M.O. 613 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 85, No. 1,010, AUGUST 1956

ICE ACCUMULATION UPON TRAWLERS IN NORTHERN WATERS

By R. F. M. HAY, M.A.

The recent case of the loss of the Grimsby trawlers *Lorella* and *Roderigo* some 90 miles to north-north-east of North Cape, Iceland on January 26, 1955 which a Court of Inquiry decided was due to an exceptionally heavy accumulation of ice on their superstructure causing them to become unstable and to capsize, has focussed attention afresh upon the risks run by trawlers which operate in these waters in winter. The meteorological implications of these risks have been dealt with elsewhere[1]; the purpose of this note is to consider some of the physical problems involved. "Icing up" was already known to have been the probable cause of the disaster, and one of the main tasks which faced the Court was to establish which physical agency or agencies were responsible for it. The Court also required to be satisfied that the conditions of weather and sea actually experienced by the ships in the days prior to their loss, could have resulted in their accumulating the large weights of ice which calculation showed would be needed to cause such large vessels to capsize.

Before describing these computations it is necessary to set out the facts which were established before the official inquiry. The *Lorella*, a steam trawler of 559 tons gross was known to have been overwhelmed by ice shortly before 1500 G.M.T. on January 26, and the *Roderigo*, a steam trawler of 810 tons gross sank from a similar cause at about 1712 G.M.T. on the same day. The ships were believed to have sunk within a few miles of each other in an approximate position 67½°N. 21°W. During the preceding four days the weather had been extremely bad. By means of the working charts drawn at the Central Forecasting Office at Dunstable and statements of trawler crews in the vicinity, it was established that there was an E.–NE. gale, force 8–10, for most of the time in the area, which probably became force 8–11 on the 26th, the day of the tragedy. There was also continuous slight or moderate snow for most of the period. Wave heights were estimated as having been around 33 ft. on the 25th and 40 ft. on the 26th, figures which in no way conflict with the statements by individual members of the crews of trawlers which were at sea in the neighbourhood at the same time.

For the investigation it was necessary to estimate air and sea temperature in the area where the ships were lost. For air temperature actual reports from all the Icelandic reporting stations (obtained direct from the Icelandic Meteorological Service) were used, together with similar reports for Greenland and Jan Mayen taken from the Central Forecasting Office working charts. Sea temperature was estimated with the aid of reports similarly provided from certain Icelandic reporting stations, together with the chart of mean sea temperature for January from the "Barents Sea atlas"[2]. These estimates were necessarily rather subjective; the writer to some extent used his synoptic experience and knowledge of how sea temperatures are affected by air temperatures over periods of a few days. The figures adopted for use in later computations are given in Table I.

TABLE I—AIR AND SEA TEMPERATURE IN AREA WHERE SHIPS WERE LOST

Date	Time	Temperature Air	Temperature Sea
	G.M.T.	*degrees Fahrenheit*	
January 23	1200	29	35
January 24	0000	25	35
January 24	1200	20	35
January 25	0000	26	34
January 25	1200	34	34
January 26	0000	27	34
January 26	1200	23	34

The various physical processes by which ice and snow could accumulate on a ship facing these conditions were next considered. In order of importance these causes were found to be:—

(i) Impact of supercooled fog droplets, including "Arctic frost smoke", or of supercooled droplets in drizzle or rain

(ii) Accumulation of snowfall

(iii) Freezing of sea spray.

Although there were numerous references in the Press to "black frost" (a phrase in use among trawlermen to describe Arctic frost smoke) as being the cause of the disaster, these allegations can be shown to have little justification on physical grounds. Inquiries have shown that on the fishing grounds the phrases "white frost" and "black frost" are used somewhat loosely by trawlermen to describe shallow fogs in which the top of the fog is respectively below and above the observer's level (which is usually the ship's bridge level), the air temperature being below freezing at the same time. The terms "white frost" and "black frost" as used by fishermen evidently describe the phenomenon known among meteorologists as "frost smoke", which has been given various descriptive terms. The chief features common to nearly all descriptions of frost smoke are that it is very shallow (only a few feet thick) and only occurs when the air is considerably colder than the sea. Frost smoke is thus often formed in association with strong winds, since such low air temperatures in relation to the sea-surface temperatures are only found in vigorous outbreaks of cold air. Close to the ice limit, however, frost smoke is experienced in association with light winds. An observation of frost smoke at ocean weather station I in December 1952 in which all these features were observed and which was described by the writer[3] is the most relevant one for the purpose of this note. However, Jacobs[4] has described an analogous phenomenon often observed by himself and by Royal Air Force pilots on Prince Edward Island in the Gulf of St. Lawrence during the winter months of 1941–43, to which the pilots gave the description "ice crystal fog". On these occasions visibility was often well below 1,000 yd. and the fog always extended up to great heights, sometimes up to

5,000 ft. For the formation of this type of deep frost smoke there appeared to be a critical minimum air-minus-sea temperature difference; unless the air temperature was at least 16°F. below the sea-surface temperature in the area this deep frost smoke did not form. It was noted also that it never formed over a surface of sea ice, and that, just as with the more common thin variety of frost smoke, it occurred with fresh to gale gusty winds.

North of Iceland on January 26, 1955 and the preceding days, visibility varied between zero and a few hundred yards. Since air temperature at no time during this period fell as much as 16°F. below sea temperature, it seems highly probable that such frost smoke as occurred was of the shallow variety. In the high seas prevailing the poor visibility undoubtedly resulted from a combination of driving sea spray together with snow, sleet and other forms of precipitation. Freezing drizzle was observed at reporting stations on the north coast of Iceland, so it is quite likely to have occurred in the area where the ships were lost. We can safely assume the air at low levels to have been saturated from one or more of these causes. Woodcock[5] has estimated the spray-water content in a West Indian hurricane at $23{\cdot}2 \times 10^{-6}$ gm./gm. of air. Since the vapour pressure of air at 26°F. is about 0·15 of its value at 80°F. (the temperature at which Woodcock made his measurements), a value of $3{\cdot}5 \times 10^{-6}$ gm./gm. for the spray-water content of air at 26°F. can be used, along with the assumption that the mean wind speed was 43 kt. (50 m.p.h.) and the area of superstructure presented to the wind was 625 sq. ft. to show that ice would have been deposited at a rate of 0·022 tons/hr. if all the suspended droplets of fog and drizzle had condensed.

The weight of snow which could have accumulated on the ships was estimated as a maximum of 0·19 tons/hr. This figure was derived on the assumption that the daily snowfall was equivalent to 0·5 in. of rain, a rather high value for the latitude, and that none of the snow was blown off the ships by the wind. The surface area of the trawlers presented to snow falling vertically was taken to be 4,000 sq. ft.

In considering the problem of the quantity of sea spray which could have been frozen on to the hull and superstructure of one of these vessels, it is permissible to start with the assumption that a proportion of the spray blown across the vessel, consisting of the smallest droplets, was supercooled; and thus to treat the problem in a manner analogous to that of aircraft icing. If we further assume that the droplets have taken up the air temperature T by the time of striking a surface on the ship, we have the following relation for the fraction m of each gramme of liquid water which is frozen on impact:

$$m = \frac{T_F - T}{L}$$

where T_F is the freezing point of sea water, T the air temperature and L the latent heat of fusion of ice. This relation is derived by assuming that the heat given out by the fraction m of the drop on freezing is balanced by the heat taken in by the two portions of the drop, weight m and $(1-m)$ respectively, in being heated from the air temperature to the freezing point of sea water. Taking the air temperature as −4·0°C. (24·8°F.) on this occasion, which is also the temperature of the ship's superstructure, while the freezing point of sea water was −1·9°C. (28·6°F.), m is found to be 0·026.

For the purposes of calculation the rather conservative estimate of 30 ft. for the average wave height was adopted, whence it follows that the wave period is 8·7 sec. On the assumption that each wave threw up 50 Kg. of spray in breaking over the ship's bows; the rate of ice accumulation from this case was computed as 0·54 tons/hr.

The calculations so far made have tended somewhat to ignore the realities of the situation, since they have reckoned that only the small proportion of ice, amounting to some 3 per cent. of the total weight of sea spray (see the preceding paragraph), derived from supercooled spray freezing on impact would be effective in "icing up" a ship. In the conditions of weather and state of sea assumed earlier the total weight of spray (at all temperatures below that of the sea) blown over the ship each hour was about 20·5 tons (probably a conservative estimate). This spray would have been largely thrown up to a fair height and often blown right over the ship's superstructure. A considerable proportion of the spray intercepted by the ship's upper works would have taken an appreciable time to flow back into the sea in any case; in such severe conditions it is certain that much of it would freeze to the superstructure before it had time to do so. Thus, although the figures already given suggest that freezing of supercooled droplets from sea spray is responsible for a much greater weight of "icing up" than either the icing from frost smoke or than the rate of accumulation of snow, there is an even greater menace to the safety of trawlers presented by the direct freezing of sea spray produced by the action of the ship herself. The estimate of the weight of sea spray arriving aboard the ship is necessarily a very rough one; it clearly depends upon many additional factors such as the behaviour of the ship herself in various conditions of wind and sea, and the speed of the ship relative to the waves. This last factor is very important. From this evidence it seems certain that both ships were hove to or "dodging"* during most of the period. This implies that they continued to steam at slow speed, just sufficient to maintain steerage way, and having the wind on one bow or another as most convenient. In such circumstances it is inevitable that the ship makes a certain amount of way through the water; perhaps a speed of 1 kt. would be a reasonable estimate. However, even allowing that only 10 per cent. of the sea spray freezes on the superstructure, the remainder being lost either by running back into the sea, or by being blown away to either side of the ship (were the ship not held head to wind all the time), or by not being frozen before being blown away aft of the ship, the ship would still "ice up" from this cause alone at a rate greater than 2 tons/hr.

