  is the mean temperature of the air columns and  $k$  a constant which is numerically equal to 67.4 when the height is to be given in metres, or to 221.1 when the height is to be given in feet. This equation is derived from the direct expression of the relation of pressure and height

$$g \rho dh = - dp.$$

The details of the technique of reducing pressure to mean sea level will be found in "Tables Météorologiques Internationales," Paris, 1890, pp. B32-B52 and pp. 182-227 (Tables VII and VIII).

The humidity of the air makes very little difference to the computation of height in our latitudes where temperature and moisture do not reach tropical figures. The best way for allowing approximately for humidity, which diminishes the density under standard conditions, is to regard the temperature as increased by one tenth of a degree for each millibar of water-vapour pressure in the atmosphere.

The vertical gradient of temperature varies according to the locality and the season, but in the reduction of temperature to sea level it is usually assumed to be at the rate of  $0.5^{\circ}$  C. per 100 m. or  $1^{\circ}$  F. per 300 ft. The International Meteorological Conference at their meeting at Innsbruck in 1905 recommended that these values should be employed in the reduction of pressure to mean sea level but the Conference at Utrecht in 1923 agreed that in special circumstances other methods of reduction should be permitted.

**Reflection.**—The reflection of light and of radiant heat is an important factor in the physics of the atmosphere. Reflection may be regular like the reflection from a smooth sheet of water or diffuse like the reflection from a sheet of white paper. The intensity of regularly reflected light depends on the angle of incidence. Of the light which comes from the sun a large proportion is reflected by the clouds. Some of this light may have passed through two or three drops before reflection. Aldrich\* has measured the reflecting power of clouds and concludes that a cloud returns 78 per cent. of the incident radiation, and that the amount of reflection is practically independent of the angle of incidence.

In some cases continuous refraction of light produces an effect equivalent to reflection. This is the explanation of MIRAGE.

**Refraction.**—The name applied to the bending to which rays of light are subjected in passing from one medium to another of different optical density. It plays an important part in many optical phenomena in the atmosphere; MIRAGE, HALOS, and RAINBOWS are refraction phenomena, the colours of the two latter being due to the fact that rays of different colours suffer a different amount of bending. Another refraction effect is that the apparent ALTITUDE of a heavenly body is greater than its real altitude because the rays of light entering the atmosphere are passing from a less dense to a more dense medium, and their final direction is nearer the vertical than their original direction.

Owing to refraction the setting sun is still seen above the horizon when its geometrical position is below that level. The rays from the lower limb of the sun are more refracted than those from the upper so that the sun may appear to be somewhat flattened. When the stratification of the air is such that there are rapid changes of density in the vertical, the sun may appear much distorted and in some cases it can fade out of sight without apparently reaching the horizon.

Under similar circumstances objects which are normally invisible may appear above the horizon. For instance the coast of France has been seen occasionally from Hastings.

**Registering Balloon.**—A small balloon, usually free, carrying a light meteorograph recording pressure, temperature, and humidity of the upper air, etc. See SOUNDING BALLOON.

**Regression Equation.**—An approximate relation, generally linear, connecting two or more quantities, derived from the CORRELATION COEFFICIENT.

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\* Washington D.C., *Smithson. misc. Coll.*, 69, No. 10, 1919.

**Relative Humidity.**—The ratio of the actual amount of water vapour in a given volume of air to the amount which would be present were the air saturated at the same temperature, expressed as a percentage, is termed the relative humidity, or for the sake of shortness, simply "humidity."

Observations of relative humidity may be made directly with a hair hygrometer, but it is more usual to compute the value from readings of dry- and wet-bulb thermometers with the aid of tables. When great accuracy is required an aspirated psychrometer is used. Continuous records are obtained by means of hair-hygrographs or from thermographs arranged to record the dry-bulb and wet-bulb temperatures.

In the British Isles relative humidity exhibits a large diurnal variation, especially in the spring and summer months and in inland situations. High values, often reaching 100 per cent., occur in the early morning hours, and low values at the time of maximum temperature in the afternoon. The seasonal range of mean relative humidity is comparatively small. See AQUEOUS VAPOUR.

**Réseau Mondial.**—An annual publication of the Meteorological Office, Air Ministry, issued under the auspices of the International Meteorological Committee. It was recognized early in the present century that the next important step in the progress of international meteorology, after the publication of normal values for pressure, temperature and rainfall for the world, was the compilation year by year of monthly means of pressure, temperature and rainfall at stations in all parts of the world, organised to secure the uniformity of practice necessary for the purposes of comparison. The Committee appointed a commission, the International Commission for the Réseau Mondial, to foster the enterprise and the publication of the data commenced in 1917 with the volume for 1911. Since then the volumes for 1910 and 1912 onwards have been published, that for 1931 being issued in 1938. The data are arranged on the basis of two stations for each ten-degree square of latitude and longitude, and in the volumes for 1910 to 1920 only land stations were included. In the volumes for 1921 onwards marine data are also included. The information published for each station includes mean pressure, mean and absolute maximum and minimum temperatures, the observed or deduced mean of 24 hourly temperature readings and the total rainfall, together with the differences from normal for all three elements.

**Reshabar** or **rrashaba**.—A name meaning "black wind" given to a strong, very gusty, north-easterly wind which blows down certain mountain ranges in southern Kurdistan. It is dry, comparatively hot in summer and cold in winter.

**Residual.**—The difference between an individual observation and the mean of a series, or the difference between an individual observation and the value derived from the adopted values of the constants which have been obtained by a discussion of the observations. Thus an observed quantity  $l$  may be known to be a function of variables  $x, y, z$ , and constants  $a, b, c$ , of the form of  $ax + by + cz = l$ . If a number of observed values of  $l$  are given for known values of  $x, y$  and  $z$ , there will be  $n$  equations to determine the 3 constants  $a, b$ , and  $c$ . The equation will not in general be accurately satisfied for any one observation, and the value of  $l - (ax + by + cz)$  is called the residual.

**Resultant.**—The sum of a number of directed quantities or vectors. See COMPONENT and VECTOR.

**Reversal.**—A change of more than  $90^\circ$  in direction between the surface wind and the wind in the upper air. A reversal may take place near the ground or at any height up to 15,000 ft. or more. Reversals are common phenomena over coasts when land and sea breezes are blowing in directions greatly different from those that the general distribution of pressure would

dictate. The most permanent case of a reversal is over the trade wind, where in the North Atlantic the north-easterly surface current is replaced by a south-westerly one in the upper air. A spectacular example of this is afforded when an eruption of the Soufriere in St. Vincent occurs, for then the dust, carried by the upper current, falls in Barbados, though it lies 100 miles to windward of St. Vincent.

**Revolving Storm.**—A term synonymous with tropical CYCLONE or HURRICANE. See also LAW OF STORMS.

**Ridge.**—An extension of an ANTICYCLONE or high-pressure area shown on a weather chart, corresponding with a ridge running out from the side of a mountain. It is the opposite to a trough of low pressure. (See Plate IV).

**Rime.**—*Soft Rime.*—Deposits of white rough ice crystals that grow out to windward of exposed objects when frost and wet fog occur together. The minute supercooled drops of water, of which the fog is composed, freeze when they come in contact with a solid object. Hoar-frost, on the other hand, is formed by the direct freezing of water vapour, generally upon objects cooled by radiation under a clear sky; the presence of fog, in so far as it checks such radiation, tends to hinder the formation of hoar-frost.

*Hard Rime.*—Masses of ice deposited chiefly on vertical surfaces as described for soft rime, but they are formed in "wet air" or supercooled drizzle at temperatures below the freezing point and thus have a structure analogous to that of small hail.

**Roaring Forties.**—A nautical expression used to denote the prevailing westerly winds of temperate latitudes (below 40° S.) in the oceans of the southern hemisphere.

**Roll Cumulus.**—Banks of cloud arranged in long parallel rolls with clear spaces in between. A form of STRATOCUMULUS. See CLOUDS.

**Rosby Diagram.**—An aerological base diagram designed by C. G. Rossby in which the potential temperature of the air on a logarithmic scale forms the ordinate and the water content of the air in grams per kilogram (mixing ratio) forms the abscissa. Equivalent potential temperature is given by sloping lines; this is the temperature which any parcel of air would assume if all the water vapour which it contains were condensed at constant pressure and the latent heat set free used to raise the air temperature. POTENTIAL TEMPERATURE is the temperature which a parcel of air would assume if it were brought to standard pressure (1000 mb.) under adiabatic conditions. Thus equivalent potential temperature is that which the air would assume if all the water vapour were condensed and the dry air then brought adiabatically to standard pressure. Sloping curved lines on the Rossby diagram give the corresponding constant equivalent potential temperatures and the isotherms and isobars of dry air.

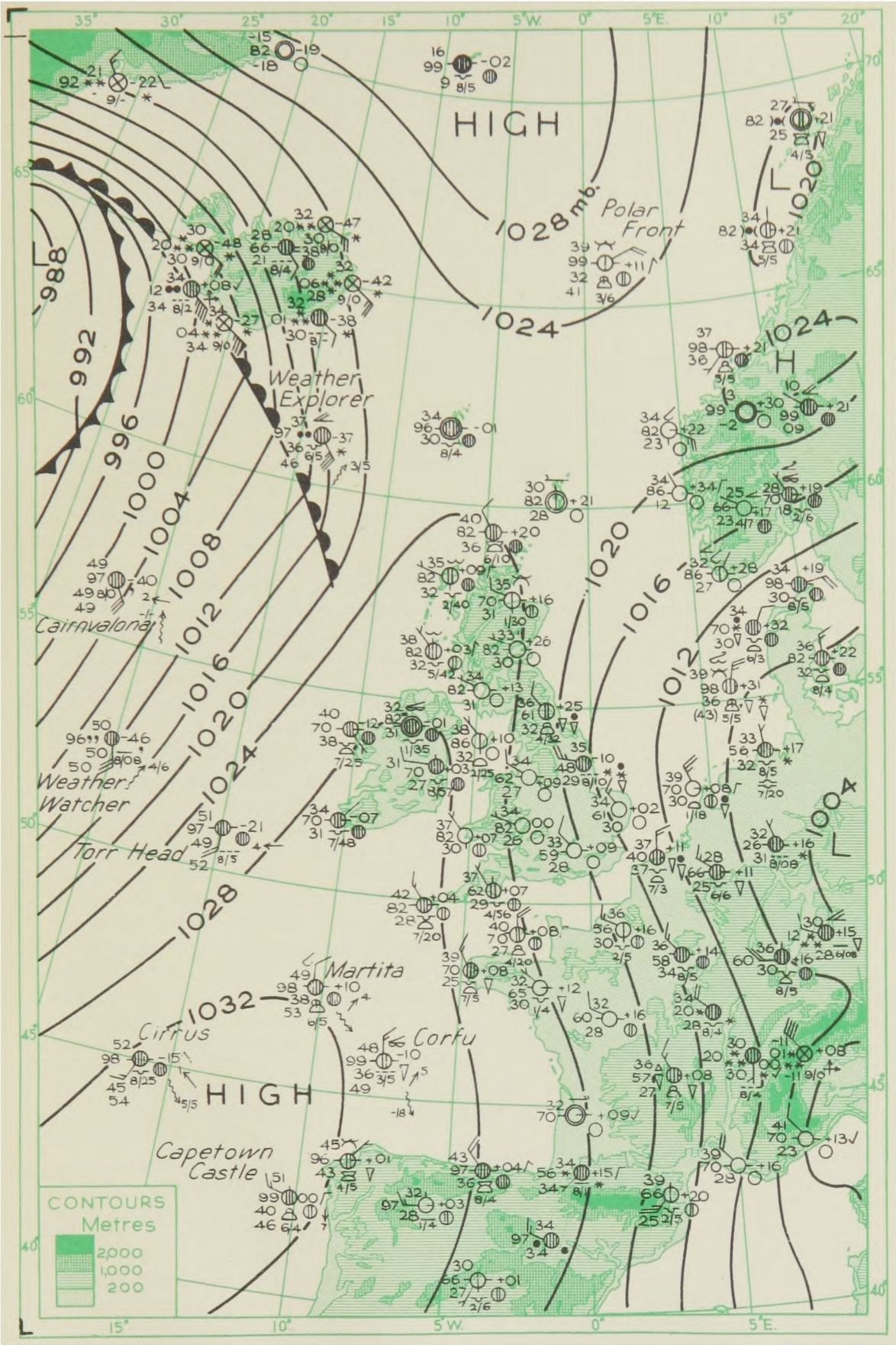
Both equivalent potential temperature and water vapour content are conservative properties of an AIR MASS, i.e. they change little from day to day and are therefore useful for identifying air masses in upper air soundings. Rossby has shown that if the equivalent potential temperature decreases with height the air is convectively unstable.

**Run-off.**—The portion of the rainfall over a DRAINAGE AREA which is discharged from that area in the form of a stream or streams.

**St. Elmo's Fire.**—A brush-like discharge of electricity sometimes seen on the masts and yards of ships at sea during stormy weather; it is also seen on mountains on projecting objects. It may be imitated by bringing a sharp pointed object, such as a needle, near a charged Leyden jar. According to Trabert's observations on the Sonnblick the character of St. Elmo's fire changes with the sign of the electricity which is being discharged into the air. The negative "fire" is concentrated so that an object like a mast is completely enveloped in fire. The positive fire takes the form of streamers some three or four inches long.

**St. Luke's Summer.**—A period of fine weather which is popularly supposed to occur about the time of St. Luke's day, October 18.





JANUARY 19, 1952, 0600 G.M.T.  
RIDGE OF HIGH PRESSURE



**St. Martin's Summer.**—A period of fine weather which is popularly supposed to occur about the time of St. Martin's day, November 11.

**Salinity.**—The salinity of a natural water, such as sea-water, is usually expressed in parts per thousand. Thus a salinity of 35 per mille (written  $35\text{‰}$ ) indicates that there are 35 lb. of salt in 1,000 lb. of sea water. Since the direct determination of total dissolved solids cannot be effected with accuracy, salinity is derived in practice by applying factors to the halide-content, which can be exactly estimated, or to the specific gravity. The value above given is a rough average for surface ocean water.

**Sand-pillar.**—See DUST-DEVIL.

**Sandstorm.**—Sandstorms occur when a strong wind carries relatively coarse sand through the air near the ground. A sandstorm rarely extends to a greater height than 50–100 ft. above the ground, though fine dust particles may be carried to greater heights, and the sand particles are not carried to appreciable distances from their source.

There is a marked distinction between sandstorms and duststorms. See DUSTSTORM.

**Sastrugi.**—(pl. : from the Russian) : Irregularities or wave formations caused by persistent winds on a snow surface. They vary in size according to the force and duration of the wind, and the state of the snow surface in which they are formed.

**Saturation.**—A given volume of ordinary air which is exposed to a plane surface of water or ice has for a given temperature a definite saturation pressure of water vapour (see AQUEOUS VAPOUR) ; this saturation pressure increases rapidly with increasing temperature. A fall of temperature would lead to CONDENSATION of some of this water vapour, while a rise of temperature would make the air unsaturated and therefore able to take up more water vapour. It may be noted that water can under certain conditions remain unfrozen at temperatures below  $0^{\circ}\text{C}$ . ( $32^{\circ}\text{F}$ .) and the saturation pressure relative to a surface of such " supercooled " water is greater than that relative to ice at the same temperature.

**Saturation Deficit.**—See AQUEOUS VAPOUR.

**Scalar.**—A quantity which is completely specified by a number as opposed to directed quantities such as wind velocity, which require for their complete specification both a number or magnitude (the wind speed) and a direction. Examples of scalar quantities in meteorology are temperature, pressure and humidity, but it must be noted that pressure gradient is not scalar but vectorial as its complete specification demands a direction as well as a number giving the magnitude. See VECTOR.

**Scintillation or Twinkling of the Stars.**—A rapid apparent variation in brightness and in colour. Scintillation occurs only with stars comparatively low down in the sky. The elevation up to which scintillation occurs has been found to vary in the course of the year. According to a series of observations made at Lyons the maximum elevation  $50^{\circ}$  occurs in March and September, the minimum  $22^{\circ}$  in June.\* Scintillation is certainly due to irregularities in the density of the air : the irregularities are carried along by the wind but how they are related to eddies and to wave motion in the atmosphere is not known.

**Scirocco.**—A warm, southerly or south-easterly wind which blows in front of a depression passing from west to east along the Mediterranean. As this wind comes from the Sahara desert it reaches the north coast of Africa as a hot, dry wind, its temperature having been further raised by the descent of the air from the inland plateau to the coastal regions. In crossing the Mediterranean evaporation occurs and the wind reaches Malta, Sicily and Italy and other parts of the European coast as a warm, moist wind.

The word scirocco seems to be used in some Mediterranean regions for a warm, southerly wind irrespective of whether it is moist or dry. Many of the warm, dry winds which are called sciroccos are probably FÖHN winds.

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\* *Météorologie, Paris*, 1927, p. 193.

**Scotch Mist.**—In mountainous or hilly regions, dense clouds are often adjacent to the ground, and precipitation may occur in the form of minute waterdrops, the apparent effect being a combination of thick mist and heavy drizzle. The upland character of the greater part of Scotland and the consequent frequency of occurrence of the phenomenon in that country have secured for it the appellation by which it is generally known in the British Isles. In the uplands of the Devon-Cornwall peninsula the same phenomenon, which is there of very frequent incidence, is known as "mizzle."

The base of a true rain cloud rarely exceeds about 7,000 ft. (2·1 Km.) in elevation, and sometimes descends to within a few hundred feet of sea level, so that Scotch mist may be experienced in comparatively low-lying regions.

**Screen, Stevenson.**—The standard housing for meteorological thermometers designed by Thomas Stevenson, C.E. It consists of a wooden cupboard, with hinged door, mounted on a steel or timber stand, so that its base is about 3 ft. 6 in. above the ground, the whole painted white. Indirect ventilation is provided through the bottom, double roof and louvered sides, and thermometers placed within it give a close approximation to the true air temperature, undisturbed by the effects of direct solar or terrestrial radiation. The "ordinary" pattern accommodates the wet- and dry-bulb, maximum and minimum thermometers. In the "large" pattern additional accommodation is provided for a thermograph and hygrograph.

**Scud.**—A word used by sailors to describe ragged fragments of cloud drifting rapidly in a strong wind, often underneath rain clouds. The meteorological term is *fractostratus*. See CLOUDS.

**Sea Breeze.**—See LAND AND SEA BREEZES.

**Sea Disturbance.**—The scale of sea disturbance is as follows :—

Scale	Description of sea
0	Calm—glassy.
1	Rippled.
2	Smooth.
3	Slight.
4	Moderate.
5	Rough.
6	Very rough.
7	High.
8	Very high.
9	Phenomenal.*

**Sea Level.**—The "level" surface which a stagnant sea would assume in the absence of waves, swell and tides. The surface is such that the normal drawn to it at any point lies in the direction of the resultant of the accelerations due to gravity and to the centrifugal force on the earth's rotation. The surface is an oblate spheroid in which the short axis coincides with the axis of the earth.

Owing to waves, swell and tides, the actual level of the sea is constantly changing, and it is therefore usual to denote its mean position at any place by the expression "mean sea level." The amplitude of the fluctuation of sea level from its mean position varies considerably from time to time and from place to place, but it is believed that the mean position, or mean sea level, remains practically constant at any place.

Mean sea level is generally used as the standard to which the contour heights of the topography of the ground are referred.

The contours given on the Ordnance Survey maps of England have hitherto been referred to the supposed position of the mean sea level at Liverpool, but recently the standard has been changed to the ascertained position of mean sea level at Newlyn in Cornwall. The Newlyn datum is 0·13 ft. below the Liverpool datum. Newlyn is more suited to the purpose since it is situated on the edge of the Atlantic Ocean and is not subject to sources of disturbance to which a place on a tidal river on an enclosed sea

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\* As might exist at the centre of a hurricane.



is liable. Contours on the Ordnance Survey maps of Ireland are referred to an assumed mean sea level at Dublin, which has been estimated to be about 8 ft. below that of the "level" surface passing through the corresponding datum at Liverpool. For definitions of normal zero in the various national surveys of Europe see *Réseau Mondial* 1914, pp. x-xi. See also LEVEL.

**Sea Temperature.**—The normal method of measuring sea temperature is to draw water in a bucket from the ship's side, forward of all ejection pipes and to read the temperature of the sample with a specially designed thermometer. The reading obtained is the mean temperature of the surface layer of the sea to the depth of about a foot, and is known as the sea surface temperature. No method has yet been devised for obtaining the temperature of the actual surface of the water. The mean annual surface temperature exceeds 80° F. over a broad belt of the equatorial region, and is somewhat less than 30° F. in the polar regions. The run of the isotherms varies in the two hemispheres and in the different oceans. The seasonal range of temperature is of the order of 10° F. in both polar and equatorial regions, and is greater in middle latitudes, where for the most part it lies between 10° F. and 30° F. The greatest range, 50° F. or more, is found in small areas, extending to the coast of the western North Atlantic and western North Pacific Oceans. The diurnal variation of sea surface temperature is very small, 1° F. or less.

**Seasons.**—The seasons in this country according to the "farmer's year" are :—autumn : September, October, November ; winter : December, January, February ; spring : March, April, May ; summer : June, July, August.

The idea of four seasons in agriculture appropriate to these islands, the winter for tilling, the spring for sowing and early growth, the summer for maturing and harvesting, and the autumn for clearing and preparing, depend upon the peculiarity of our climate. Where the land is ice-bound in winter or rainless in summer another distribution has to be made.

Between the tropics there is nothing that can properly be called summer and winter ; the seasons depend upon the weather and rainfall, and not upon the position of the sun, and the periods of growth are adjusted accordingly. In India, or the north-western part of it, the divisions of the year are the cold weather, the hot weather, and the rains. At the polar margins the change from winter to summer and vice versa is so sudden that there the transition seasons, spring and autumn, largely disappear.

The selection of months to represent the seasons according to the farmer's year is guided by the consideration that each season shall comprise three months. This uniformity in the length of the seasons, leads at times to paradoxical results. Thus, in a particular year, the warmest week may occur late in May or early in September, i.e. in spring or autumn and not in summer as defined above ; or again, the coldest week may occur late in November or early in March, i.e. in autumn or spring, and not in winter as defined above. From the point of view of weather, we have in this country about five months of moderate winter weather between October and April, and four months of summer weather from the middle of May to the middle of September, a short spring and a short autumn ; but the seasonal variations are not nearly so large here as they are in continental countries, and the change from winter to summer and vice versa is much less abrupt. Temperature, rainfall and sunshine data for individual stations and for districts are published in the *Weekly Weather Report* of the Meteorological Office and enable one to follow the course of the seasons in the British Isles. In the "Book of Normals of Meteorological Elements for the British Isles," Section II, are given normal values for each week of the year of mean temperature, rainfall and sunshine for each of twelve districts into which the British Isles have been divided. For information regarding the progress of rainfall from month to month in a normal year, the reader may consult in addition the "Rainfall Atlas of the

British Isles," published by the Royal Meteorological Society. Some interesting particulars of the temperature of the several seasons in the British Isles are also given in "Temperature Tables of the British Isles," M.O. 154, 1902, which includes diagrams showing the average daily maximum, minimum and mean temperatures, and the highest and lowest values respectively recorded on each day throughout the year in the period 1871-1900 at four observatories: Aberdeen, Valentia, Falmouth and Kew. The curves of mean temperature variation from day to day show numerous irregularities, but in their general form show a more or less progressive increase and decrease between a minimum in December or January and a maximum in July or August.

**Secondary Cold Front.**—A COLD FRONT in polar air, following the first cold front. If the polar current is unstable, there is sometimes an irregular series of secondary cold fronts of limited length, accompanied by heavy squalls and sometimes by thunder. The fall of temperature is often due mainly to the precipitation, and after the squall passes, the temperature sometimes recovers almost to its previous value.

**Secondary Depression or "Secondary."**—The isobars around a DEPRESSION are frequently not quite symmetrical, they sometimes show bulges or distortions, which are accompanied by marked deflections in the general circulation of the wind in the depression; such distortions are called secondaries; they may appear merely as sinuosities in the isobars, but at other times they enclose separate centres of low pressure and show separate wind circulations from that of the parent depression. In short, a secondary is a small area of low pressure accompanying a larger primary depression.

A secondary depression generally travels with its primary, but in addition the secondary, as a rule in the northern hemisphere, rotates about the primary in a counter-clockwise direction. On one synoptic chart the secondary may be shown on the western side of the primary depression while on the following day it may be on the eastern side of the depression, having as it were rolled round the southern side of the primary. Frequently the secondary becomes deeper while the primary becomes less intense; when such is the case the primary and the secondary tend to form a complex dumb-bell shaped depression, the two centres of low pressure revolving round each other in a counter-clockwise direction. Ultimately the secondary absorbs the parent depression, the two coalescing and forming one. When the secondary appears first as a sinuosity it often gives rise to precipitation of a more or less continuous type. As it develops and gradually attains a wind circulation about its own centre the weather tends to resemble that of an ordinary depression. Sometimes the secondary becomes so intense and deep that it gives rise to very violent and destructive gales. On the other hand, a secondary may have, as frequently happens in summer, a very feeble wind circulation and such a secondary sometimes gives rise to thunderstorms. The weather, however, associated with these systems is very capricious.

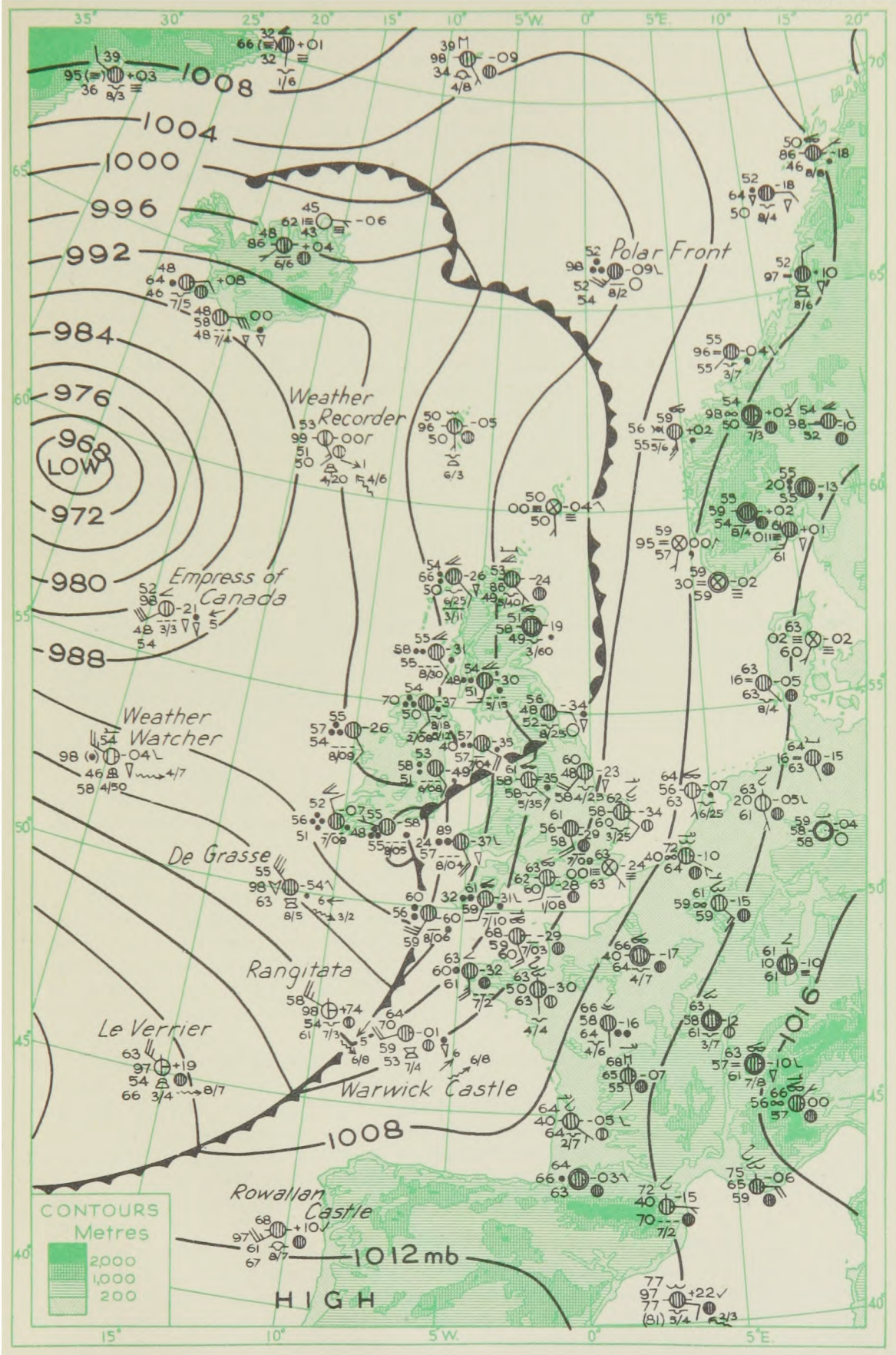
The wind circulation in a secondary obeys BUYS BALLOT'S LAW, and thus in the northern hemisphere, the wind circulates around it in a counter-clockwise direction. The region between the primary depression and the secondary is generally one of light and variable airs, the strongest winds being found on the side away from the main depression.

Many new depressions with warm sectors first appear as secondaries.

**Secular Trend.**—In statistics, a persistent tendency for a variate to increase or decrease with the passage of time, apart from irregular variations of shorter period. In meteorology, examples are the increase of pressure and temperature at St. Helena and the decrease of rainfall at Sierra Leone.\* Such changes obviously cannot continue indefinitely, and they are probably parts of oscillations of greater length than the available statistics. Secular trends can be determined by smoothing the data sufficiently, or by correlating with "time."

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\* See *London, Geophys. Mem.*, No. 33, 1926.



SEPTEMBER 13, 1951, 0600 G.M.T.  
SECONDARY DEPRESSION





**Seiche.**—The name given to the quasi-tides which were first observed to occur in the Lake of Geneva. It was known for some three centuries that the water of this lake is apt to rise and fall, sometimes by a few inches, occasionally by several feet. The phenomena were first investigated in detail by Professor Forel of Lausanne, and it was found that oscillations of the water were to be observed every day, with amplitudes varying from a millimetre to about a metre, and with periods between 20 and 40 minutes.

The phenomena are described and discussed in considerable detail in G. H. Darwin's "The Tides," where it is shown that the oscillations in the level of the surface are to be explained as long waves in relatively shallow water. Anything which heaps up the water at one end of the lake, and then ceases to act, must tend to produce an oscillation of the whole. Among the important causes of seiches are winds, small earthquakes which tilt the bed of the lake, and probably the atmospheric oscillations which are recorded as waves by the microbarograph. Some of the Japanese lakes show marked periods round about eight minutes, in agreement with the periods of greatest frequency in the microbarograph in fine weather.

Another type of seiche, called a temperature seiche, was discovered by Watson and Wedderburn in some of the Scottish lakes. There is often a stratum of abrupt change of temperature below the surface of a lake, and the observers mentioned noted waves in this layer of transition.

Seiches are to be found in all lakes, and analogous phenomena are to be noted in landlocked areas of the sea. There is now a considerable literature dealing with the subject, and special reference should be made to papers in the Transactions of the Royal Society of Edinburgh from 1905 onwards, by Chrystal and his pupils White, Watson and Wedderburn.

**Seismograph.**—An earthquake recorder or instrument for automatically recording the tremors of the earth. A seismological observatory requires three seismographs to show the vertical and two horizontal components of the motion of the ground.

**Seisms.**—Oscillations of the crust of the earth. See EARTHQUAKES, MICROSEISMS.

**Seistan Wind.**—A strong northerly wind which blows in summer in the province of Seistan, in eastern Persia. It continues for about four months, and is, therefore, known as the "wind of 120 days." It sometimes reaches hurricane force.

**Serein.**—Fine rain falling from an apparently clear sky. It is very rare.

**Shade Temperature.**—The temperature of the air indicated by a thermometer sheltered from precipitation, from the direct rays of the sun and from heat radiation from the ground and neighbouring objects, and around which air circulates freely. A standard shelter such as the Stevenson Screen is intended to satisfy these conditions. Provided certain precautions are taken the result is a close approximation to the actual temperature of the air. See SCREEN.

**Shadow of the Earth.**—The shadow of the solid earth is the region from which direct sunshine is cut off by the intervention of the globe. The height of the shadow overhead is frequently made manifest by the changing illumination of the clouds. A small cloud which is in sunshine and appears a beautiful pink at one minute is in shadow the next and fades to a dull grey, whilst higher clouds are still illuminated. At such a time the background of the clouds is blue, for the air at greater heights is still illuminated by direct sunshine.

The shadow thrown on the air itself can also be observed with ease. Soon after sunset a dark segment is to be noticed in the eastern sky encroaching on the "counterglow" the band of reddish tint which runs round the horizon. This dark segment is the earth's shadow. As the boundary of the shadow rises the upper edge of the counterglow remains almost stationary and both are usually lost when the sun is about  $4^{\circ}$  below the horizon and the elevation of the boundary of the shadow is about  $10^{\circ}$ .

Whilst the shadow is perceptible all the air to the east of the observer is illuminated by light which has been scattered by the atmosphere, but the air at great heights is illuminated also by direct sunshine. The shadow is the part of the sky in which the additional light which comes to the observer from such great heights is inappreciable. The boundary is sharp when the line of sight is nearly parallel to the sun's rays but when the shadow climbs the observer is looking obliquely across the sun's rays and the boundary becomes indefinite and is lost.

When the sun is about  $10^\circ$  below the horizon, directly illuminated air is to be seen only near the western horizon; the upper limit of the illuminated segment is the boundary of the earth's shadow. This boundary is sometimes called the **TWILIGHT ARCH**. By the time the sun is  $18^\circ$  below the horizon, if not before, the whole of the atmosphere within sight is in shadow, and **TWILIGHT** has ended.

**Shamal.**—A north-westerly wind which blows in summer over the Mesopotamian plain. It is often strong during the daytime but decreases at night.

**Shower.**—In describing present or past weather, the following distinction is made between the use of the terms "showers" and "occasional precipitation." In general, showers are of short duration and the fair periods between the showers are usually characterised by definite clearance of the sky. The clouds which give the showers are, therefore, isolated. The precipitation does not usually last more than fifteen minutes, although it may sometimes last for half an hour or more. Typical showers occur in the W. or NW. current of **POLAR AIR** behind a depression which has passed eastwards. This current is warmed from below and becomes unstable, hence these showers are called instability showers; in the Beaufort notation they are termed "passing showers" and are denoted by "p." Occasional precipitation, on the other hand, usually lasts for a longer time than the showers and the sky in the periods between the precipitation is usually cloudy or overcast.

**Silver Thaw.**—An expression of American origin. After a spell of severe frost the sudden setting in of a warm, damp wind may lead to the formation of ice on objects, which being still at a low temperature cause the moisture to freeze upon them and give rise to a "silver thaw." See **GLAZED FROST**.

**Simoom.**—A hot, dry suffocating wind or whirlwind which occurs in the deserts of Africa and Arabia. It usually, but not invariably, carries a large quantity of sand. It does not usually last long, not more than about 20 minutes. It is most frequent in the spring and summer.

**Sine Curve.**—See **HARMONIC ANALYSIS**.

**Single Observer Forecasting.**—The method of forecasting used by isolated observers when cut off from weather information from neighbouring areas.