Table I shows that the *Lorella* and the *Roderigo* probably experienced a thaw on the 25th lasting a few hours. In support of this conclusion we also have the evidence of Skipper Tomlinson of the S.T. *Stafnes* who stated that on that morning (the exact time was not stated) he "saw the *Roderigo* who was also 'dodging' near us. At the time it was snowing very hard and still blowing a gale from the north-east. We would be about 2 miles off him and I got a good look at him through the glasses and he did not appear to be iced up. He did not appear to be in any trouble. . . ." Thus we can establish that the fatal accumulation of ice upon *Roderigo* must have occurred in a period of a little more than 24 hr.; and, if we accept the figures given above, the weight of

---

* Word in common use among trawlermen meaning steaming slowly and keeping head into wind all the time.

"icing up" which would have occurred in this interval from sea spray and the other causes described, would be of the order of 50 tons or possibly more. Evidence given at the Inquiry showed that this weight of ice was just about the amount needed to overturn and capsize these vessels. It is perhaps significant that, while the two ships kept fairly close company, the *Roderigo* which was the larger ship (810 tons) sank about three hours after the *Lorella* (559 tons). An expert opinion was given to the writer that, sometime before disaster overtook them, these ships had already accumulated an amount of ice which was more than enough to prove fatal, as soon as the ships' heads fell away from the wind: and that this accounted for their becoming unmanageable so quickly once this happened, when the wind was able to exert an added pressure on the iced-up superstructures. At the same time their centres of gravity were continually being raised by ice accumulating higher on the superstructure while the sea kept the hull plates clear of ice at the lower level.

It is also important to remember that the estimates of the rates of "icing up" given earlier, apply for the mean of the air and sea temperatures in Table I. From the arguments already developed it can be shown that the rate of "icing up" from freezing of droplets on impact will be twice as rapid at a temperature of 21·0°F. as it is at 24·8°F.; a suggestive figure when the individual air temperatures in Table I are considered. Inspection of the isotherms of mean air temperature for January given in the "Barents Sea atlas" shows that the mean horizontal air-temperature gradient in a direction south-south-east to north-north-west in this area (i.e. across the Denmark Strait from Iceland to Greenland) is around 1°F. for each 20 nautical miles, and that a similar steep horizontal temperature gradient also exists near Bear Island. Evidently the "icing-up" hazard is greatly increased for a vessel proceeding northwards in these areas, and, in fact, for a vessel approaching anywhere near the ice limit. In the winter months the ice limit runs nearly northwards from south of Bear Island past South Cape (Spitsbergen) to the vicinity of Bell Sound. The west coast of Spitsbergen and the sea in the offing are usually ice free, the ice limit trending in a south-south-west direction from the vicinity of Hakluyt's Headland (north-west of Spitsbergen) to Jan Mayen and thence south-westwards to the middle of the Denmark Strait.

REFERENCES

1. HAY, R. F. M.; Meteorological aspects of the loss of *Lorella* and *Roderigo*. *Mar. Obs., London,* **26,** 1956, p. 89.
2. London, Meteorological Office; Monthly Meteorological charts and ocean current chart of the Greenland and Barents Sea (in the press).
3. HAY, R. F. M.; Frost smoke and unusually low air temperature at ocean weather station India. *Mar. Obs., London,* **23,** 1953, p. 218.
4. JACOBS, L.; Frost smoke. *Mar. Obs., London,* **24,** 1954, p. 113.
5. WOODCOCK, A. H.; Sea salt in a tropical storm. *J. Met., Lancaster, Pa,* **7,** 1950, p. 397.

DURATION OF HIGH RELATIVE HUMIDITIES

By L. P. SMITH, B.A.

In a previous paper[1], attention was drawn to the humidities reported in the summer months from observing stations situated near hill masses. Hourly values of relative humidity, calculated from readings of dry-bulb and wet-bulb thermometers at synoptic stations are in constant use in plant-disease investigations and the data for five consecutive years have now been scrutinized. From these data it was possible to compute a mean duration of high relative humidities for each of the months June to September during 1950–54 for 43 stations. Owing to the opening and closing of R.A.F. stations the data were not always complete, but a satisfactory cover was maintained by the adoption of a method of weighting by simple proportion with respect to

TABLE I—SEASONAL AND MEAN MONTHLY TOTALS OF HOURS WITH RELATIVE HUMIDITY 90 PER CENT. OR MORE

Station	Seasonal totals, June–September					Mean monthly totals 1950–54				Mean seasonal total
	1950	1951	1952	1953	1954	June	July	Aug.	Sept.	
Speke	414	530	364	598	400	100	107	137	118	462
Finningley ...	444	604	371	823	...	(124)	(98)	(180)	(160)	(562)
Shawbury ...	567	635	756	837	756	153	139	223	195	710
Squires Gate ...	838	621	636	874	797	189	146	201	217	753
Felixstowe ...	727	620	491	888	1,079	177	179	192	213	761
Abingdon ...	951	749	653	848	753	167	167	224	234	792
Manchester ...	948	761	742	754	823	161	200	237	207	805
Dishforth... ...	816	894	650	890	798	166	157	266	221	810
Llandow	...	925	783	...	...	(207)	(219)	(208)	(206)	(840)
Leeming	827	965	...	...	...	(196)	(163)	(266)	(230)	(855)
Middleton St. George	...	...	655	898	824	(221)	(177)	(261)	(213)	(872)
Calshot	1,116	777	677	...	...	(192)	(215)	(212)	(263)	(882)
Manby	...	...	...	1,095	967	(253)	(175)	(242)	(215)	(885)
Waddington ...	...	871	705	...	1,268	(218)	(204)	(255)	(252)	(929)
South Farnborough	1,224	952	710	864	979	195	195	(254)	296	(940)
Mildenhall ...	891	931	817	1,122	991	217	199	259	275	950
Defford	838	943	936	...	990	(193)	(197)	(300)	(265)	(955)
Driffield	1,000	1,048	747	964	1,017	208	210	288	250	956
West Raynham ...	991	916	640	1,143	1,097	231	200	265	261	957
Church Fenton ...	1,071	1,036	...	...	...	(213)	(172)	(328)	(246)	(959)
Cottesmore ...	830	1,024	767	1,107	1,080	223	196	245	297	961
Birmingham ...	1,046	986	842	981	1,033	226	198	279	274	977
Cranfield... ...	839	792	945	1,074	1,242	209	216	278	276	979
Exeter	1,306	999	789	...	...	222	198	289	292	1,001
Tangmere ...	1,032	1,029	896	969	1,123	213	235	273	290	1,011
Silloth	1,109	938	1,061	915	1,138	223	251	289	270	1,033
Hurn	1,165	996	967	974	1,156	227	234	289	301	1,051
Pembroke ...	1,168	986	942	...	...	270	239	317	(236)	(1,059)
Bovingdon ...	...	...	...	1,205	1,329	(255)	(235)	(297)	(277)	(1,064)
Acklington ...	1,269	1,177	697	1,265	1,062	287	226	320	261	1,094
Watnall	1,030	1,055	941	1,297	1,249	275	225	303	301	1,104
Little Rissington	1,219	1,001	983	1,223	1,312	232	236	335	344	1,147
Bristol	1,170	1,160	1,054	1,247	1,149	263	259	325	306	1,153
Valley	1,310	1,221	962	1,045	1,256	277	292	311	278	1,158
Chivenor... ...	1,066	1,291	1,115	...	...	261	271	343	(295)	(1.170)
Lyneham ...	1,278	1,052	1,089	1,270	1,414	262	270	330	359	1,221
St. Eval	1,304	1,140	1,115	...	...	296	291	347	(297)	(1,231)
Lympne	1,191	1,214	998	1,277	1,544	274	303	328	340	1,245
Blackbushe ...	...	...	...	1,185	1,300	(311)	(286)	(312)	(342)	(1,251)
Aberporth ...	...	...	...	1,399	1,257	(319)	(283)	(350)	(307)	(1,259)
West Malling ...	1,322	1,335	1,065	1,280	1,364	266	280	358	370	1,274
Plymouth ...	1,306	1,183	...	...	...	(281)	(337)	(334)	(329)	1,281
Boscombe Down	1,318	1,208	1,282	1,395	1,478	271	295	360	410	1,336

Values shown in brackets are weighted.