Most weather forecasts prepared by Meteorological Services are based on synoptic charts and are issued to the public by radio, telegraph, telephone, etc., or through the press. These forecasts are often accompanied by synoptic data from which the recipient can draw his own weather charts. When, as sometimes happens for various reasons, this information is not available, the "Single Observer" must rely on his own observations of cloud, wind, temperature, pressure, etc., to tell him what weather to expect. The development of the theory of air streams and their boundary "fronts" enables the changes in the atmosphere to be more readily interpreted and provides the links by which various weather maxims may now be joined together.

Although the forecasts issued by the single observer cannot compare in accuracy with those based on synoptic charts, a certain amount of success can be obtained for a few hours ahead, especially if the observer has lived

long enough in one are to become familiar with local peculiarities. See also **WEATHER MAXIM** and "The Fishery Barograph," a note on the use of the barograph in anticipating gales.

**Sirocco.**—See **SCIROCCO**.

**Site.**—In order to secure observations comparable with those at other stations, the site of a meteorological **STATION** has to be carefully selected in accordance with certain rules which are set out in the "Observer's Handbook". A rain-gauge requires a certain amount of protection from the wind, but for the other outdoor instruments the more open the site, the better. A compromise is usually effected. The latitude, longitude and height of the ground on which the rain-gauge stands are used to define the position of a station.

**Skewness.**—See **MEDIAN**.

**Sky, State of the.**—Fraction of the sky obscured by cloud on a scale of 0 (cloudless) to 8 (an entirely overcast sky in which no patches of blue sky are visible). In the **BEAUFORT NOTATION** letters, b, blue sky whether with clear or hazy atmosphere, c, cloudy, i.e. detached opening clouds, o, sky overcast with one impervious cloud, and u, ugly, threatening sky are also used in addition or alone to indicate the general appearance of the sky. (See "Observer's Handbook.")

**Sleet.**—Precipitation of snow and rain together or of melting snow and rain. In some countries there is no special term for this form of precipitation. In America the term is used in a different sense: Humphreys (in "Physics of the Air") defines it as "ice pellets, mere frozen raindrops or largely melted snowflakes re-frozen—frozen during the fall of the precipitation through a cold layer of air near the surface of the earth—that rattle when they strike a window."

**Slide Rule, Pilot Balloon.**—A slide rule designed to facilitate the rapid computation of the components of the wind velocity from observations of altitude and azimuth of a **PILOT BALLOON**. Provision is also made, in the most recent type, for computing the height when the "tail" method of observation is employed.

**Sling Thermometer.**—A thermometer mounted on a frame pivoted about a handle so that it can be whirled in the hand, thus providing "ventilation." If the bulb is shielded from direct solar radiation satisfactory readings of air temperature can thus be obtained in a simple and inexpensive manner. A pair of thermometers, dry- and wet-bulb, similarly used, constitute a "sling" or "whirling" psychrometer. See also **PSYCHROMETER**.

**Small Hail.**—See **HAIL**.

**Snow** is precipitation in the form of ice crystals of feathery or needlelike structure. The crystals may fall singly, or a large number of them may be matted together in the form of large flakes.

The characteristic shape of the simplest ice crystal is a small flat triangular or hexagonal plate, but most snow crystals show much more complicated structures, ranging from needles to six-pointed stars with numerous spreading branches. More than 2,000 forms have been photographed by W.A. Bentley at Jericho, Vermont, Canada. The method of formation of such stars has been described by O. Lehmann, who has watched under the microscope the development of star crystals of iodoform and other substances from a slightly supersaturated solution of the substance.

According to Lehmann the first step in the process is the formation of a minute flat crystal in the form of a regular hexagon. The crystal continues to grow in that form until it is seen from the lighter colour of the solution immediately bordering on it, that the supersaturation is now confined to the parts of the liquid which are more distant from the crystal, while the solution

in immediate contact with the crystal is only just saturated. Thereafter the crystal grows more slowly and only as the more concentrated liquid finds its way to the crystal by diffusion. The parts of the crystal nearest to the concentrated liquid (that is, the corners of the hexagon) are those first affected by this process of diffusion; consequently from this stage the crystal begins to develop pointed rays which grow outwards from the six angles of the original hexagon. This process proceeds until the rays are so long as to allow relatively concentrated solution to diffuse in between them; this in turn induces sideways growths of spikes from the original arms of the star. If now a weakening of the concentration of the outside solution occurs, then the arms of the star will cease to grow outwards, but facets will tend to form at their ends and the growth of the side spikes will continue. Alternations of increasing and decreasing concentration will produce varied forms of crystal.

Wegener showed that symmetrical branching snow crystals might be expected to form by a similar process in air below freezing point, having a moisture content in excess of that corresponding to saturation with respect to ice at the air temperature.

Recently our knowledge has been extended by Nakaya and various collaborators, who have found it possible to reproduce artificially the various forms of simple ice crystals and star-shaped snow crystals observed in nature. Nakaya found that delicate fern-like snow crystals were produced in his apparatus with an air temperature of the order of  $-20^{\circ}\text{C}$ . and an abundant supply of moisture. At much lower temperatures only irregular crystal aggregates could be produced. (See *London, Quart. J. R. met. Soc.*, **64**, 1938, pp. 619-24.)

A foot depth of freshly fallen snow is equivalent roughly to one inch of rain, but the ratio varies considerably with the depth and texture of the snow. After deposition progressive changes of texture and therefore of density occur. For a full discussion of the snow and ice forms met with in nature, see G. Seligman "Snow Structure and Ski Fields" (Macmillan, 1936).

**Snow, day of.**—In British climatology any period of 24 hours ending at midnight G.M.T. upon which snow is observed to fall is regarded statistically as a "day of snow."

**Snowdrift.**—When snow falls on a day of strong wind it does not readily settle in open places, but will normally do so wherever there is a region which is sheltered from the full force of the wind. Much of the dislocation of traffic caused by heavy falls of snow is due to the "drifts" formed in this way. Drifts may even be formed when no snow is falling, by the action of the wind upon already fallen snow; snow carried in this way is called drift-snow.

The word, therefore, has two meanings:—

- (1) an accumulation of snow, forming drift;
- (2) snow that drifts with the wind.

Two international symbols were adopted at Warsaw in 1935 to denote drift snow, namely  $\rightarrow$  to be used when the snow is drifting at ground level, and  $\uparrow$  to be used when the drifting is occurring at a high level so as to affect vertical velocity.

**Snow-gauge.**—A device for the retention and measurement of snow. In the Hellmann-Fuess snow-gauge the snow is caught in a receiver supported on a balance, the displacement of which is continuously recorded, so that an autographic record of snowfall (and of the fall of rain and hail also) is obtained. Most snow-gauges are, however, merely rain-gauges fitted with jackets or other devices to make them suitable for collecting solid precipitation, and for melting it before taking the reading.

**Snow Line.**—The lower limit in altitude of the region of perpetual snow. In high polar latitudes the snow line is at sea level; in northern Scandinavia it is at about 4,000 ft., in the Alps at about 8,500 ft., in the Himalayas at



about 15,000 ft. These figures are only approximate, as the height of the snow line varies on the north and south sides of a mountain and from one mountain to another in the same latitude or region. It has no direct relation to the mean annual temperature, depending more on the summer temperature, but many other factors exert an influence, such as amount of snow in winter, prevailing winds, exposure and steepness of the slopes, etc.

**Snow Lying.**—This expression (International symbol ☒) is used for occasions when one-half or more than one-half of the ground representative of the station is covered with snow. The ground representative of the station is defined as "the flat land easily visible from the station and not differing from it in altitude by more than 100 ft." British statistics of snow lying refer only to occasions when this state of affairs exists at the hour of morning observation.

**Snow Rollers.**—Cylinders of snow, formed and rolled along by the wind.

**Soft Hail.**—See HAIL.

**Soil Moisture.**—A factor of obvious importance in relation to the growth of plants, soil moisture is also of meteorological interest because it affects the thermal diffusivity of the soil and, therefore, the rate at which heat can be conducted upwards or downwards. In the instrument designed by W.S. Rogers (see *Annual Report of the East Malling Research Station*, 1935, p. 111), soil moisture is measured by determining the "capillary pull" of the soil. This force is due mainly to the surface tension of the water film surrounding the soil particles, and it varies with the amount of moisture in the soil, the size of the soil particles and the degree of compactness of the soil. The instrument consists of a water-filled porous pot connected with a pressure gauge or manometer. The pot is buried to the required depth and the capillary pull is indicated by the pressure gauge.

**Solano.**—An easterly wind which brings rain to the south-east coast of Spain and in the Straits of Gibraltar.

**Solar Constant.**—The solar constant is the intensity of the RADIATION in the solar beam in free space at the earth's mean distance from the sun. Observations of solar radiation have been made for many years on high mountains in desert climates at stations organised by Dr. G. C. Abbot and his colleagues of the Smithsonian Institution. In the fundamental observations the spectral distribution of the intensity of radiation is determined for various altitudes of the sun and the intensity outside the atmosphere is deduced by extrapolation. The consistency of the observations has improved steadily since 1905, but not all of the vagaries of atmospheric absorption can be allowed for, and even in 1934 the probable error of a single determination of the solar constant had not been reduced below 1 per cent. Dr. Abbot has maintained that the observations indicate appreciable variations in the solar constant. Thus he finds that the annual mean, expressed in terms of the usual unit, the calorie per square centimetre per minute, was 1.933 in 1929 and 1.947 in 1934. The variations are associated with changes in the constitution of the radiation. The energy of the long waves does not vary. It is in the blue and violet, and especially in the ultra-violet, that fluctuations occur. In other words, if Dr. Abbot's interpretation of the observations can be accepted, the sun is a variable star which undergoes changes of colour. On the other hand it must be mentioned that a detailed careful examination\* of the published statistics has led Dr. M. M. Paranipe to the conclusion that "there is no direct evidence that the solar constant is subject to variations."

The value of the constant may be taken as 1.94 cal./cm.<sup>2</sup>/min. This is equivalent to 135 mw./cm.<sup>2</sup>

\* *London, Quart. J.R. met. Soc.*, 64, 1938, p. 473

**Solar Day.**—See EQUATION OF TIME, CALENDAR.

**Solar-Radiation Thermometer.**—See BLACK-BULB THERMOMETER.

**Solarimeter.**—An instrument designed by L. Gorczynski for determining the intensity of solar radiation. It consists essentially of a sensitive thermopile of low thermal capacity and low resistance connected in series with a millivoltmeter. According to the method of mounting, it may be used to determine the intensity of the normal solar radiation or the vertical component of the total radiation from sun and sky. If a recording millivoltmeter is substituted for the direct-reading instrument, the combination is known as a "solarigraph."

**Solstice.**—The time of maximum or minimum declination of the sun, when, for a few days, the altitude of the sun at noon shows no appreciable change from day to day. The summer solstice for the northern hemisphere, when the sun is farthest north of the equator, is about June 22, and the winter solstice, when it is farthest south, is about December 22. After the summer solstice the days get shorter until the winter solstice and vice versa.

**Sounding Balloon.**—For the purpose of measuring pressures and temperatures, etc. in the upper air, a balloon is employed larger than a pilot balloon, having a diameter (at ground level when inflated with hydrogen) of about four feet. This balloon carries a light meteorograph attached to a bamboo framework or "spider." In order that the meteorograph may be some distance from the balloon, which is likely to become heated owing to sunshine, a special launcher is employed; this launcher gradually unwinds a length of cotton thread as the balloon ascends, finally leaving the meteorograph some hundred feet below the balloon. The balloon rises, expanding as it goes, and ultimately bursts, probably having reached an altitude of over 12 miles. The remains of the balloon, together with the instrument, then fall to the ground, the bamboo framework protecting the instrument from mechanical injury. A label is attached asking the finder to return the meteorograph. It occasionally happens that a balloon, which for some reason does not burst, floats for many hours and is carried hundreds of miles before falling to earth. The meteorograph designed by the late W. H. Dines, weighs  $2\frac{1}{2}$  ounces, including the aluminium case, while the bamboo framework weighs about  $1\frac{1}{4}$  ounces. Owing to this light weight, no parachute or other appliance, in addition to the bamboo framework, is needed to break the fall.

The meteorograph referred to is constructed as follows. The pressure recorder operates by means of an aneroid box, the sides of which are connected by arms with the scribing point and the record plate, thus an expansion or contraction of the box results in a movement of the point across the plate. The thermograph for recording temperature consists of an invar rod and a thin strip of nickel silver, rigidly fastened together at their lower ends, and connected to a lever by spring joints at their upper ends. The expansion and contraction of the strip of nickel silver relative to the nearly invariant invar rod, cause a vertical movement of the scribing point relative to the plate. During calibration, definite marks at known pressures and temperatures are made on the actual record plate, and the final trace can be compared with these marks. The actual trace on a silvered plate is very durable, and even if the meteorograph lies out in the open for months before being found, the record is unlikely to be damaged.

A modification of the above arrangements is required for temperature records over the sea. If a meteorograph were carried by a single balloon, the instrument would be lost owing to sinking should the balloon burst. It is necessary, therefore, to employ two balloons of a larger size than those mentioned above. The two balloons are flown tandem fashion, and the top balloon is inflated to have a lift of about 8 lbs., while the lower balloon has a lift of some 2 lbs. A sea-anchor float is carried about 30 ft.



*Normal Pressure for the Several Months at Various Heights over south-east England.*

(Computed from Sea-level Pressures at Kew, and the Temperatures in Table IV, 2, Computer's Handbook II. § 2. p. 55.)

Height	January	February	March	April	May	June	July	August	September	October	November	December	Range
Km.	Pressure in millibars.												
15	116	116	116	118	121	123	125	125	124	122	119	117	9
14	136	135	136	138	142	144	146	146	145	142	139	137	11
13	159	159	159	162	165	168	170	170	169	166	163	160	11
12	187	186	186	189	193	196	199	198	198	194	191	188	13
11	218	217	217	221	226	229	232	232	231	227	223	220	15
10	255	254	254	259	264	267	270	270	269	265	260	256	16
9	297	297	297	302	307	311	314	313	312	308	303	299	17
8	346	346	346	350	356	360	363	362	361	356	351	347	17
7	401	401	400	405	410	415	417	416	416	411	406	402	17
6	463	462	462	467	472	476	478	478	477	472	468	464	16
5	532	532	531	535	540	544	546	546	545	540	536	533	15
4	610	609	608	612	616	620	621	621	620	616	612	610	12
3	696	695	693	697	701	704	705	705	704	700	697	695	13
2	792	790	789	791	795	797	798	797	798	794	792	790	9
1	899	897	895	897	900	901	902	900	902	898	897	896	7
Gd.	1018	1016	1014	1014	1016	1016	1016	1015	1017	1014	1014	1014	4

At all heights above the ground level the maximum pressure occurs in the hottest months. The seasonal variation in the normal pressure at sea level is small.

*Table of Results obtained with Sounding Balloons in the United Kingdom.*

Normal Temperature at different levels in the atmosphere up to twelve kilometres for the several months of the year.

Height in. Km.	January	February	March	April	May	June	July	August	September	October	November	December	Year
	°A.	°A.	°A.	°A.	°A.	°A.	°A.	°A.	°A.	°A.	°A.	°A.	°A.
12	217	218	219	220	221	222	222	221	221	219	218	217	220
11	17	17	17	19	20	21	22	22	21	20	19	18	19
10	20	20	20	22	24	25	26	26	26	24	23	21	23
9	24	23	24	26	29	31	34	33	33	31	28	25	28
8	30	29	30	32	36	38	41	41	41	38	35	32	35
7	37	36	37	39	42	45	47	48	47	45	41	38	42
6	43	43	44	46	49	52	55	55	54	51	49	45	49
5	50	49	50	52	56	59	61	62	61	58	55	52	55
4	57	56	57	59	62	65	67	68	67	64	61	58	62
3	63	62	63	65	68	71	73	74	73	70	67	64	68
2	67	66	67	70	73	76	78	79	78	75	72	69	73
1	71	71	73	76	79	82	83	83	81	79	75	72	77
Gd.	76	76	77	82	85	88	89	89	86	83	80	77	82

Taken from *London, Geophys. Mem.*, No. 2 (W. H. Dines), 1911.

**Southerly Buster.**—A name given in south and south-east Australia to a sudden change of wind usually from a north-westerly direction to a southerly direction, which is accompanied by a sudden fall in temperature. This change of direction occurs behind a cold front, and if the rise of pressure is considerable the southerly wind is violent. The arrival of the southerly wind is usually marked by a long crescent-shaped roll of cloud. The temperature sometimes falls as much as 30° F. or 40° F. in half an hour. These storms are sometimes accompanied by thunder and lightning. They are similar to the PAMPEROS of South America and the LINE-SQUALLS of our latitudes. They are most prevalent from October to March.

**Spring.**—See SEASONS.

**Squall.**—A strong wind that rises suddenly, lasts for some minutes, and dies comparatively suddenly away. It is frequently, but not necessarily, associated with a temporary change in direction. The most important squalls in the British Isles, especially from the view-point of aviation, are the **LINE-SQUALLS** in which the heavy increase in velocity is accompanied by a veer of some 3 to 8 points and with which are associated the long arch of low black cloud (which gives the squalls their name) and rain or hail with a sudden drop of temperature. Squalls are to be distinguished from gusts, the constant fluctuations which occur in any wind due to local obstructions and surface friction.

**Squall Line.**—The name originally given to what is now known as the **COLD FRONT** of a depression. It marks the line along which cold air is undercutting warm air. Its passage is marked usually by squalls (hence the older name), and, in such countries as the British Isles, it is often associated with heavy cloud and rain or hail. With its passage the barometer rises abruptly and there is a sudden or rapid fall of temperature. See **LINE-SQUALL**.

**Stability.**—A state of steadiness not upset by small displacements or disturbances. See **INSTABILITY**.

**Standard.**—A prescribed measure or scale of any kind, such as a weight, length, volume, etc., which is used as a unit or scale of reference. The legal magnitude of a unit of measure or weight.

**Standard Atmosphere\*.**—The International Standard Atmosphere which is used as the basis of graduation of altimeters assumes at mean sea level a temperature of 15° C., a pressure of 760 mm. (1013.2 mb.), and a lapse rate of 6.5°C./Km. from sea level up to 11 Km., above which the temperature is assumed constant at - 56.5° C.

For purposes such as aircraft design for which this International Standard is not sufficient, the standard atmospheric temperatures defined by the table on p. 181 (issued by the Ministry of Aircraft Production) may be assumed.

**Tropical Summer Standard.**—These temperatures are based on statistics of the Indian Meteorological Department, 1935–1937, and are representative of tropical conditions and those prevailing in the "Near East".

**Temperate Summer Standard.**—These temperatures are based on observations at Kew and Sealand over the period 1921–1935 and on records of the Duxford Meteorological Flight. The arbitrary maximum has been chosen so that European conditions are covered for design purposes.

**Sub-arctic Winter Standard.**—These temperatures are based on observations at Petropavlovsk (lat. 59° 41' N.) 1902–1909, Abisko (lat. 68° 21' N.) 1907–1929 and Obdorsk (lat. 66° 31' N.) 1936.

**Standard Deviation.**—If  $n$  observations of a quantity are  $x_1, x_2, \dots, x_n$ , and their mean or average is  $\bar{x}$ , defined by  $n\bar{x} = \text{sum of the } n \text{ individual observations}$ , the standard deviation  $\sigma$  is defined by the equation:—

$$n\sigma^2 = (x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \dots + (x_n - \bar{x})^2$$

When the observations are distributed according to the **NORMAL LAW OF ERRORS**, there are certain theoretical advantages in using  $(n - 1)\sigma^2$  instead of  $n\sigma^2$  on the left hand side of the equation above, but in practice the difference between the two formulae is small.

The square of the standard deviation is called the *variance*.

**Standard Error.**—The **STANDARD DEVIATION** is usually calculated on the assumption that the mean of the sample of observations available is the true mean of the element. This is not generally correct, the true mean being

\* The International Civil Aviation Organization (I.C.A.O. Doc. 7041) adopted a standard atmosphere with the same specification except that height is expressed in engineering geopotential units. The atmospheres are, numerically, almost identical. To obtain the I.C.A.O. atmosphere for "Km." from "engineering geopotential Km." note that 1 engineering geopotential metre equals 9.80665 m.<sup>2</sup> sec.<sup>-2</sup> and is thus slightly different from the meteorological geopotential metre of 9.80000 m.<sup>2</sup> sec.<sup>-2</sup>

unknown. An approximate allowance for this source of error may be made by dividing the sum of squares of departures from mean by  $n - 1$  instead of by  $n$ , giving as the most probable value of the standard deviation about the true mean

$$\sqrt{\frac{\sum (x_r - \bar{x})^2}{n - 1}}$$

This is often termed the "standard error" of the sample.

**Standard Gravity.**—See GRAVITY.

**Standard Time.**—Time referred to the mean time of a specified meridian. The meridian of Greenwich is the standard for western Europe. The standard meridian for other countries is generally chosen, so that it differs from Greenwich by an exact number of hours or half-hours. (See also ZONE TIME.)

**State of the Ground.**—See GROUND, STATE OF.

**State of the Sky.**—See SKY, STATE OF THE.

**Station.**—In meteorology, the word signifies a fixed place where regular meteorological observations are made. Stations vary greatly from one another in equipment and in the character and extent of the observations made, but at all stations which report to a central Meteorological Office the observations are made on a uniform plan and according to a set time-table, so that the results or summaries of them can be published in an orderly way, rendering comparisons easy and reliable.

The number of stations in the British Isles is about 5,500; by far the majority of these are maintained by voluntary observers who in most cases report measurements of rainfall only.

The International Congress of Meteorologists which assembled at Vienna in 1873, adopted a classification of stations, based on the scheme of observations to be taken, as follows:—

(1) First-order stations of the International Classification. Normal meteorological observatories: at which continuous records, or hourly readings, of pressure, temperature, wind, sunshine, and rain, with eye observations at fixed hours of the amount, form, and motion of clouds and notes on the weather, are taken.

(2) Second-order stations of the International Classification. Normal climatological stations: at which are recorded daily, at two fixed hours at least, observations of pressure, temperature (dry- and wet-bulb), wind, cloud and weather, with the daily maxima and minima of temperature, the daily rainfall and remarks on the weather. At some stations the duration of bright sunshine is also registered.

(3) Third-order stations of the International Classification. Auxiliary climatological stations: at which the observations are of the same kind as at the normal climatological stations, but (a) less full, or (b) taken once a day only, or (c) taken at other than the recognised hours.

This classification serves to indicate the kind of differences which still exist between meteorological stations at which observations are made of elements besides rainfall, but the classification does not take effective cognizance of types of stations which are now in operation for certain specific purposes. For example:—

(a) *At telegraphic reporting stations*, observations are made daily at some or all of the hours 0h., 3h., 6h., 9h., 12h., 15h., 18h., 21h. G.M.T., and telegraphed to the central office for use in the preparation of synoptic charts for weather forecasting. Other kinds of observations have been introduced, particularly cloud height, change in barometer in last 3 hours, visibility, sea disturbance.

(b) *At stations on airfields*, observations are often made every hour for the benefit of pilots. Visibility, cloud, and the motion of upper currents are important items of the programme. In addition, these stations are equipped as first-order stations and a corresponding programme of work is carried out.

## STANDARD ATMOSPHERIC CONDITIONS FOR DESIGN PURPOSES

(May, 1941)

Air Density at Zero Height (Barometer 1013.2 mb., Temp. 15° C.) is 0.07652 lb./ft.<sup>3</sup>

I.C.A.N. conditions				Sub-arctic winter		Temperate summer		Tropical summer	
Height feet	Relative pressure	° C.	Relative density	° C.	Relative density	° C.	Relative density	° C.	Relative density
0	1.000	15.00	1.000	-20.0	1.138	27.00	0.960	41.00	0.917
1,000	0.964	13.02	0.971	-18.0	1.089	25.02	0.932	39.02	0.890
2,000	0.930	11.04	0.943	-17.0	1.046	23.04	0.905	37.04	0.864
3,000	0.896	9.06	0.915	-16.4	1.006	21.06	0.878	35.06	0.838
4,000	0.864	7.08	0.888	-16.2	0.969	19.08	0.852	33.08	0.813
5,000	0.832	5.09	0.862	-16.4	0.934	17.09	0.826	31.09	0.788
6,000	0.801	3.11	0.836	-17.1	0.901	15.11	0.801	29.11	0.764
7,000	0.771	1.13	0.810	-18.3	0.872	13.13	0.776	27.13	0.740
8,000	0.743	-0.85	0.786	-20.2	0.846	11.15	0.753	25.15	0.717
9,000	0.715	-2.83	0.762	-22.1	0.821	9.17	0.730	23.17	0.695
10,000	0.688	-4.81	0.739	-24.0	0.796	7.19	0.707	21.19	0.674
11,000	0.661	-6.79	0.715	-26.0	0.771	5.21	0.684	19.21	0.651
12,000	0.636	-8.77	0.693	-28.0	0.748	3.23	0.663	17.23	0.631
13,000	0.611	-10.76	0.671	-30.0	0.724	1.24	0.642	15.24	0.610
14,000	0.587	-12.74	0.650	-31.9	0.701	-0.74	0.621	13.26	0.591
15,000	0.564	-14.72	0.629	-34.0	0.680	-2.72	0.601	11.28	0.571
16,000	0.542	-16.70	0.609	-35.9	0.658	-4.70	0.582	9.30	0.553
17,000	0.520	-18.68	0.589	-37.7	0.636	-6.68	0.562	7.32	0.534
18,000	0.499	-20.66	0.570	-39.6	0.616	-8.66	0.544	5.34	0.517
19,000	0.479	-22.64	0.551	-41.2	0.595	-10.64	0.526	3.36	0.499
20,000	0.459	-24.62	0.532	-43.1	0.575	-12.62	0.508	1.38	0.482
21,000	0.441	-26.61	0.515	-44.9	0.557	-14.61	0.492	-0.61	0.466
22,000	0.422	-28.59	0.498	-46.5	0.537	-16.59	0.474	-2.59	0.450
23,000	0.404	-30.57	0.481	-48.1	0.518	-18.57	0.458	-4.57	0.434
24,000	0.387	-32.55	0.464	-49.7	0.499	-20.55	0.441	-6.55	0.419
25,000	0.371	-34.53	0.448	-51.3	0.482	-22.53	0.427	-8.53	0.404
26,000	0.355	-36.51	0.432	-53.0	0.465	-24.51	0.411	-10.51	0.389
27,000	0.340	-38.49	0.417	-54.6	0.448	-26.49	0.397	-12.49	0.375
28,000	0.325	-40.47	0.402	-56.0	0.431	-28.47	0.383	-14.47	0.362
29,000	0.311	-42.46	0.388	-57.5	0.416	-30.46	0.369	-16.46	0.349
30,000	0.297	-44.44	0.374	-59.0	0.400	-32.44	0.356	-18.44	0.336
31,000	0.283	-46.42	0.360	-60.1	0.383	-34.42	0.342	-20.42	0.323
32,000	0.271	-48.40	0.347	-61.4	0.369	-36.40	0.330	-22.40	0.311
33,000	0.258	-50.38	0.334	-62.8	0.353	-38.38	0.317	-24.38	0.299
34,000	0.247	-52.36	0.322	-64.0	0.340	-40.0	0.305	-26.36	0.288
35,000	0.235	-54.34	0.310	-65.0	0.326	-40.0	0.290	-28.34	0.277
36,000	0.224	-56.32	0.298	-65.0	0.310	-40.0	0.277	-30.32	0.266
37,000	0.214	-56.50	0.284	-65.0	0.296	-40.0	0.265	-32.30	0.255
38,000	0.204	-56.50	0.271	-65.0	0.282	-40.0	0.252	-34.28	0.246
39,000	0.194	-56.50	0.258	-65.0	0.269	-40.0	0.240	-36.27	0.236
40,000	0.185	-56.50	0.246	-65.0	0.256	-40.0	0.229	-38.25	0.227
41,000	0.176	-56.50	0.234	-65.0	0.244	-40.0	0.218	-40.23	0.218
42,000	0.168	-56.50	0.223	-65.0	0.232	-40.0	0.208	-42.21	0.209
43,000	0.160	-56.50	0.213	-65.0	0.222	-40.0	0.198	-44.19	0.201
44,000	0.153	-56.50	0.203	-65.0	0.211	-40.0	0.189	-46.17	0.194
45,000	0.145	-56.50	0.193	-65.0	0.201	-40.0	0.179	-48.15	0.186
46,000	0.139	-56.50	0.184	-65.0	0.192	-40.0	0.172	-50.13	0.179
47,000	0.132	-56.50	0.176	-65.0	0.183	-40.0	0.163	-52.11	0.173
48,000	0.126	-56.50	0.167	-65.0	0.174	-40.0	0.156	-54.09	0.165
49,000	0.120	-56.50	0.160	-65.0	0.167	-40.0	0.148	-56.08	0.160
50,000	0.114	-56.50	0.152	-65.0	0.158	-40.0	0.141	-58.06	0.153

(c) *At agricultural-meteorological stations* ("crop weather" stations) special attention is given to the temperature of the soil at depths of 4 in. and 8 in.

(d) *At health-resort stations*, special observations are made in the late afternoon mainly for purposes of publicity. These observations are telegraphed to London and issued to the daily press as a special bulletin.

**Statistics.**—Accumulations of numerical facts. The science of statistics is concerned with the development of methods of dealing with numerical data (generally in large quantities), representing their essential features by a small number of PARAMETERS, and determining the relations between two or more variables. See STANDARD DEVIATION, NORMAL LAW (OF ERRORS), CORRELATION.

**Stefan's Law.**—The law, discovered empirically by Stefan and afterwards demonstrated theoretically by Boltzmann, that the total radiation in all directions from an element of a perfect radiator is proportional to the fourth power of its absolute temperature. See RADIATION, *Black-body radiation*.

**Steppe.**—A name given to the grassy, treeless plains in Russia and Siberia. The word is sometimes extended to mean similar plains and regions of semi-ARID climate elsewhere.

**Storm.**—The term "storm" is commonly used for any violent atmospheric commotion, such as a violent gale, a thunderstorm, a line-squall, a rainstorm, duststorm or snowstorm.

Winds with velocity between 64 and 75 m.p.h. (force 11 on the BEAUFORT SCALE) are classed as storm winds

**Storm Cone.**—See GALE WARNING.

**Storm, Eye of.**—See EYE OF STORM.

**Stratocumulus (Sc.).**—*A layer or patches composed of globular masses or rolls; the smallest of the regularly arranged elements are fairly large; they are soft and grey, with darker parts. These elements are arranged in groups, in lines, or in waves, aligned in one or in two directions. Very often the rolls are so close that their edges join together; when they cover the whole sky—on the continent, especially in winter—they have a wavy appearance.*

**Stratosphere.**—The external layer of the atmosphere, in which there is no convection. It has also been called the advective region for this reason. The temperature of the air generally diminishes with increasing height until a point is reached where the fall ceases abruptly. Above this point lies the stratosphere, which is a region in which the temperature is practically constant in the vertical direction. The term "isothermal layer" has sometimes been applied to it, but this is misleading, as the temperature changes in a horizontal direction. Further, a large proportion of ascents with sounding balloons made in different parts of the world reveal an increase of temperature with height in the lowest layers of the stratosphere. The horizontal temperature gradient is never large, but an inspection of the diagram reproduced under SOUNDING BALLOON, representing the result of a large number of soundings in the British Isles, shows that the range of temperature in the stratosphere equalled or exceeded the range on the earth's surface in that set of observations.

We are still without any effective explanation of the origin of differences of temperature which are found in the stratosphere; they must probably be classed among the most fundamental characteristics of the general circulation of the atmosphere and among the primary causes of the changes of weather, but hardly any light has been thrown on the mechanism of the process.

Reliable observations of humidity in the stratosphere are few, but those made by Brewer and others\* over England using the Dobson-Brewer

\* DOBSON, G. M. B., BREWER, A. W. and CWILONG, B. M.; *Meteorology of the lower stratosphere. Proc. roy. Soc., London, A, 185, 1946, p. 144.*



frost-point hygrometer gave relative humidities of only a few per cent. and a mixing ratio of the order of 0.01 gm./Kg. The observations were restricted to occasions of relatively low TROPOPAUSE.

The height at which the stratosphere commences is often about 10 Km., but varies. It is higher in the regions nearer the equator. See TROPOSPHERE.

**Stratus (St.).**—*A uniform layer of cloud, resembling fog, but not resting on the ground. When this very low layer is broken up into irregular shreds it is designated fractostratus (Fs.).*

**Subsidence.**—The word used to denote the slow downward motion of the air over a large area which accompanies DIVERGENCE in the horizontal motion of the lower layers of the atmosphere. The greatest divergence is from regions of rapidly rising barometer and the subsidence is probably of the order of 100 to 200 ft. per hour in many cases. In stationary unchanging anticyclones the subsidence is due to the outward air flow at the earth's surface only, and is then very much slower. The subsiding air is warmed dynamically (see ADIABATIC) and its relative humidity therefore becomes low, occasionally falling below 10 per cent. at about 4,000 to 6,000 ft. after prolonged subsidence. The downward movement and consequent warming increases with height, up to 10,000 ft. or perhaps more, so that the LAPSE-rate of temperature is decreased, and INVERSIONS are often developed. The vertical velocity is obviously zero at the ground, but turbulence often mixes up the lower layers and brings some of the warm dry air to the ground. Subsidence normally results in fine dry weather, but fog, stratus or stratocumulus clouds may occur in certain conditions.

**Sumatra.**—A squall which occurs in the Malacca Strait, blowing from between SW. and NW. There is a sudden change of wind from a southerly direction and a rise in speed is accompanied by a characteristic cloud formation—a heavy bank or arch of cumulonimbus which rises to a great height. These squalls usually occur at night, and are most frequent between April and November. They are generally accompanied by thunder and lightning and torrential rain. There is a sudden fall of temperature at the moment the squall arrives.

**Summer.**—See SEASONS.

**Sun.**—A luminous sphere around which the earth moves in an orbit at an average distance of 92,900,000 miles. It is 865,000 miles in diameter, 332,800 times as massive as the earth and 1.41 times as dense as water. According to astrophysical theory the sun has a temperature range from 46,000,000° C. at the centre to 6,000° C. in the outer shell. The outer shell can be observed from the earth, and its absorption spectrum indicates the presence of all terrestrial elements although these could not exist as atoms at the centre. The RADIATION emitted from the sun ranges from the far ultra-violet to the far infra-red giving a spectral distribution of a block-body radiator at about 6,000° C. The surface of the sun is subject to disturbances known as sunspots.

**Sun-dogs.**—A popular name for mock suns or PARHELIA.

The origin of the name sun-dog is not known. Possibly it implies that a parhelion follows the sun through the sky in the course of the day like a dog its master. The drawback to this explanation is that as a general rule sun-dogs do not last very long.

**Sun Pillar.**—A vertical column of light above (and sometimes below) the sun, most often observed at sunrise or sunset. The colour may be white, pale yellow, orange or pink. The phenomenon, which is due to the reflection of sunlight from small snow crystals, may be seen over a wide area. On March 13, 1924, it was observed all over the south of England from Cornwall to Norfolk.

**Sunrise, Sunset.**—The times at which the sun appears to rise and set, in consequence of the rotation of the earth on its axis. Owing to the effect of atmospheric refraction, which increases the apparent angular altitude of the sun when near the horizon by about 34', sunrise is earlier and sunset later than geometrical theory indicates. There is a further uncertainty caused by the fact that the sun has an appreciable diameter so that time elapses between the first and last contacts with the horizon. For meteorological purposes allowance is made for refraction and it is assumed that sunrise and sunset occur when the centre of the sun's disc is on the horizon.

The times of sunrise and sunset vary with the latitude and with the declination of the sun. Diagrams illustrating the variations, so far as the British Isles are concerned, are given in the "Observer's Handbook".

**Sunrise and Sunset Colours.**—The general explanation of the variety of colours that are to be seen in the sky about the time of sunrise or sunset is as follows. White light such as that from the sun may be regarded as composite, the constituents being light of all the colours of the spectrum. When the light waves meet obstacles in their course, such obstacles as the molecules of the atmospheric gases or larger obstacles such as particles of dust, the waves are broken and secondary waves proceed in all directions from the obstacles. The direct light is therefore reduced in strength and the further the light goes through an atmosphere of such obstacles the more the strength is reduced, the energy being used up in producing scattered light. This effect is more pronounced with blue light, for which the wave-length is short, than with red light for which the wave-length is longer. Accordingly a beam of white light passing through air loses the constituents of shorter wave-length and becomes yellow, then orange, and finally red.

This accounts for the changing colour of the sun as it nears the horizon. The scattering by air alone merely makes the setting sun yellow but if there is dust in the air or even the nuclei on which water vapour is condensed then the sun becomes orange or red before it sets.

Clouds which are illuminated by the light from the setting sun are also red, whilst other clouds which are illuminated by scattered light in which the blue constituents are present are white or grey; higher clouds illuminated by light which has only passed through less dense and cleaner air may also appear white.

The colours of the sky itself are to be explained in the same way. When sunlight has already travelled a great distance through the lower atmosphere it has lost the constituents of short wave-length, and in the light which remains to be scattered the longer wave-lengths predominate. Further in the passage of scattered light to the eye of the observer the longer wave-lengths have the preference.

When we look at the sky in a particular direction we receive light which has been scattered by the atmosphere at all heights; in the light scattered at great heights blue may predominate, whilst that coming from the lower levels may be red. The combination of light from both ends of the spectrum gives us purple. On the other hand in other parts of the sky the middle wave-lengths may predominate and the resulting colours are green or yellow. It may even happen that the result is practically white as in the *Dämmerungsschein* sometimes observed above the sun when it is near the horizon.

Detailed descriptions of the changing illumination of the sky about the time of twilight have been published by several observers, among the most detailed being that in a work by Gruner and Kleinert (Hamburg, 1927) devoted to observations in Switzerland.

The popular and ancient belief that a "red sky at night" is a good prognostic of fine weather is probably justified since the "red sky" implies present fine weather over a considerable area to the west. Statistical investigations in London bear this out to some extent, and also the tendency for a "red sky in the morning" to be followed by rain. (See *London, Met. Mag.*, 61, 1926, p. 16.)

**Sunshine.**—RADIATION from the sun is a mixture of radiations of different wave-lengths at different intensities. The sunshine which renders objects visible to the eye comprises that portion of the whole of the radiation from the sun which has wave-lengths varying from about  $0.4\mu$  ( $\mu$  = one thousandth of a millimetre) to about  $0.8\mu$ , the former corresponding with violet light and the latter with red light, while in between the two are found the other "colours of the rainbow" in the order indigo, blue, green, yellow, orange. As received at the confines of the earth's atmosphere the intensity of the violet light is much greater than that of the red light, but the radiation of shorter wave-length is more readily scattered by the earth's atmosphere than that of longer length, hence the proportions at the surface are very different. When the sunlight has to pass through a long length of dust-laden atmosphere, as at sunset in many cases, the longer wave-lengths so preponderate that red is the dominant colour of the setting sun.

The therapeutic qualities of ultra-violet light have received much attention of late. Sunshine rich in this light is found at high levels above the lower and denser layers of the atmosphere.

Records obtained in the British Isles with the Campbell-Stokes recorder show that sunshine is more abundant on the coast than inland, and that, broadly speaking, the mean sunshine per day increases from the north towards the south in all months of the year, in spite of the fact that at mid-summer the possible daily duration of sunshine in the north of Scotland is about two hours greater than in the south of England.

Low records are also obtained in industrial areas, due to obscuration by smoke, and in the mountainous areas of western Scotland, the Pennines and the west of Ireland. In these areas the mean daily duration in the period 1906–35 was less than 3.5 hours per day (29 per cent. of the possible duration). On the south coast of England the mean daily duration is locally as high as 5.0 hours (41 per cent. of the possible). In the sunniest areas, six hours or more of sunshine are recorded on about one day in three.

Monthly and annual averages for numerous stations are given in *Averages of Bright Sunshine for the British Isles* published quinquennially. Charts and discussions of the data will be found in "The distribution over the British Isles of the average duration of bright sunshine" by J. Glasspoole and D. S. Hancock (*London, Quart. J. R. met. Soc.*, 62, 1936, p. 247), "The frequency of days with specified duration of sunshine" by E. G. Bilham and Miss L. F. Lewis (*London, Prof. Notes*, No. 69, 1935), and "The climate of the British Isles" by E. G. Bilham (Macmillan, 1938) and in the "Climatological Atlas of the British Isles".

**Sunshine Recorder.**—An instrument for recording the duration of bright sunshine. In the Campbell-Stokes recorder a spherical glass lens focuses the solar image on a graduated card held in a frame of special design. The duration of sunshine is indicated by the length of the burnt track of the image. (See "Observer's Handbook.")

**Sunspot Numbers.**—The numbers which are used to represent the variation in the sun's surface from year to year as regards spots. The occurrences of dark spots, sometimes large, sometimes small, which are to be seen from time to time on the sun's face between its equator and forty degrees of latitude north or south, have long been the subject of observation. An irregular periodicity in their number was discovered by Schwabe of Dessau in 1851, using 25 years of observation. Professor R. Wolf of Zürich, by means of records in a variety of places, made out a continuous history of the sun's surface from 1610 to his own time, which is now continued by his successor, Professor Wolfer. The sunspot number  $N$  is obtained by the formula  $N = k(10g + f)$ , in which  $g$  is the number of groups of spots and single spots,  $f$  is the total number of spots which can be counted in these groups and single spots combined,  $k$  is a multiplier representing "personal equation" which depends on the conditions of observation and the telescope employed. For himself, when observing with a three-inch telescope and a power of 64, Wolf took  $k$  as unity.

The method of obtaining the number seems very arbitrary, but from the examination of photographic records by Balfour Stewart and others, it is proved that the numbers correspond approximately with the "spotted area" of the sun. One hundred as a sunspot number corresponds with about 1/500 of the sun's visible disc covered by spots, including both umbras and penumbras (see "The Sun," by C. G. Abbot, 2nd edition 1929).

Spots are now regarded as vortical disturbances of the sun's atmosphere. The sense in which the vortices rotate can be determined by spectroscopic observations. It is doubtful whether individual sunspots have any direct influence on terrestrial phenomena, but the epoch at which sunspots are numerous are those at which other forms of solar activity develop. The clearest evidence for this association is in the case of auroral displays and magnetic storms. The amplitude of the regular diurnal changes in terrestrial magnetism, even on quiet days free from magnetic storms, is increased at the epochs of high sunspot numbers. There is evidence that the amount of heat received from the sun is higher at such epochs, and that in certain tropical regions rainfall and cloudiness increase.

The mean interval between the maxima in sunspot numbers is 11.1 years but the recurrence is by no means strictly periodic; the maxima are not of equal strength and the interval fluctuates between 9 and 13 years.

The following is the list of sunspot numbers since 1750:—

TABLE OF SUNSPOT NUMBERS, 1750–1956\*

	0	1	2	3	4	5	6	7	8	9
1750 .. ..	83	48	48	31	12	10	10	32	48	54
1760 .. ..	63	86	61	45	36	21	11	38	70	106
1770 .. ..	101	82	66	35	31	7	20	92	154	126
1780 .. ..	85	68	38	23	10	24	83	132	131	118
1790 .. ..	90	67	60	47	41	21	16	6	4	7
1800 .. ..	14	34	45	43	48	42	28	10	8	2
1810 .. ..	0	1	5	12	14	35	46	41	30	24
1820 .. ..	16	7	4	2	8	17	36	50	64	67
1830 .. ..	71	48	28	8	13	57	122	138	103	86
1840 .. ..	63	37	24	11	15	40	62	98	124	96
1850 .. ..	66	64	54	39	21	7	4	23	55	94
1860 .. ..	96	77	59	44	47	30	16	7	37	74
1870 .. ..	139	111	102	66	45	17	11	12	3	6
1880 .. ..	32	54	60	64	64	52	25	13	7	6
1890 .. ..	7	36	73	85	78	64	42	26	27	12
1900 .. ..	10	3	5	24	42	64	54	62	48	44
1910 .. ..	19	6	4	1	10	47	57	104	81	64
1920 .. ..	38	26	14	6	17	44	64	69	78	65
1930 .. ..	36	21	11	6	9	36	80	114	110	89
1940 .. ..	68	48	31	16	10	33	93	152	136	135
1950 .. ..	84	69	31	14	4	38	142			

\*See BRUNNER W.; Tabellen und Kurven zur Darstellung der Häufigkeit der Sonnenflecken in den Jahren 1749–1944, *Astr. Mitt., Zurich*, No. 145, 1945, Table I. Data from 1945 to 1956 supplied by the Astronomer Royal.

**Supercooling.**—Although, in ordinary circumstances, water changes to ice when its temperature falls below the "freezing point," 0° C., it is possible, by careful control, to preserve the liquid state at much lower temperatures—the water is then said to be supercooled.

Supercooling is for most purposes little more than a scientific curiosity, but the small droplets within a cloud provide an important exception; it is, indeed, a normal condition within a cloud at temperatures well below the ordinary freezing point. Altocumulus clouds are for the most part water clouds although their average temperature approaches zero Fahrenheit. All clouds which penetrate vertically through the 32° F. isothermal surface (average height, 6,000 ft. in England), contain supercooled droplets, and it is necessary to go to cirrus levels (average temperature about – 10° F.) to find clouds almost invariably in the form of ice crystals.

Various theories have been propounded to explain the supercooling by introducing such factors as surface tension, salt solution and electrification. While these are known to depress the normal freezing point they fail, however, to provide an effect of the necessary magnitude. There is, furthermore, good reason to believe that such theories are unnecessary, except to indicate contributory factors. As long ago as 1724, Fahrenheit succeeded in supercooling a glass bulb full of water; more recently, water in bulk has been cooled to  $-6^{\circ}\text{C}$ . ( $21^{\circ}\text{F}$ .) and small droplets to  $-20^{\circ}\text{C}$ . ( $-4^{\circ}\text{F}$ .). Liability to supercooling must be regarded, then, as a natural physical property of water. The freezing process requires that the molecules shall set themselves in the characteristic orderly manner defining the crystalline structure, and provided the liquid is practically undisturbed, there is no mechanism for initiating the process. The supercooled state is said to be unstable, but more strictly it should be regarded as just stable—a very small but nevertheless finite disturbance appears to be necessary to overcome this stability. A small cloud particle which virtually floats in the air is subject to very small internal disturbances and remains stable as a liquid. As would be expected the larger the drop the less likely it is to remain undisturbed and large raindrops rarely undergo much supercooling without freezing.

Amongst the many minor properties of water which have a profound bearing on meteorology, its liability to supercooling takes an important place. Hail, rime and glazed frost, including the dangerous phenomena of ice accretion on aircraft in flight, are all dependent upon the occurrence of supercooling. There are grounds for believing that the formation of raindrops generally requires snowflakes falling and melting, and that the flakes are formed in a region of small supercooled droplets, and grow as the result of the difference of vapour pressure over water and ice. On reaching a region of supercooled droplets, these flakes grow rapidly owing to the difference in vapour pressure over water and ice. Thus the possibility of supercooling has probably an important effect on precipitation and, therefore, on many fundamental problems of the atmosphere.

**Supersaturation.**—See CONDENSATION.

**Surface of Discontinuity.**—In idealised theory, this is regarded as a real impenetrable boundary surface separating the atmosphere into two portions which differ in temperature, humidity and wind velocity. Actually the discontinuity is usually primarily one of temperature and therefore of density, the pressure at any point on the surface being the same on the two sides. If the surface is sloping, the isobaric surfaces are refracted at the surface of discontinuity, so that there is a discontinuity of wind velocity. The term is most often used in connection with FRONTS. The frontal surfaces are frequently not very sharp, but the term discontinuity is justified when one is dealing with large-scale phenomena. The SURFACES OF SUBSIDENCE are generally sharp.

**Surface of Subsidence.**—A SURFACE OF DISCONTINUITY is often developed in a subsiding mass of air, which is usually polar in origin. The primary cause is the dynamical warming due to the descending motion, as the result of which the air above the discontinuity has a low relative humidity. Frequently there is a sharp temperature INVERSION. These discontinuities are most frequent in anticyclones, and are then either horizontal or inclined at a very small angle. They also frequently occur some distance below a frontal surface (see FRONT), sloping down towards the line of the front on the ground, but inclined at only a small angle, usually of the order of 1 in 200. This angle is quite sufficient to give a pronounced wind discontinuity. The term "surface of subsidence" was introduced to apply more especially to such sloping surfaces, and to distinguish them from the frontal surfaces proper. The origin of the sharp inversion is not yet clearly understood, but it is frequently connected with the cloud-sheet (either continuous or broken)

which is found under the inversion, at least while it is developing. These clouds are maintained by convection and turbulence, which are especially active when POLAR AIR is passing over a warmer sea surface, extending up to a limit which becomes lower and sharper as the air subsides. Above this level the descending air warms at the dry ADIABATIC rate, and below it at a lower average rate, depending on the amount of cloud. Radiation also helps to sharpen the inversion.

**Surge.**—First used by Abercromby to denote a general change of pressure superposed upon the changes which are due to the movements of DEPRESSIONS and ANTICYCLONES. Sometimes between two consecutive weather maps the isobaric systems are seen to have travelled across the map but to have changed their shape little, while on closer examination, it is found that pressure over the whole area has risen. A change of this type is referred to as a "surge."

**Swell.**—Swell is wave motion in the ocean caused by a disturbance which may be at some distance away; the swell may persist after the originating cause of the wave motion has ceased or passed away. It often so continues for a considerable time with unchanged direction, as long as the waves travel in deep water. The height of the waves rapidly diminishes but the length and velocity remain the same, so that the long low regular undulations, characteristic of swell, are formed. Swell is often observed to have a wavelength greatly in excess of that of waves seen during a storm: the probable explanation is that the longer waves are then masked by the shorter and steeper storm waves. Swell observations are useful as denoting the direction in which sea disturbance due to tropical cyclones or other storms has taken place.

**Symbols, International Meteorological**—See WEATHER.

**Sympiesometer.**—A form of BAROMETER, now obsolete, in which the greater part of the atmospheric pressure was balanced by enclosing air above the liquid. By using glycerine as the barometric fluid, a very open scale was obtained in a compact instrument, but temperature effects were troublesome.

**Synoptic.**—An adjective derived from the noun Synopsis "a brief or condensed statement presenting a combined or general view of something." In meteorology the word is generally used either in connexion with charts or with wireless or telegraphic messages. A synoptic chart shows the weather conditions over a large area at a given instant of time. Such charts are discussed under WEATHER MAP. A synoptic message contains reports from a selection of observing stations in a large area chosen to give a representation of the weather over that area.

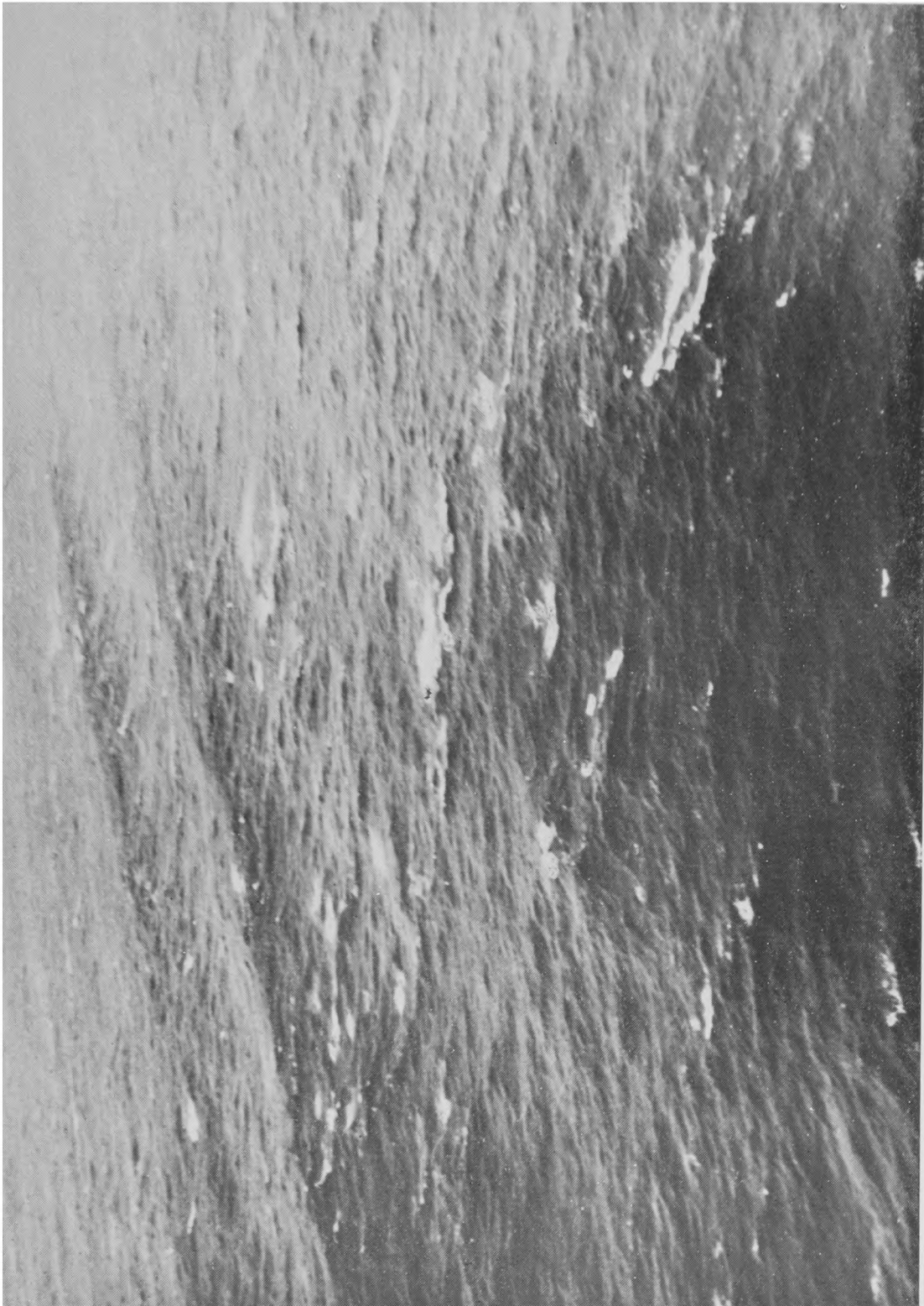
**Temperature.**—The condition which determines the flow of heat from one substance to another. Temperature must be clearly distinguished from HEAT, heat being a form of energy, while temperature is a factor which affects the availability of the energy. Temperature may be measured according to various scales, those in most frequent use being FAHRENHEIT, CELSIUS and ABSOLUTE TEMPERATURE. The word is used in a special sense in ACCUMULATED TEMPERATURE.

For the highest and lowest recorded air temperatures see EXTREMES.

**Temperature Gradient.**—When observations were first taken in the free air and the change of temperature with height became known, the term "temperature gradient" was used to express this change. The term thus meant the change of temperature in unit height. The word GRADIENT is used in other cases to denote the change of elements in the horizontal. Thus by "pressure gradient" is meant change of pressure per unit horizontal distance. It is better that the meaning of the word should be confined to change in the horizontal and the term "lapse-rate" has therefore been introduced for changes of temperature in the vertical leaving the term "temperature gradient" for changes of temperature in the horizontal.

**Tendency.**—See BAROMETRIC TENDENCY.





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FIG. 27.—Swell proceeding ahead of a tropical storm (actually approaching Nassau, Bahamas from West Indian hurricane). Note that the swell waves are long, low and long-crested. The wind is blowing almost at right angles to the direction of motion of the swell (i.e. parallel to the crests), as is made clear by the breaking of sea waves in the foreground.





**Tension of Vapour.**—An old term for the pressure exerted by a vapour. See AQUEOUS VAPOUR.

**Tenuity Factor.**—In BALLISTICS, the ratio of the density of air having the observed pressure at the surface, and temperature equal to the ballistic temperature, to the density of air at pressure 30 in. of mercury and temperature 60° F.

**Tephigram.**—A diagram on which is represented the condition of the atmosphere at different levels in terms of its temperature  $t$  and entropy  $\phi$ , hence the name  $t\phi$ gram.

**Tercentesimal Scale.**—The name adopted by Sir Napier Shaw for the approximate absolute scale of temperature, the tercentesimal temperature being obtained by adding 273° to the Centigrade temperature. See ABSOLUTE TEMPERATURE.

**Terrestrial Magnetism.**—The earth has been happily described as a great magnet; the distribution of magnetic force at its surface may as a first approximation be regarded as that due to a uniformly magnetized sphere, whose magnetic axis, however, is inclined at some 10° or 12° to the axis of rotation (polar axis) of the earth. The actual magnetic poles are the one to the north of Canada (between Victoria and Baffin Islands), the other in the Antarctic (South Victoria Land). At these poles the dip needle is vertical, and the horizontal component of magnetic force vanishes; the compass needle has no guiding force and points anyhow. These poles do not coincide with the poles of the axis of uniform magnetization, nor are they at opposite ends of a diameter. At what may be called the magnetic equator, which is nowhere very far (comparatively speaking) from the geographical equator, the vertical force vanishes: the dip needle is horizontal, and the horizontal force has its largest values. The horizontal force in London is only about half that where the magnetic equator crosses India. The direction of the horizontal component of magnetic force is exactly true north-south (i.e., the magnetic declination is zero) only along two lines or narrow belts. One of these crosses Canada, the United States, and South America; whilst the other after crossing Finland, eastern Russia and Egypt, encircles China, Japan and a large part of Siberia in a large oval loop, and thence passes near to Sumatra and across western Australia towards the south magnetic pole. Within the region bordered on the west by the first and on the east by the second of these *agonic lines*, and within the east-Asian loop, declination is westerly. If we travel westward from the Asiatic-European agonic line the declination becomes increasingly westerly until we pass the western limits of Europe. Thus, the mean values for 1936 are at Helwan (Cairo)\* 0° 13' E., at Seddin 4° 45' W., at Val-Joyeux (Paris) 9° 57' W., at Abinger (Surrey, England) 11° 20' W., at Eskdalemuir (Dumfriesshire, Scotland) 13° 47' W., at Valentia (Kerry, Ireland)\* 16° 22' W., and at Coimbra (Portugal)\* 13° 3' W. The values of the magnetic elements and the positions of isomagnetic lines change gradually with time, having what is known as "secular change" (see SECULAR TREND), the rate and the sense of which vary with time and locality. At London a change from easterly to westerly declination occurred about 1760; westerly declination increased to 24·6° in about 1818, since when there has been a continuous swing of the north end of the needle towards east. The rate of decrease in westerly declination in the British Isles has increased in recent years, the average annual rate since 1920 being 12' as compared with about 9' between 1910 and 1920 and 5' between 1900 and 1910. In the same area the horizontal force has been decreasing since 1911, but changes in inclination (dip) are small at present. Various theories (including the existence of a permanently magnetized core, the rotation of electric charge or of separate electric charges, direct magnetization by rotation) have been advanced in explanation of the cause of the earth's magnetism but none has been adequate to explain all the observed facts.

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\* Results derived from absolute observations only.

*Diurnal variation.*—In addition to secular change the earth's magnetic field experiences regular diurnal variation and also frequent irregular changes of varying magnitude. In magnetically quiet conditions, and more especially in non-polar localities, the regular diurnal changes are largest in daylight hours. In the northern hemisphere the prominent part of the daily variation in declination is a westerly movement from about 7h. to 13h. (local time), followed by a slower easterly movement. Speaking generally, the range of the diurnal variation in declination is least near the equator, where it may average less than 3', and greatest near the magnetic poles, where it may exceed 1°. On the average quiet day in England the lowest value of horizontal force occurs between 10h. and noon, and the highest value in the evening or early forenoon according to the season; dip is greatest at from 9h. to 11h. (earlier in summer than in winter) and least at about 6h. in winter and at 18h. to 20h. in summer. Not only the type but the range of the diurnal variation varies with the season: the range being least in winter and largest in one of the summer months. At Kew Observatory, for instance, the diurnal inequality ranges in December and in the summer of the average year of the period 1890–1900 were respectively:—declination, 3·3', 11'; dip, 0·6', 2·1'; horizontal force, ·00011, ·00039 C.G.S. units. The range of the regular diurnal variation and the mean absolute daily range vary considerably from year to year, showing a remarkably similar progression to that of sunspot frequency. In a year of sunspot maximum the range of the diurnal variation may be 50 per cent. or more larger than a few years earlier or later at sunspot minimum. The relative increase in diurnal inequality range associated with increase in sunspot number tends to be greatest in winter months; it appears to vary with locality and is not the same for all the magnetic elements. In magnetically disturbed conditions diurnal variations of a characteristic type also occur. These differ from the quiet-day variations in appearance and dimensions to an extent depending upon the degree of disturbance; in particular, the displacements occurring during the night-time hours become of the same order as those during the daytime. There is also a small lunar variation.

*Disturbance.*—Disturbance or irregular fluctuation is present in varying degree on all but a comparatively few days, and is more prominent as the magnetic polar regions are approached. Disturbance at Eskdalemuir is on roughly twice the scale of that at Kew; and disturbance at Lerwick again is on quite twice the scale of that at Eskdalemuir. Irregular disturbance changes in high latitudes are not only larger than, but may differ in sense and general character from, those simultaneously in progress in lower latitudes. In the latter regions of the earth disturbance changes tend to be largest in the horizontal component of force, but irregular changes in vertical force become increasingly important in higher latitudes. The frequency of occurrence of disturbance is greater in equinoctial than in other months; and, in Europe, greater between 15h. and 4h. G.M.T. than at other hours, being least during the three or four hours before noon. The incidence of disturbance is greater in sunspot maximum than in sunspot minimum years, but the numerical relationship with the available measures of solar activity is smaller in the case of measures of magnetic activity than in the case of the range of the diurnal inequality. Disturbed, and also quiet, magnetic conditions tend to recur after the lapse of one or more solar rotation periods. No very close relationship has been established as yet between the degree of magnetic disturbance on a given day and solar conditions (as at present observed) on the same or on the few preceding days.

*Causes of magnetic variations.*—According to a widely accepted theory, due in the first instance to Balfour Stewart, the solar diurnal (and the much smaller lunar diurnal) magnetic variations are ascribed primarily to the existence of electric currents circulating in the upper atmosphere, such currents being engendered by electromotive forces induced by the large-scale tidal or quasi-tidal motions of the highly ionized upper atmospheric

strata across the permanent magnetic field of the earth. The necessarily high degree of ionization of the atmospheric shell in question is attributed to the agency of solar ultra-violet radiation, and the known facts as to the magnetic diurnal variations suggest that the degree of ionization and, therefore, the intensity of the ionizing agent, varies with season and with the phase of the solar cycle. Magnetic disturbance reaches its maximum in the polar regions and is apparently due to intense electric currents located in the upper atmosphere near to the zones of maximum auroral frequency (see AURORA). According to the Birkeland-Störmer theory the high ionization of these polar belts is held to be produced by solar corpuscular emissions which, owing to the deflective force exerted by the earth's magnetic field, impinge on the atmosphere in a somewhat restricted region around each magnetic pole, giving rise to aurora. It is now well known that there is a close association between the problems of terrestrial magnetism and of radio-transmission and it is probable that work in these allied fields will go far to elucidate many of the mysteries as to the properties and also the movements of the upper atmosphere. Certain of the inferences drawn from radio-transmission and other data as to the properties of the highly ionized region of the atmosphere have led to the suggestion that the regular diurnal magnetic variations and possibly those on disturbed days may be the result of the diamagnetic effect caused by ions (produced by ultra-violet radiation) spiralling about the earth's magnetic field in the region of long free paths. (See also *London, Quart. J.R. met. Soc.*, 59, 1933, pp. 3-15.)

**Terrestrial Radiation.**—See sub-heading under RADIATION.

**Thaw.**—The transition by melting from ice to water; the term used to indicate the break-up or cessation of a FROST. In the British Isles the final disappearance of frost is due usually to the displacement of cold northerly or easterly winds by warm winds from the Atlantic, e.g., the final break-up early in March of the prolonged frost of February, 1895, was due to the interruption of the air supply from the cold continent by the invasion as a southerly wind of a relatively warm current of air associated with the approach of a depression from the Atlantic. In more northern latitudes the "spring thaw" is a periodic event, denoting the seasonal progression, the unlocking of ice-bound seas, and the melting of the snow. In these latitudes in western Europe, though not in Canada or Asia, the sun is generally at sufficient altitude about noon, except near mid-winter, to effect a partial thaw by day, even in the midst of a protracted frost, if the sky is clear.

**Theodolite, Pilot Balloon.**—An instrument consisting of a telescope mounted to permit of rotation in altitude and azimuth, and fitted with divided circles to permit of those co-ordinates being read. The telescope is fitted with a right-angled prism so that the observer continues to look horizontally into the eyepiece no matter what the altitude of the balloon.

**Thermal Equator.**—The line passing through the centre of the belt of high temperature which exists near the geographical equator. The thermal equator varies with the season, migrating north in the northern-hemisphere summer and south in the southern-hemisphere summer; the amount of its migration, however, is less than that of the sun. It is also considerably influenced by the distribution of land and sea and the effect of ocean currents; for this reason its mean position does not coincide with the geographical equator, but lies to the north of it.

**Thermal Wind.**—The thermal wind in any layer of the atmosphere equals the vector difference between the geostrophic wind at the bottom of the layer and the geostrophic wind at the top of the layer (see WIND, *Variation of wind with height*, p. 219).

**Thermodynamics.**—That part of the science of heat which deals with the transformation of heat into other forms of energy and vice versa. See ENERGY and ENTROPY.

**Thermogram.**—The continuous record of temperature yielded by a THERMOGRAPH.

**Thermograph.**—A recording THERMOMETER. Many patterns are in use, the sensitive member being either a bimetallic spiral (Meteorological Office pattern), a Bourdon tube (Richard), a resistance element (Cambridge and similar recorders), a steel bulb filled with mercury (Negretti and Zambra distance thermograph) or an air bubble in the tube of a mercury-in-glass thermometer (photographic thermographs).

**Thermometer.**—An instrument for determining temperature, usually by means of the changes in volume of mercury or spirit contained in a glass tube with a bulb at one end. Mercury is preferred in all cases when the instrument is not required to indicate below  $-40^{\circ}$  F. or to show the minimum temperature over an interval.

In meteorology, the temperature of the air is usually required and precautions must be taken to avoid errors due to the effects of radiation, etc. Sufficient accuracy for practical purposes is obtained by exposing thermometers in a STEVENSON SCREEN. Alternatively, the thermometers may be whirled or aspirated as in the Assmann PSYCHROMETER.

A spirit thermometer may be made to indicate the minimum temperature by inserting in the stem, before sealing, a dumbbell-shaped light glass index, and mounting the thermometer horizontally. As the temperature falls, the index is drawn towards the bulb, but is left behind when the temperature rises. A mercurial thermometer may be made to indicate the maximum temperature by constricting the stem just above the bulb. Mercury is forced through the constriction when the temperature rises, but is unable to return when the temperature falls.

For special purposes, use may be made of changes in electrical conductivity, of thermo-electric currents or of the dissimilar expansion of different metals, for indicating or recording temperature.

**Thickness lines.**—Synoptic lines of constant height interval between standard pressure surfaces. They are used in the process of graphical addition for finding the contour lines of isobaric surfaces. Since on a hydrostatic basis the mean temperature of the air column between two given pressure surfaces is proportional to the height interval between them, the chart of thickness lines gives a graphical representation of the distribution of mean temperature between the specified pressures.

**Thunder.**—The noise which follows a flash of lightning, attributed to the vibrations set up by the sudden heating and expansion of the air along the path of the lightning, followed by rapid cooling and contraction. The distance of the lightning flash may be roughly estimated from the interval that elapses between seeing the flash and hearing the thunder, counting a mile for every five seconds.

The long continuance of the thunder is explained by the fact that the sounds from different parts of the lightning flash have different distances to travel to reach the observer. The changes in intensity are partly due to the crookedness of the flash but they may also be caused by variations in the amount of energy developed along its course. The fact that what appears to the eye to be a single flash may really be half a dozen flashes, all occurring within a second or less and following the same path, complicates the question. The sound may echo back from mountain sides but whether echoes from the clouds add to the reverberation is doubtful.

The distance at which thunder can be heard is, as a rule, surprisingly small, being usually less than 10 miles, though distances ranging up to 40 miles and over have been reported in extreme cases. Mr. R. S. Breton writing to the *Meteorological Magazine*\* from Tung Song, S. Siam, stated that he had timed thunder reaching him 200 seconds after flashes from a distant storm and that it was not rare for thunder to be heard there 180 seconds after the lightning. C. Veenema† quotes observations of 255 and 310 seconds made at Norderney, Prussia, on September 5, 1899. Observations made with the aid of balloons or on mountains have shown that sound does not travel easily downwards, and for this reason thunder

\* *London, Met. Mag.*, 63, 1928, p. 113.

† *Wetter, Berlin*, 34, 1917, p. 192.

caused by lightning flashes to the ground carries farther than thunder caused by flashes in the clouds. The sound travels farthest at night when the surface layers are in a stable condition, which is favourable for sound transmission.

**Thundercloud.**—A towering cumulus cloud which is always associated with thunderstorms. The technical name is CUMULONIMBUS. See also CLOUDS.

**Thunderstorm.**—Thunderstorms are caused by the powerful rising currents within fully developed CUMULONIMBUS clouds. In the British Isles they are neither so numerous nor so severe as in the tropics. They are most frequent in our eastern and midland districts, and a large majority, including all the really violent examples, occur in the summer half-year, especially from May to August. They are most frequent in the afternoons and evenings of sunny days, and in such conditions the heavy rain or hail causes marked local cooling and sometimes violent out-rushing squalls.

On the western coastal districts of the British Isles the storms are of a somewhat different type and occur with nearly equal frequency in the summer and winter seasons (see table on p. 194).

The conditions required for a thunderstorm are, first, an adequate supply of moisture for cloud development (in the British Isles the cloud base is probably always below 10,000 ft., and almost always below 6,000 ft.); secondly, a LAPSE-rate of temperature in excess of the saturated ADIABATIC through a range of height of not less than 10,000 ft. above the cloud base, and usually much more in the case of severe storms. There are many hot summer days, especially in anticyclones, when these conditions are not fulfilled, so that the hottest summers are not in general the most thundery. The requisite conditions exist most frequently in shallow DEPRESSIONS or COLS. Given the favourable conditions up above, it is quite possible for severe storms to develop at night, provided there is some initial impulse to start off the cloud formation. This impulse is probably supplied by CONVERGENCE—an important factor at any time of day. Sometimes the convergence occurs along COLD FRONTS, which are often accompanied by thunderstorms, but only when the upper air conditions are suitable. They do not therefore, constitute an independent class of thunderstorms. The cold-front storms often sweep broadside over the country, while some other storms develop along a belt and move end on, occasionally lasting for some hours at one place. In general thunderstorms drift with the wind at their level, but the variation of wind with height, and the development and dissolution of parts of the cloud mass, often make their movements complex. They occasionally travel at a high speed (up to 50 mi./hr.) from some southerly point, while near the ground the wind is relatively light, and usually blows from an easterly point. Many travelling storms can be traced back to heated areas on the continent.