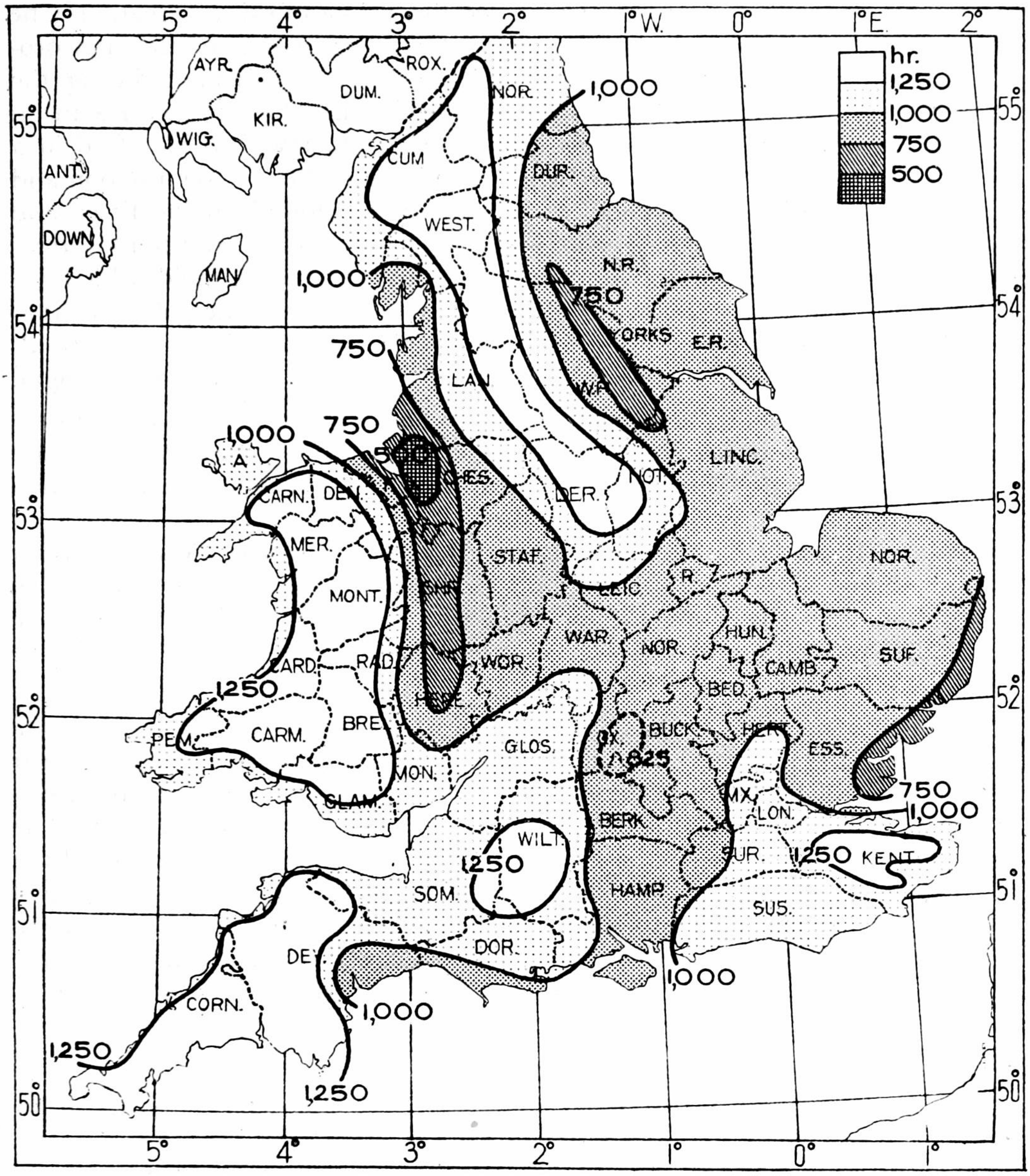


FIG. 1—MEAN SEASONAL (JUNE–SEPTEMBER) TOTAL OF HOURS OF RELATIVE HUMIDITY 90 PER CENT. OR MORE

neighbouring observations. The means so obtained are of limited validity and cannot be regarded as normals, but their relative values are extremely interesting and confirm the previous impression of the important part played by the position of the station relative to the neighbouring hill masses.

The table shows the four-monthly seasonal totals of hours with a relative humidity of 90 per cent. or above for each of the five years together with the mean value for each month and the mean June to September total; the stations are listed in an approximate order of increasing dampness. If the mean seasonal totals are plotted and isopleths for 500, 750, 1,000 and 1,250 hr. are drawn the map shown at Fig. 1 is obtained.

Examination of this map shows that the area with the least number of hours of high humidity is in north Cheshire around the Wirral, this being based on the low total recorded at Speke. The exact dimensions of this area can only be surmised from the limited data available, but examination of the meteorological records of the many airfields which existed in this area during the Second World War might lead to greater precision. The area with a mean seasonal duration of 750 hr. or less extends from Blackpool to Hereford in a narrow belt along the Welsh Marches. A similar zone lies between Ripon and Doncaster in the lee of the Pennines and another is found on the Essex and Suffolk coast. The last-named zone is the only trace of the traditional "dry" areas. The low mean total at Abingdon (792 hr.), an airfield which lies between the Cotswolds and the Chilterns, suggests the existence of a "shallow low" in the plain of Oxfordshire. There is a striking uniformity of mean totals from north Yorkshire to the Isle of Wight and from Staffordshire to East Anglia.

The areas with the highest number of mean hours with a relative humidity of 90 per cent. or above are, by inference, the high ground of the Pennines and the Welsh mountains. The south-west peninsula is another obvious humid area but the consistent high totals on Salisbury Plain and in Kent are somewhat surprising. It might be asserted that both Lympne and West Malling are at some considerable height, but the total for Manston in 1950 was 1,193 hr. in comparison with the 1,191 hr. for Lympne; no effect of altitude could be deduced from such figures. However, lower values might be hoped for in the Vale of Kent or the Vale of Sussex.

One final point could be made with regard to the proximity of the station to a hill mass. In the year 1954, Finningley did not report; the ratio of its four-year mean to that of Driffield, Dishforth and Watnall is 0·59, 0·68 and 0·50 respectively. The 1954 totals for these stations were 1,017, 798 and 1,249 hr. The 1954 estimate for Finningley based on this evidence would be the mean of the products 1,107×0·59, 798×0·68 and 0·50×1,249 hr. which gives a figure of 589 hr. During the 1954 investigation observations from Finningley were in fact replaced by those from Lindholme which lies 5 miles to the north; the actual total at Lindholme was 1,029 hr! The "dry zone" behind a hill may have very sharp edges.

REFERENCE

1. SMITH, L. P.; Humidities in the lee of hill masses. *Met. Mag., London*, **83**, 1954, p. 1.

MEAN RANGE IN AN AUTOREGRESSIVE SERIES

By A. F. JENKINSON, M.A.

Summary.—The mean range in samples of 30 from a normally-distributed autoregressive series is evaluated. An estimate of the standard deviation of daily values of a meteorological element can be obtained by dividing the mean monthly range by 3·5.

Evaluation of the mean range.—Kendall[1] shows that if $x_1, x_2, \ldots x_n$ are equidistant observations of an autoregressive series defined by

$$x_{t+1} = r\,x_t + \varepsilon_{t+1} \qquad \ldots\ldots (1)$$

and if $F_1(x)$ is the probability that $x_i \leqslant x$ for all i, and if $F_2(x, x)$ is the probability that both $x_i \leqslant x$ and $x_{i+1} \leqslant x$ for all i, then the distribution function $G_n(x)$ of the largest member of the sample is given by

$$G_n(x) = \frac{\{F_2\,(x, x)\}^{n-1}}{\{F_1\,(x)\}^{n-2}}. \qquad \ldots\ldots (2)$$

Now if the variables x_i are distributed with unit standard deviation then we can write

$$\left.\begin{aligned} F_1(x) &= \int_{-\infty}^{x} \frac{1}{\sqrt{(2\pi)}} e^{-\frac{1}{2}y^2} dy \\ F_2(x, x) &= \int_{-\infty}^{x} \frac{1}{\sqrt{(2\pi)}} e^{-\frac{1}{2}y^2} \left\{ \int_{-\infty}^{(x-ry)/\sqrt{(1-r^2)}} \frac{1}{\sqrt{(2\pi)}} e^{-\frac{1}{2}z^2} dz \right\} dy \end{aligned}\right\} \quad \ldots\ldots (3)$$

Using equations (3) I evaluated $F_1(x)$ and $F_2(x, x)$ for $x = 3, 2\cdot5, \ldots. 0\cdot5, 0$ and for $r = 0\cdot9, 0\cdot8, 0\cdot7, 0\cdot6$. I then obtained the corresponding values of $G_n(x)$ from equation (2) for $n = 30$, and hence computed the mean value and standard deviation of the largest member of the sample. The values of the mean range, which is twice the mean value of the largest member, are given in Table I, together with the value for $r = 0$ from Tippett[2].

TABLE I—MEAN RANGE IN SAMPLES OF 30 FROM A NORMAL AUTOREGRESSIVE SERIES

r	0·9	0·8	0·7	0·6	0
Mean	3·2	3·5	3·7	3·8	4·1

Now the daily values of a meteorological element can be taken to be normally-distributed observations of an autoregressive series, with r having the value of about 0·8. We have therefore a method of estimating the standard deviation of daily values, by dividing the mean monthly range by 3·5. The ratios for London (Kew) mean temperatures and pressures are 3·6 and 3·5 in January and 3·6 and 3·4 in July.