Showers in deep POLAR CURRENTS are often accompanied by thunder, especially near the western seaboard in winter, and in eastern districts on summer days, with a temperature frequently below normal even at the surface, but with a much greater deficiency above. Such storms are usually of slight to moderate intensity.

For an account of the distribution of thunderstorm frequency in other parts of the world see *London, Geophys. Mem.*, No. 24, 1925.

**Tide, Influence on Winds.**—In some bays and estuaries where the rise and fall of the tide is considerable a slight motion of the air, landward where the tide is coming in or seaward where the tide is going out, is said to have been observed, giving rise to an appreciable wind in calm weather or to an increase in force and gustiness where the tide assists the direction of the general wind at the time. The subject cannot, however, be said to have really been investigated and such winds if they exist will be extremely local and transitory in character. To establish them fully they would have to be distinguished not only from the general wind prevailing over a wide area at the time, but also from other local winds, in particular from land and sea breezes. Sailors and others have also asserted that weather changes set in with "the turn of the tide" and the upcoming tide in estuaries is said to produce showers of a very local type, not extending far from the river banks,

Immunity from Thunderstorms in various parts of the United Kingdom as shown by observations extending mainly over the 35 years 1881-1915.

Table of "odds against one," expressing the random chance of a thunderstorm on any day in the several seasons of the year.

		ENGLAND											
		Station	Spring	Summer	Autumn	Winter							
SCOTLAND	NORTH	Sumburgh Hd. (Shetland) ..	804	178	317	350							
		Deerness (Orkneys) ..	152	34	61	54							
		Stornoway (Lewis) ..	200	82	132	82							
		Wick (E. Coast) ..	133	37	132	242							
		Fort Augustus (Inland) ..	114	44	302	192							
		Dunrobin Castle (N.E.Coast)	459	74	530	1,578							
		Nairn (N.E. Coast) ..	188	30	397	1,578							
		Aberdeen (E. Coast) ..	100	19	176	630							
		Dundee (E. Coast) ..	63	16	109	1,051							
		Leith (E. Coast) ..	123	24	186	350							
		Laudale (W. Coast) ..	37	24	40	29							
		Rothsay (Island) ..	43	32	71	78							
		Glasgow (W. Coast) ..	59	22	144	112							
		Pinmore (Sub Coastal) ..	81	39	86	89							
		Douglas (Isle of Man)	53	20	43	174							
IRELAND	NORTH	Malin Hd. (N. Coast)	105	34	127	139							
		Blacksod Point (W. Coast) ..	133	62	176	82							
		Markree Castle (Inland) ..	53	24	105	46							
		Armagh (Inland) ..	88	24	415	411							
		Donaghadee (E. Coast)	97	38	167	350							
		Dublin (E. Coast) ..	63	16	85	224							
		Birr Castle (Inland) ..	86	35	211	350							
		Valentia (S.W. Coast)	66	52	70	47							
		Roches Point (S. Coast)	74	37	109	185							
SCILLY AND CHANNEL ISLANDS		St. Mary's (Scilly) ..	91	44	68	68							
		St. Aubins (Jersey) ..	35	17	27	52							

on days when the weather conditions are such that precipitation is imminent. Abercromby observed a well-defined tidal variation of the trade wind in Fiji and Hazen found a marked increase of thunderstorms in the United States with a rising as opposed to a falling tide. There is always the risk that meteorological events may be related in the popular mind with tidal changes, simply because the latter afford a convenient subdivision of the 24-hour day with which to associate changes that may really have been distributed over periods of several hours.

**Tides, Atmospheric.**—The attraction of the sun and moon should theoretically raise tides in the atmosphere as well as in the hydrosphere. The solar atmospheric tides are masked by the much greater thermal effects but the lunar atmospheric tide exists as a very small independent wave, which has been exhaustively investigated by Prof. S. Chapman (see e.g. *London, Proc. roy. Soc., A.*, 151, 1935, pp. 105–17). There are two maxima and two minima in each lunar day; the amplitude is greatest in the tropics but nowhere reaches 100 microbars (0.1 mb.).

**Time.**—When the centre of the sun is due south of an observer, the time is called 12h., or noon, *local apparent time* (L.A.T.). The sun is said to “transit” at this time. The interval between two consecutive transits of the sun can be divided into 24 equal parts, and the times where the lines of division fall are numbered 13h., 14h. . . . 23h., 24h. (or midnight), 1h., 2h. . . . 12h. Local apparent time is recorded by sunshine recorders and sundials.

The interval of time between successive transits of the sun is not quite constant, but goes through a cycle of changes during the year. This is due to the two facts that the orbit of the earth is elliptical, and that the earth's axis is not at right angles to its orbit. For details, books on astronomy may be consulted. As it would be very inconvenient in daily life if the length of the day varied in this way, astronomers have invented an imaginary body called the “mean sun.” The apparent position of this body is always very close to that of the real sun, and on the average of a year the apparent positions of the two coincide. The apparent motion of the mean sun is such that it rotates uniformly round the earth at all times of the year. At a transit of the mean sun the time is called 12h. (or noon) *local mean time* (L.M.T.). The interval between successive transits is called a DAY, and each day is divided into 24 equal parts called hours, which are numbered as before. All hours are equal to one another, and all days are equal to one another in duration. To get local mean time from local apparent time it is necessary to add (or subtract if sign is minus) the so-called EQUATION OF TIME which is given very accurately in the *Nautical Almanac* and elsewhere, and sufficiently accurately for meteorological purposes in the “Observer's Handbook”. The equation of time varies from about  $+14\frac{1}{2}$  minutes in the middle of February to about  $-16\frac{1}{2}$  minutes at the beginning of November.

Local mean time at Greenwich is called *Greenwich Mean Time* (G.M.T.).

The difference between the local mean times at two places depends only on the difference in longitude between the two places. Since the earth makes one complete rotation relative to the mean sun in 24 hours,  $360^\circ$  of longitude corresponds with 24 hours, and therefore,  $1^\circ$  of longitude corresponds with 4 minutes of time. Hence L.M.T. for any place is derived from G.M.T. by subtracting or adding a correction to G.M.T. at the rate of 4 minutes of time for each degree of longitude of the place, according as the place is to the west or east of the meridian of Greenwich.

In order to avoid the great inconvenience which would be produced if every place adopted its own local mean time, it has been enacted that Greenwich mean time should be used for all common purposes in this country, except in summer, when clocks are advanced by one hour. See **BRITISH SUMMER TIME**.

The statement commonly made that the sun is in the south at noon is thus seen to be true only when "noon" means 12h. local apparent time. Considerable divergencies occur from place to place and from time to time if "noon" means 12 o'clock by legal time.

In meteorological work Greenwich mean time and local mean time are used as far as possible for purposes of defining the hours of observation—summer time is not generally used. Meteorologists are closely interested in good timekeeping, because punctuality is of importance in taking meteorological observations. The records of self-recording instruments are for many purposes useless unless marks are made on the records at known times, so that allowance can be made for the irregularities in running of the clock. Regulation of clocks in this country is effected by telegraphic, radio-telegraphic, and radiotelephonic signals originating from Greenwich Observatory, where the standard clock is controlled by frequent observations of the fixed stars. Time signals of high accuracy are also obtainable by telephone.

**Tornado.**—(1) In west Africa, the squall which accompanies a thunder-storm; it blows outwards from the front of the storm at about the time the rain commences. West African tornadoes occur most frequently during the transition months between rainy and dry seasons.\*

(2) A very violent whirl of small area averaging a few hundred feet in diameter, which gives wind velocities estimated to exceed 200 m.p.h. in some examples. Such tornadoes are most frequent in the United States, east of the Rocky Mountains, especially in the central plains of the Mississippi region; they occur also in Australia, and are not unknown in Europe, although less intense. In the United States tornadoes are associated with thundery conditions, especially in SECONDARY DEPRESSIONS, where the inter-action of winds with a large difference in temperature gives opportunity for violent vertical convection. The tornado is a local phenomenon, and usually travels towards the north-east with an average speed of about 30 mi./hr. In the comparatively narrow track of the tornado, trees are uprooted and buildings are completely destroyed, the large and rapid decrease of pressure near the centre of the tornado allowing the air inside buildings to produce almost an explosive effect. Heavy rain, and generally thunder and lightning occur with the tornado.†

The few tornadoes known to have occurred in Europe have been of comparatively small intensity, although they have caused a certain amount of damage. Examples occurred in South Wales on October 27, 1913, in Holland on August 10, 1925, and in London on October 22, 1928.

**Torricelli, Evangelista.**—The inventor of the barometer, born at Piancaldoli in 1608. In 1641 he became amanuensis to Galileo for three months until Galileo's death. Subsequently he was professor to the Florentine Academy until his death in 1647. Torricelli deduced from the fact that water would only rise about 32 ft. in a suction pipe, that the air had weight, and could, therefore, exert a definite pressure equivalent to a height of 32 ft. of water or  $2\frac{1}{2}$  ft. of mercury. This conclusion was confirmed by the well-known Torricellian experiment.

**Trace of Rain.**—The word "trace" is entered in the daily record sheet when some rain (or other form of precipitation) is known to have fallen and the amount in the gauge is less than that required to give a definite entry. If the gauge contains less than .01 in., but more than half the amount (.005 in.), the measurement should be entered as .01 in. For measurement in millimetres the limiting value is half-a-tenth of a millimetre, i.e. .05 mm.

The word "trace" is entered:—

(1) When, although there is no water in the gauge, the observer knows definitely from his own observation that some rain (or other form of

\* Hubert: "Mission Scientifique au Soudan." Paris, 1916, pp. 169 and 221.

† De Courcy Ward: "The tornadoes of the United States as climatic phenomena." London, Quart. J. R. met. Soc., 43, 1917, pp. 317-29.



precipitation such as snow, hail, sleet, drizzle) has fallen since the preceding observation. This happens sometimes, especially in dry warm weather, without the gauge being even damp.

(2) When the observer finds less than .005 in. of water in the gauge and he knows definitely that this trace of water is not the result of a drop or two draining from the sides of the can after emptying the rain water out of it at a previous time of observation.

**Trade Winds.**—This is the name given to the winds which blow from the tropical high pressure belts towards the equatorial region of low pressure, from the NE. in the northern hemisphere and SE. in the southern hemisphere. The name originated in the nautical phrase "to blow trade," meaning to blow in a regular course or constantly in the same direction, afterwards shortened to "trade." The word is allied to the words "track" and "tread" and its use in the sense of commerce was a later development of meaning not implied in its original application. The monsoons were formerly grouped with the true trades under the same name. Other names were also given to the trade winds either as a whole or locally. Of these the term "general wind" has survived in some countries, as for example, the modern Spanish "vientos generales." Columbus discovered the regularity of the NE. trade in his first transatlantic voyage in 1492, and this is usually accepted as the discovery of the trade winds, though previous navigators must have encountered them to some extent, probably as far back as the time of the Phoenicians. The Spaniards soon learned the value of the trade winds and in latter years the galleons regularly utilised the NE. trade of the Pacific in their journeys from Acapulco (Mexico) to Manila. More or less detailed descriptions of the trades are extant, dating back to the sixteenth century, and knowledge of their characteristics was gradually accumulated by mariners. Lieutenant M. F. Maury, U.S.N., was the first to treat the trade winds statistically, which he did by means of data collected from ships on a uniform plan. The results were included in his "Wind and Current Charts" and "Sailing Directions," published about the middle of the nineteenth century. As a result of Maury's work, the most important part of which consisted in finding the quickest sailing-ship routes through the Doldrums, passages were very materially shortened.

Excluding the Indian Ocean north of the equator, which is subject to the régime of the monsoons, the trade wind belts occupy a region extending over 1,000 to 1,400 miles of latitude in all oceans both north and south of the equator. The average direction of the wind is not the same in different longitudes of the same ocean. Thus in the North Atlantic, proceeding from the eastern to the western side of the ocean, the trade wind veers from NE., or even from NNE. or N. in some months, through ENE. to E., or to a point slightly S. of E. In the southern hemisphere corresponding differences are found, the changes being from S. or SSE., through SE. to E., or even a little N. of E. The trade winds represent the circulation of the air on the eastern and equatorial sides of the great permanent oceanic anticyclones which are found in latitudes of about 30° N. and S. It is interesting to note that the western margins of the anticyclones are in all oceans much less clearly marked than are the eastern margins. The easterly winds on their equatorial sides, such as those of the Caribbean Sea, are really part of the equatorial flow and the name of "intertropical flow" has been suggested for them. It is the usual custom to call all the winds between these high-pressure areas and the Doldrums by the name of trade winds, but the really characteristic trades are the flows from the eastern sides of the anticyclones, which are, roughly speaking, NE. in the northern hemisphere and SE. in the southern hemisphere.

The trade winds are not, as is popularly supposed, perfectly steady and regular either in force or direction. They vary, within limits, from day to day, from season to season, and from year to year. This applies to all oceans, but the Atlantic trades are more regular than those of the Pacific, and the

SE. Atlantic trade is more regular than the NE. Atlantic trade. Following the seasonal changes in the sun's declination, the trade winds, together with the Doldrums and the region of light and variable wind on the poleward side of the trades, move on the average northward and southward. There is, however, a considerable time lag behind the sun, thus the NE. Atlantic trade does not reach the most northerly latitude until August. The rate of motion is greatest just after the equinoxes. The annual range varies in different oceans, different longitudes and different hemispheres, but averages about  $5^{\circ}$  of latitude. Usually the total width of the belt fluctuates, the motions of the north and south sides not being the same. In the Atlantic and Pacific Oceans the SE. trade crosses the equator during the northern summer, but the NE. trade never extends south of the equator. In the Indian Ocean the SE. trade never crosses the equator. The day-to-day fluctuations of the trade winds have their origin in the day-to-day variations in the position and intensity of the oceanic anticyclones, which affect not only the force and direction of the trades but also the limiting latitudes.

A table showing the strength of the Atlantic trades is given below.

*Average monthly strength of the trades of the Atlantic in miles per hour*

		January	February	March	April	May	June	July	August	September	October	November	December	Year
NE. trade	..	10	11	11	12	11	10	9	7	8	6	8	10	9.4
SE. trade	..	12	13	12	13	13	13	11	13	13	12	13	13	12.6
St. Helena	..	14	13	13	12	11	12	12	15	17	15	16	15	13.8

The St. Helena observations made at an altitude of 1,960 ft. have been reduced by 15 per cent. for the purposes of the table, which it is considered gives the velocities that would have been recorded at sea level. The other figures are derived from Captain Hepworth's investigation of the NE. trade in lat.  $10^{\circ}$  N. to  $30^{\circ}$  N., between long.  $30^{\circ}$  W. and the west coast of Africa, and of the SE. trade in lat.  $0^{\circ}$  to  $20^{\circ}$  S., long.  $0^{\circ}$  to  $10^{\circ}$  W., and lat.  $10^{\circ}$  to  $30^{\circ}$  S., long.  $0^{\circ}$  to  $10^{\circ}$  E. It should be noted that the coast of Africa disturbs the regularity of the NE. trade in the eastern part of the area selected. In the above table, Captain Hepworth's results have been reduced by a little more than a mile per hour to bring them into conformity with the conversion values of the Beaufort wind numbers now in use by the Meteorological Office. It will be seen that the St. Helena winds are appreciably stronger than the SE. trade marine observations and show a much more definite seasonal variation. No satisfactory explanation of this fact has been given. The St. Helena and NE. trade observations are almost exactly complementary; thus September, the month of weakest NE. trade, is the month of strongest wind at St. Helena and so on. Maury derived a ratio of the strength of the NE. and SE. Atlantic trades from the observed speeds of sailing ships, and this ratio (6 to 8.8) is exactly the same as the ratio NE. trade/St. Helena for the year in the above table and does not differ greatly from the ratio NE. trade/SE. trade. Seasonal variation is seen to be marked in the case of the NE. trade.

As in the Atlantic, the NE. trade wind of the Pacific lies to the west of and not opposite to the SE. trade wind, on account of the similarity of curvature of the eastern coast lines of these two oceans. No definite figures can be quoted for the strength of the Pacific trades, but they are certainly less than those of the Atlantic, and the relative strengths of the NE. and SE. trades are reversed, the SE. Pacific trade exhibiting least strength and steadiness. The SE. trade of the Indian Ocean is most stable when the SW. monsoon is blowing north of the equator from May to September.

Comparatively little exact information is available as to the diurnal variation of the trades. Gallé found that the SE. trade of the Indian Ocean reaches a maximum at night from May to October, but observations at Porto Rico and St. Helena give day maxima, less marked at the latter island. There are many local wind modifications of the trades on continental coasts or among islands. An interesting feature of the NE. trade is the very large area of dustfall from the Canary Isles to south of Cape Verde, extending as far as longitude 40° W.

The explanation of the origin of the trade winds which is given in all books on physical geography is due originally to a paper published by Edmund Halley in 1686. It attributes the flow of air northward and southward on either side of the equator to the replacement of air which has been heated by the warmth of the equatorial belt and has, in consequence, ascended. Halley's explanation of the easterly component was not satisfactory, and John Hadley gave the true explanation of this in 1735 by bringing the effect of the earth's rotation into account. Halley also developed the theory of the return upper currents, the "counter-trades," or ANTI-TRADES, blowing from SW. in the northern hemisphere and NW. in the southern hemisphere. At the present time the only satisfactory explanation of the trades and counter-trades is to be found by associating these winds with the pressure distributions obtaining at the surface and at a suitable height in the upper air. Thus, as has been stated, the surface trades form part of the circulation round the great oceanic anticyclones. The untenability of Halley's theory is seen by considering the winds at Suva, Fiji (lat. 18° S., long. 177° E.). Here the frequency of SE. wind is only about 10 per cent. Winds from all directions are experienced, that from NE. being the most frequent. Yet the situation of the island in respect to the equatorial belt of high temperature is similar to that of St. Helena, where the SE. Atlantic trade blows steadily. The greater part of the air brought to equatorial regions by the trades turns eastward and passes away round the western boundaries of the oceanic anticyclones. Some part of it may go to feed the rainstorms of the Doldrums.

Direct upper-air observation has shown that the height to which the NE. Atlantic trade attains is normally little over 3,000 ft., but very great variations are found to occur, and it may attain the height of 13,000 ft. It blows sometimes at the summit of the Peak of Teneriffe (12,160 ft.). Similar fluctuations have been found in the height at which the counter-trade is met which has been observed to vary from 6,000 ft. to 30,000 ft. The counter-trade of the North Atlantic Ocean is associated with the high pressure area which exists over the western Sahara at altitudes of 6,000 ft. and upwards. The counter-trade of the South Atlantic is similarly associated with a high-pressure area at this height over southern Africa. The normal directions for the counter-trade, proceeding northward over the region of the NE. trade, are successively SE., S. and SW., finally becoming westerly over the region of the Azores. For the SE. trade they are successively NE., N., NW., finally becoming westerly. These directions are confirmed by such observations as are available. The counter-trades therefore form connecting links between the upper easterly current over equatorial regions and the upper westerly current of temperate latitudes. Over the western parts of the oceans the upper winds over the trades are easterly. This part of the circulation has a much greater area in the Pacific, where the surface oceanic anticyclones lie much closer to the eastern shores than they do in the Atlantic.

The weather in trade-wind regions is normally fine and quiet, though four of the six areas in which tropical cyclones occur lie within their boundaries. The typical cloud is the detached trade cumulus but ROLL CUMULUS is of frequent occurrence. There is normally an increase of wind with height above the sea up to a point which Cave in 1909 at Barbados found to be about 1,600 ft. Temperature inversion and low humidity have been found above the trade cumulus in the Atlantic and Indian Oceans.

**Trajectory.**—The path traced out by a particle of air in its movement over the earth's surface.

If the wind arrows around an ANTICYCLONE are examined they will be found to suggest a spiral outward motion of the air, while in a DEPRESSION the spiral motion is inward towards the centre. Thus, if an anticyclone and a depression remained stationary in close proximity for a sufficient period of time a particle of air might be found which after rotating around the anticyclone in the outward spiral was drawn into the depression, its path finally leaving the earth's surface, as the air rose at the centre of the latter system. A path of this kind used to be regarded as typical of air movements associated with anticyclones and depressions. The fact was overlooked that a depression itself as a system normally moves with a velocity about as large as that of the individual air particles in their rotation round it and that before a particle has had time to make a complete rotation, the system will have moved away and the particle no longer remain under its influence.

Shaw and Lempfert in the "Life History of Surface Air Currents", a publication of the Meteorological Office issued in 1906, examined the matter by tracing the actual motion of air along the surface as deduced from selected series of hourly maps and by noting the progress of the air from map to map. An examination of their charts will reveal how inadequate the older idea was to express the true trajectory of a given particle in a depression. As the distribution of cloud and precipitation in a depression is dependent upon the properties gained by the air within it in the course of that air's travel, the importance of the study of air trajectories becomes manifest.

During the years that have elapsed since the publication of the "Life History of Surface Air Currents" much further work has been done on the subject, and the Norwegian school of meteorologists, especially, emphasise the importance to the forecaster of the source of any given portion of air, whether polar or tropical, and of the subsequent travel of that air.

**Tramontana.**—A local name in the Mediterranean for a northerly wind. It is usually dry and cool.

**Transparency.**—The capacity for allowing rays of light or some other form of radiation to pass. Thus glass is transparent for the visible radiation of light. Rock-salt is specially transparent for the infra-red radiation. See VISIBILITY and DIATHERMANCY.

**Tremor.**—See EARTHQUAKES.

**Tropical Air** (formerly equatorial air).—Air originating in low latitudes, normally about 30° N., occasionally even further to southwards (see AIR MASS). Tropical air which reaches the British Isles generally originates in the Atlantic, and when it reaches our coasts it is characterised by stability in the lowest few thousand feet, usually with low stratus clouds and often fog or drizzle. It is modified as it moves inland, especially in summer, when fair but close weather readily develops from it.

Occasionally tropical air is of continental (African) origin, and if it comes up over France it gives fine and mild (in summer very warm) weather.

The WARM SECTORS of most depressions consist of tropical air. A current composed of tropical air is called a tropical current.

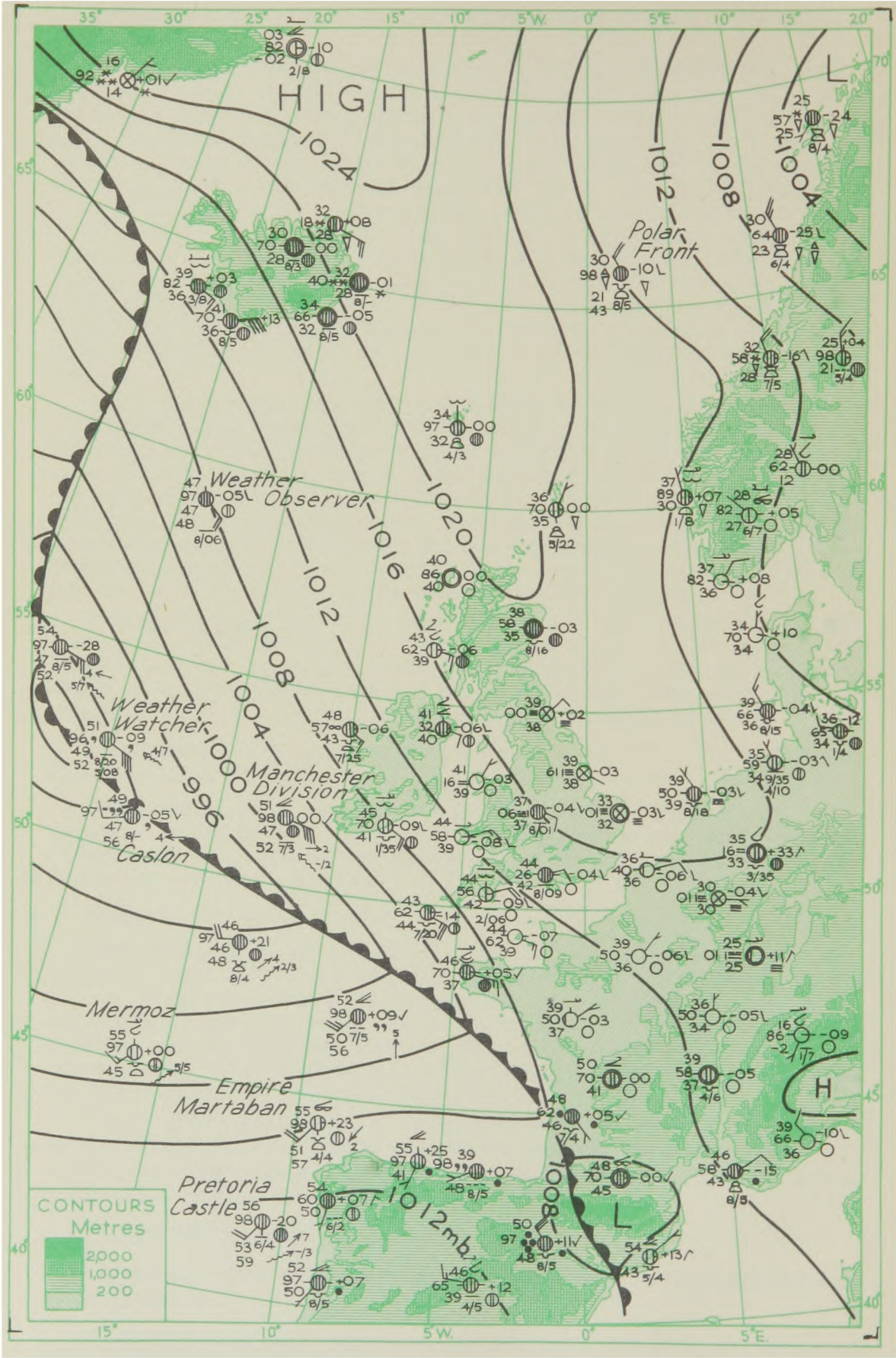
**Tropical Cyclone.**—See CYCLONE.

**Tropopause.**—The name given by Sir Napier Shaw to the upper limit of the troposphere.

**Troposphere.**—A term suggested by Teisserenc de Bort for the lower layers of the atmosphere. The temperature falls with increasing altitude up to a certain height (see LAPSE), and the part of the atmosphere in which







MARCH 12, 1952, 0600 G.M.T.  
TROUGH OF LOW PRESSURE

this fall occurs is called the troposphere. In these latitudes ( $50^{\circ}$ ) it extends from the surface for a thickness of some 7 miles, or 11 kilometres; in the tropics the thickness may reach 10 miles, or 16 kilometres.

**Trough.**—The trough line of a circular DEPRESSION is the line through the centre perpendicular to the line of advance of the centre.

During the passage of a depression over any given place the pressure at first falls and later rises; the trough line passes over the place during the period of transition from the falling to the rising barometer. On the southern side of a depression north of the equator, the passage of the trough is frequently very well marked by phenomena of the type of a LINE-SQUALL, a sudden rise of pressure takes place, the wind veers, the temperature drops and there are frequent squalls of rain or hail; the phenomena observed really indicate the passage of a COLD FRONT.

The word trough is widely used in a more general sense than that given above for any "valley" of low pressure, and is thus the opposite of a RIDGE of high pressure.

There is usually (not invariably) a FRONT along the trough. If it is sharply defined, it corresponds to the old V-SHAPED DEPRESSION. Plate VI shows such a trough; it is an occlusion with warmer surface air behind it.

**Tundra.**—Treeless lands of northern Canada and Eurasia which lie mainly just inside or just outside the Arctic circle. In these regions the monthly mean temperature is below the freezing point most of the year and very low minima occur in winter. During 2 or 3 months in summer, however, the average monthly temperature rises above the freezing point and is between  $40^{\circ}$  and  $50^{\circ}$  F. in the warmest month, when occasional high temperatures may be experienced during the daytime. Nevertheless the ground a foot below the surface remains frozen solid. On the slopes the surface water drains away, but much of the flat ground becomes marshy. At this season a stunted shrubby or grassy vegetation grows.

**Turbulence.**—The irregular or "eddy" motion which appears in fluids, whether liquid or gaseous, when they flow past solid surfaces or when neighbouring streams flow past or over each other, provided the velocity of flow is greater than a certain limit. The distinction between "laminar" flow and "turbulent" motion in tubes was first demonstrated experimentally by Osborne Reynolds in 1883.

There is no mathematical definition of turbulent flow; fluid motion is said to be turbulent when it is impossible to specify the details of the motion and we have to be content with a knowledge of the mean flow. It is, however, possible to form a reasonable picture of the effect of turbulent motion on the properties of the atmosphere, much as it is possible to trace the effects of the molecular motion of a fluid without tracing the motions of individual particles.

The motion of the atmosphere is usually turbulent, at least in the lower layers. The WIND consists of a series of GUSTS and lulls, but the degree of turbulence present fluctuates considerably, owing to the opposing effects of solar and terrestrial RADIATION, and to the varying "roughness" of the ground. Solar radiation promotes the generation of turbulence by day by setting up an unstable state in the lowest air layers, indicated by the presence of a high LAPSE RATE; at night turbulence tends to be damped out whenever the flow of outgoing radiation can cool the earth sufficiently to set up a large inversion of temperature near the ground. The "roughness" of the ground is due to obstacles of such different magnitudes as grass, trees, houses and hills.

Mathematical methods were first applied to the discussion of the effects of turbulence in the atmosphere by G. I. Taylor,\* who showed that the effects of eddies might be regarded as endowing the atmosphere with a coefficient of viscosity and a coefficient of heat conduction far greater than the ordinary coefficients of molecular viscosity and conduction. Taylor showed that the components of the eddying velocity in three dimensions, horizontally down wind, horizontally cross wind, and vertically, were roughly equal. This yields an equipartition in three dimensions of the energy associated with the eddies, much as the energy of molecular motion shows equipartition. So far as the equipartition between the horizontal components is concerned, a test can be made by means of the records of wind velocity and direction from a pressure-tube anemometer. It can be readily shown that if we take a portion of the ribbon-like trace shown on the velocity chart, and measure  $V.$  max. and  $V.$  min., the velocities in the gusts and lulls respectively, and if  $\theta$  is the angular width of the corresponding direction trace, then the condition that the down wind and cross wind components shall be on the average equal is

$$\frac{V. \text{ max.} - V. \text{ min.}}{V. \text{ max.} + V. \text{ min.}} = \sin \frac{\theta}{2}$$

Taylor showed that, on the average, this condition is fairly closely fulfilled.

In Taylor's discussion the effects of turbulence are stated in terms of a coefficient  $K$ , which has the value  $\frac{1}{2} \bar{w} d$  where  $\bar{w}$  is the mean vertical velocity in the eddy, and  $d$  is the diameter of the eddy.  $K$  is the coefficient which replaces the ordinary molecular coefficient of kinematic viscosity or the coefficient of thermal conduction, in the ordinary equations of motion or of heat transfer. Taylor gave the variation of wind with height in terms of his coefficient  $K$  and showed that the calculated distribution is in reasonable agreement with the observed facts.

The decrease of wind velocity as the earth's surface is approached is a measure of the rate at which the momentum of the air is being destroyed at the surface. To keep matters steady there must be a continual downward flow of momentum, brought about by an exchange of air masses in the vertical, i.e. by turbulence. Such an exchange must simultaneously cause a transfer of heat and mass, and of contents of the air mass such as WATER VAPOUR and impurities—hence the association between invasions of TEMPERATURE and FOG (see for example the work of O. G. Sutton on the rate of evaporation from the water surface).

The result of applying the classical equations of DIFFUSION, heat conduction and viscous motion to problems of turbulence with little or no change save in the order of magnitude of the corresponding coefficients did not prove entirely satisfactory. In the kinetic theory of gases the value of the diffusion coefficient depends, among other things, on the length of the mean free path of the molecules, and in 1925 Prandtl introduced for turbulent fluids the conception of a "mixing length" (*Mischungsweg*) analogous to the molecular free path, but with the difference that the mixing length depends on the position with respect to the boundary. In the atmosphere the problem is complicated by the varying roughness of the ground and by the changing stability of flow; these factors have been investigated by Rossby, Sverdrup and Paeschke.

It is also necessary to distinguish between small scale phenomena, such as the wind flow over a small sheet of water or the diffusion of smoke from a factory, which can be considered as taking place within a relatively thin boundary layer, and large scale phenomena such as the approach of the surface wind to the GRADIENT WIND, which are controlled by the permanent boundary layer, some 2,000 ft. deep, of the earth's atmosphere.

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\* "Eddy motion in the atmosphere." *London, Philos. Trans., A.* 215, 1915, pp. 1-26.



In discussing the vertical transfer of heat by turbulence, account must be taken of the lapse-rate. Heat is transferred in the direction from high potential temperature to low potential temperature. When the lapse-rate is less than the adiabatic turbulence transfers heat downwards; when the lapse-rate exceeds the adiabatic the transfer is upwards. In either case the effect of the mixing produced by turbulence is to cause the lapse-rate to approach the adiabatic.

**Twilight.**—Twilight is caused by the intervention of the atmosphere between the sun and the earth's surface. When the sun is some distance below the horizon the upper layers of air are still illuminated and are reflecting light to us. The amount of reflected light diminishes as the sun's distance below the horizon increases, because higher and more diffuse layers alone are seen in direct sunlight. In the later stages of twilight the light which reaches us has been reflected more than once.

So early as the 11th century the period of Astronomical Twilight between sunset and the disappearance of the last trace of daylight was determined as ending when the sun was  $18^\circ$  below the horizon. Another period, Civil Twilight, is recognised ending when the sun is about  $6^\circ$  below the horizon and conditioned by the insufficiency of light for outdoor labour after that time. Of course both definitions imply skies free from cloud and haze.

The following table shows the duration of astronomical and civil twilight according to these definitions.

			Equator				50°				60°			
			A.T.		C.T.		A.T.		C.T.		A.T.		C.T.	
			h.	m.	h.	m.	h.	m.	h.	m.	h.	m.	h.	m.
Winter solstice	..	..	1	16	0	26	2	1	0	45	2	48	1	9
Equinoxes	..	..	1	10	0	24	1	52	0	37	2	31	0	48
Summer solstice	..	..	1	15	0	26	—		0	51	—		1	59

At midsummer between the Arctic Circle and latitude  $48\frac{1}{2}^\circ$  there is a belt with no true night, twilight extending from sunset to sunrise.

The following figures are quoted from Kimball and Thiessen for the intensity of illumination during twilight with a cloudless sky; they refer to the illumination of a horizontal surface.

At sunset, 33 foot-candles = 1,600 times light due to full moon in zenith.

Sun  $6^\circ$  below horizon, 0.4 foot-candles = 19 times light due to full moon in zenith.

Sun  $18^\circ$  below horizon, .0001 foot-candles = .004 times light due to full moon in zenith.

For comparison the intensity of the illumination due to the sun in the zenith is given as 9,600 foot-candles.

**Twilight Arch.**—This term has been used with more than one meaning. Probably the best practice is to confine it to the boundary between the illuminated segment and the dark sky above as seen in the later stages of twilight. In Von Bezold's nomenclature several twilight arches are recognized; the first western twilight arch is the boundary seen even before sunset between the extended tinted band or segment of light along the horizon and the blue sky above: this arch persists through the development and disappearance of the "purple light" and may be visible together with the second western or true twilight arch.

The boundary of the SHADOW OF THE EARTH as seen just after sunset Von Bezold calls the "first eastern twilight arch". The name twilight arch is confined to this phenomenon in the fourth issue of the first edition of the Glossary.