REFERENCES

1. KENDALL, M. G.; Exercises in theoretical statistics. London, 1954.
2. TIPPETT, L. H. C.; On the extreme individuals and the range of samples taken from normal population. *Biometrika, Cambridge,* **17**, 1925, p. 364.

UNUSUAL FROST POINTS AND DUST HAZE IN THE STRATOSPHERE ON MARCH 9 AND 10, 1955

By J. K. MACKENZIE

Summary.—Measurements of humidity in the stratosphere during the Meteorological Research Flight's high-level aircraft ascents on March 9 and 10, 1955 showed the stratosphere over southern England to be appreciably moister than has usually been found. Haze was widespread in the stratosphere on the 9th. It is possible that these conditions were due to a nuclear explosion in Nevada, United States on March 2, 1955[1].

Introduction.—During 1954 the Meteorological Research Flight made 35 ascents in a Canberra aircraft, making measurements of frost point in the stratosphere up to a height of about 50,000 ft. The mean of these measurements is shown by one of the curves in Fig. 1, values of −115°F. or less being usually found above 45,000 ft. and −105°F. being exceeded on only one occasion. The ascent made on August 5, 1954 gave frost points of −90°F. at 45,000 ft., −89°F. at 48,000 ft. and −99°F. at 50,000 ft. There was no obvious explanation for these high readings although there was some evidence of a secondary tropopause structure at 48,000 ft., the main tropopause being at 40,000 ft. No haze was seen at high levels on this occasion.

A sequence of ascents on March 9, 10 and 11, 1955, again showed very high values of stratospheric humidity, and a possible explanation for these is discussed below.

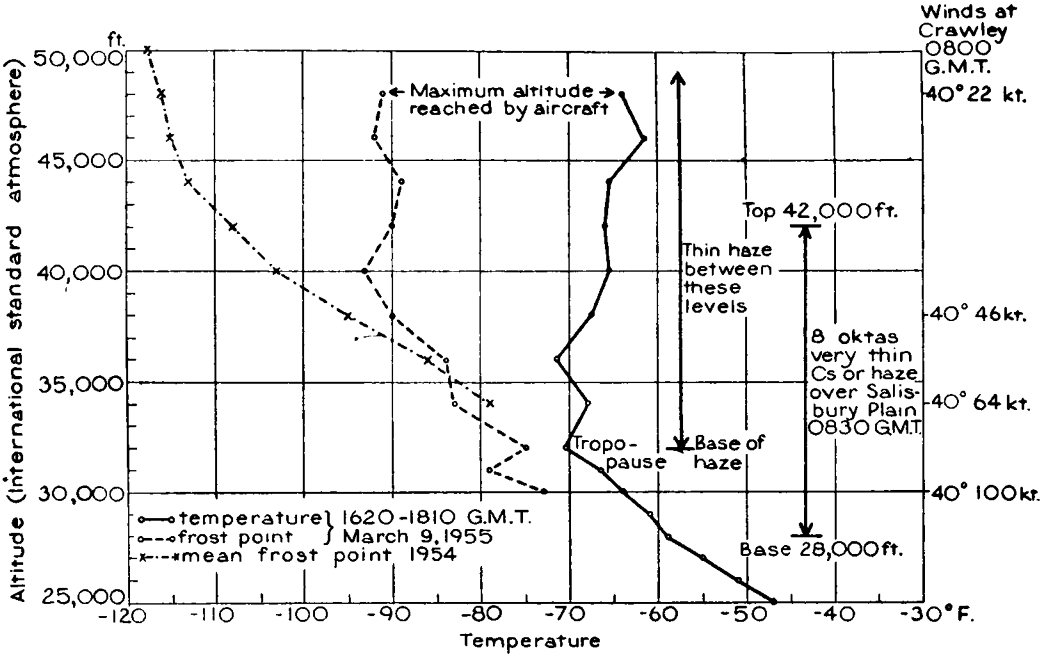


FIG. 1—AIRCRAFT ASCENT OF MARCH 9, 1955 (1620–1810 G.M.T.) COMPARED WITH MEAN FROST POINTS OF 35 CANBERRA ASCENTS MADE IN 1954

Observations.—The sequence of ascents made by observers of the Meteorological Research Flight was as follows:—

During a routine meteorological reconnaissance flight from Farnborough at 0830 G.M.T. on March 9, 1955, 8 oktas of extremely thin cirrus cloud or haze was observed over Salisbury Plain between 28,000 ft., the height of the tropopause, and 42,000 ft. This aircraft was not equipped for meteorological measurements, and it was decided to investigate further the nature of this cloud as soon as the aircraft equipped with meteorological instruments, which was unserviceable at the time, could be prepared.

The Meteorological Research Flight's Canberra aircraft made an ascent on the afternoon of March 9, 1955, at 1620 G.M.T. The frost points are plotted as in Fig. 1. These indicate that what was thought to have been cloud was, in fact, haze; and that its top now extended to at least 48,000 ft., 20,000 ft. or so into the stratosphere. The frost points, although well below saturation values, indicated that the stratosphere was unusually moist.

The Canberra made another ascent at 1140 G.M.T. on March 10, 1955, and Table I lists the sequence of measurements made during these different ascents. No haze was observed on this occasion, but the frost points were higher than usual and increased from −106°F. at 44,000 ft. to −102°F. at 48,000 ft. A second ascent made with this aircraft at 1620 G.M.T. on the 10th showed that the frost points in the stratosphere over southern England had evidently continued to decrease throughout the day. Finally, the ascent at 1200 G.M.T. on the 11th showed the frost points to be in the region of the mean values for 1954.

Discussion.—The presence of the haze and the high humidities in the stratosphere suggested that the air there had recently been at lower levels, and

TABLE I—SUMMARY OF ASCENTS MADE ON MARCH 9, 10 AND 11, 1955 AND MEANS OF 1954 ASCENTS

International Standard Atmosphere Height	Pressure	Mean of 35 ascents 1954		March 9, 1955 1620–1810 G.M.T.		March 10, 1955 1140–1330 G.M.T.		March 10, 1955 1620–1800 G.M.T.		March 11, 1955 1200–1400 G.M.T.	
		Temperature	Frost point	Temperature	Frost point	Temperature	Frost point	Temperature	Frost point	Temperature	Frost point
ft.	mb.					*degrees Fahrenheit*					
50,000	116	−61	−117·5	...	...	...	...	...	...	...	...
48,000	127	−58	−116	−63·5	−91	−72	−102	−68·5	−111	−71	−117
46,000	140	−58	−115	−61·5	−92	−69	...	−70·5	−111	−70	...
44,000	155	−60	−113	−65	−89	−73·5	−106	−71	−108	−74	...
42,000	170	−63	−108	−66	−90	−70·5	...	−71	−103	−83	...
40,000	187	−61	−103	−65·5	−93	−76·5	− 98	−76·5	− 99	−85·5	...
39,000	179	...	...	...	...	−76	...	...	...	−84	...
38,000	206	−65	− 95	−69·5	−90	−75	...	...	...	−83·5	...
37,000	216	...	...	...	...	−78·5	...	...	...	−85·5	...
36,000	227	−65	− 86	−71·5	−84	−78	...	...	...	−83·5	−89
35,000	238	...	...	...	...	−76·5	− 88	...	...	...	...
34,000	250	−64	− 79	−68	−83	−73·5	...	...	...	−75	...
33,000	262	...	...	...	...	−71·5	...	...	...	...	...
32,000	274	−57·5	− 72·5	−70·5	−75	−69	...	...	...	−68	...
31,000	287	...	...	...	−66	−67	...	...	...	...	...
30,000	301	−48	− 65	−64	−73	−63	− 69	...	...	−60	− 70

TABLE II—UPPER WIND TRAJECTORIES MARCH 2–9, 1955

200 mb.

Date	Time G.M.T.	Lat.	Long.	Date	Time G.M.T.	Lat.	Long.	Date	Time G.M.T.	Lat.	Long.
9.3.55	0900	Wash	(England)	7.3.55	0300	81°N.	25°W.	4.3.55	2100	48°N.	52°W.
	0300	56°N.	4°E.	6.3.55	2100	79°N.	35°W.	3.3.55	1500	47°N.	60°W.
8.3.55	2100	59°N.	6°E.		1500	76°N.	45°W.		0900	47°N.	68°W.
	1500	63°N.	12°E.		0900	72°N.	50°W.		0300	49°N.	81°W.
	0900	66°N.	18°E.		0300	66°N.	50°W.	2.3.55	2100	49°N.	90°W.
	0300	70°N.	19°E.	5.3.55	2100	61°N.	46°W.		1500	50°N.	105°W.
7.3.55	2100	74°N.	17°E.		1500	56°N.	43°W.		0900	50°N.	117°W.
	1500	80°N.	10°E.		0900	53°N.	44°W.				
	0900	81°N.	4°W.		0300	50°N.	46°W.				

300 mb.

Date	Time G.M.T.	Lat.	Long.	Date	Time G.M.T.	Lat.	Long.
9.3.55	0900	Wash	(England)	7.3.55	2100	69°N.	15°W.
	0300	58°N.	7°E.		1500	65°N.	20°W.
8.3.55	2100	63°N.	11°E.		0900	59°N.	19°W.
	1500	68°N.	19°E.		0300	59°N.	15°W.
	0900	72°N.	10°E.	6.3.55	2100	60°N.	12°W.*
	0300	73°N.	10°W.				

* This position was in an upper high where the gradients were slack and variable, and so no further backtracking was attempted at this level.

some of the investigation was directed at discovering whether it could have been caused by a nuclear explosion.

It is seen from Table I that, on the ascent of March 9, 1955, there was a frost point of −91°F. at 48,000 ft. compared with the usual value of −116°F. The appropriate mixing-ratio values for air having these frost points are respectively 0·017 gm./Kg. and 0·0019 gm./Kg. This shows the mixing ratio on this occasion was nine times the usual value. This gives us an idea of the large increase in water-vapour content on this occasion.

For the morning ascent on the 10th a piece of adhesive tape was fixed on the leading edge of the wing, and the tape and the inside of the aircraft's hygrometer were examined with a Geiger counter after the flight in the hope of discovering evidence of radioactive particles. None however was found. This could have been due either to insufficient sensitivity of the instrument or to no particles having been encountered. No haze was observed on this flight.

An estimate of the trajectory of the air in which these measurements were made is given in Table II. The length of the trajectory at 200 mb. was 8,875 statute miles. It is seen that the final position of the 200-mb. wind trajectory is very approximately 600 miles north of the Atomic Proving Ground in Nevada where an explosion took place on March 2, 1955. It seems feasible therefore that this could have caused the haze and high humidities observed.

A very rough estimate of the size of the haze cloud and the region of increased humidity can be made by considering Fig. 2 which gives, with considerable extrapolation, suggested isopleths of frost-point excess in relation

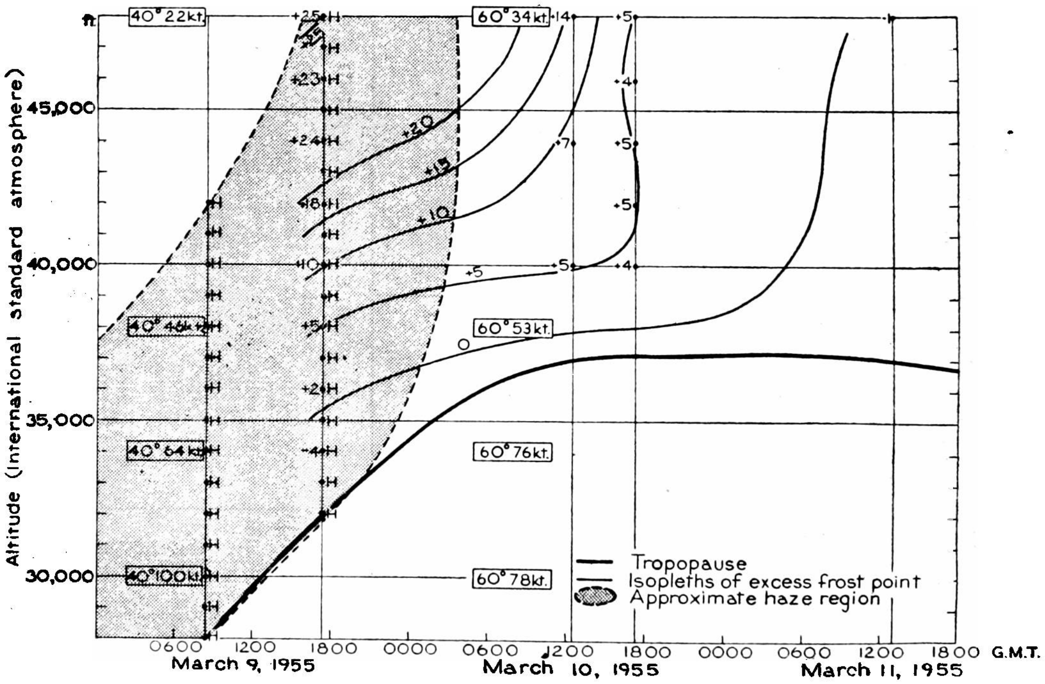


FIG. 2—HAZE AND EXCESS OF FROST POINT ABOVE 1954 MEAN OBSERVED IN THE STRATOSPHERE, MARCH 9–10, 1955

The observed excess of frost point is plotted against each aircraft ascent and the pressure of haze is indicated by the letter H. The radar-wind observations at Crawley at 0800 G.M.T. on March 9 and 10 are indicated in boxes at approximately the correct time.

to the mean 1954 curve and also an estimate of the haze area. The winds between 300 and 100 mb. over southern England on the 9th and 10th were relatively constant, increasing by about 10 kt. and veering 20° during the period. Taking mean values of wind it seems likely that the horizontal extent of the haze cloud at 200 mb. was at least 1,000 miles. The first arrival of the moist patch was not observed but it seems that it was considerably greater in extent than the haze area. The excess of frost points disappeared last at the highest altitudes of measurement.

Conclusion.—As it stands the evidence for these observations being caused by this explosion is at the best suggestive only. The presence of haze in the stratosphere from volcanic eruptions or forest fires has been noted several times in the past[2], and it is not at all unlikely that at atomic explosion would produce these phenomena. Similarly, a large upward transport of moisture into the stratosphere would be produced by a very large explosion, and it would be expected that the moist patch produced would exceed the size of the haze patch and also that it would persist for a considerable period. But whether or not these particular observations were produced by this mechanism, it seems evident that even at 50,000 ft. humidity in the stratosphere can on occasions vary considerably from day to day. If it had proved possible to obtain comprehensive measurements of this type and to link them definitely with an explosion, a considerable quantity of data on diffusion in the stratosphere would have been obtained.

REFERENCES

1. London, The Times. Nuclear bomb on 300 ft. tower. March 2, 1955, p. 8.
2. BULL, G. A.; Blue sun and moon. *Met. Mag., London,* **80,** 1951, p. 1.

AN UNUSUAL REFRACTION PHENOMENON SEEN FROM A HIGH-FLYING AIRCRAFT

By C. S. DURST, B.A. and G. A. BULL, B.Sc.

The following is an account of the sighting of a strange cloud by F.O. Kortens, captain, and F.O. Fraser, navigator, of a Canberra aircraft on November 29, 1955.

They were flying at 45,000 ft. above 8 oktas of cirrus cloud estimated at 40,000–42,000 ft. At 1204 G.M.T., when the aircraft was in position 66°20′N. 2°30′E., they witnessed a phenomenon which they likened to published photographs of an atomic explosion. The aircraft heading at the time was 30° true and the bearing of the phenomenon relative to the fore and aft line of the aircraft was 12°.

At 1204 G.M.T. (Stage 1) the captain saw a "bowler-hat" cloud effect protrude above the cirrus below and ahead of him (see Fig. 1). This was white for the first few seconds but quickly turned to a deepish yellow-orange, yellow being predominant. This expanded vertically and sideways at the top but the base remained the same width. Also another cloud broke through at the top of this cloud. The navigator saw this (Stage 2) and confirms it. At this stage, the colour had become yellow, the white traces disappearing completely.

The next stage (Stage 3) in development was an extension upwards of the small "break-through" into a column. Also the "bowler-hat" was expanding sideways and upwards all the time, but its base remained relatively constant.

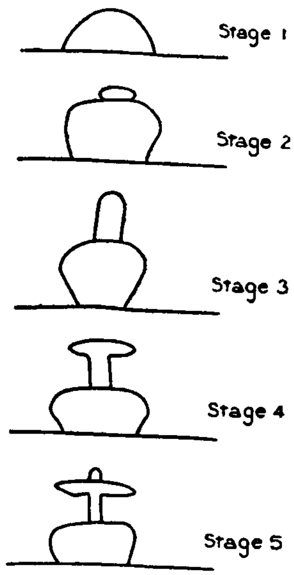


FIG. 1

The colour remained yellowish but the base near the horizon became darker, brown or "dirty" in colour. Next a "mushroom" head appeared on top of the pillar (Stage 4). This mushroom was again yellow but the base of the "bowler-hat" did not change much in colour. The final stage (Stage 5) was a sideways extension of the "mushroom" head and a further vertical extension of the pillar above the "mushroom". The colour remained constant.

The time from first sighting to the fifth stage was 1 min. 15 sec. The phenomenon from first to last was seen for 5 min. when the crew had to return, round 180° for the flight back to base. They were unfortunately unable to look backward after turning for the flight home.

The captain reported that it was three times as big as any cumulonimbus cloud he had ever seen in his life. He could not give a range; it was a long way off, certainly farther than 100 miles but he could not be more precise. At the fifth stage, the base to the top of the column was two-and-a-half to three times the width of the widest part of the cloud.