**Type.**—Different distributions of atmospheric pressure are characterised by more or less definite kinds of weather, and accordingly when a certain form of pressure distribution is seen on a chart the weather is described as belonging to such-and-such a type. The types are therefore defined by the shape or general trend of the isobars, thus an "anticyclonic" or a "cyclonic" type denotes that an ANTICYCLONE or a DEPRESSION is the main feature of the pressure distribution; on the other hand a "westerly" type indicates that the isobars run in more or less parallel lines over a considerable distance from west to east, having the lowest pressure to the north; a "northerly" type will have isobars running north and south with the low pressure to the east, etc.

The weather associated with each type varies with the season but members of the same type have nearly always something in common; thus, an anticyclonic type has usually rainless weather, the cyclonic, wet weather; the southerly type in the northern hemisphere will in general be relatively warm and the northerly type cold. The westerly type is a very persistent one and often gives rise to long periods of rather unsettled weather. The easterly type gives in winter suitable conditions for severe frosts while in summer in at least the southern part of the British Isles the weather is usually very warm.

**Typhoon.**—A name of Chinese origin (meaning "great wind") applied to the tropical CYCLONES which occur in the western Pacific Ocean. They are of essentially the same type as the West Indian hurricane of the Atlantic and the cyclone of the Bay of Bengal.

**"Ulloa's Circle" or "Ring."**—A white rainbow or fog bow. See RAINBOW and BOUGUER'S HALO.

**Ultra-violet Radiation.**—See RADIATION.

**Units.**—All physical measurements consist of two parts, (1) a number and (2) an indication of the magnitude of the "unit" number, i.e. the magnitude of the measurement if the number became 1. Thus we may say that a certain article has a length of 10 in. or of 25·4 cm. Here the units are inch and centimetre respectively, the numbers are 10 and 25·4 respectively, and in view of the relation between the inch and centimetre the two measurements are consistent.

Much difficulty has arisen in meteorology because the units of length and of temperature in common use in the British Isles, namely, the inch and the Fahrenheit degree, differ from those in use on the continent, the centimetre and the Centigrade degree.

For that reason both British units and continental units are employed in Meteorological Office publications. The following are the British equivalents of the more important continental units.

#### *Length*

1 centimetre (10 millimetres) = 0·39370 inch.

1 kilometre = 0·62137 mile.

#### *Velocity*

1 metre per second = 2·23694 miles per hour = 3·28084 feet per second  
= 1·9426 knots.

1 kilometre per hour = 0·6214 miles per hour = 0·912 feet per second  
= 0·5396 knots.

1 mile per hour = 0·8684 knots.

#### *Pressure*

1 mercury millimetre = 1·3332 millibar.

#### *Temperature*

Freezing point (32° F.) = 0° Centigrade = 273° Absolute  
= 491·4° F. Absolute.

Boiling point (212° F.) = 100° Centigrade = 373° Absolute  
= 671·4° F. Absolute.

*Absolute humidity*

1 gramme per cubic metre = 0.3596 grains per cubic foot.

*Rate of rainfall*

1 millimetre per minute = 2.3622 inches per hour.

See also ELECTRICAL UNITS.

**Upbank Thaw.**—A state of affairs in which the usual fall of temperature with height is reversed, a thaw, or an increase of temperature occurring on mountains, sometimes many hours before a similar change is manifested in the valleys.

It is due to the superimposition of a warm wind blowing from a direction differing from that of the surface wind, and occurs most usually at the break-up of a frost, on the approach of a cyclonic system, but sometimes during the prevalence of anticyclonic conditions, when a down-current of air is dynamically heated in its descent from a great height. Under these conditions, at 9h. on February 19, 1895, at the end of a great frost, the temperature at the summit of Ben Nevis was 17.6° F. higher than at Fort William, 4,400 ft. below.

This INVERSION of the normal temperature gradient is a contributory cause of the phenomenon known as GLAZED FROST.

**Upper Air.**—That part of the atmosphere which is not in close proximity to the earth's surface. The detailed study of the upper air is an important branch of meteorological science. The observations of pressure, temperature, humidity, etc., on which it is based, are obtained in a number of ways involving the use of aeroplanes, RADIO-SONDES and radar. The winds of the upper air are observed by means of PILOT BALLOONS and RADAR BALLOONS.

**V-shaped Depression.**—A name formerly used for a sharply defined trough of low pressure, with the isobars in the form of a V. It is usually a COLD FRONT or OCCLUSION, more rarely a WARM FRONT. The term is virtually obsolete, but the expression "V-shaped trough" is occasionally used. Plate V shows such a trough; it is an occlusion with warmer surface air behind it.

**Valley Breeze.**—A breeze which blows during the day up valleys and mountain slopes. During the day the air in the valley is warmed and decreases in density; it rises, therefore, and flows up the valley and up the slopes of the mountain. See ANABATIC.

**Vapour Concentration**, earlier termed "**Vapour Density**".—See ABSOLUTE HUMIDITY.

**Vapour Pressure.**—The pressure exerted by a vapour when it is in a confined space. In meteorology, vapour pressure refers exclusively to the pressure of water vapour. When several gases or vapours are mixed together in the same space each one exerts the same pressure as it would if the others were not present; the vapour pressure is that part of the whole atmospheric pressure which is due to water vapour. See AQUEOUS VAPOUR.

**Vector.**—A straight line of a definite length drawn from a definite point in a definite direction. A vector quantity is a quantity which has direction as well as magnitude. In meteorology the wind and the motion of the clouds are examples of vector quantities; the directions, as well as the magnitudes, are required, whereas in the case of the barometer or the temperature, the figures expressing magnitude tell us everything. They are called SCALAR quantities. All vectors obey the parallelogram law. That is to say, that any vector A may be exactly replaced by any two vectors B and C, provided that B and C are adjacent sides of any parallelogram, and A the diagonal through the point where B and C meet. Also the converse holds.

The position of an airship, a given time after starting, is an example. The two vector quantities that bring about the final result are the velocity and the direction of the airship through the air, and the velocity and direction of the air, i.e. the wind. Suppose an airship pointing south-west and with speed of 40 miles an hour. After two hours its position on a calm day is

80 miles south-west of the starting point. Now suppose the airship has to move in a S. wind of 30 miles an hour; after two hours this wind alone would place the airship 60 miles north of the starting point. The real position will be given by drawing two lines representing these velocities and finding the opposite corner of the parallelogram of which they form adjacent sides. See COMPONENT.

**Veering.**—The changing of the wind in the direction of the motion of the hands of a watch, in either hemisphere. The opposite to BACKING.

**Velocity.**—Velocity is the ratio of the space passed over by the moving body to the time that is taken. It is expressed by the number of units of length passed over in unit time, but in no other sense is it equal to this space. It can be expressed in a variety of units. For winds, metres per second, kilometres per hour and miles per hour are most common. When a velocity is variable a very short time is chosen in which to measure it. Thus the statement “at 11h. the wind was blowing at the rate of 60 m.p.h.” means that for one second or so at just 11h. the wind had such a rate, that had that rate continued for an hour, the air would have travelled 60 miles in that hour.

**Vendavales.**—Strong squally SW. winds in the Straits of Gibraltar and off the east coast of Spain. They are associated with depressions and bring thick rough weather with heavy rain. They blow mainly between September and March.

**Veranillo.**—The two or three weeks of fine weather which break the rainy season near midsummer in tropical America.

**Verano.**—The long dry season near midwinter in tropical America.

**Vernier.**—A contrivance for estimating fractions of a scale division when the reading to the nearest whole division is not sufficiently accurate. The vernier is a uniformly divided scale which is arranged to slide alongside the main scale of an instrument. An example of a vernier (on a barometer) and the method of reading is given in the “Observer’s Handbook”.

**Virazon.**—A Spanish word meaning SEA BREEZE.

**Virga.**—Wisps or falling trails of precipitation, evaporating before reaching the ground; applied principally to ALTOCUMULUS and ALTOSTRATUS.

**Virtual Temperature.**—The virtual temperature of a sample of air containing water vapour is that temperature at which completely dry air of the same total pressure would have the same density as the given sample.

It is easily shown that

$$T' = T / (1 - (1 - k) e / p)$$

where  $T'$  is the absolute virtual temperature,  $T$  the absolute temperature,  $e$  the water vapour partial pressure,  $p$  the total pressure and  $k$  the ratio of the densities of water vapour and dry air at the same temperature and pressure.  $k = 5/8$  nearly.

**Viscosity.**—The “internal friction” or resistance to distortion which is exhibited by all real fluids to a greater or lesser extent, and which tends to dissipate any relative motion of the fluid, the energy lost to the motion being converted into heat. Maxwell (Theory of Heat) defines viscosity as follows:—“The viscosity of a substance is measured by the tangential force on unit area of either of two horizontal planes at the unit of distance apart, one of which is fixed, while the other moves with the unit of velocity, the space between them being filled with the viscous substance.” The coefficient of viscosity as defined above is usually represented by the symbol  $\mu$ . In liquids  $\mu$  decreases with increasing temperature. For water at  $0^\circ\text{C}$ .  $\mu = .0179$ , while at  $100^\circ\text{C}$ .  $\mu = .0028$ . For air at  $0^\circ\text{C}$ .  $\mu = 172 \times 10^{-6}$ , and at  $100^\circ\text{C}$ .  $\mu = 217 \times 10^{-6}$ . If  $\rho$  be the density of the fluid,  $\nu = \mu/\rho$  is called the kinematic viscosity. The kinematic viscosity of water is less than that of air.

A *very viscous fluid* is distinguished from a soft solid by the fact that any disturbing force, however small, will produce a sensible effect provided that it is continued for a sufficiently long time. See TURBULENCE.

**Visibility.**—A term used in describing the transparency of the atmosphere and defined by the maximum distance at which an object can be seen and the clearness with which its details can be discerned. From practical considerations the convention has been adopted that an object is regarded as visible only when it can be recognized by an observer who has a prior knowledge of the character of the object through having seen it on occasions when the atmosphere was clear.

Strictly speaking "visibility" is a composite quality and not a direct measure of atmospheric transparency. The transparency  $t$  may be expressed as the proportion of light transmitted through unit distance of the atmosphere. It is simpler in practice to use the obscuring power  $n$  of the atmosphere. The unit of obscuring power is the "nebule" which is defined by E. Gold as the condition that 100 nebules reduce the intensity of light to 1/1000 part of its initial value. The number of nebules in a length of 1000 m. of air varies from 1 in conditions of excellent visibility to about 10,000 in a very dense fog in which the distance of visibility is only 10 m.

For the same atmospheric transparency the distance of visibility may vary between rather wide limits and in the case of visibility of lights at night, the distance increases with the intensity of the light used and with the darkness of the background. It would therefore be scientifically more appropriate to specify the transparency as the fundamental quantity, and to derive from it the visibility under different conditions of illumination or intensity of light and darkness of background. But the composite quality has practical advantages because (a) it can be observed with fair approximation in a simple direct way without much technical training or instrumental equipment. Both would be necessary to give reasonably accurate measurements of transparency and illumination in the daytime; (b) it gives the recipient the information which he wants in the form in which he wants it.

Visibility depends chiefly upon the amount of solid or liquid particles held in suspension by the air and to a smaller extent upon the uniformity of temperature and humidity in the layers of air through which an object is viewed. Visibility may vary very considerably in different directions. On a sunny day visibility is usually better, i.e. objects can be seen more clearly, when looking away from the sun than when looking towards it. On a cloudy day, provided rain is not falling, it is frequently equally good in all directions.

In a general way visibility is usually good in air which originates in high latitudes and which has had a relatively direct track while moving towards the equator. Where the equatorial movement is less rapid the visibility tends to deteriorate as the air moves southwards. On the other hand air which originates in lower latitudes and moves polewards usually has less good visibility than air originating near the poles.

The visibility of objects on the ground, when looked at from above, is sometimes bad even when the visibility between two points on the ground is good. This condition is due to a layer of haze at a definite height above the ground. Haze is due to the presence of solid particles in the air and is often due to large towns. A light north-easterly wind sometimes carries a smoke haze 70 miles south-west of London while even longer tracks have been noted to leeward of large industrial areas. The smoke haze has been found to have a sharply-defined upper level but the height of this surface above the ground varies.

J. Aitken made measurements with a "dust counter" which determined the number of hygroscopic particles per cubic centimetre in the atmosphere. He found values ranging between 16 and 7,000 in the open country and as many as 48,000 for London. The apparatus used took no account of the size or composition of the particles.

More recently, J. S. Owens has used a more sensitive form of dust counter in which a measured volume of air is drawn through a disc of filter paper of standard size. The discoloration of this disc is compared with a scale of shades and the number of particles per cubic centimetre estimated. He has found in Norfolk with a light NE. wind 100–200 particles per cubic centimetre with a size of 0.3–1.7 microns, while in London smoke the number may rise to 50,000 per cubic centimetre. In London in winter with the air fairly clear the amount of suspended matter is of the order of 1 milligram per cubic metre of air but it may fall much below this figure on clear nights between midnight and 6 a.m. During a dense fog the amount may rise rapidly to 5 milligrams per cubic metre.

In measuring visibility peculiarities of the eye play an important part. The visibility involves the light emitted by the object and the capacity of the eye to receive it. The visibility or otherwise of an object depends upon the contrast between it and its surroundings and when depending upon differences of illumination, this difference must be a certain percentage of the total illumination. Differences of form and colour also play a part, the red fading first as the intensity of illumination is decreased, then the green and so on until finally a uniform grey is seen.

During the day in non-foggy weather the visibility will usually be decreased compared with that obtaining in the early morning and near to and after sunset, on account of turbulence. In regions where there are ascending columns of air the refractive index of the air at any height will often differ from that in a descending column of air or air at rest, on account of slight differences of temperature and density. The light coming to the eye from an object will be refracted in passing from one column of air to another and objects are distorted and become indistinct in consequence. This effect is observed frequently over sandy deserts.

To obtain a numerical measure of visibility a number of objects are selected at fixed distances. These distances are 20, 40, 100, 200 and 400 metres, 1, 2, 4, 7, 10, 20, 30 and 40 kilometres. The most distant of the selected objects which can be seen and recognized is noted and its distance away provides a measure of the visibility. As far as possible objects are selected which show against the sky line or if this is not possible, those which show distinctly in contrast with their background.

A simple instrument has been devised recently by E. Gold to measure the visibility at night. The principle underlying the use of the instrument is to add to the obscurity of the atmosphere an artificial obscurity by means of light filters until a known light, when viewed through the filters, becomes just indistinguishable. The visibility meter consists of a long narrow filter or screen which is sealed between two glass plates to protect it. The filter transmits light of all wave-lengths, and its density increases uniformly from a clear end to a dark end. The glass protector is mounted in a wooden frame and on this frame is a graduated scale. The frame carries also a movable piece or slider which contains a short filter also sealed between glass plates. This filter is precisely similar to the fixed filter but its density increases in the opposite direction to that of the fixed filter. Thus the combined density of the two superposed filters is uniform over the area of the movable filter. The slider has a pointer which moves along the graduated scale and enables readings to be taken which correspond with the uniform density of the combined filters. By means of tables the appropriate visibility corresponding to a specified scale reading can be obtained.

**Volcanic Dust.**—See DUST.

**Warm Front.**—The boundary line between advancing warm air and a mass of colder air over which it rises. The surface of separation or frontal surface rises from the warm front over the cold air at a smaller angle than at a COLD FRONT, about 1 in 100 to 1 in 150 being usual figures.

The rising of the warm air over the cold air usually causes considerable precipitation in advance of the front, while after it has passed there is either

no precipitation or only slight rain or drizzle as a rule. Warm fronts are chiefly characteristic of high latitudes, and in the British Isles are most often found in winter. See DEPRESSION.

**Warm Sector.**—In the early stages of the life history of at least the majority of the DEPRESSIONS of temperate latitudes, and of more important SECONDARIES, there is a sector of warm air, which disappears as the system deepens and the cold front catches up the warm front (see OCCLUSION). The warm sector is usually composed of TROPICAL AIR, sometimes of polar maritime air.

**Water.**—The name used for a large variety of substances such as sea water, rain water, spring water, fresh water, of which water in the chemical sense is the chief ingredient. Chemically pure water is a combination of hydrogen and oxygen in the proportion by weight of one part to eight, or by volume, at the same pressure and temperature, of two to one, but the capacity of water for dissolving or absorbing varying quantities of other substances, solid, liquid or gaseous, is so potent that the properties of chemically pure water are known more by inference than by practical experience. They are in many important respects different from those of the water of practical life. Ordinary water is a palatable beverage, and is a medium in which a variety of forms of vegetable and animal life can thrive, but pure water freed from dissolved gases is perfectly sterile and quite unpalatable.

Ordinary water has a mass of 1 gram per cubic centimetre (62·3 lbs. per cubic foot) at 4° C. (39° F.). Sea water contains dissolved salts to the extent of as much as 35 parts per 1,000 parts of water, and its density varies from 1·01 to 1·05 gm./cm<sup>2</sup>.

Rain water falling in country districts is the purest form of ordinary water; it contains only slight amounts of impurity derived from the atmosphere. Spring water contains varying amounts of salts dissolved from the strata of soil or rock through which it has percolated; the most common of these salts is carbonate of calcium, which is specially soluble in water that is already aerated with carbonic acid gas; sulphates of calcium and other earthy metals are also found, and sometimes a considerable quantity of magnesia. These dissolved salts give the waters of certain springs a medicinal character. In some districts underground water is impregnated with common salt and its allied compounds to such an extent that it is no longer called water, but brine.

When impure water evaporates, the gas that passes away consists of water alone, the salts, which are not volatile, are left behind; similarly when water freezes in ordinary circumstances the ice is formed of pure water, the salts remain behind in the solution; so that, except for the slight amount of impurity due to mechanical processes, pure water can be got from sea water or any impure water, either by distilling it, or by freezing it.

Besides the solid constituents which give it a certain degree of what is called "hardness," ordinary water contains also small quantities of gases in solution, mainly oxygen and carbonic acid. When the water freezes the ice consists of pure water, and the dissolved gases collect in crowds of small bubbles.

The thermal properties of water, in the state of purity represented by rain water, are very remarkable. Starting from ordinary temperatures, such as 290° A. (62·6° F.) and going upwards in the scale, the water increases in bulk, and part evaporates from the surface, until the boiling point is reached, a temperature which depends upon the pressure, as indicated on p. 116. Then the water gradually boils away without any increase of temperature, but with the absorption of a great amount of heat. Going downwards, the volume of the water contracts slightly until the temperature of 277° A. (4° C., 39·1° F.) is reached; that is known as the temperature of maximum density of water. From that point to the freezing point of water, there is a slight expansion of one eight-thousandth part, and in the act of freezing there is a large expansion amounting to one eleventh of the volume of water. It is in consequence of this change of density in freezing that ice

floats in water with one eleventh of its volume projecting, if the ice is clean, solid ice, and the water of the density of fresh water. Salt water would cause a still larger fraction to project, but floating ice carries with it a considerable amount of air in cavities and sometimes a load of earth so that the relation of the whole volume of an iceberg to the projecting fraction is not at all definite.

**Water Atmosphere.**—A general term used to indicate the distribution of water vapour above the earth's surface. The limitation of the quantity of water vapour in the atmosphere by the dependence of the pressure of saturation upon temperature, places the distribution of water vapour on a different footing from that of the other gases. Water vapour evaporated at the earth's surface is distributed in the troposphere by convection, which may cause so much rarefaction and consequent cooling that some of the water vapour condenses to form cloud.

**Watershed.**—In physical geography the line separating the head streams tributary to different river systems or basins, i.e. the line enclosing a CATCHMENT AREA.

**Waterspout.**—The term used for the funnel-shaped TORNADO cloud when it occurs at sea.

Waterspouts are seen more frequently in the tropics than in higher latitudes. Their formation appears to follow a certain course. From the lower side of heavy cumulonimbus clouds a point like an inverted cone appears to descend slowly. Beneath this point the surface of the sea appears agitated, and a cloud of spray forms. The point of cloud descends until it dips into the centre of the cloud of spray; at the same time the spout assumes the appearance of a column of water. The diameter of the pillar is very variable, estimates ranging from 20 or 30 feet to as much as 200 feet or more. The height from the sea to the cloud base probably ranges from two or three hundred feet up to more than 1,000 feet.

The photographs in Figs. 28 and 29 taken from an aircraft represent an exceptionally fine example which occurred in the eastern Mediterranean off the coast of Palestine on October 27, 1943, between 0905 and 0915 G.M.T. The diameter of the pillar estimated from the known length of the ships is from 200 to 300 feet, the dome of spray about twice this diameter and about 200 feet high, and the height between the sea and the cloud base 1,500 to 2,000 feet. The circulation of the spout was clockwise and it was accompanied by a definite noise "of rushing wind". The spout was moving slowly from north to south; during the time when it was visible it grew thinner and darker, and formed a bend which developed into a definite loop.

The duration of a waterspout varies from 10 minutes to half an hour, and its upper part is often observed to be travelling at a different velocity from its base until it assumes an oblique or bent form. Its dissolution begins with attenuation, and it finally parts at about a third of its height from the base and quickly disappears. The wind in its neighbourhood follows a circular path round the vortex, and although very local, is often of considerable violence, causing a rough and confused, but not high, sea. Numerous reports speak of waterspouts being in the nature of a hollow cylinder of waterdrops with a more or less transparent central core.

**Water Vapour.**—See AQUEOUS VAPOUR.

**Watt.**—The unit of power associated with the practical system of ELECTRICAL UNITS. It is the rate at which energy is transformed into heat in a lamp using 1 ampère at 1 volt.

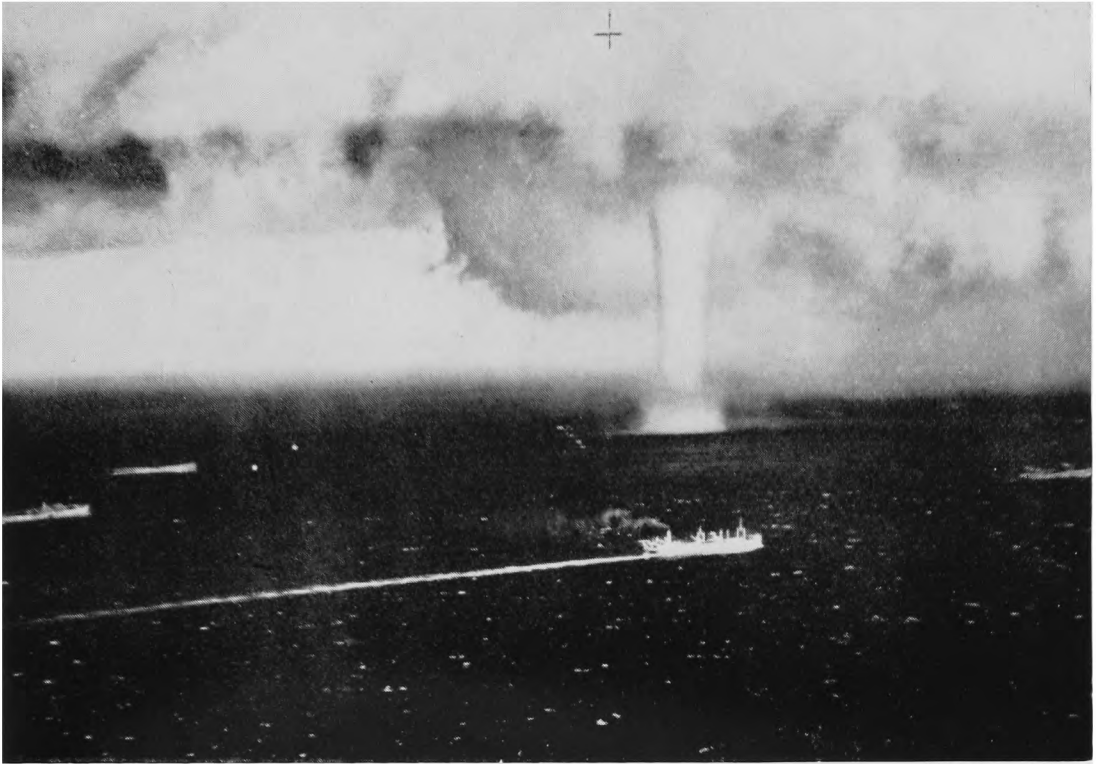
$$\begin{aligned} 1 \text{ watt} &= 1 \text{ ampère-volt} = 1 \text{ joule per second.} \\ &= 10^7 \text{ ergs per second.} \end{aligned}$$

$$1,000 \text{ watt} = 1 \text{ kilowatt} = 1\frac{1}{2} \text{ horse-power.}$$

Units derived from the watt are used by meteorologists for the measurement of the intensity of radiation.

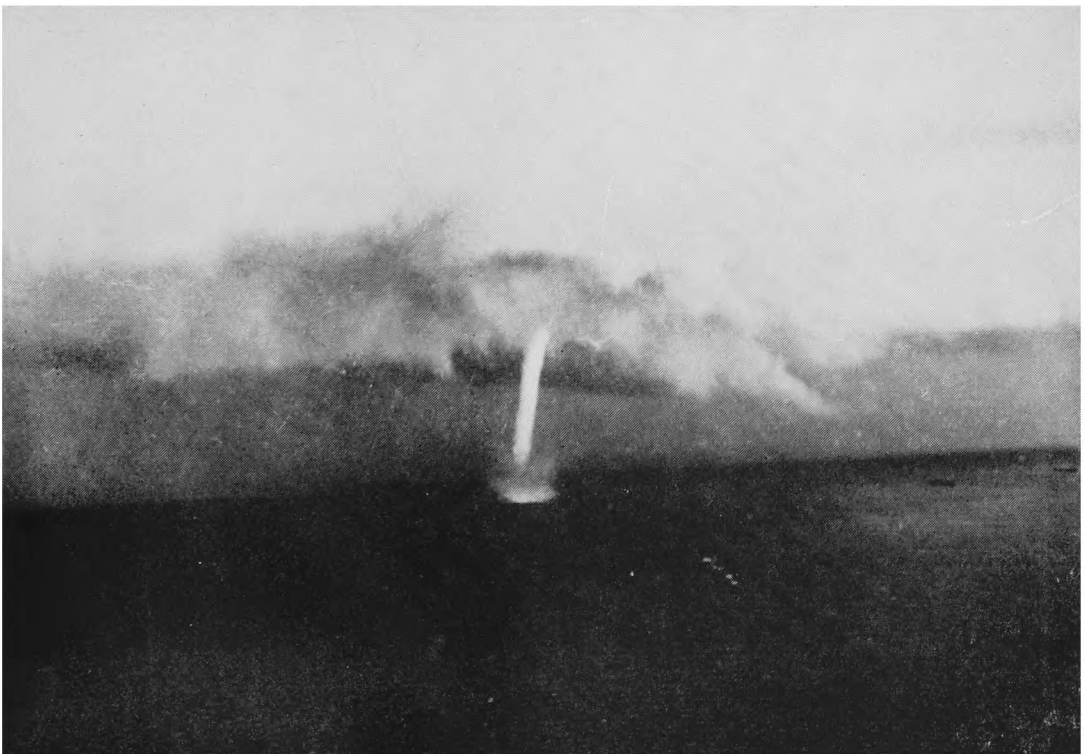
$$\begin{aligned} 1 \text{ milliwatt per cm.}^2 &= 1 \text{ kilowatt per Dm}^2 \\ &= .01435 \text{ gram calories per cm.}^2 \text{ per min.} \end{aligned}$$





*Photo by R.A.F.*

FIG. 28.—Waterspout in the eastern Mediterranean, October 27, 1943, 0910 G.M.T.  
View from aircraft at 100 feet, waterspout  $\frac{1}{4}$ — $\frac{1}{2}$  mile distant.



*Photo by R.A.F.*

FIG. 29.—Waterspout in the eastern Mediterranean, October 27, 1943, 0914 G.M.T.  
View from aircraft at 500 feet, waterspout  $\frac{1}{4}$ — $\frac{1}{2}$  mile distant.



**Wave Motion.**—The commonest example of wave motion is that seen on the surface of the sea, which is disturbed by gravitational waves of a sinusoidal form, the waves having a progressive motion perpendicular to their length. In progressive waves on deep water the water has no steady forward motion, and oscillates about its mean position. Tidal waves are those in which the motion of the fluid is mainly horizontal and, therefore, sensibly the same for all particles in a vertical line. Gravitational waves can also occur in the atmosphere, and Helmholtz suggested that when a cold current is separated from a warm current by a relatively sharply defined surface of separation, gravitational waves should form in the surface of separation. The fundamental feature of wave motion is the alternation of potential and kinetic energy. Further, the disturbance is in general not propagated with the velocity of the masses involved in it.

The term wave motion can be applied to a wide variety of vibrating systems. Waves of compression and rarefaction in the atmosphere are motions transverse to the direction of propagation of the disturbance. The period of such a motion is the interval from one maximum of pressure to the next maximum.

**Waves.**—Any regular periodic oscillations, the most noticeable case being that of waves on the sea. The three magnitudes that should be known about a wave are the amplitude, the wave-length, and the period. The amplitude is half the distance between the extremes of the oscillations, in a sea wave it is half the vertical distance between the trough and crest, the wave-length is the distance between two successive crests, and the period is the time interval between two crests passing the same point. In meteorological matters the wave is generally an oscillation with regard to time, like the seasonal variation of temperature, and in such cases the wave-length and the period become identical.












































If a quantity varies so as to form a regular series of waves it is usual to express it by a simple mathematical formula of the form  $y = a \sin (nt + a)$ . Full explanation cannot be given here; it must suffice to say that the method of expressing periodic oscillations by one or more terms of the form  $a \sin (nt + a)$  is known as "representing by a sine curve", or "a Fourier series", or as "HARMONIC ANALYSIS".

Any periodic oscillation either of the air, water, temperature, or any other variable, recurring more or less regularly, may be referred to as waves. During the passage of sound waves the pressure of the air at any point alternately rises above and falls below its mean value at the time. A pure note is the result of waves of this sort that are all similar, that is to say, that have the same amplitude and wave-length. The amplitude is defined in this simple case as the extent of the variation from the mean, while the wave-length is the distance between successive maximum values. The period is defined as the time taken for the pressure to pass through the whole cycle of its variations and return to its initial value. Another good example of wave form is provided by the variations in the temperature of the air experienced in these latitudes on passing from winter to summer. This is not a simple wave form because of the irregular fluctuations of temperature from day to day, and the amplitude of the annual wave cannot be determined until these have been smoothed out by a mathematical process. Fourier has shown that any irregular wave of this sort is equivalent to the sum of a number of regular waves of the same and shorter wave-length. In America "heat waves" and "cold waves" are spoken of. These are spells of hot and cold weather without any definite duration, and do not recur regularly.

**Waves of Explosions** are among the causes which may produce a rapid variation of pressure which begins with an increase, and is followed by a considerable decrease. The transmission is in the same mode as that of a wave of sound. (See AUDIBILITY.) The damage done by a wave of explosion is often attributed to the low pressure which follows the initial rise. In the same way the destructive effect of wind is sometimes due to the reduction of pressure behind a structure, resulting in the bulging outwards of the structure itself in its weaker parts.

**Weather.**—The term weather may be taken to include all the changing atmospheric conditions which affect mankind, but by meteorologists it is more commonly used in a limited sense to denote the state of the sky and whether rain, snow or other precipitation is falling. Atmospheric obscurity in the form of fog or mist is also included. In order that the different types of weather might be recorded concisely, a system of notation was introduced by Admiral Sir Francis Beaufort which, with some slight modifications and additions, is in use at the present time. Particulars will be found under BEAUFORT NOTATION.

Another method, which has the advantage of being independent of language, of recording the different types of weather concisely and also of recording optical phenomena is by means of symbols. These have been agreed to and revised internationally from time to time and Fig. 30 consists

FORMS OF METEOROLOGICAL SYMBOLS approved by the INTERNATIONAL METEOROLOGICAL ORGANIZATION, WARSAW, 1935.		
	PURE AIR	 SHOWER OF SNOW
	HAZE	 SHOWER OF RAIN & SNOW (SLEET)
	MIST	 SOFT HAIL
	FOG $v < 1\text{km.}$	 SMALL HAIL
	SHALLOW FOG	 HAIL
	GROUND FOG	 DISTANT LIGHTNING
	FROST FOG	 THUNDERSTORM
	DRIZZLE	 DRIFTING SNOW (HIGH UP)
	RAIN	 SNOWSTORM
	SNOW	 DRIFTING SNOW (NEAR THE GROUND)
	SLEET	 DUST OR SANDSTORM
	GRANULAR SNOW	 DUST DEVIL
	GRAINS OF ICE	 SNOW LYING
	ICE NEEDLES	 DEW
	SHOWER OF RAIN	 HOAR FROST
		 GLAZED FROST
		 SOFT RIME
		 HARD RIME
		 GALE
		 SUNSHINE
		 SOLAR HALO
		 LUNAR HALO
		 SOLAR CORONA
		 LUNAR CORONA
		 RAINBOW
		 AURORA BOREALIS
		 MIRAGE
		 ZODIACAL LIGHT

The occurrence of a phenomenon in the vicinity of the station is denoted by enclosing the symbol within brackets ( ). Indices 0, 2 may be used to denote intensity.

FIG. 30.

of a chart showing the symbols approved by the International Meteorological Organization at Warsaw, 1935.

**Weather Map.**—A weather map, as the name implies, is one on which may be found particulars relating to the weather over the area represented by the map. The particulars may refer to a given instant of time or to the mean conditions over a period.

A single observer can only observe the weather conditions over a very limited area ; but by means of an organised corps of observers, synchronous observations covering a wide area can be made and communicated to a central office, where they may be used in the construction of a weather map which is in this case sometimes also called a **SYNOPTIC** chart.

The meteorological elements most frequently found on a synoptic chart or weather map are :—the barometer readings, corrected and reduced to mean sea level, together with the **BAROMETRIC TENDENCY** ; the direction and strength of the wind ; the temperature ; the state of the **WEATHER** indicated by means of letters and symbols, showing whether it is raining, snowing or otherwise ; the amount and type of cloud and the visibility. Such a chart when completed presents a bird's eye view of the general weather situation, and a series of such charts gives the foundations on which our weather forecasts are based. In order, however, to make a forecast for any given area, it is necessary for the weather map to include particulars of the weather distribution both inside and outside the given area. Therefore, by international agreement, weather information is now distributed by wireless telegraphy by most countries, some giving the information concerning their own country only and others, in addition, giving a collective message embracing observations from many countries. It is now possible to construct daily a weather map based upon observations taken over most of the inhabited regions of the northern hemisphere.

**Weather Maxim.**—From the earliest times man has generalised about the weather with the result that a very large number of weather maxims have come into existence, the maxims being intended as means whereby the weather to come may be foretold. A voluminous collection was compiled and published by Richard Inwards under the title of "Weather Lore."

It may be said at once that only a few of these sayings are true, that a large number contain only a partial truth, that some are mutually contradictory, and that many are entirely fallacious. This lack of correctness must be ascribed to the propensity of man to count the "hits" and to neglect the "misses."

Many maxims concern themselves with the weather that actually occurs on a specified day and draw conclusions from these conditions as to the weather during a following period. Of these, a typical case is that of **St. Swithin's Day** (July 15) in England, of which it is said—

"If St. Swithin's greets, the proverb says,  
The weather will be foul for forty days."