The following additional information was obtained, partly during an interview with F.O. Kortens. The temperatures recorded in the log at the 10-min. intervals as a routine were

Time (G.M.T.)	1130	1140	1150	1200	1210	1220	1230	1240	1250	1300
Temperature (°C.)	−40	−42	−42	−40	−40	−40	−42	−40	−40	−41

The aircraft was flown at a constant height of 45,000 ft. but every half hour this height was checked and a small correction of perhaps 200 ft. was made to bring it back to the fixed level. During the 180° turn, which had to be made because of fuel requirements, a sudden change in temperature of about 6°C. was noticed by the pilot. He thought it was a rise but it might have been a fall and he could not be certain of the amount. The angle subtended by the phenomenon when at its maximum development was about 1°. This was deduced from a comparison of the estimated size on the windscreen with that of the moon which was seen later. The width of the phenomenon was about twice the diameter of the moon. The distance travelled by the aircraft in 5 min. would be about 40 miles.

The following is a note by Mr. E. J. Sumner of the Central Forecasting Office on the thermal structure in the vicinity of the tropopause near ocean weather station M (66°N. 2°E.) at 1200 G.M.T. on November 29, 1955.

The radio-sonde ascent from the O.W.S. *Polar Front* at station M (1500 G.M.T. on November 29) ended at 650 mb. The required information therefore had to be deduced from observations at surrounding stations made earlier or later than this time. It so happened that air at 40,000–50,000 ft. over Keflavik at 0300 G.M.T. on the 29th would have passed near to the *Polar Front* at 1200 G.M.T. (see Fig. 2) and would subsequently have passed near to Östersund and Stockholm.

The 0300 G.M.T. ascent at Keflavik showed a clear-cut tropopause at 37,400 ft. with a more or less isothermal layer up to 150 mb. (43,500 ft.) which was the base of an inversion to 135 mb. (45,500 ft.) with a temperature rise of 4°. Thereafter, to 100 mb., the limit of the ascent, the temperature fell again. From surrounding stations it was evident that this structure was only present over a limited area. Further south the tropopause itself was higher, and a rise of temperature set in immediately in the stratosphere.

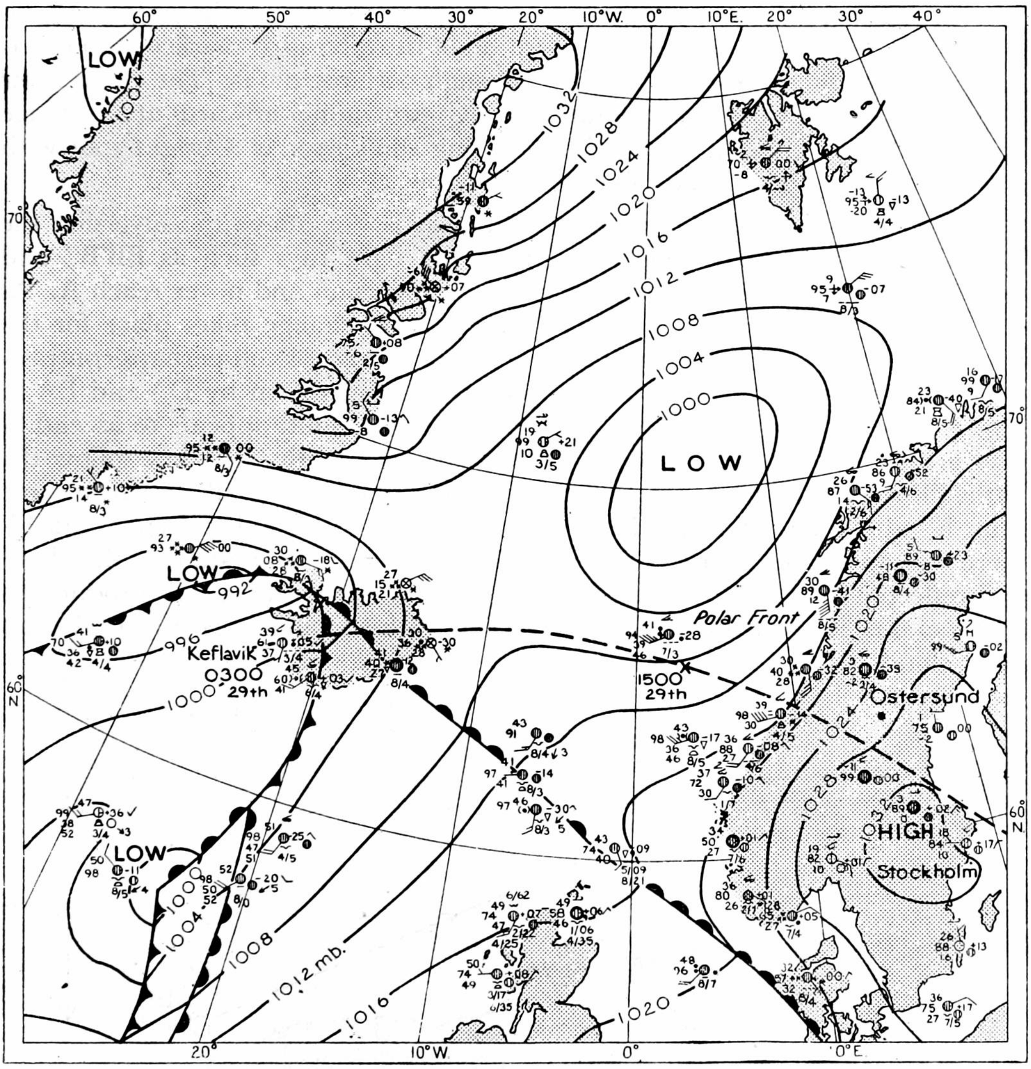


FIG. 2—SYNOPTIC CHART, 1200 G.M.T. NOVEMBER 29, 1955

The subsequent track of air at 40,000–50,000 ft. over Keflavik at 0300 G.M.T. is shown by the broken line.

Subsequently at Ostersund and Stockholm (0300 G.M.T. on November 30) there was some evidence that the structure previously shown at Keflavik the previous day had been preserved, but in the meantime the tropopause had risen a little and the inversion, previously well in the stratosphere, had got mixed up with the type of lower stratospheric structure shown a little further south. This was also an inversion but a more gradual one.

The existence of a shallow inversion around 44,000–45,000 ft. well in the stratosphere must have been confined to a limited area and existed only for a few hours at any one place, because subsequent ascents (e.g. 0900 G.M.T. at Keflavik) showed no such structure. However, the more common structure with an inversion commencing at the tropopause and extending several thousand feet into the lower stratosphere (e.g. Oslo, 1500 G.M.T. on November 29) must have been present for a much longer time a little further south of the trajectory.

The frontal structure in the lower layers over the Norwegian Sea was rather complex. As to the cloud structure, although cumulonimbus and hail showers had been reported by the *Polar Front* late the day before (the 28th), at midday on the 29th the cloud was almost stratiform, probably nimbostratus up to at least 12,000 ft. and possibly to 20,000–25,000 ft. with a "lumpy" top as was shown by the occurrence of altocumulus castellatus early on the 29th at station M. Also isolated cumulonimbus may still have occurred well to the north and north-east of the *Polar Front* at station M, the height of the top, however, not being much beyond 20,000 ft.

Figs. 3 and 4 show what is thought to have been the sequence of events. The top of the inversion is shown by the line PQ, the bottom, which may have been only a few feet below, by RS. The position of the aircraft is marked A and it is supposed to be descending somewhat, through perhaps 100 ft. The cloud layer is depicted below, with a cumulonimbus (BC) protruding upwards at a distance of 200 miles which is lit up by the declining sun's rays as a bright spot with perhaps a dark background of cloud in shadow.

At the point A in Fig. 3 where the aircraft is just above the inversion the cumulonimbus cloud is invisible because the light rays such as BB′B″ and CC′C″ suffer refraction and reflection at the inversion and never reach A. As soon as the aircraft passes across PQ a dramatic change takes place for the cumulonimbus cloud is suddenly seen as a round bright knoll perhaps contrasting with a dark cloud behind, the direct rays being shown by DA and EA in Fig. 4. As the aircraft descends further this bright cloud appears to ascend as rays are received by reflection in PQ as well as directly, i.e. they follow the paths FF′A as well as the direct path EA. The reflected ray will appear to come from F″ above following the broken line on the diagram. Between F and F″ there will appear to be a column of cloud due to rays originating at the cloud and reflected internally at the inversion. The reflecting layer will produce an image of the cloud surrounding the bright spot which will appear inverted as an anvil cloud.