The most cursory examination of this over a few years will amply demonstrate its unreliability. There is, however, a further point about the saying, illustrative of the vagaries to be found in weather lore, and that is that neighbouring nations within a circumscribed area have similar predictions but relating to other, and widely separated, days in the calendar. In France, the day of augury is that of **St. Medard** (June 8), in Germany that of the **Seven Sleepers** (June 27), and in Belgium, that of **St. Godelieve** (July 27).

Other sayings concern themselves with the weather in a part of a given month, and state that that weather has a controlling influence on another period. Once again, even cursory examination reveals the lack of truth. March may come in "like a lion" but that does not mean that it will go out "like a lamb."

Many other sayings relate to the behaviour of animals. Of these it may be said that whilst it is highly probable that animals respond to present conditions, no satisfactory evidence has yet been adduced that they are capable of forecasting coming conditions.

Other sayings that have gained much currency, concern themselves with the moon, ascribing to that satellite the power of influencing terrestrial weather; but this influence has never been demonstrated in an adequate manner to the satisfaction of meteorologists.

Still other maxims deal with sky colours. Of these, perhaps the best known is the one—

“A red sky at night  
Is the shepherd's delight :  
A red sky at morning  
Is the shepherd's warning.”

which often proves reliable but, on the other hand, quite often proves “ a broken reed.”\*

In short, no weather maxim should be accepted, no matter how often it may be quoted, or how traditional, unless it has been subjected to statistical examination over a long period and has not been found wanting, or unless it can be definitely connected with specific conditions, as shown by the weather chart.

Most weather maxims are quite unable to survive the searching tests implied in the foregoing paragraph. A few of the sailor's sayings, however, come out better. Of these, three may be mentioned. The saying—

“ First rise after low  
Foretells a stronger blow ”

is often true of the squalls associated with the COLD FRONT of a DEPRESSION. Similarly, the couplet—

“ Long foretold, long last ;  
Short notice, soon past ”

is often true inasmuch as the more extensive depressions with their large areas of bad weather travel more slowly, as a rule, than do the smaller ones, and thus their warning signs last longer. Yet again, the—

“A nor-wester is not long in debt to a sou-wester ”

is often true, due to the fact that depressions frequently follow one another closely.

**Weather Report.**—Statement of the values of meteorological elements observed at a specified place and time. The elements included depend upon the purpose for which the report is required.

It is a record of an observation not a forecast.

**Wedge.**—Between two DEPRESSIONS there is often a region of high pressure where the isobars are shaped like an inverted V with a rounded point; as the first depression moves away the pressure rises but as the second approaches it begins to fall. This region of high pressure is termed a “ wedge ” and sometimes a “ ridge.” It is really a wedge of high pressure between the two depressions. Since depressions move generally in an easterly direction, it follows that the motion of the wedge is also generally eastwards. The weather in the front part of a wedge is often very fine with north-westerly to northerly winds and very good visibility. When cirrus clouds are seen they will nearly always be found to be travelling rapidly from the north-west. On the central part of the wedge the winds are frequently light and variable in direction, but when this part passes the winds begin to freshen from the S. or SW., the skies become cloudy, the visibility deteriorates and rain usually follows as the new depression approaches. When the weather rapidly clears up after the passage of a depression it may be taken as an indication of the approach of a wedge and thus of a period, perhaps only a few hours, of mainly fine weather. See also RIDGE.

**Weighting.**—In statistics, varying the share which different figures contribute to some final result in accordance with their reliability or for other

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\* See *London, Met. Mag.*, 61, 1926 p. 15

reasons. For example, in calculating the SOLAR CONSTANT from the observations made at stations of the Smithsonian Astrophysical Observatory, observations under the most favourable conditions are given a weight of four, while those only just good enough for inclusion receive a weight of one. The former are counted four times, the latter only once.

**Wet Air.**—A term used to define the condition when objects become wet even when rain is not falling. It occurs when a warm, saturated or practically saturated air mass replaces a cold dry air mass and is denoted by the letter *e* in the Beaufort notation.

**Wet Bulb.**—A thermometer whose bulb is covered with muslin wetted with pure water, used in conjunction with a "dry" bulb, reading the air temperature, as a PSYCHROMETER. The reading of the wet bulb also has some independent value at temperatures much above the freezing point, for the discomfort accompanying a given high temperature of the air varies greatly with the humidity, and is more nearly defined by the wet-bulb reading than by the temperature of the air. 90° F. is the highest that has been observed on board ship in the Red Sea. No higher reading is definitely known.

**Wet-bulb Potential Temperature.**—The wet-bulb temperature which the air will take up when brought adiabatically to a standard pressure. It has the property of remaining invariant for ADIABATIC processes, even when water is precipitated from, or evaporated into, the air mass. It is thus very valuable for determining the origin of an AIR MASS.

**Wet Day.**—A wet day is defined for statistical purposes as a period of 24 hours, commencing normally at 9 h., on which 0·04 in. or 1·0 mm. or more of rain is recorded. See also RAIN DAY.

**Wet Fog.**—A fog, accompanied by a very high relative humidity, which wets objects exposed to it. Many town fogs are due largely to smoke, and can occur with relatively dry air.

**Wet Spell.**—The definition of the term "WET SPELL" is analogous to that of the term "DRY SPELL." Thus a wet spell is a period of at least 15 consecutive days to each of which is credited 0·04 in. of rain or more. See also RAIN SPELL.

**Whirlwind.**—A small revolving storm of wind in which the air whirls round a core of low pressure. Whirlwinds sometimes extend upwards to a height of many hundred feet, and cause duststorms when formed over a desert.

**Willy-Willy.**—The name given in Western Australia to a severe CYCLONE.

**Wind.**—In the New English Dictionary wind is defined as "air in motion: a current of air, of any degree of force perceptible to the senses, occurring naturally in the atmosphere, usually parallel to the surface of the ground." The motion of air is not restricted by nature to be "parallel to the surface of the ground" but that is the component of the motion which in ordinary circumstances is indicated by the weather-cock and by the anemometer.

The definition of wind as the motion of air and the invention of the wind-vane go back to before the Christian era. It was recognised by the Greeks that different types of weather were associated with winds from different directions. The Tower of the Winds at Athens, which is octagonal and dates back to the 2nd century B.C., carries on its eight sides the names of the winds and symbolic figures intended presumably to represent the character of the winds. A description of the figures is given by Theophrastus in his treatise "On winds and on weather signs" and is quoted by Sir Napier Shaw in the first volume of his "Manual of Meteorology" together with an estimate of the corresponding weather.

The habit of naming local winds according to their character or to some peculiarity associated with the direction from which they blow persists in

the Mediterranean even to the present time. MISTRAL is the master wind and BORA (north), GREGALE or greco (from the direction of Greece), LEVANTER and PONENTE (from the direction of the rising and setting sun), and TRAMONTANA (from the mountains), are all named from their direction. The habit extends to the Persian Gulf with SHAMAL, nashi, kaus and suhaili but is less common elsewhere, and in the British Isles HELM WIND is the only example.

When navigation gradually extended over the whole globe other winds were soon recognised. The TRADE WINDS which carry air continuously towards the equator owe their name to the fact that they always keep a steady course. The ROARING FORTIES or the BRAVE WEST WINDS refer to the persistent westerly winds which circulate round the globe in about latitude  $40^{\circ}$  of the southern hemisphere; and the well-known MONSOON winds which supply the Indian peninsula with water in the summer are named from their seasonal character.

Superposed on these winds which form part of the general ATMOSPHERIC CIRCULATION other local circulations have to be reckoned with. An important kind of wind is the eddy or vortex in which the air circulates round an axis. Vortex motion in water is easily visible but for air the motion has to be inferred from the visible material, leaves or dust, which is carried by the current. On a small scale the eddies are recognised as a common experience of the effect of obstacles upon the moving air and are known as GUSTS and LULLS, and on a larger scale they are experienced as WHIRLWINDS, TORNADOES, tropical HURRICANES and TYPHOONS and possibly also in some forms of CYLONIC DEPRESSION though in recent years the vortex theory of cyclonic depressions has been superseded by the Norwegian theory of the POLAR FRONT.

*The approach to numerical expression.—The Beaufort scale.*—To give a full expression of the wind, account has to be taken of its force as well as its direction. The direction is measured in a horizontal plane and is easily indicated by the familiar weather-cock which points in the direction from which the air is flowing past it. In modern times the direction of the wind is reported either by the point of the COMPASS (true) from which the wind blows, or by its AZIMUTH in degrees from north through east. A wind which changes its direction in the same way as the hands of a clock is said to be VEERING and one which changes in the reverse direction is said to be BACKING.

The observation of wind force offers more difficulty and estimates are based on the effect of wind on movable objects. Almost anything which is supported so that it is free to move under the influence of wind can be used. Interest in the observation was a primary consideration for ships when they depended upon their sails for their motion and the earliest estimates of the force of the wind come from the experience of sailors. A scale was first put into numerical form by Admiral Beaufort and was standardised for use in the Navy in about 1805 (see *London, Quart. J. R. met. Soc.*, 52, 1926, p. 161), but was not finally adapted for use on land until 1906. A sequence of twelve grades of wind was enumerated from 0, flat calm, to 12, the force of a hurricane, and is still in use as the BEAUFORT SCALE.

Speeds greater than that of a hurricane have been recorded on the earth's surface, and after Sir Douglas Mawson's expedition to the Antarctic it was suggested that the Beaufort scale should be extended beyond force 12 to allow for the speeds of the local blizzards to 100–200 m.p.h. The highest speed recorded on the earth's surface is one of 231 m.p.h. at the Observatory of Mount Washington at a height of 6,284 ft. on April 12, 1934.

The estimation of wind on a ship at sea is easier than at a station on land because the evidence provided by the state of the sails can be associated with the effect of the wind on the water; and that serves as a reminder that the surface, either of land or sea, always disturbs the flow of the air,



and part of the wind's energy must be expended in producing the visible motion of the water. In that respect the sea has great advantages over the land for the observer because it presents a uniform surface to the moving air, and in modern times since sailing ships have been replaced by steamers estimates of wind force at sea depend very largely on the disturbance produced by the wind on the surface of the water.

The obstacles presented by the land to the air-motion—trees, houses, hills and other obstructions natural or artificial—have very curious effects upon the flow of air and the motion often develops into eddies of varying dimensions (see *TURBULENCE*). A good specimen is sometimes developed by a strong wind at a street corner. For this reason the estimation of wind force for meteorological purposes requires careful consideration.

*The measurement of wind; anemometers and their records.*—An instrument for measuring the force or speed of the wind is called an ANEMOMETER. A form of pressure anemometer was invented by Sir Christopher Wren in the 17th century. Until recent years the cup-anemometer, introduced by Prof. Robinson of Armagh Observatory in 1846, was perhaps the most widely used of all anemometers. It was put into recording form by Beckley in 1856. The study of winds was carried out at the Royal Observatory, Greenwich, and at a special establishment of the Meteorological Council at Holyhead, where various forms of anemometer were installed. After the Tay Bridge disaster in 1879, special attention was devoted to the measurement of gusts, and a pressure tube anemometer to record the variation in the force of the wind was devised by W. H. Dines. The testing of anemometers at the present time is carried out at the National Physical Laboratory at Teddington, where apparatus is available for creating an artificial wind in a wind tunnel.

Since the Dines anemometer was brought into use the structure of the wind near the ground has been the subject of detailed study and continuous records are now being obtained at some 45 stations in the British Isles. A study of the records has enabled a distinction to be drawn between GUSTS, the fluctuations of short period in the force of the wind which are attributed to the mechanical interference caused by the irregularities of the surface, and the longer period SQUALLS which are regarded as being of meteorological origin. The mean hourly wind in the British Isles has rarely if ever exceeded 70 m.p.h., whereas gusts of over 100 m.p.h. have been recorded on several occasions, the highest authentic record being of 113 m.p.h. at St. Ann's Head on January 18, 1945. A remarkable example of a sudden squall was provided by the anemograph at Kew Observatory on June 1, 1908, when a wind of less than 10 m.p.h. rose almost instantaneously to nearly 60 m.p.h. in a thunder squall.

Many other notable results are illustrated in a paper by E. Gold on "Wind in Britain" (*London, Quart. J.R. met. Soc.*, 62, 1936, p. 167), and the results of a detailed investigation of "The Structure of Wind over Level Country" in Bedfordshire, based on the work of the late M. A. Giblett, are described in *Geophysical Memoirs*, No. 54, 1932.

By international agreement the knot is now (1956) the meteorological unit of wind speed. For countries using British units, velocities are often given in miles per hour, and sometimes even in feet per second. The equivalents of the various units are as follows:—

$$1 \text{ Km./hr.} = 0.278 \text{ m./sec.} = 0.621 \text{ m.p.h.} = 0.540 \text{ kt.} = 0.911 \text{ ft./sec.}$$

The equivalent speeds of the Beaufort forces are given under *BEAUFORT SCALE*. For engineering purposes the wind is expressed by the force that it exerts on unit surface and these equivalents are also included in the Beaufort table.

The measurement of wind in the free air offers fewer complications than that at the surface. Various methods have been introduced during the present century (see PILOT BALLOON, NEPHOSCOPE), and measurements by RADIO-SONDE are now contemplated. It is important to remember that the measurement of wind obtained by observation of a pilot balloon gives the average wind over the range of height between consecutive observations and not the wind at a definite level.

*Summaries of surface wind and their representation.*—By international agreement the wind is represented on synoptic charts by arrows pointing towards the station, with feathers to show the force; a full-length feather represents two steps of the Beaufort scale, a short feather one step. This practice was adopted in the Meteorological Office (except for the *Marine Observer*) on March 30, 1936.

The usual method of summarising observations of surface wind for climatic purposes is to form a table of the frequency of winds from the several points of the compass. The summaries may be represented pictorially on charts by means of WIND ROSES.

Instead of a frequency summary it may be an advantage for certain purposes, such as the planning of air-transport routes, to determine the resultant wind, either the vector sum of the individual observations or its components along two specified directions at right angles. Components are often given along the directions north and east; or for calculating the wind resistance which a pilot is likely to meet in flying along a definite route, they may be calculated along and perpendicular to the direction of the route.

Another form of mean wind which is of importance in gunnery is known as the ballistic wind.

*Buys Ballot's law.*—In the early days of the development of synoptic meteorology it was noticed that the flow of air was more accurately described as being along the direction of the isobars than across them, and that the closer the isobars were together the stronger was the wind. This relationship was formulated by the Dutch meteorologist Buys Ballot as BUYS BALLOT'S LAW and has come to be recognized as one of the fundamental principles of dynamical meteorology. It has been the subject of a good deal of scientific work, and with the aid of Coriolis's proposition expressing the relation of pressure to velocity, which was rediscovered by Ferrel, the law has been put into mathematical form. A wind which exactly balances the pressure gradient is known as the GEOSTROPHIC WIND, and when allowance is made for the curvature of the path of the air as the GRADIENT WIND.

The relationship was found to be much closer over the sea than over the land, and it was recognized that this was due to the interference of the earth's surface with the smooth flow of the wind. The various effects that wind produces locally during its travel, the banging of doors, the raising of waves, the movement of trees, etc., all dissipate some of its energy by converting it from a steady flow into eddy motion and ultimately into the irregular motion of heat. In consequence, there is usually a rapid increase in the speed of the wind with increasing height above the surface until the undisturbed wind of the free air is reached. The rate of increase depends upon the degree of mixing or TURBULENCE of the surface and of the upper layers and is greatest when the mixing is least. A comparison of the wind in the lower layers of the free air with the gradient by E. Gold in 1908 showed that agreement between the two is usually reached at a height of about 1,500 ft.

*Diurnal variation of wind.*—The changes in the degree of turbulence at the earth's surface have been invoked by Espy and Köppen to explain the observed variations in the speed of the wind at different times of the day.

At the earth's surface the speed of the wind is greatest by day when the mixing of the layers of air due to thermal convection brings momentum from

the upper layers to the surface, and is least at night. In the upper air at a height of 1,000 ft. the reverse variation is observed, the highest speeds occurring at night and the lowest during the day, and at intermediate heights two maxima are sometimes recorded. The difference is well illustrated in Fig. 31, which shows the diurnal variation of speed in January and July at the top and bottom of the Eiffel Tower. A diurnal variation of wind is not likely to be appreciable except in the lowest layers, the height to which it extends depending on the speed of the surface wind and on the degree of turbulence. The results are set out in Brunt's "Physical and Dynamical Meteorology." Very little information is available about the diurnal variation of wind over the sea but such evidence as there is shows that it is not likely to be large. On the coasts the diurnal variation is complicated by the effect of LAND AND SEA BREEZES.

There is also a diurnal variation of wind direction shown as a tendency for veering during the day and backing at night, but this is liable to be over-ruled by local influences.

*Variation of wind with height.*—The increase of wind with height is a matter of considerable practical importance. As a rough approximation it has been estimated that over the sea the wind at the surface is reduced to about two-thirds of its speed in the free air, whilst over the land it may be reduced to one-third; though no definite figure applicable to all occasions and places can be given.

In the immediate neighbourhood of the ground the variation of wind with height is represented fairly accurately for practical purposes by the formula:  $V_h = V_{100} (a \log_{10} h + b)$  where  $V_h$  is the velocity at a height  $h$  ft.,  $V_{100}$  the velocity at 100 ft. and  $a$  and  $b$  are constants. For an open exposure over level country in the day-time  $a$  may be taken as 0.335 and  $b$  as 0.33.

In the layers affected by surface friction a formula for the variation of wind with height, depending on the coefficient of turbulence, was worked out in 1915 by G. I. Taylor in this country, following the earlier work of Ekman, and by Hesselberg and Sverdrup in Norway, and has since been elaborated by others. According to the theory the lines representing the wind at successive levels are a series of vectors, the extremities of which lie on an EQUIANGULAR SPIRAL with its pole at the extremity of the vector representing the GEOSTROPHIC WIND. The irregularities of the surface, however, make it difficult to apply the formula in individual cases.

Above the level affected by surface turbulence the wind will approach the geostrophic velocity provided that the pressure distribution is not changing rapidly. Hence above about 1,500 ft. the variation of wind with height depends on the variation of pressure gradient with height, which in its turn is dependent on the distribution of temperature which changes the atmospheric density and consequently the distribution of pressure.

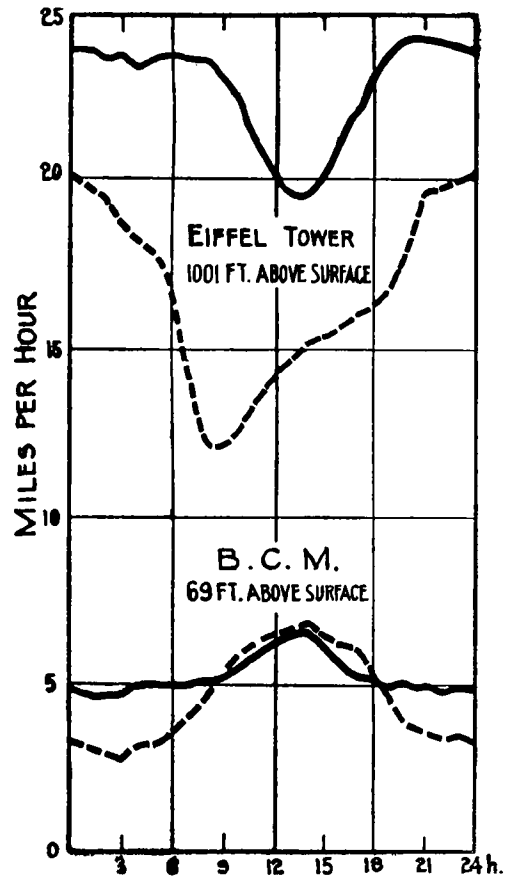


FIG. 31.—Diurnal variation of wind speed at the top of the Eiffel Tower and at the Bureau Central Météorologique (B.C.M.) near the base.

January ——— July - - - - -

As a general principle the wind in the free air at the top of any layer differs from the wind at the bottom by a vector component depending on the distribution of temperature, which has come to be known as the thermal wind. In regions where the distribution of temperature does not change greatly with height, the thermal wind increases with height and its direction is along the isotherms keeping the low temperature on its left. It follows from these results, as Brunt has pointed out, that wind will increase with height if the temperature gradient is in the same direction as the barometric gradient, i.e. if low temperature is associated with low pressure; whereas it will decrease with height if the reverse is the case. If the geostrophic wind blows from high temperature to low the wind will veer with height, whereas if it blows from low to high it will back with height.

The magnitude of the thermal wind may be judged from the fact that in the latitude of the British Isles a temperature gradient of  $1^{\circ}$  C. per 100 Km. over a height of 1 Km. will give a thermal wind of 3 m./sec. or 11 Km./hr.; or in British units a gradient of  $1^{\circ}$  F. per 50 miles will give a thermal wind of 4 m.p.h. or  $6\frac{1}{2}$  Km./hr. at 3,000 ft. at a temperature of about  $30^{\circ}$  F.

*Causes of wind.*—The primary cause of wind has to be traced to differences in solar and terrestrial radiation setting up irregularities of temperature which give rise to convection either upwards or downwards. Gravity is the operative force, working in some cases through the agency of pressure difference.

Water falling on the surface of the earth flows downhill until it comes to the sea, making room for the water that follows it; similarly on an earth which was not rotating we should expect the air cooled over high land to flow down to lower levels. Sir Napier Shaw has given the name *KATABATIC* to the winds which automatically flow downhill. Local examples of this type of wind are not far to seek; in a mild form they are recognised by every agriculturist and are the cause of the disastrous valley frosts of early spring; in a more vigorous form they may be experienced as the fjord winds of Norway, and on an even larger and more violent scale in the outflowing winds from Greenland in the northern hemisphere and from the Antarctic continent in the southern. Katabatic winds are recognised as an important feature of the meteorology of the Mediterranean, especially in the winter months; the *BORA* and the *TRAMONTANA* are definitely of that character and probably the *MISTRAL* also. These winds occur in the rear of cyclonic depressions and accentuate the general flow of cold air southwards from the polar regions which goes to feed the north-east trade winds.

If air is heated at the bottom of a chimney or vertical shaft it will rise up the shaft if it can be replaced at the bottom by a flow into the shaft, and in that sense the raising of the air causes the horizontal motion. The creation of an artificial wind by blowing air with a bellows or air-pump is also a matter of common experience.

These processes have their analogies in the atmosphere and at one time were regarded as supplying a sufficient explanation of many of the winds of the globe. On a small scale the heating of the land by day causes the air to rise and air from the sea flows in to take its place, and this with the complementary process at night explained the well-known phenomena of *LAND AND SEA BREEZES*; on a larger scale and with the year instead of the day as the time unit, the heating of the Asiatic continent in the summer was regarded as giving rise to an inflow of air towards the continent and so explained the *MONSOONS*. Similarly, the air at the equator being warmer than the air of other latitudes, was regarded as pushed up by the colder air flowing southwards and this was held to account for the permanent flow of the *TRADE WINDS*.

It was not until the time of Hadley (1735) that it was recognised that the rotation of the earth itself gave rise to a change of motion which would affect any moving air in such a way that instead of pursuing its course in a great circle it would be deviated to the right in the northern hemisphere and to the left in the southern. This force was used by Hadley to explain the deviation of the trade winds from due north and south to north-east and south-east.

For more than a century the explanation was accepted and air was regarded as flowing from high pressure to low with some deviation caused by the earth's rotation. Since the time of Buys Ballot, however, pressure gradient has come to be regarded as the distribution of force which steers the wind rather than the force which causes it.

In fact, in recent years it has even been suggested that the pressure gradient may itself be built up by the motion of the air rather than the reverse; and there is much to be said for the suggestion. If, for example, two currents flowing in opposite directions pass one another, each having the other on the right, account has to be taken of the fact that the rotation of the earth would interfere with their motion and cause a displacement of the air to the right and there would thus be a tendency for the air currents to drift towards each other and hence form a ridge of high pressure between them; and in like manner if the flows were reversed so that the natural effect of the rotation was for the currents to flow away from one another the result would be that the boundary between the two would form a trough of low pressure which, with the assistance of local convection, might lead to the formation of a central area of low pressure with a cyclonic circulation.

*The energy of wind.*—A feature of the subject which has received little attention is the amazing energy of the motion of the air. It has been shown (*Nature, London*, 128, 1931, p. 226) that for any part of a horizontal field of isobars at which the velocity of the air is in geostrophic accord with the gradient, the energy of a layer of air of uniform thickness, contained within a square lying between a pair of consecutive isobars, is the same for any part of the field (due allowance being made for variation of density and latitude) and can be expressed by the formula  $\frac{1}{2} \frac{hb^2}{\rho \omega^2} \text{cosec}^2 \phi$  where  $h$  is the height of the layer,  $b$  the isobaric interval,  $\rho$  the density,  $\omega$  the earth's angular velocity and  $\phi$  the latitude.

Hence the energy of a square column of air 100 m. high between isobars with a pressure interval of 2 mb. is about 35 million kilowatt-hours in latitude  $60^\circ$ , and 104 million kilowatt-hours in latitude  $30^\circ$ .

*Pressure exerted by wind.*—The pressure  $P$  in lb. per sq. ft. exerted by a wind of velocity  $V$  m.p.h. is customarily expressed as  $P = 0.003 V^2$ .

**Wind Rose.**—A diagram showing, for a definite locality or district, and usually for a more or less extended period, the proportion of winds blowing from each of the leading points of the compass. As a rule the "rose" indicates also the strength of the wind from each quarter, and the number or proportion of cases in which the air was quite calm.

The simplest form of wind rose is shown in Fig. 32 in which the number or proportion of winds blowing from each of the principal eight points of the compass is represented by lines converging towards a small circle, the proportion of winds from each direction being indicated by the varying length of the lines. The figure in the circle gives the number, or percentage, of cases in which the air was calm.

The Baillie wind rose was introduced by Nav.-Lieut. C. W. Baillie in 1892. In this form of wind rose, the arrows which fly with the wind show by their length the frequency of winds of various directions and by their thickness the frequencies of the various forces—light winds, Beaufort forces 1 to 3; moderate winds, 4 to 7; and gales, 8 to 12. The circle supplies a scale for estimating the frequency of winds from any direction; the length from the heads of the arrows to the circle measures 5 per cent. of the total number of observed winds (100 per cent. = 2 inches), the radius of the circle being one-fifth inch or equivalent to 10 per cent. on

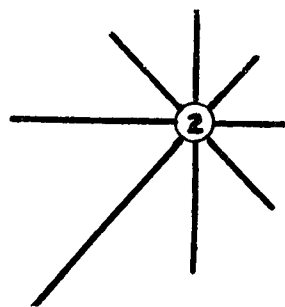


FIG. 32.—Simplest form of wind rose.

the scale. The directions of the observed winds are given to the nearest second point of the true compass. The upper figure in the centre of the wind rose indicates the total number of observations upon which it is based and the lower figure gives the percentage of observations of calms.

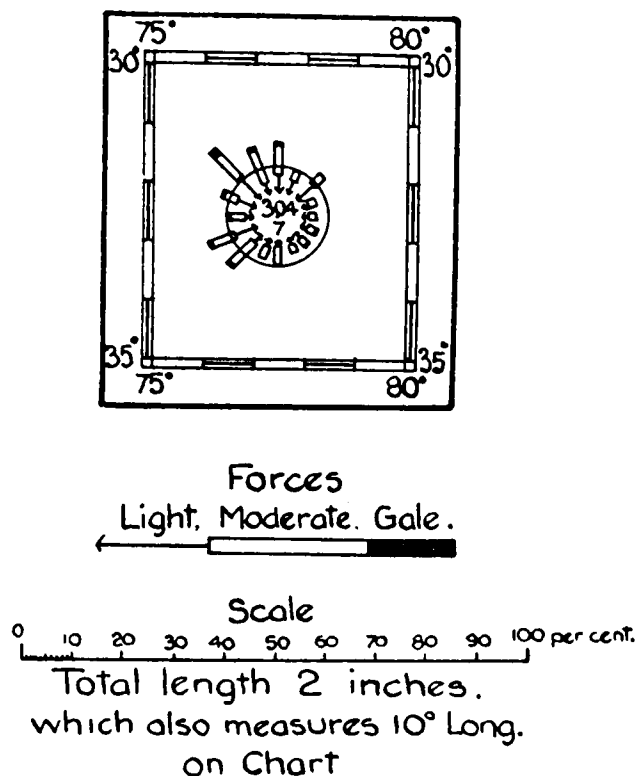


FIG. 33.—The Baillie wind rose.

A rose may be devised in a similar manner to indicate the relation of other meteorological phenomena, such as temperature, cloud, etc., to the direction of the wind.

A wind rose in which the winds for all 12 months are shown on one diagram was devised a few years ago by Shaw and Garbett.\* The eight-point rose is octagon shaped; along each side of the octagon are drawn 12 arrows indicating for each month the frequency of light, moderate and strong winds from the particular direction expressed as a percentage of the total number of winds observed during the month. The percentage numbers of calms in each of the 12 months are given in the centre. This method of representation has been adapted for aviation purposes to show on one diagram winds for one month at different levels in the upper air. The levels selected are those recommended by the International Commission for Aerial Navigation, viz., surface, 500 m. above the surface, 1,000 m., 2,000 m. and 3,000 m. above mean sea level. Thus along each side of the octagon there are five arrows (or columns) indicating for each level the frequency of winds of different speeds blowing from the particular direction expressed as a percentage of the total number of winds observed at that level. The winds are grouped in eight directions and the ranges of speed in each group in miles per hour are 0-3, 4-15, 16-31, 32-47, 48-62, 63 and over. For a specimen see "Report of International Meteorological Conference" at Warsaw, 1935 (I.M.O. Publication, No. 29), Vol. 2, chart at end.

**Wind Vane.**—A device for indicating the direction from which the wind is blowing. In the Meteorological Office pattern a horizontal arm pivoted on a steel spindle is provided with a pointer at one end and an aerofoil of stream line section at the other. Below the vane is a fixed framework showing the four cardinal points. If well exposed and accurately balanced, almost

\* *London, Quart. J.R. met. Soc.*, 59, 1933 p. 39

any type of vane will show the correct direction in moderate or strong winds, but ornamental vanes are rarely sensitive enough for meteorological purposes in light winds.

**Winter.**—See SEASONS.

**Wireless Telegraphy.**—This subject is of interest to meteorologists in many ways. One of the first practical applications of wireless telegraphy was in the transmission of weather reports from ships to land. Such reports were supplied to the Meteorological Office from ships in the Atlantic in 1907. Synoptic reports summarising meteorological observations over a large area were first broadcast from the Eiffel Tower in 1911. The interchange of weather information between the services of different countries is now mostly by wireless telegraphy. Information for the public is broadcast by wireless telephony.

The phenomena which interfere with the operation of wireless telegraphy and telephony and are known as "ATMOSPHERICS" are due to the lightning in distant thunderstorms.

The transmission of wireless messages to very great distances is affected by the condition of the higher strata in the atmosphere. It is on account of the conductivity of these strata, known as the Kennelly-Heaviside layer, that the electromagnetic waves are able to pass round the globe.

**Year.**—The time taken by the earth to revolve once in its orbit round the sun. See CALENDAR.

**Zenith.**—The point of the sky in the vertical produced upwards from the observer. The word is now commonly used as denoting a more or less extensive stretch of sky immediately overhead.

**Zenith, Magnetic.**—Direction indicated by the upper end of a freely suspended magnetic needle. In London, for 1937, the direction was 23° south-south-east of the geographical zenith.

**Zephyr.**—A westerly breeze with pleasant warm weather supposed to prevail at the summer solstice.

**Zero.**—The "point of origin" in graduating an instrument. In Centigrade and Réaumur thermometers the zero of temperature is taken to be the melting point of ice, which is accordingly marked "0" on the scale. Fahrenheit took as his zero the lowest temperature he could obtain from mixtures of ice and common salt. In these cases the zero is an arbitrarily selected point, and negative values are accordingly possible. Theory indicates that a temperature below  $-273^{\circ}$  C. is impossible and that point is accordingly called the "absolute zero" of temperature, and marked "0" on the absolute scale. An error in positioning the entire scale of an instrument may be looked upon as an incorrect allocation of the zero and the term "zero error" is commonly applied to it.

**Zodiac.**—The series of constellations in which the sun is apparently placed in succession, on account of the revolution of the earth round the sun, are called the Signs of the Zodiac, and in older writings give their names and symbols to the months, thus:—

March	is associated with	Aries, the Ram.
April	" "	Taurus, the Bull.
May	" "	Gemini, the Heavenly Twins.
June	" "	Cancer, the Crab.
July	" "	Leo, the Lion.
August	" "	Virgo, the Virgin.
September	" "	Libra, the Scales.
October	" "	Scorpio, the Scorpion.
November	" "	Sagittarius, the Archer.
December	" "	Capricornus, the Goat.
January	" "	Aquarius, the Watercarrier.
February	" "	Pisces, the Fishes.

Owing to precession, the position of the equator relative to the zodiacal constellations has altered a good deal since classical times. The sun now enters Aries late in April and reaches the other zodiacal constellations with the same retardation ; but in text books of astronomy the point at which the sun crosses the equator at the spring equinox, March 21, is still called the first point of Aries.

**Zodiacal Light.**—A cone of faint light in the sky, which is seen stretching along the Zodiac from the western horizon after the twilight of sunset has faded, and from the eastern horizon before the twilight of sunrise has begun. In our latitudes it is best seen from January to March after sunset, and in the autumn before sunrise. In the TROPICS it is seen at all seasons in the absence of moonlight. The light is usually fainter than that of the Milky Way. The luminosity is probably due to the scattering of sunlight by an exceedingly rare gas which is rotating round the sun like an extended atmosphere. There is no sharp limit to this atmosphere and indeed the *Gegenschein*, a luminous patch to be observed in the midnight sky opposite to the position of the sun is thought to be due to sunlight reflected from beyond the earth's orbit. According to Jeffreys the apparent luminosity of the zodiacal light is about  $10^{-7}$  of that of the sky by day. He deduces that the density of the gas from which the zodiacal light is reflected is of the order  $10^{-18}$  gm./cm<sup>3</sup>.

**Zone of Silence.**—See AUDIBILITY.

**Zone Time.**—Formerly it was the custom for each country to adopt as standard of civil time the local mean time of its principal astronomical observatory; thus in England, Ireland and France time was regulated by the local mean times at Greenwich, Dublin and Paris respectively. Consequently Irish time was 25 minutes after English time and French time was about 5 minutes ahead of English time.

To avoid the confusion so produced zone time was introduced and is now almost universally adopted. Under this system national standards of time differ from one another by multiples of half an hour or one hour corresponding with  $7\frac{1}{2}^{\circ}$  or  $15^{\circ}$  of longitude (see TIME). In countries such as the United States, which cover vast distances in longitude, two or three zone times are in use simultaneously. The current practice in respect of zone time is set out on a chart published by the Hydrographic Office, Admiralty, and will be found in Whitaker's Almanack.

## SATURATED ADIABATIC LAPSE RATES

[illegible]



## Conversion of degrees Fahrenheit into degrees absolute.

° F.	0	1	2	3	4	5	6	7	8	9
	degrees absolute									
0 ..	255.2	255.8	256.3	256.9	257.4	258.0	258.6	259.1	259.7	260.2
10 ..	260.8	261.3	261.9	262.4	263.0	263.6	264.1	264.7	265.2	265.8
20 ..	266.3	266.9	267.4	268.0	268.6	269.1	269.7	270.2	270.8	271.3
30 ..	271.9	272.4	273.0	273.6	274.1	274.7	275.2	275.8	276.3	276.9
40 ..	277.4	278.0	278.6	279.1	279.7	280.2	280.8	281.3	281.9	282.4
50 ..	283.0	283.6	284.1	284.7	285.2	285.8	286.3	286.9	287.4	288.0
60 ..	288.6	289.1	289.7	290.2	290.8	291.3	291.9	292.4	293.0	293.6
70 ..	294.1	294.7	295.2	295.8	296.3	296.9	297.4	298.0	298.6	299.1
80 ..	299.7	300.2	300.8	301.3	301.9	302.4	303.0	303.6	304.1	304.7
90 ..	305.2	305.8	306.3	306.9	307.4	308.0	308.6	309.1	309.7	310.2
100 ..	310.8	311.3	311.9	312.4	313.0	313.6	314.1	314.7	315.2	315.8
110 ..	316.3	316.9	317.4	318.0	318.6	319.1	319.7	320.2	320.8	321.3

## Conversion of barometric height in inches of mercury at 32° F. and latitude 45°, to atmospheric pressure in millibars.

Inches	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
	millibars									
28.00 ..	948.2	948.5	948.8	949.2	949.5	949.9	950.2	950.5	950.9	951.2
28.10 ..	951.6	951.9	952.2	952.6	952.9	953.2	953.6	953.9	954.3	954.6
28.20 ..	954.9	955.3	955.6	956.0	956.3	956.6	957.0	957.3	957.7	958.0
28.30 ..	958.3	958.7	959.0	959.3	959.7	960.0	960.4	960.7	961.0	961.4
28.40 ..	961.7	962.1	962.4	962.7	963.1	963.4	963.7	964.1	964.4	964.8
28.50 ..	965.1	965.4	965.8	966.1	966.5	966.8	967.1	967.5	967.8	968.1
28.60 ..	968.5	968.8	969.2	969.5	969.8	970.2	970.5	970.9	971.2	971.5
28.70 ..	971.9	972.2	972.6	972.9	973.2	973.6	973.9	974.2	974.6	974.9
28.80 ..	975.3	975.6	975.9	976.3	976.6	976.9	977.3	977.6	978.0	978.3
28.90 ..	978.6	979.0	979.3	979.7	980.0	980.3	980.7	981.0	981.4	981.7
29.00 ..	982.0	982.4	982.7	983.0	983.4	983.7	984.1	984.4	984.7	985.1
29.10 ..	985.4	985.8	986.1	986.4	986.8	987.1	987.5	987.8	988.1	988.5
29.20 ..	988.8	989.1	989.5	989.8	990.2	990.5	990.8	991.2	991.5	991.9
29.30 ..	992.2	992.5	992.9	993.2	993.5	993.9	994.2	994.6	994.9	995.2
29.40 ..	995.6	995.9	996.3	996.6	996.9	997.3	997.6	997.9	998.3	998.6
29.50 ..	999.0	999.3	999.6	1000.0	1000.3	1000.7	1001.0	1001.3	1001.7	1002.0
29.60 ..	1002.4	1002.7	1003.0	1003.4	1003.7	1004.0	1004.4	1004.7	1005.1	1005.4
29.70 ..	1005.7	1006.1	1006.4	1006.8	1007.1	1007.4	1007.8	1008.1	1008.4	1008.8
29.80 ..	1009.1	1009.5	1009.8	1010.1	1010.5	1010.8	1011.2	1011.5	1011.8	1012.2
29.90 ..	1012.5	1012.8	1013.2	1013.5	1013.9	1014.2	1014.5	1014.9	1015.2	1015.6
30.00 ..	1015.9	1016.2	1016.6	1016.9	1017.3	1017.6	1017.9	1018.3	1018.6	1018.9
30.10 ..	1019.3	1019.6	1020.0	1020.3	1020.6	1021.0	1021.3	1021.7	1022.0	1022.3
30.20 ..	1022.7	1023.0	1023.3	1023.7	1024.0	1024.4	1024.7	1025.0	1025.4	1025.7
30.30 ..	1026.1	1026.4	1026.7	1027.1	1027.4	1027.7	1028.1	1028.4	1028.8	1029.1
30.40 ..	1029.4	1029.8	1030.1	1030.5	1030.8	1031.1	1031.5	1031.8	1032.2	1032.5
30.50 ..	1032.8	1033.2	1033.5	1033.8	1034.2	1034.5	1034.9	1035.2	1035.5	1035.9
30.60 ..	1036.2	1036.6	1036.9	1037.2	1037.6	1037.9	1038.2	1038.6	1038.9	1039.3
30.70 ..	1039.6	1039.9	1040.3	1040.6	1041.0	1041.3	1041.6	1042.0	1042.3	1042.6
30.80 ..	1043.0	1043.3	1043.7	1044.0	1044.3	1044.7	1045.0	1045.4	1045.7	1046.0
30.90 ..	1046.4	1046.7	1047.1	1047.4	1047.7	1048.1	1048.4	1048.7	1049.1	1049.4
31.00 ..	1049.8	1050.1	1050.4	1050.8	1051.1	1051.5	1051.8	1052.1	1052.5	1052.8

## LIST OF

The following pages give the equivalents in various languages of a number of the terms identical in all languages, and these have been omitted from the lists. The complete list

ENGLISH	DANISH	DUTCH
Absorption (atmospheric)	Atmosfærisk Absorption	Absorbite (atmospherische)
Accumulated temperature	Temperaturoverskud	Overmaat van temperatuur
Accuracy	Nøjagtighed	Nauwkeurigheid
Actinic rays	Aktiniske Straaler	Actinische (photographisch werkzame) stralen
Afterglow	Efterglød	Naschemering
Air	Luft	Lucht
Air-meter	Vindhastighedsmaaler, Anemometer	Windsnelheidsmeter
Air pockets	Lufthuller	Remou's
Air trajectory	Luft-Strømningslinje	Luchtbaan
Altimeter	Højdemaaier	Hoogtemeter
Altitude	Højde	Hoogte
Anabatic	Anabatisk	Stijgend
Anemogram	Anemogram	Windregistreering
Anemometer	Vindstyrkemaaler, Anemometer	Windmeter
Anemoscope	Anemoskop	Windaanwijzer
Anthelion	Modsol (Bisol)	Tegenzon
Anticyclone	Anticyklon	Gebied van hooge drukking- maximum
Antitrades	Antipassat	Antipassaat
Anvil cloud	Ambolt Sky	Aambeeld wolk
Aqueous vapour	Vanddamp	Waterdamp
Arid	Tørt	Droog, aride
Atmosphere	Atmosfære	Dampkring, atmosfeer
Atmospheric pollution	Luftens Urenhed	Verontreiniging van de Atmosfeer (dampkring)
Atmospheric pressure	Lufttryk	Luchtdrukking
Atmospherics	Luftelektriske Forstyrrelser	Luchtstoringen
Attached thermometer	Paasat Termometer	Aangehechte Thermometer
Audibility	Hørevidde	Hoorbaarheid
Aurora	Polarlys, Nordlys	Poollicht, Noorderlicht
Autumn	Efteraar	Herfst
Avalanche wind	Faldvind	Lawine-wind
Average	Middel—	Gemiddelde, middelwaarde
Backing	Vinden drejer til venstre, dreier mod Solen	Krimpend
Ball lightning	Kuglelyn	Bolbliksem
Balloon	Ballon	Ballon
Bearing	Pejling	Peiling
Beaufort notation	Beaufort's Vejr-Kode	Beaufort teekens
Beaufort scale of wind force	Beaufort's Vindskala	Beaufortschaal voor windkracht

**EQUIVALENTS**

defined in the Glossary. Many of the words were found to be practically of translations are available for reference in the Meteorological Office Library.

FRENCH	GERMAN
Absorption (atmosphérique)	Absorption (atmosphärische)
Températures accumulées	Wärmesumme, Temperatursumme
Exactitude, précision	Genauigkeit
Rayons actinique	Aktinische Strahlen
Lueurs crépusculaires	Nachglühen
Air	Luft
Anémomètre à main	Anemometer, Windmesser
Trous d'air	Luftlöcher
Trajectoire de l'air	Luftbahn, Trajektorie
Altimètre	Höhenmesser
Altitude	Höhe
Anabatique	Anabatisch, konvektiv
Anémogramme	Anemogramm, Windregistrierung
Anémomètre	Windmesser
Anémoscope	Windfahne
Anthélie	Gegensonne
Anticyclone	Antizyklone, Hoch, Hochdruckgebiet
Contre Alizés	Antipassat, Gegenpassat
Nuage en enclume	Ambosswolke
Vapeur d'eau	Wasserdampf
Aride	Trocken
Atmosphère	Atmosphäre, Lufthülle
Impuretés atmosphériques	Staubgehalt, Beimengungen, Verunreinigung der Luft
Pression atmosphérique	Luftdruck
Atmosphériques	Atmosphärische Störungen (drahtl. Telegraphie)
Thermomètre de baromètre	Attachiertes (eingefügtes) Thermomete
Audibilité	Hörbarkeit
Aurore	Nordlicht
Automne	Herbst
Vent d'avalanche	Lawinenwind
Moyenne	Mittelwert
Mouvement levogyre	Zurückdrehen
Recul du vent	
Eclair en boule	Kugelblitz
Ballon	Ballon
Azimut, relèvement (terme de marine)	Peilung
Notation de Beaufort	Beauforts Wetterskala
Echelle de Beaufort pour la force du vent	Beauforts Windstärkeskala

## LIST OF EQUIVALENTS

ENGLISH	DANISH	DUTCH
Black-bulb thermometer	Sortkugletermometer	Zwarte-bolthermometer (stralingsthermometer)
Blizzard	Blizzard	Sneeuwstorm of sneeuwdrift
Blood-rain	Blod-Regn	Bloedregen
Blue of the sky	Himlens blaa Farve	Hemelblauw
Brave West Winds	Brave Vestenvinde	Westenwind gebied
Breeze	Bris, Brise	Bries (wind)
Bumpiness	Ujævnhed i Luften	Onrust van de Atmospheer
Buoyancy	Opdrift	Veerkracht
Calibration	Kalibrering	IJking
Calm	Vindstille	Windstille
Cap	Skykappe	Kap(je)
Catchment area	Nedbørsopland	Draagoppervlakte
Clear sky, Day of	Klar Dag	Heldere dag
Climatic changes	Klimaændring	Klimaatschommelingen
Cloud-burst	Skybrud	Wolkbreuk
Cloudiness	Skydække	Bewolking ('s-graad)
Clouds	Skyer	Wolken
Col	Saddel	Zadel
Cold front	Kold Front	Koud front
Cold wave	Kuldebølge	Kou-inval. Kougolf
Compass	Kompas	Kompas
Conduction	Ledning	Geleiding
Corona	Korona	Krans
Crepuscular rays	Tusmørkestraaler	Schemeringstralen
Curve fitting	Udjævning med Kurve	Kromme aanpassen
Damp air	Fugtig Luft	Vochtige lucht
Dawn	Daggry	Dageraad, Morgenschemering
Day	Dag	Dag
Débâcle	Isbrud, Isgang	IJsgang
Density	Tæthed	Dichtheid
Depression	Lavtryk	Depressie, minimum
Desert	Ørken	Woestijn
Desiccation	Udtørring	Uitdroging
Deviation	Deviation	Afwijking
Dew	Dug	Dauw
Diathermancy	Gennemstraalelighed	Doorlaatbaarheid voor warmte
Diffraction	Bøjning	Buiging, diffractie
Diurnal	Daglig	Dagelijksch
Doldrums	Doldrum	Kalmtegorfels
Drizzle*	Støvrejn	Motregen, miezeren
Drops	Draaber	Druppels
Drought	Tørke	Droogte
Dry spell	Tørt Tidsram	Tijdperk van Droogte

\* American equivalent, mist

—continued

FRENCH	GERMAN
Thermomètre à boule noire	Schwarzkugelthermometer
Blizzard	Blizzard, Schneesturm
Pluie de sang	Blutregen
Bleu du ciel	Blaues Himmelslicht, Himmelsbläue
Braves vents d'ouest (terme de marine)	Brave Westwinde
Brise	Brise
Turbulence de l'air	Böigkeit (" Bockigkeit ")
Force ascensionnelle	Auftrieb
Calibrage	Kalibrierung, Eichung
Calme	Kalme, Windstille
Capuchon (pileus dans l'Atlas)	Kappe
Bassin de réception	Einzugsgebiet
Ciel clair, Définition d'un jour de,	Heiterer Tag
Changements ou Variations climatériques	Klimaänderung
Pluie torrentielle	Wolkenbruch
Nebulosité	Bewölkung
Nuages	Wolken
Col	Sattel (zwischen zwei Antizyklonen)
Front froid	Kaltfront
Vague froide	Kältewelle
Boussole, compas	Kompass
Conduction	Leitung
Couronne	Korona, Hof
Rayons crépusculaires	Dämmerungstrahlen
Choix de courbes	Kurvenanpassen
Air humide	Feuchte Luft
Aube	Dämmerung
Jour	Tag
Débâcle	Beginn des Eisgangs (Aufgang der Flüsse)
Densité	Dichtigkeit
Dépression	Depression
Désert	Wüste
Desséchement	Austrocknung
Déviation	Abweichung, Ablenkung
Rosée	Tau
Diathermansie	Diathermansie, Wärmedurchlässigkeit
Diffraction	Diffraktion
Diurne	Täglich
Pot-au-noir	Doldrums, Stillen, Kalmengürte
Bruine	Sprühregen, Nieseln, Rieseln
Gouttes	Tropfen
Sécheresse	Dürre
Série (ou période) sèche	Trockenperiode



—continued

FRENCH	GERMAN
Durée de l'Insolation	Sonnenscheindauer
Brune (obscurité)	(Die Zeit vom Ende der bürgerlichen Dämmerung bis zur vollen Dunkelheit)
Poussière	Staub
Tempête de sable	Staubwirbel, Sandhose
Refroidissement dynamique	Dynamische Abkühlung
Courants telluriques	Erdströme
Tremblement de terre	Erdbeben
Tourbillon	Wirbel
Equation du temps	Zeitgleichung
Air équatorial	Äquatorialluft
Equinoxe	Äquinoktien, Tag- und Nachtgleiche
Erreur	Fehler
Evaporation	Verdunstung
Détente	Ausdehnung
Exposition	Aufstellung
Desséchement	Austrocknung
Extrêmes	Extreme
Œil de la Tempête	Auge des Sturms
Lit du vent (marine)	(Richtung, aus der der Wind weht)
Inertie	Fallzeit (des Barometers)
—	Die Temperatur, bei der die Ablesungen eines in mb. eingeteilten Barometers in einer bestimmten Breite keiner Korrektion bedürfen
Floe	Eisfeld
Débit	Abfluss
Brouillard	Nebel
Arc en ciel blanc	Nebelregenbogen
Prévision	Vorhersage
(Intraduisible en français—Sorte de bouillie de glace)	Siggeis
Gel, Congélation	Frieren
Fréquence	Häufigkeit
Frottement	Reibung
Front	Front
Gelée	Frost
Entonnoir de la trombe	Trichter, Schlauch, Rüssel-Wolke
Prévision à assez longue échéance	Voraussichtliche Weiterentwicklung der Wetterlage
Coup de vent	Sturm
Avertissement de tempête	Sturmwarnung
Prévision du type de temps	Allgemeine Wetterlage
Brise de glacier	Gletscherwind
Verglas	Glatteis
Température du sol gazonné	Temperatur am Erdboden
Gravité	Schwere
Grand cercle, orthodromie	Grosser Kreis
Rayon vert	Grüner Strahl
Sol geté	Bodenfrost

## LIST OF EQUIVALENTS

ENGLISH	DANISH	DUTCH
Ground, State of	Jordoverfladens Tilstand	Grondtoestand
Gust	Vindstød, Vindkast	Windstoot
Hail	Hagl	Hagel
Halo	Ring, Maanegaard, Solgaard, Halo	Halo (kring)
Haze	Dis	Nevel
Heat	Varme	Warmte, hitte
High	Højtryk	Hoogedrukgebied
Hoar-frost	Rimfrost	Ruige vorst
Horse latitudes	Heste-Breder	Stiltegordels
Humidity	Fugtighed	Vochtigheid
Hurricane	Orkan	Orkaan
Hydrometer	Hydrometer Areometer	Vochtweger
Ice	Is	Ijs
Iceberg	Isfjeld, Isbjerg	Ijsberg
Iceblink	Isblink	Ijsbinker
Ice sheet	Isdække	Ijslaag
Increment	Tilvækst	Vermeerdering, toeneming
Index correction	Nulpunktskorrektion	Index-correctie
Indian Summer	Indiansk Sommer	Nazomer
Isopycnic	Isopycne	Isopyknen
Katabatic	Fald (vind)	Dalend
Kite	Drage	Vlieger
Labile	i ustabil Ligevægt	Labiell, wankelbaar
Lag	Indstillingstid	Achterblijven
Land and sea breezes	Land og Havbris (-vind)	Land en zeewind
Lapse	Lodret Temperatur-Gradient	Verval, verloop
Latitude	Bredde	Breedte
Level	Vandstand, Niveau	Waterpas, vlak, niveau
Lightning	Lyn	Bliksem, weerlicht
Line-squall	Bygelinie	Bui
Liquid	Vædske	Vloeibaar
Local time	Lokal Tid, Stedtid	Plaatselijke tijd
Longitude	Længde	Lengte
Looming	Ragen op i Taagen	Opdoemen
Low	Lavtryk	Laag, depressie, minimum
Lunar	Maane-	Maans-
Mackerel sky	Himmel med Makrelskyer	Schaapjeswolken
Mares' tails	Kattehaler	Paardestaarten (windveeren)
Mercury	Kviksølv, Kvægsølv	Kwik
Mirage	Spejling	Luchtspiegeling
Mist	Let Taage	Nevel
Monsoon	Monsun	Moesson
Month	Maaned	Maand
Moon	Maane	Maan
Mountain breeze	Bjergvind	Bergwind



—continued

FRENCH	GERMAN
Etat du sol	Zustand des Bodens
Rafale	Windstoss
Grêle	Hagel
Halo	Halo
Brume sèche	Dunst
Chaleur	Wärme
Anticyclone	Hoch, Hochdruckgebiet
Gelée blanche	Rauhreif
Zone des calmes tropicaux	Rosbreiten
Humidité	Feuchtigkeit
Ouragan	Hurrikan
Hydromètre	Hydrometer
Glace	Eis
Iceberg	Eisberg
Reflét éblouissant de la glace	Eisblink
Couche de glace	Eisschild
Différentielle	Inkrement
Correction instrumentale	Index-Korrektion, Instrumental-Korrektion
—	Indianer-Sommer, in Deutschland gleichbedeutend mit Altweibersommer
Isopycniques	Isopyknen
Catabatique	Katabatisch
Cerf-volant	Drachen
Equilibre instable	Labil
Retard	Nachhinken, Trägheit
Brise de terre et brise de mer	Land- und Seewinde (brisen)
Décroissance de la température avec la hauteur	Abnahme, Abfall
Latitude	Breite
Niveau	Ebene, Höhenlage, Niveau
Foudre, éclair	Blitz
Ligne de grain	Böe (mit breiter Front)
Liquide	Flüssigkeit
Heure locale	Ortszeit
Longitude	Länge
Mirage, déplacement de l'horizon	—
Dépression	Tief, Tiefdruckgebiet
Lunaire	Lunar
Ciel moutonné	(Ein mit cc. oder ac. undul bedeckter Himmel)
Cirrus en queue de cheval	Federwolke (Cirrus), Windbaum
Mercure	Quecksilber
Mirage	Luftspiegelung, Fata Morgana
Brume	Nebel
Mousson	Monsoon
Mois	Monat
Lune	Mond
Brise de montagne	Bergwind

## LIST OF EQUIVALENTS

ENGLISH	DANISH	DUTCH
Night sky, Light of	Nattehimlens Lys	Nachtelijken hemel, licht van den
Normal law of errors	Typiske Fejllov	Foutenwet
Observer	Observator	Waarnemer
Oscillation	Svingning	Schommeling
Overcast day	Overtrukket, Graavejrsdag	Betrokken dag
Pack ice	Pakis	Pakijs
Pallium	—	(Pallium)
Paranthelia	Bisole	Bijtegenzon
Paraselenae	Bimaaner	Bijmaan
Parhelion	Bisol	Bijzon
Passing shower	Vandrende Byger	Losse bui
Percolation	Nedsiven	Doorsikking
Persistence	Uforanderlighed	Aanhouden
Personal equation	Personlig Fejl	Persoonlijke fout
Phenomenon	Fænomen	Verschijsel
Pilot balloon	Pilot Ballon	Loodsballon
Pitot tube	Pitot Rør	Pitotbuis
Pluviometer	Regnmaaler	Regenmeter
Pocky cloud	—	(Mammato-cumulus)
Polar air	Polarluft	Poollucht
Precipitation	Nedbør	Neerslag
Pressure	Tryk	Druk
Probability	Sandsynlighed	Waarschijnlijkheid
Probable error	Sandsynlig Fejl	Waarschijnlijke fout
Prognostics	Vejrregler, Vejrtegn	Verwachtingen
Pumping	Pumpning	Pompen
Purple light	Purpurlys	Purpurlicht
Radiation	Straaling	Straling
Rain	Regn	Regen
Rain, Artificial	Kunstig Regn	Regen, kunstmatige
Rain-band	Regnbaand	Regenband
Rainbow	Regnbue	Regenboog
Rain day	Regndag	Regendag
Raindrops	Regndraaber	Regendruppels
Rainfall	Nedbør	Regenval
Rain-gauge	Regnmaaler	Regenmeter
Rain-making	Kunstig Fremstilling af Regn	Regenmaken, regenverwekken
Rain shadow	Læ	(Regen schaduw, beschutting)
Rain spell	Regnperiode	Regen periode
Recurvature of storm	Afbøjning af Stormbane	Terugloopen van den storm
Reduction	Reduktion	Herleiding
Reflection	Reflektion	Terugkaatsing
Refraction	Refraktion	Breking, refractie
Residual	(1) Rest- (2) Afvigelse	Achterblijvend, overblijvend
Reversal	Vindomslag med Højden	Omkeering
Revolving storm	Hvirvelstorm	Wervelstorm

—continued

FRENCH	GERMAN
Lumière du ciel nocturne	Licht des Nachthimmels
Courbe en cloche ou Courbe de Gauss	Fehlergesetz
Observateur	Beobachter
Oscillation	Oszillation, Schwankung
Jour couvert (completement couvert)	Trüber Tag
Pack ice	Packeis
Pallium	(Eine gleichemässige, graue Wolken- decke, aus der gewöhnlich Regen fällt)
Paranthélie	Nebengegensonne
Parasélène	Nebenmond
Parhélie	Nebensonne
Averse passagère	Schauer
Percolation	Filtrierung, Durchsickerung
Persistence	Persistenz, Beständigkeit
Equation personnelle	Persönliche Gleichung
Phénomène	Phänomen
Ballon-pilote	Pilotballon
Tube de Pitot	Pitot-Röhre
Pluviomètre	Pluviometer, Regenschauer
Nuage en poche, Nuage en sac	(Mammato-cumulus)
Air polaire	Polarluft
Précipitation	Niederschlag
Pression	Druck
Probabilité	Wahrscheinlichkeit
Erreur probable	Wahrscheinlicher Fehler
Pronostics	Prognose, Vorhersage
Pistonnage	Pumpen (beim Barometer)
Lueurs pourpres	Purpurlicht
Radiation	Strahlung
Pluie	Regen
Pluie artificielle	Künstlicher Regen
Bande de la pluie (dans le spectre)	Regenbande (im Spektrum)
Arc en ciel	Regenbogen
Jour de pluie	Regentag
Gouttes de pluie	Regentropfen
Chute de pluie	Regenfall, Niederschlag
Pluviomètre	Regenschauer
Pluie artificielle	Regenmachen
Région abritée de la pluie	Regenschatten
Série de pluie	Regenperiode
Courbure de la trajectoire d'un cyclone	Umbiegen der Sturmbahn
Réduction	Reduktion
Réflexion	Reflektion
Réfraction	Refraktion, Brechung
Résiduel	Abweichung
Inversion dans la direction du vent, renversement du vent	Umkehrend
Tempête tournante	Drehsturm

## LIST OF EQUIVALENTS

ENGLISH	DANISH	DUTCH
Ridge	(1) Ryg (2) Kile	Rug
Rime	Rim	Rijp
Roaring Forties	De brølende Vinde paa 40°	Westenwind
Roll cumulus	Skypølser	Rol-cumulus
Salinity	Saltholdighed	Zoutgehalte
Sand pillar	Sandsøjle	Zandpilaar
Sastrugi	—	Sastrug
Saturation	Mætning	Verzadiging
Scotch mist	—	(Bergnevel)
Screen, Stevenson	Stevensons Termometerhus	Stevenson's hut
Scud	Drivsky, Stormsky	Flarden, rafels
Sea breeze	Søbris, Havbris	Zeewind
Sea disturbance	Søgang	Zeegang
Sea level	Havets Overflade	Zeeniveau
Seasons	Aarstider	Jaargetijden
Secular trend	Sekulær Gang	Seculaire gang
Seisms	Jordrystelser	Seismen, aardbevingen
Serein	Regn fra en klar Himmel	Helder
Shade temperature	Temperatur i Skyggen	Temperatuur in de schaduw
Shower	Byge	Stortbui
Silver thaw	Rimslag	Ruige vorst
Site	Beliggenhed	Ligging
Sleet*	Slud	Natte sneeuw
Slide rule, Pilot balloon	Pilot Ballon Regnestok	Rekenschuif of rekenliniaal (voor loods-ballon)
Sling thermometer	Slyngtermometer	Slingerthermometer
Snow	Sne	Sneeuw
Snow drift	Snefog, Sneknog	Sneeuwjacht
Snow line	Snegrænse	Sneeuwgrens
Snow lying	Snedække	Sneeuwbedekking
Snow rollers	—	(Sneeuwrollen)
Soft hail	Hagl, Snehagl	Losse hagel
Solarisation	Direkte Solstraaling	Solarisatie
Solstice	Solhverv	Zonnestilstand
Sounding balloon	Ballon sonde	Registreerballon
Spring	Foraar	Lente
Squall	Byge	Windvlaag
Squall line	Bygelinie	Buienlijn
Standard	Norm	Standaard, normaal
Standard deviation	Middelfejl	Middelbare fout
Standard time	Standard Tid	Standaard tijd
State of the sky	Skydække	Bewolking, hemelbedekking
Storm	Uvejr	Storm
Storm cone	Kegle til Stormvarsel	Stormkegel
Subsidence	Nedsynken	Bezwijken, ineenzakken
Summer	Sommer	Zomer
Sun-dial	(1) Solskive (2) Solur	Zonnewijzer
Sun pillar	Sol-Søjle	Zuil boven de zon
Sunrise, sunset	Solopgang, Solnedgang	Zonsopgang, ondergang
Sunrise and sunset colours	Morgenrøden Aftenrøden	Morgenrood, avonrood (schemeringskleuren)
Sunshine	Solskin	Zonneschijn
Sunspot number	Solpletantal	Zonnevlekken getal
Supersaturation	Overmætning	Overzadiging
Surface of discontinuity	Diskontinuitetsflade	Discontinuiteitsoppervlak

\* American equivalent, frozen rain.

—continued

FRENCH	GERMAN
Crête de haute pression ou dorsale	Rücken (beim Hoch)
Givre	Rauhreif
—	Brave Westwinde
Cumulus en rouleaux	Roll-Kumulus
Salinité	Salzgehalt
Trombe de sable	Staubsäule
Sastrugi	Sastrugi
Saturation	Sättigung
—	(Dicker Bergnebel mit Nieselregen)
Abri	Hütte, Stevenson
Diablotin, Nuage coureur, " Scud "	Fractonimbus
Brise de mer	Seebrise
Agitation de la mer	Seegang
Niveau de la mer	Meeresniveau
Saisons	Jahreszeiten
Variations séculaires	Säkularschwankung
Seismes	Seismische Bewegungen
Serein	Tau
Température sous abri	Schattentemperatur
Averse	Schauer
—	Reif
Exposition	Lage
Neige et pluie mêlées (pas de terme special en français)	Schnee und Regen gemischt (Schlackenwetter)
Règle à calcul pour le dépouille- ment des sondages aérologiques	Rechenschieber für Auswertung von Pilotballonbeobachtungen
Thermomètre-fronde	Schleuderthermometer
Neige	Schnee
Chasse-neige	Schneetreiben
Limite des neiges perpetuelles	Schneegrenze
Couverture de neige	Schneelage
Rouleaux de neige	Schneeroller
Grésil	Graupel
Solarisation	Solarisation
Solstice	Solstitium, Sonnenwende
Ballon-sonde	Sondierballon
Printemps	Frühling
Grain	Böe
Ligne de grain	Böenlinie
Standard, Etalon	Standard, Normal
Ecart moyen	Mittlere Abweichung
Temps legal	Normalzeit
Etat du ciel	Himmelszustand (Menge der Bewölkung)
Tempête	Sturm
Cône de Tempête	Sturmkegel
Subsidence	Absinken
Été	Sommer
Cadran solaire	Sonnentägig
Colonne solaire	Sonnensäule
Lever, coucher du soleil	Sonnenaufgang, Sonnenuntergang
Couleurs du levant, du couchant	Dämmerungsfarben
Insolation	Sonnenschein
Nombres des taches solaires	Sonnenfleckenzahl
Sursaturation	Übersättigung
Surface de discontinuité	Diskontinuitätsfläche

## LIST OF EQUIVALENTS

ENGLISH	DANISH	DUTCH
Surface of subsidence	Subsidsensflade	Vlak van geringsten weer-
Surge	—	Druk golf [stand
Swell	Dønning	Deining
Tension of vapour	Damptryk	Spanning van den damp
Terrestrial magnetism	Jordmagnetisme	Aardmagnetisme
Thaw	Tø	Dauw
Thunder	Torden	Donder
Thundercloud	Tordensky	Donderwolke, onweerswolke
Thunderstorm	Tordenvejr, Tordenbyge	Onweer
Tide, Influence on winds	—	Getij, invloed op wind
Time	Tid	Tijd
Trace (of rainfall)	Spor	Spoor (regen)
Trade winds	Passat	Passaatwinden
Trajectory	Bane	Baan
Transparency	Gennemsigtighed	Doorzichtigheid
Tremor	Skælv	Tremor (siddering, trilling)
Tropic	(1) Troperne (2) Vendekreds	Keerkring
Trough	Udløber af lavt Lufttryk	Dal, trog
Twilight	Tusmørke	Schemering
Twilight arch	Jordskygge	Schemering boog
Typhoon	Tyfon	Typhoon
Units	Enheder	Eenheden
Upper air	Højere Luftlag	Bovenlucht, hogere luchtlagen
Valley breeze	Dalvind	Dalwind
Vapour pressure	Damptryk	Dampdruk
Veering	Vinden drejer til højre	Ruimend
Velocity	Hastighed	Snelheid
Vernier	Nonius	Nonius
Visibility	(1) Synsvidde (2) Sigtbarhed	Zicht
Water	Vand	Water
Watershed	Vandskel	Waterscheiding
Waterspout	Skypumpe	Waterhoos
Water vapour	Vanddamp	Waterdamp
Wave motion	Bølgebevægelse	Golfbeweging
Waves	(1) Bølger (2) Sø	Golven
Weather	Vejr	Weer
Weather maxim	Vejrregel	Weerregel
Wedge	Kile	Wig
Weighting	Tillægge Vægt	Afwegen
Wet bulb	Vaadt Termometer	Natte bol
Wet day	—	Natte dag, regendag
Wet fog	vaadt Taage	Natte mist
Whirlwind	Hvirvelvind	Dwarrelwind, wervelwind
Wind	Vind	Wind
Wind vane	Vindfløj	Windvaan
Winter	Vinter	Winter
Wireless telegraphy	Radiotelegrafi, Traadløs Telegrafi	Draadlooze Telegraphie
Year	Aar	Jaar
Zero	(1) Nul (2) Nulpunkt	Nul
Zodiac	Dyrekredsen	Dierenriem
Zone of silence	Tavshedszone	Stiltezone
Zone time	Zonetid	Zone-tijd

—continued

FRENCH	GERMAN
Surface de subsidence	Abgleitfläche
Variation générale	Allgemeines Ansteigen des Luftdrucks
Houle	Schwall, Dünung
Tension de Vapeur	Dampfdruck
Magnétisme terrestre	Erdmagnetismus
Dégel	Tau
Tonnerre	Donner
Nuage d'orage	Gewitterwolke
Orage avec tonnerre	Gewittersturm
Marée, Influence sur les vents	Flut, Einfluss auf Winde
Temps (durée)	Zeit
Traces de pluie	Spur, Unmessbarer Niederschlag
Vents alizés	Passatwinde
Trajectoire	Trajektorie, Luftbahn
Transparence	Transparenz, Durchlässigkeit
Vibration	Beben, Zittern
Tropique	Wendekreis
Creux	Troglinie (der Depression)
Crépuscule	Dämmerung (Zwielicht)
Arc crépusculaire	Dämmerungsbogen
Typhon	Taifun
Unités	Einheiten
Haute atmosphère	Obere Luftschichten, Hohe (höhere) Atmosphäre
Brise de vallée	Talwind
Pression de vapeur	Dampfdruck
Mouvement dextrogyre	Ausschiessen (des Windes)
Virement où virage	
Vitesse	Geschwindigkeit
Vernier	Nonius
Visibilité	Sicht
Eau	Wasser
Versant	Wasserscheide
Trombe marine	Wasserhose
Vapeur d'eau	Wasserdampf
Mouvement en vague	Wellenbewegung
Ondes	Wellen
Temps (météorologique)	Wetter
Proverbe météorologique	Wetterregel, Wetterspruch, Volkswetterregel, Bauernregel
Coin de haute pression	Keil (Hochdruckkeil)
Pesant	Gewicht
Thermomètre mouillé	Feuchtes Thermometer
Jour humide	Regentag
Brouillard humide	Nässender Nebel
Tourbillon de vent	Wirbelwind
Vent	Wind
Girouette	Windfahne
Hiver	Winter
Télégraphie sans fil	Drahtlose Telegraphie
Année	Jahr
Zéro	Null, Nullpunkt
Zodiaque	Zodiakus, Tierkreis
Zone de silence	Zone des Schweigens
Temps du fuseau	Zonenzeit

## LIST OF

The following pages give the equivalents in various languages of a number of the terms languages, and these have been omitted from the lists. The complete list of translations

ENGLISH	ITALIAN	NORWEGIAN
Absorption (atmospheric)	Assorbimento (atmosferico)	Absorpsjon (Luftens)
Accumulated temperature	Temperatura accumulata	Temperaturoverskudd
Accuracy	Accuratezza	Nøiaktighet
Actinic rays	Raggi attinici	Aktiniske stråler
Afterglow	Tramonto purpureo (del sole)	Efterglød
Air	Aria	Luft
Air-meter	Misuratore di aria	Vindhastighetsmåler, Anemometer
Air pockets	Tasche di aria	Lufthuller
Air trajectory	Traiettoria dell'aria	Lufttrajektor, Luftmasses
Altimeter	Altimetro	Høidemåler [bane
Altitude	Altitudine	(1) Høide (2) Høidevinkel
Anabatic	Anabatico	Anabatisk
Anemogram	Anemogramma	Anemogram
Anemometer	Anemometro	Vindhastighetsmåler, Anemometer
Anemoscope	Anemoscopio	Anemoskop
Anthelion	Antelio	Motsol
Anticyclone	Anticiclone	Anticyklon
Antitrades	Contro alisei	Antipassat
Anvil cloud	Nube a incudine	Amboltsky
Aqueous vapour	Vapor acqueo	Vanndamp
Arid	Arido	Arid, ørken-
Atmosphere	Atmosfera	Atmosfære
Atmospheric pollution	Polluzione atmosferica	Forurensning av luften
Atmospheric pressure	Pressione atmosferica	Lufttrykk
Atmospherics	Atmosferici	Luftelektriske forstyrrelser
Attached thermometer	Termometro unito al Barometro	Barometertemometer
Audibility	Audibilità	Hørevidde
Aurora	Aurora	Polarlys, Nordlys, Sydlis
Autumn	Autunno	Høst
Avalanche wind	Vento a valanga	Skred-vind
Average	Media	Middel
Backing	Salto di vento	Venstredreiende
Ball lightning	Fulmine globulare	Kulelyn
Balloon	Pallone	Ballong
Bearing	Azimut	Peiling
Beaufort notation	Indicazione di Beaufort	Beauforts værkode
Beaufort scale of wind force	Scala di Beaufort della forza del vento	Beauforts vindskala
Black-bulb thermometer	Termometro a bulbo annerito	Sortkuletermometer
Blizzard	Blizzard (vento con nevischio)	(1) Blizzard (2) Snekave, Snestorm
Blood-rain	Pioggia di sangue	Blodregn
Blue of the sky	Bleu del cielo	Himlens blå farve
Brave West Winds	Brava vento di ovest	Nordlige vestenvindsbelte
Breeze	Brezza	Bris*
Bumpiness	Turbolenza dell'aria	Hiving
Buoyancy	Leggerezza	Opdrift

\* Light breeze, svak vind ; strong breeze, liten kuling.