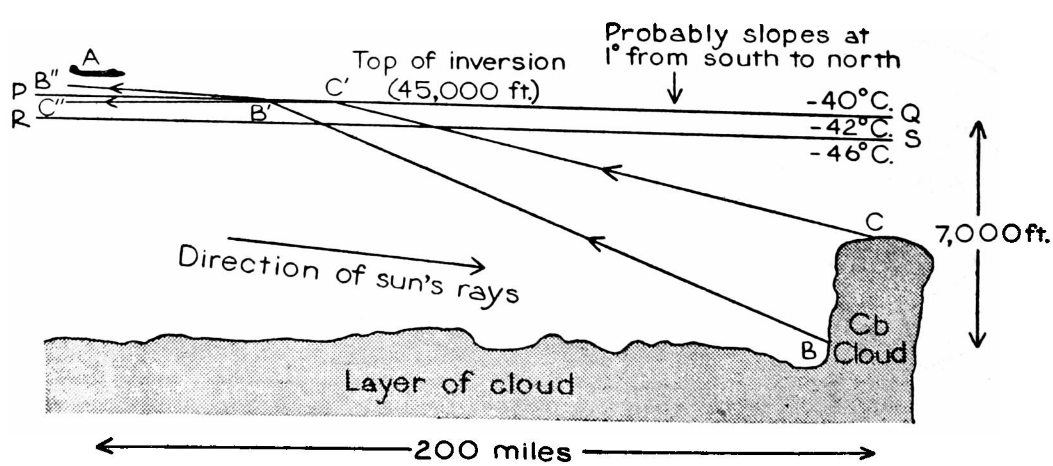
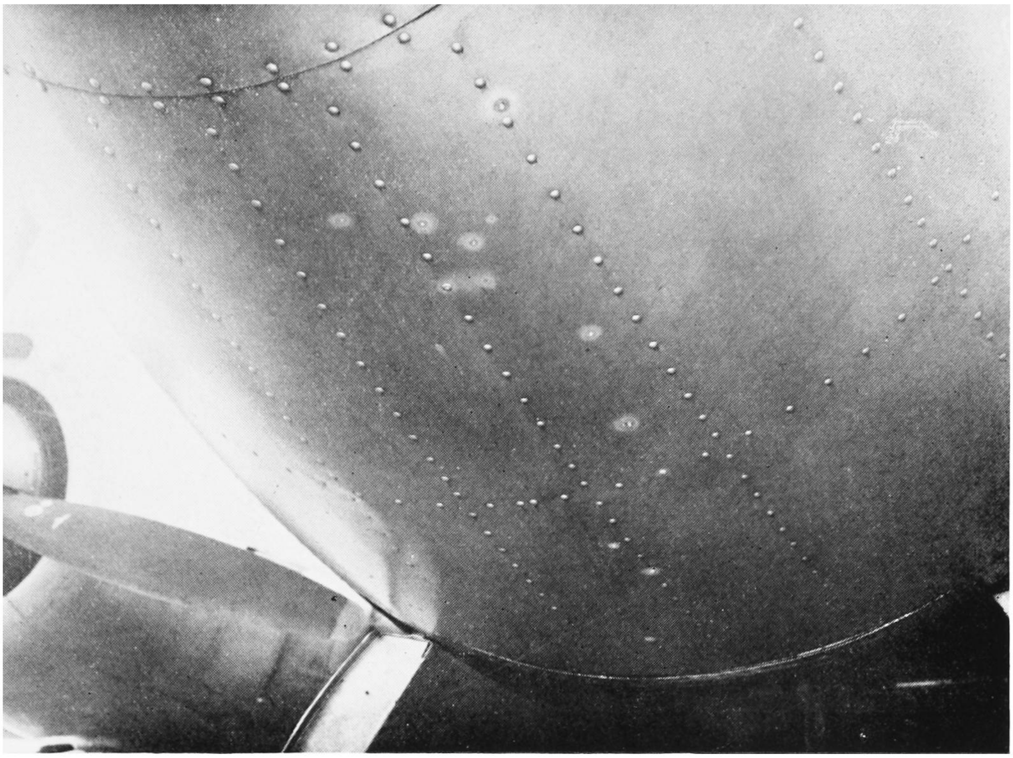
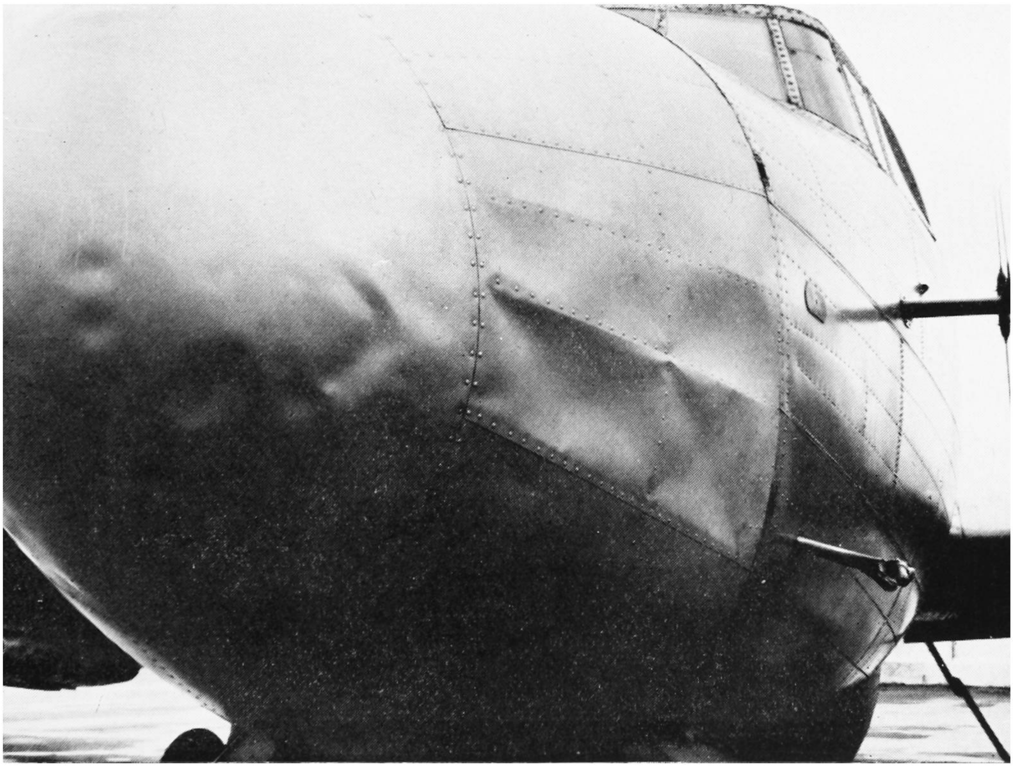