**EQUIVALENTS**

defined in the Glossary. Many of the words were found to be practically identical in all are available for reference in the Meteorological Office Library.

PORTUGUESE	SPANISH	SWEDISH
Absorção atmosférica	Absorción atmosférica	Absorption (Atmosfärens)
Temperatura acumulada	Temperatura acumulada	Värmesumma
Exatidão	Precisión	Nogrannhet
Raios actínicos	Rayos actínicos	Fotografiskt verksamt ljus
Fenómenos ópticos durante o crepusculo	Resplandor montaño (2ª fase)	Efterglöd
Ar	Aire	Luft
Aspirador graduado	Anemómetro de mano	Känslig vindmätare
Poços aereos	Pozos de aire	Luftgropar
Trajectória do ar	Trayectoria del aire	Luftpartikelbana
Altimetro	Altímetro	Höjdmätare
Altitude	Angulo de altura	Höjdvinkel
Anabatico	Anabático	Anabatisk
Anemodiagrama	Anemograma	Vindregistrering
Anemometro	Anemómetro	Anemometer, vindmätare
Anemoscopio	Anemoscopio	Anemoskop, vindfana-flöjel
Antélio	Antihelio	Motsol. Antheli
Anticiclone	Anticiclón	Anticyklon. Högtryck
Contra-moção	Contraalísio	Antipassad
Nuvem em forma de bigorna	Nube en yunque	Städ-moln
Vapor aquoso	Vapor acuoso	Vattenånga
Árido	Arido	Arid. öken-
Atmosfera	Atmósfera	Luftkrets. Atmosfär
Polução atmosférica	Impureza atmosférica	Luftens förorening
Pressão atmosférica	Presión atmosférica	Lufttryck
Atmosféricos	Atmosféricos	Atmosfäriska störningar. "Luftis "
Termómetro adjunto	Termómetro unido	Termometern på barometern
Audibilidade	Audibilidad	Hörbarhet
Aurora	Aurora	Norrsken, Sydsken, Polarsken
Outono	Otoño	Höst
Rajada de vento	Viento del alud	Fallvind vid snöskred
Média	Promedio	Medeltal
De sentido retrógrado	Rolada a la izquierda	Motsolsvridning
Relampago esférico	Rayo en bola	Klotblix
Balão	Globo	Ballong
Rumo	Rumbo náutico	Bäring
Notação Beaufort	Notación de Beaufort	Beauforts beteckningar
Escala Beaufort, da força do vento	Escala de Beaufort	Beauforts vindskala
Termómetro de reservatório negro	Termómetro de bola negra	Svartkuletermometer
" Blizzard "	Ventisca	Blizzard
Chuva de sangue	Lluvia de sangre	Blodregn
Azul do ceu	Azul del cielo	Himmelens blåa färg
Ventos fortes de W	Vientos generales del oeste	—
Brisa	Brisa	Bris
Agitação	Meneo	Gropighet, byighet
Carga de flutuação	Boyanza	Fri lyftkraft

## LIST OF EQUIVALENTS

ENGLISH	ITALIAN	NORWEGIAN
Calibration	Calibrazione	Kalibrering
Calm	Calma	Vindstille
Cap	Cappa	Hette, Skykappe
Catchment area	Area di presa	Bekken
Clear sky, Day of	Giorno di cielo chiaro (sereno)	Klar dag
Climatic changes	Cambiamenti di clima	Klimaendringer
Cloud-burst	Spiraglio fra le Nubi	Skybrudd
Cloudiness	Annuvolamento	Skydekke
Clouds	Nube	Skyer
Col	Col (regione di media pressione)	Sadel
Cold front	Fronte fredda	Kaldfront
Cold wave	Onda fredda	Kuldebølge
Compass	Bussola	Kompass
Conduction	Conduzione	Ledning
Corona	Corona	Korona, Krans
Crepuscular rays	Raggi crepuscolari	Tusmørkestråler
Curve fitting	Curva idonea	Utjevning ved kurve
Damp air	Aria umida	Klam luft
Dawn	Alba	Daggry
Day	Giorno	(1) Dag (2) Døgn
Débacle	Disgelo	Isgang
Density	Densità	Tetthet
Depression	Depressione	Lavtrykk, Lavtrykksområde
Desert	Deserto	Ørken
Desiccation	Desiccazione	Uttørring
Deviation	Deviazione	Deviasjon
Dew	Rugiada	Dugg
Diathermancy	Diatermano	Diatermansi, Gjennemstråle- lighet for varme
Diffraction	Diffrazione	Diffraksjon, bøining
Diurnal	Diurno	Daglig
Doldrums	Zona di calma equatoriale	Doldrum, Ekvatoriale stillebelter
Drizzle	Spruzzatore	Yr, Duskregn
Drops	Goccia	Dråper
Drought	Siccità	Tørke
Dry spell	Periodo di siccità	Tørkeperiode
Duration of sunshine	Durata dello splendore del sole	Varighet av solskinn
Dusk	Crepuscolo	Tusmørke, Skumring
Dust	Pulviscolo	Støv
Dust-devil	Vento vorticoso (in regione sabbiosa e secca)	Støvhvirvel
Dynamic cooling	Raffreddamento dinamico	Dynamisk avkjøling
Earth currents	Corrente terrestre	Jordstrømmer
Earthquake	Terremoto	Jordskjelv
Eddy	Piccolo vortice	Bakevje turbulent
Equation of time	Equazione del tempo	Tidsjevning
Equatorial air	Aria equatoriale	Tropeluft
Equinox	Equinozio	Jevndøgn
Error	Errore	Feil
Evaporation	Evaporazione	Fordunstning
Expansion	Espansione	Utvidelse

—continued

PORTUGUESE	SPANISH	SWEDISH
Calibração	Calibración	Kalibrering, pröfning
Calma	Calma	Lugnväder. Blekstilt
Lenticular, barrete	Toca	Molnhätta
Area de captação	Cuenca	Flodområde
Dia de ceu limpo	Día despejado	Dag med klar himmel
Variações climatéricas ou climáticas	Cambios climáticos	Klimatändringar
Bátega de água	Turbión	Skyfall
Nebulosidade	Nubosidad	Molnighet
Nuvens	Nubes	Moln
Sela, garganta	Collado	Sadel
Frente fria	Frente frio	Kallfront
Vaga de frio	Ola de frio	Köldvåg
Bussola	Compás de bitácora	Kompass
Condução	Conducción	Ledning, värmeledning
Corôa	Corona	Krans
Raios crepusculares	Rayos crepusculares	Skymningsstrålar
Curva ou linha representativa	Adaptación gráfica	Anpassning af en kurva
Ar humido	Aire húmedo	Fuktig luft
Aurora	Aurora	Gryning
Dia	Día	Dygn
Desgêlo	Gran deshielo	Islossning
Densidade	Densidad	Täthet
Depressão	Depresión	Minimum, lågtryck
Deserto	Desierto	Öken
Secúra	Desecación	Uttorkning
Desvio	Desviación	Afvikelse
Orvalho	Rocío	Dagg
Diatermicidade	Diatermancia	Diatermanski
Difração	Difracción	Diffraktion, böjning
Diurno	Diurno	Daglig
Regiões equatoriais de calmas	Zona de calmas ecuatoriales	Ekvatoriala kalmerna
Chuvisco	Llovizna	Dugg. Duggregn
Gôtas	Gotas	Droppar
Séca	Sequía	Torka
Periodo sêco	Periodo seco	Torr period
Duração do brilho do sol	Horas de insolación	Antal solskenstimmar
Crepúsculo	Anocheceer	Skymning (Astronomisk)
Poeira	Polvo	Stoft
Turbilhão de poeira	Tolvanera	Damm-hvirfvel
Resfriamento dinamico	Enfriamiento dinámico	Dynamisk afkylning
Correntes teluricas	Corrientes telúricas	Jordströmmar
Tremor de terra	Temblor de tierra	Jordskalf. Jordbäfnig
Remoinho	Remolino	Hvirfvel
Equação do tempo	Ecuación de tiempo	Tidsekvation
Ar equatorial	Aire ecuatorial	Ekvatorial-luft
Equinoxio	Equinoccio	Dagjämning
Erro	Error	Fel
Evaporação	Evaporación	Avdunstning
Expansão	Dilatación	Utvidgning

## LIST OF EQUIVALENTS

ENGLISH	ITALIAN	NORWEGIAN
Exposure	Esposizione	Eksponering, opstilling
Exsiccation	Essicazione	Uttørring
Extremes	Estremi	Ekstremer
Eye of storm	Occhio della tempesta	Stormøie
Eye of wind	Occhio del vento	Vindøie
Falling time (of barometer)	Tempo di discesa del barometro	Barometrets falletid
Fiducial temperature	Temperatura per la riduzione a O° delle letture barometriche	Barometrets referenstem- peratur
Floe	Mare ghiacciato	Isflak
Flow-off	Deflusso	Avløp
Fog	Nebbia	Tåke
Fog bow	Arcobaleno bianco	Tåkebue, Hvit regnbue
Forecast	Previsione	Værvarsel
Frazil ice	Ghiaccio in aghetti o piastrine	—
Freeze, Freezing	Gelare, congelamento	Frost
Frequency	Frequenza	Frekvens, Hyppighet
Friction	Frizione	Friksjon
Front	Fronte	Front
Frost	Brina	Frost
Funnel cloud	Nube a imbuto	Skypumpe
Further outlook	Previsione a lunga scadenza	Langtidsvarsel
Gale	Vento fresco	Sterk kuling*
Gale warning	Avviso di vento fresco	Kulingvarsel, Stormvarsel
General inference	Inferenza generale	Væroversikt
Glacier breeze	Brezza glaciale	Brevind
Glazed frost	Gelicidio	Isslag
Grass temperature	Temperatura del suolo erboso	Temperatur i gresset
Gravity	Gravità	Tyngdekraft
Great circle	Circolo massimo	Storcirkel
Green flash	Raggio verde	Den grønne stråle
Ground frost	Brina sul terreno (suolo gelato)	—
Ground, State of	Terreno (superficie della terra), stato del	Markens tilstand
Gust	Colpo di vento	Rosse, Vindkast, Vindstøt
Hail	Grandine	Hagl
Halo	Alone	Halo, Ring, Værgard:— (1) Solgard (2) Månegard
Haze	Nebbia (secca), caligine	Ølrøk, Moe
Heat	Calore	Varme
High	Alta (pressione)	Høitrykk, Høitrykksområde
Hoar-frost	Brina	(1) Rim (2) Tåkerim
Horse latitudes	Latitudine delle calme	Hestebredder
Humidity	Umidità	Fuktighet
Hurricane	Uragano	Orkan
Hydrometer	Idrometro	Areometer

\* Beaufort force 8; force 7, stiv kuling; force 9, liten storm

—continued

PORTUGUESE	SPANISH	SWEDISH
Exposição	Instalación	Utställning
Dissecação, Exsicação	Exsecación	Uttorkning
Extremas	Extremas	Extremer
Olho da tempestade	Ojo de la tempestad	Stormens öga
Ponto irradiante	Filo del viento	Mot vinden
Morosidade do barómetro	Inercia del barómetro	Inställningstid
Temperatura fiducial	Temperatura compensadora	Temperatur, då barometern visar rätt
Blocos de gelo flutuantes	Témpano	Isflak
Area de inundação	Caudal	Afrinning
Nevoeiro	Niebla	Dimma
Arco de nevoeiro	Arco de la niebla	Dimregnbåge
Previsão	Predicción	Väderleksförutsägelse
Gêlo frazil	Chispas de hielo	Tallriksis
Geáda, glacial	Helar, Helada	Frysa. Fryspunkt
Frequência	Frecuencia	Frekvens
Fricção	Rozamiento	Friktion
Frente	Frente	Front
Geáda	Escarcha	Frost
Nuvem em funil	Nube en embudo	Skorstensmoln
Previsão prolongada	Indicación ulterior	Utsikter för i öfvermorgon
Vento forte	Temporal	Hård vind eller storm
Aviso de vento forte	Aviso de temporal	Stormvarning
Inferencia ou conclusão geral	Inferencia general	Sammanfattning
Brisa glaciária	Brisa de glaciár	Jökelvind
Geáda vidrada ou prateáda	Lluvia helada	Isbark
Temperatúra da relva	Temperatura junto al suelo	Grästemperatur
Gravidade	Gravedad	Tyngdkraft
Circulo maximo	Círculo máximo	Storcirkel
Raio verde	Rayo verde	Gröna strålen
Geáda no terreno	Helada	Frost med skador
Estado do terreno	Estado del terreno	Markens tillstånd
Rajáda	Ráfaga, Racha	By
Saraiva	Granizo	Hagel
Halo	Halo	Halo
Cerração	Calina, Calima	Disa
Calôr	Calor	Värme
Altúra	Alta	Högtryck
Geáda branca	Escarcha	Rimfrost
Regiões de calma	Zona de calmas tropicales	Rosbredderna
Humidade	Humedad	Fuktighet
Furacão	Huracán	Orkan
Hidrómetro	Hidrodensímetro	Areometer

## LIST OF EQUIVALENTS

ENGLISH	ITALIAN	NORWEGIAN
Ice	Ghiaccio	Is
Iceberg	Iceberg (montagna di ghiaccio)	Isfjell, Isberg
Iceblink	Macchia luminosa nel cielo sopra il ghiaccio	Isblink
Ice sheet	Coperta di ghiaccio (lenzuolo)	Innlandsis
Increment	Incremento	Tilvekst
Index correction	Indice delle correzioni	Nullpunktskorreksjon
Indian summer	Estate indiana	Indian summer
Isopycnic	Superfici di uguale densità	Isopyknisk
Katabatic	Katabatico	Fall (vind)
Kite	Cervo-volante	Drage
Labile	In equilibrio instabile	Labil
Lag	Pigro	Innstillingstid
Land and sea breezes	Brezze di terra e di mare	Solgangsvind :— (1) Landbris, (2) Sjøbris
Lapse	Decremento della temperatura con l'altezza	Vertikal temperaturgradient
Latitude	Latitudine	Bredde
Level	Livello	Nivå
Lightning	Lampo	Lyn, Kornmo*
Line-squall	Linea della tempesta	Linjebyge
Liquid	Liquido	Væske
Local time	Tempo locale	Lokaltid
Longitude	Longitudine	Lengde
Looming	Ingrandimento apparente	Forstørrelse ved tåke
Low	Profondo	Lavtrykk, Lavtrykksområde
Lunar	Lunare	Måne-
Mackerel sky	Cielo con nubi ondulate	Makrellskyhimmel
Mares' tails	Code di cavallo (nube)	Meiskyer, Revehaler
Mercury	Mercurio	Kvikksølv
Mirage	Miraggio	Luftspeiling, Hildring
Mist	Nebbia	Tåkedis
Monsoon	Monzone	Monsun
Month	Mese	Måned
Moon	Luna	Måne
Mountain breeze	Brezza di montagna	Fjellvind
Night sky, Light of	Luminosità del cielo di notte	Nattehimlens lys
Normal law of errors	Legge normale degli errori	Feilloven
Observer	Osservatore	Observatør, iakttagar
Oscillation	Oscillazione	Oscillasjon, Svingning
Overcast day	Giorno caliginoso	Overskyet dag

\* Distant lightning.

—continued

PORTUGUESE	SPANISH	SWEDISH
Gêlo	Hielo	Is
" Iceberg "	" Iceberg." Montaña flotante de hielo	Isberg
" Iceberg "	Resplandor del hielo	Isblink
Lençol de gelo	Sábana de hielo	Ismassa
Acrescimo	Incremento	Inkrement
Correcção do index	Corrección de índice	Indexkorrektion
Verão de S. Martinho	Veranillo de San Martin, Veranillo del membrillo	Indiansommar
De igual densidade	Isopícnica	Isodens
Catabatico	Catabático	Katabatisk
Papagaio	Cometa	Drake
Lábil (instavel)	Lábil	Labil
Atraso ou demora	Retardo	Eftersläpning
Brisas da terra e do mar	Brisas de tierra y de mar. (Terral y virazón)	Land-och sjöbris
Deminuição da temperatura com a altura	Degradación de temperatura	Vertikalgradient
Latitude	Latitud	Latitud. Bredd
Nível	Nível	Vågrät. Nivå
Relampago, raio	Relámpago	Blixt
Linha de borrasca, ou frente fria duma depressão	Linea de turbonada	Linjeby
Liquido	Líquido	Vätska
Hora local	Hora local	Ortstid
Longitude	Longitud	Longitud. Längd
Amplificação aparente	Espectros de calina, Espejismo de calina	Hägring
Baixo	Baja	Lågtryck
Lunar	Lunar	Mån-
Céu cinzento	Cielo aborregado	Makrilmoln
Caudas de cavalo	Rabos de gallo, colas de gato	Hästsvarsar
Mercurio	Mercurio	Kvicksilfver
Miragem	Espejismo	Hägring
Névoa, nebrina	Neblina	Disa
Monção	Monzón	Monsun
Mês	Mes	Månad
Lua	Luna	Måne
Brisa da montanha	Brisa de montaña	Berg-och dalvind
Luz do céu á noite	Claridad del cielo nocturno	Natthimlens ljus
Lei normal dos erros	Ley normal de los errores	Gauss' fellag
Observador	Observador	Observatör
Oscilação	Oscilación	Svängning. Variation
Dia enevoado	Día cubierto	Mulen dag

## LIST OF EQUIVALENTS

ENGLISH	ITALIAN	NORWEGIAN
Pack ice	Ghiaccio ammonticchiato	Pakkis
Pallium	Pallium (nube)	Jevnt skylag
Paranthelia	Parantelio	Motsol
Paraselanae	Paraselenio	Bimåner
Parhelion	Parelio	Bisol
Passing shower	Pioggia di breve durata	Vandrende byger, Vandrende skurer
Percolation	Percolazione	Nedsiving
Persistence	Persistenza	Vedvaren
Personal equation	Equazione personale	Personlig feil
Phenomenon	Fenomeno	Fenomen, foreteelse
Pilot balloon	Pallone pilota	Pilotballong
Pitot tube	Tubo di Pitot	Pitotrør
Pluviometer	Pluviometro	Pluviometer, Regnmåler
Pocky cloud	Nube a tasca	Mammato-
Polar air	Aria polare	Polarluft
Precipitation	Precipitazione	Nedbør
Pressure	Pressione	Trykk, Lufttrykk
Probability	Probabilità	Sannsynlighet
Probable error	Errore probabile	Sannsynlig feil
Prognostics	Prognostici	Værmerker, Værregler
Pumping	Instabilità (barometro)	Pumpning
Purple light	Luce purpurea	Purpurlys
Radiation	Radiazione	Stråling
Rain	Pioggia	Regn
Rain, Artificial	Pioggia artificiale	Kunstig regn
Rain-band	Banda della pioggia	Regnbånd
Rainbow	Arcobaleno	Regnbue
Rain day	Giorno di pioggia	Dag med nedbør > 0.2 mm.
Raindrops	Gocce di pioggia	Regndråper
Rainfall	Caduta di pioggia	Nedbør
Rain-gauge	Pluviometro	Regnmåler
Rain-making	Pioggia artificiale	Regnmakeri
Rain shadow	Area di poca pioggia	Le for nedbør
Rain-spell	Lungo periodo di pioggia	Regnværperiode
Recurvature of storm	Deviazione della tempesta	Tilbakebøining av tropisk stormbane
Reduction	Riduzione	Reduksjon
Reflection	Riflessione	Refleksjon, Speiling
Refraction	Rifrazione	Refraksjon, Brytning
Residual	Residuo	Avvikelse fra utjevnet verdi
Reversal	Rovesciamento (del vento)	Vindomslag med høiden
Revolving storm	Ciclone tropicale	Hvirvelstorm
Ridge	Sommità	Kile, Rygg
Rime	Nebbia gelata	(1) Tåkerim (2) Rim
Roaring Forties	—	Sydlig vestenvindsbelte, De brave vestenvinde
Roll cumulus	Roll-cumulus	Skyruller
Salinity	Salinità	Saltgehalt, Saltholdighet
Sand pillar	—	Sandhvirvel
Sastrugi	Ondulazioni sulla neve	Skavler
Saturation	Saturazione	Metning
Scotch mist	Precipitazione da nebbia fine	Tåkeyr



—continued

PORTUGUESE	SPANISH	SWEDISH
Pacote de gelo " Pallium "	Banco de hielos a la deriva Palio. (Pallium)	Packis Regnmolnstäcke
Parantélio	Parantheios	Motbisol. Parantheli
Paraselenia	Paraselenes	Bimåne
Parhélio	Parhelio	Bisol. Parheli
Aguaceiro passageiro	Chubascos pasajeros	Övergående skur
Filtração	Filtración	Perkolation
Persistencia	Persistencia	Persistens. " Erhaltungstendenz "
Equação pessoal	Ecuación personal	Personlig ekvation
Fenómeno	Fenómeno	Fenomen
Balão piloto	Globo piloto	Pilotballong
Tubo de Pitot	Tubo de Pitot	Pitotrör
Pluviómetro	Pluviómetro	Regnmätare
Nuvem bexigosa	Nubes abolsadas	Mammato-
Ar polar	Aire polar	Polarluft
Precipitação	Precipitación	Nederbörd
Pressão	Presión	Tryck. Lufttryck
Probabilidade	Probabilidad	Sannolikhet
Error provavel	Error probable	Sannolikt fel
Prognosticos	Pronósticos	Väderlekstecken
Oscilação	Tembleteo	Pumpning
Luz purpúrea	Luz purpúrea	Purpursken
Radiação	Radiación	Strålning
Chuva	Lluvia	Regn
Chuva artificial	Lluvia artificial	Konstgjordt regn
Risca de chuva	Banda de absorción de la lluvia	Regnband
Arco-íris	Arco iris	Regnbåge
Dia de chuva	Día de lluvia	Nederbördsdag
Pingos de chuva	Gotas de lluvia	Regndroppar
Chuva caída	Precipitación	Nederbörd
Pluviómetro	Pluviómetro	Nederbörds-mätare
Chuva artificial	Pluvificación	Regnmakeri
Area protegida das chuvas	Sequia orográfica	Regnskugga
Período chuvoso	Periodo lluvioso	Regnperiod
Encurvamento da tempestade	Incurvación de la tempestad	Stormens riktningsändring
Redução	Reducción	Reduktion
Reflexão	Reflexión	Reflektion. Återkastning
Refracção	Refracción	Refraktion. Brytning
Residual, restante	Desviación	Residu
Reversão	Reversión	Vindomkastning med höjden
Ciclone, furacão	Ciclón, tifón, huracán, baguío	Hvirfvelstorm
Crista	Loma	Rygg af högt lufttryck
Neváda	Cenceñada (Niebla helada)	Dimfrost
—	Ponientes duros australes	—
Cumulus em forma de rôlo	Rollo-cumulos, ó cumulos en rollo	Vals-Cumulus
Salinidade	Salinidad	Salthalt
Coluna de areia	Tolvanera	Sandstod
" Sastrugi "	" Sastrugi "	Skaflor
Saturação	Saturación	Mättning
Nebrina da Escocia	Neblina escocesa	Regndimma

## LIST OF EQUIVALENTS

ENGLISH	ITALIAN	NORWEGIAN
Screen, Stevenson	Capanna (meteorologica di Stevenson)	Stevensons bur
Scud	Fracto-nimbo	—
Sea breeze	Brezza di mare	Sjøbris
Sea disturbance	Burrasca marina	Sjøgang
Sea level	Livello del mare	Havsnivå
Seasons	Stagione	Årstider
Secular trend	Ciclo secolare	Sekulær endring
Seisms	Sismo	Jordrystelser
Serein	Sereno (pioggia con cielo)	Regn fra klar himmel
Shade temperature	Temperatura all'ombra	Temperatur i skyggen
Shower	Rovescio	Skur, byge
Silver thaw	Galaverna	Rimslag
Site	Luogo	Beliggenhet
Sleet	Pioggia gelata	Sludd
Slide rule, Pilot balloon	Regolo calcolatore per palloni piloti	Regnestav for pilotballonger
Sling thermometer	Termometro a fionda	Slyngetermometer
Snow	Neve	Sne
Snow drift	Neve gelata ammonticchiata	(1) Snefokk, Snedrev (2) Snedrive
Snow line	Limite delle nevi (perpetue)	Snegrense
Snow lying	—	Snedekke
Snow rollers	Cilindri di neve	—
Soft hail	Grandine molle	Hagl*
Solarisation	Insolazione	Eksposering for sollys
Solstice	Solstizzio	Solhverv
Sounding balloon	Pallone sonda	Registrerballong
Spring	Primavera	Vår
Squall	Tempesta	Vindbyge, Byge
Squall line	Fronte della tempesta	Bygelinje
Standard	Di ugual misura, campione	Standard
Standard deviation	Deviazione tipo	Middelfeil
Standard time	Tempo medio locale	Normaltid
State of the sky	Stato del cielo	Skydekke
Storm	Burrasca, temporale	(1) Uvær, (2) Storm
Storm cone	Segnale di tempesta	Stormvarselskjegle
Subsidence	Subsidenza	Subsidsens, Nedsynkning
Summer	Estate	Sommer
Sun-dial	Orologio solare	Solur
Sun pillar	Colonna solare	Solsøile
Sunrise, sunset	Sorgere del sole, tramonto del sole	Solopgang, Solnedgang
Sunrise and sunset colours	Colori del sorgere e del tramonto del sole	Morgenrøden, Aftenrøden
Sunshine	Splendore del sole	Solskinn
Sunspot number	Numero delle macchie solari	Solflekktall
Supersaturation	Soprasaturazione	Overmetning
Surface of discontinuity	Superficie di discontinuità	Diskontinuitetsflate
Surface of subsidence	Superficie di subsidenza	Subsidsensflate

\* Kornsne is used for granular snow.

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PORTUGUESE	SPANISH	SWEDISH
Abrigo Stevenson	Garita de Stevenson	Stevenson's bur
Fracto-nimbus	Correos	Molnflagor
Brisa do mar	Virazón	Sjöbris
Perturbação do mar	Estado del mar	Sjögång
Nível do mar	Nivel del mar	Havsytan
Estações	Estaciones del año	Årstider
Variação secular	Tendencia secular	Sekulärvariation
Sismo	Sismos	Seismer
Sereno	Sereno, relente	Regn från klar himmel
Temperatura á sombra	Temperatura a la sombra	Temperatur i skuggan
Aguaceiro	Chubasco	Skur
Degêlo prateado	Escarcha plateada	Glattis. Silfverdagg
Situação	Situación	Förläggning
Geáda miuda	Aguanieve	Snöblandadt regn
Régua de cálculo para balões pilotos	Regla de cálculo para globos pilotos	Räknesticka för ballong- viseringar
Termómetro funda	Termómetro honda	Slungtermometer
Neve	Nieve	Snö
Neve amontoada	Ventisquero y ventisca	Drifsnö
Linha de neve	Límite de las nieves perpétuas	Snögräns
Neve jacente	La nieve cubre el suelo	Snötäcke
Rolos de neve	Rollos de nieve	Snöbultar
Graniso	Nieve granulada	Trindsnö
Exposição ao sol	Insolación	Utsättning för solljuset
Solsticio	Solsticio	Solstånd
Balão sonda	Globo sonda	Ballon-sonde
Primavéra	Primavera	Vår
Borrasca	Turbonada	Stormby. Stormil
Linha de borrasca ou frente fria duma depressão	Linea de turbonada	Bylinje
Padrão	Patrón, tipo, norma, modelo	Etalon
Desvio da normal	Desviación tipo	Medelfavvikelse
Hora normal	Hora civil	Normaltid. Gemensam tid
Estado do céu	Nubosidad	Himmels utseende
Tempestade	Tempestad, temporal, borrasca	Storm
Cone, aviso de tempestáde	Señales de tempestad	Stormvarningskon
Abatimento	Subsidencia	Efterströmning
Verão	Verano	Sommar
Relojio de sol	Cuadrante solar	Solvisare. Solur
Coluna solar	Columna solar*	Ljuspelare
Nascer do sol e pôr do sol	Orto, ocaso	Soluppgång. Solnedgång
Colorações ao nascer e pôr do sol	Coloraciones del orto y ocaso	Skymningsfärger
Brilho do sol	Horas de sol	Solsken
Número de manchas solares	Números de Wolf	Solfläckstal
Sobressaturação	Sobresaturación	Öfvermättning
Superfície de descontinuidade	Superficie de discontinuidad	Diskontinuitetsyta
Superfície de abatimento	Superficie de subsidencia	Subsidensyta

\* Also obelisco luminoso.

## LIST OF EQUIVALENTS

ENGLISH	ITALIAN	NORWEGIAN
Surge	Cambiamento di pressione	Utstrakt trykkendring
Swell	Onde (di mare) persistenti	Dønning
Tension of vapour	Tensione del vapore	Vanndampens trykk
Terrestrial magnetism	Magnetismo terrestre	Jordmagnetisme
Thaw	Liquefazione	Tø
Thunder	Tuono	Torden
Thundercloud	Nube da tuoni	Tordensky
Thunderstorm	Temporale	(1) Tordenvær (2) Tordenbyge
Tide, Influence on winds	Marea, influenza dei venti	Tidevannets innflydelse på vinden
Time	Tempo	Tid
Trace (of rainfall)	Traccia (della pioggia) (piccola quantità)	Spor (av nedbør)
Trade winds	Venti alisei	Passat
Trajectory	Traiettoria	Trajektor, Bane
Transparency	Trasparenza	Gjennemsiktighet
Tremor	Tremoto	Jordskjelv
Tropic	Tropico	(1) Vendekrets (2) Troperne
Trough	—	Lavtrykksrenne
Twilight	Crepuscolo	Tusmørke, Skumring
Twilight arch	Arco crepuscolare	Jordskygge
Typhoon	Tifone	Tyfon
Units	Unità	Enheter
Upper air	Aria superiore	Høiere luftlag
Valley breeze	Brezza di valle	Dalvind
Vapour pressure	Tensione del vapore	Vanndampens trykk
Veering	Rotazione	Høiredreiende
Velocity	Velocità	Hastighet
Vernier	Verniero	Nonius
Visibility	Visibilità	(1) Synsvidde (2) Siktbarhet
Water	Acqua	Vann
Watershed	Linea di displuvio	Vannskille
Waterspout	Tromba marina	Skypumpe
Water Vapour	Vapore di acqua	Vanndamp
Wave-motion	Moto ondoso	Bølgebevegelse
Waves	Onde	Bølger
Weather	Tempo (meteorologico)	Vær
Weather Maxim	Aforismi sul tempo	Værmerke, Værregel
Wedge	Cuneo	Kile, Rygg
Weighting	Pesata	Tildele vekt
Wet Bulb	Bulbo bagnato	Vått termometer
Wet Day	Giorno umido	Dag med nedbør > 1.0 mm.
Wet Fog	Nebbia umida	Våt tåke
Whirlwind	Turbine	Hvirvelvind
Wind	Vento	Vind
Wind Vane	Anemoscopio	Vindfløi
Winter	Inverno	Vinter
Wireless Telegraphy	Telegrafia senza fili	Radiotelegrafi
Year	Anno	År
Zero	Zero	(1) Null (2) Nullpunkt
Zodiac	Zodiaco	Dyrekretsen
Zone of Silence	Zona del silenzio	Taushetssone
Zone Time	Fuso orario	Sonetid

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PORTUGUESE	SPANISH	SWEDISH
—	Variación de conjunto	Allmän tryckstegring
—	Mar de leva, Mar sordo, Mar tendida	Dynning
Tensão do vapor	Tensión del vapor	Ångtryck
Magnetismo terrestre	Magnetismo terrestre	Jordmagnetism
Degêlo	Deshielo, fusión	Dagg
Trovão	Trueno	Åska
Nuvem de trovoáda	Nube tormentosa, nubarrón	Åskmoln
Trovoáda	Tormenta	Askväder
Mare, influencia sobre os ventos	Marea, influencia sob e los vientos	Tidvattnets inflytande på vinden
Hora	Hora (Tiempo)	Tid
Vestígios de chuva	Lluvia inapreciable	Ngt (pronounced något)
Ventos regulares	Vientos alisios	Passader
Tragectória	Trayectoria	Trajectorie
Transparencia	Transparencia	Genomskinlighet
Tremor	Temblor de tierra	Jordstötär
Trópico	Trópico	Vändkrets. Tropik
Linha de baixa pressão	Vaguada	Tråg
Crepúsculo	Crepúsculo	Skymning
Arco crepuscular	Arco crepuscular	Skymningsbåge
Tufão	Tifón o baguío	Tyfon
Unidades	Unidades	Enheter
Camada superior do ar	Atmósfera superior	Högre atmosfären
Briza do vale	Brisa de valle	Dalvind
Tensão de vapor	Tensión del vapor	Ångtryck
Sentido directo	Rolada a la derecha	Medsolsvridning
Velocidade	Velocidad	Hastighet
Nónio	Nonio	Nonie
Visibilidade	Visibilidad	Siktbarhet, synvidd
Agua	Agua	Vatten
Aguas vertentes	Divisoria	Vattendelare
Tromba de agua	Tromba marina, manga	Skydrag
Vapor de agua	Vapor acuoso	Vattenånga
Movimento ondulatorio	Movimiento ondulatorio	Vågrörelse
Ondas	Ondas, olas	Vågor
Tempo	Tiempo	Väder. Väderlek
Maximas ou aforismos	Refrán meteorológico	Väderleksregel
Cunha	Cuña	Ås
Peso	Ponderación	Förse med vikter
Reservatório molhado	Termómetro húmedo	Våta kulan
Dia humido	Día de lluvia	Regndag
Nevoeiro humido	Niebla húmeda	Vätande dimma
Remoínho	Torbellino	Hvirfvelvind
Vento	Viento	Vind
Catavento	Veleta	Vindfana
Inverno	Invierno	Vinter
Telegrafia sem fios	Radiotelegrafia	Trådlös telegrafi. Radio
Ano	Año	År
Zéro	Cero	Noll
Zodíaco	Zodiaco	Djurkrets
Zona de silencio	Zona de silencio	Tyst zon
Fusos horários	Hora del huso	Zontid