FIG. 3—AIRCRAFT ABOVE THE INVERSION

[*To face p.* 240

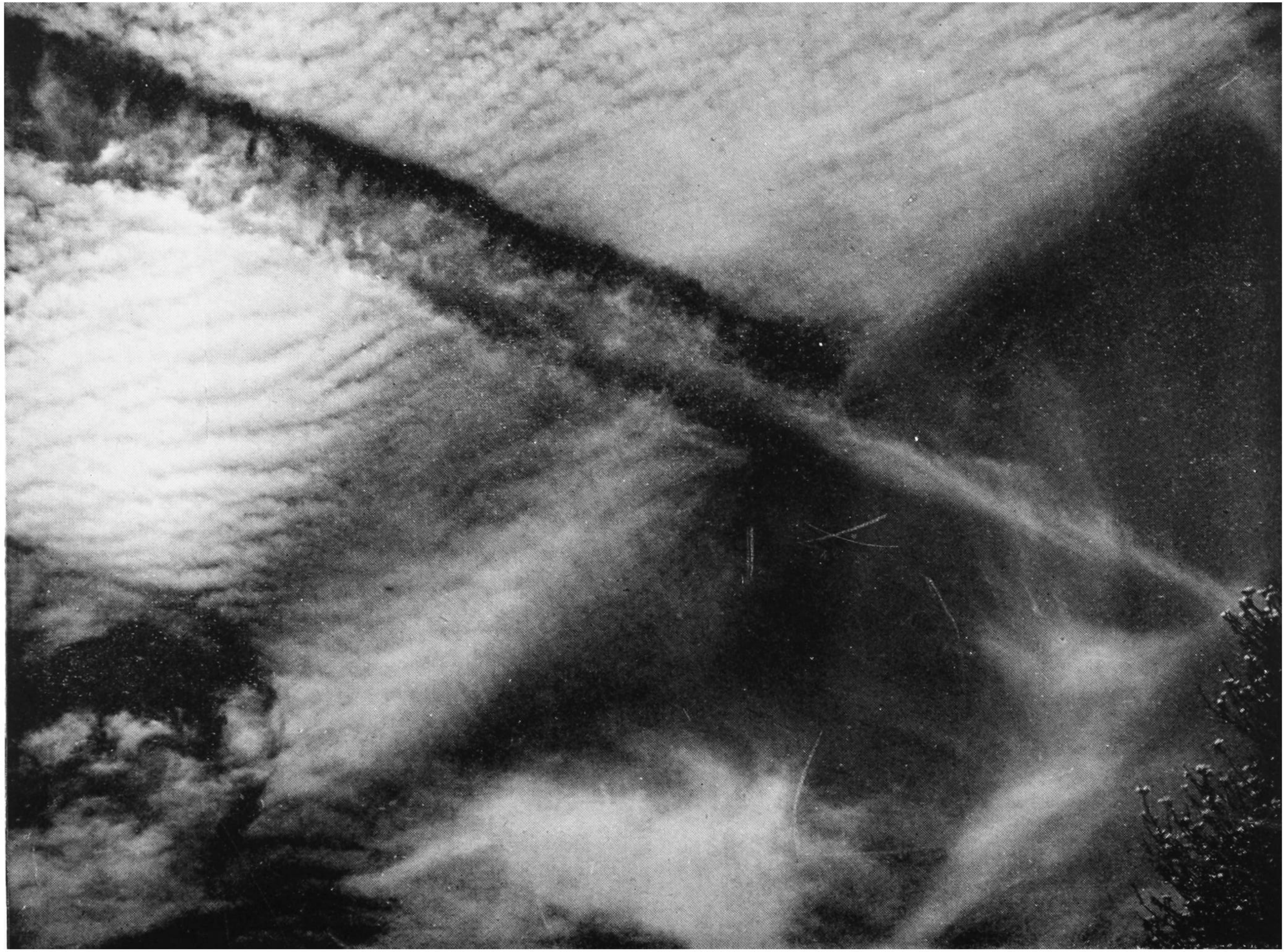


HOLES IN AIRCRAFT CAUSED BY LIGHTNING



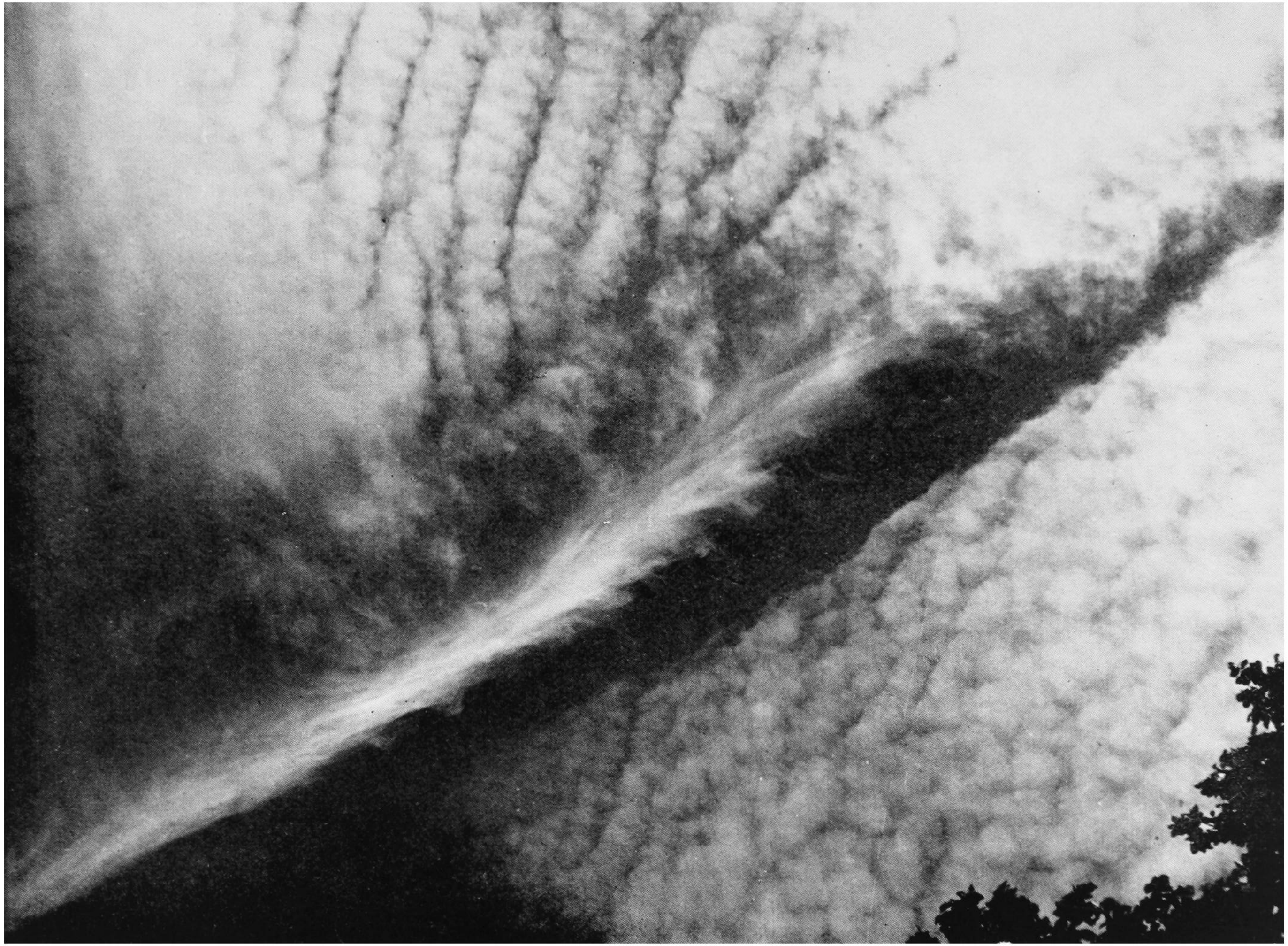
BUCKLING CAUSED BY LIGHTNING

EFFECT OF LIGHTNING ON AIRCRAFT
(see p. 248)



Reproduced by courtesy of D. T. Tribble

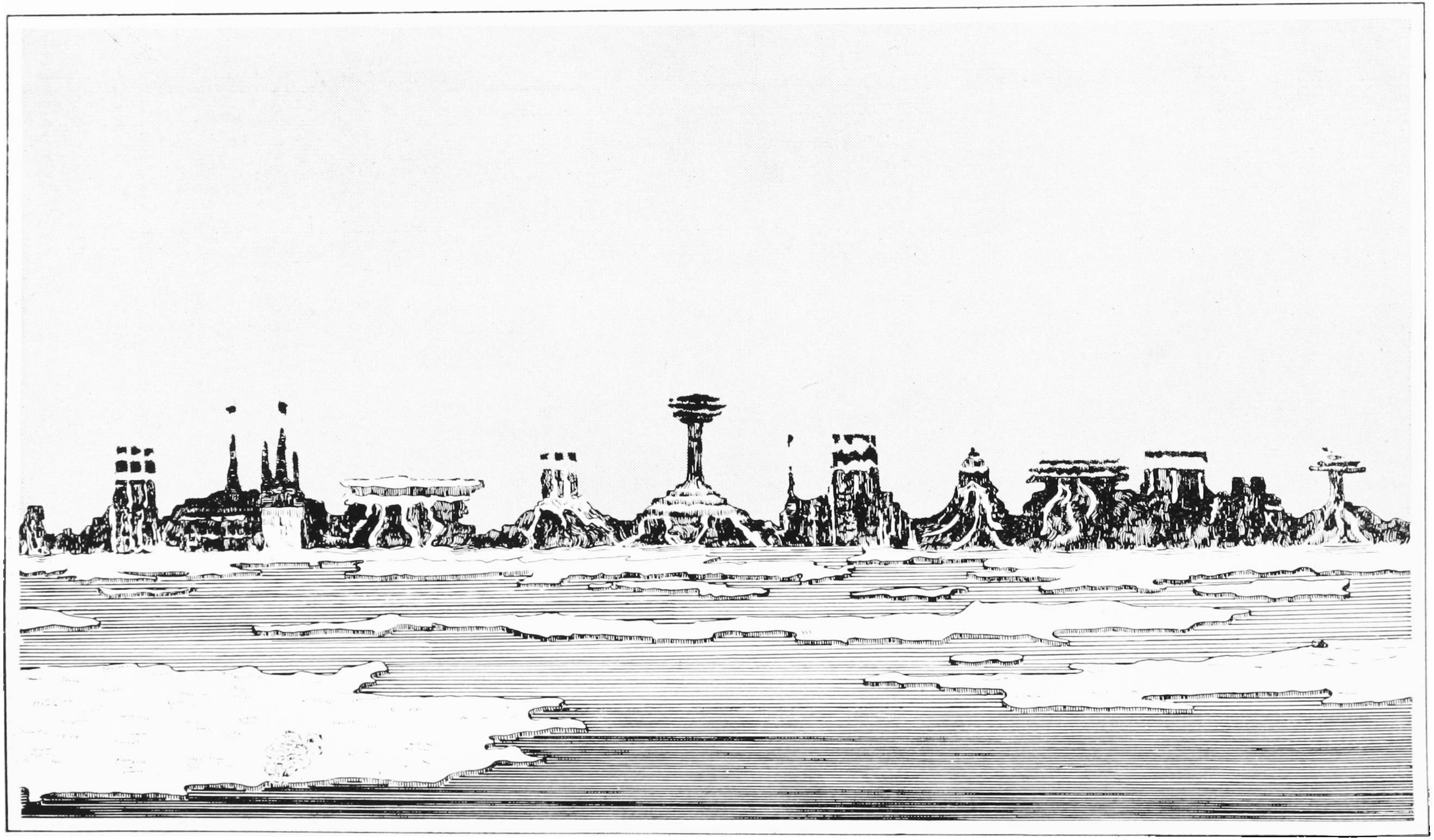
DISTRAIL OBSERVED AT WEMBLEY
(see p. 249)



Reproduced by courtesy of D. T. Tribble

DISTRAIL OBSERVED AT WEMBLEY

This photograph was taken looking almost vertically upwards
(see p. 249)



Reproduced from Trans. roy. Soc. Edinb. 9 1821, p.299

FIG. 5—TELESCOPIC APPEARANCE OF THE EAST COAST OF GREENLAND, AT THE DISTANCE OF 35 MILES, WHEN UNDER THE INFLUENCE OF AN EXTRAORDINARY REFRACTION JULY 18, 1820 (POSITION 71° 20′N. 17° 30′W.)
(see p. 242)

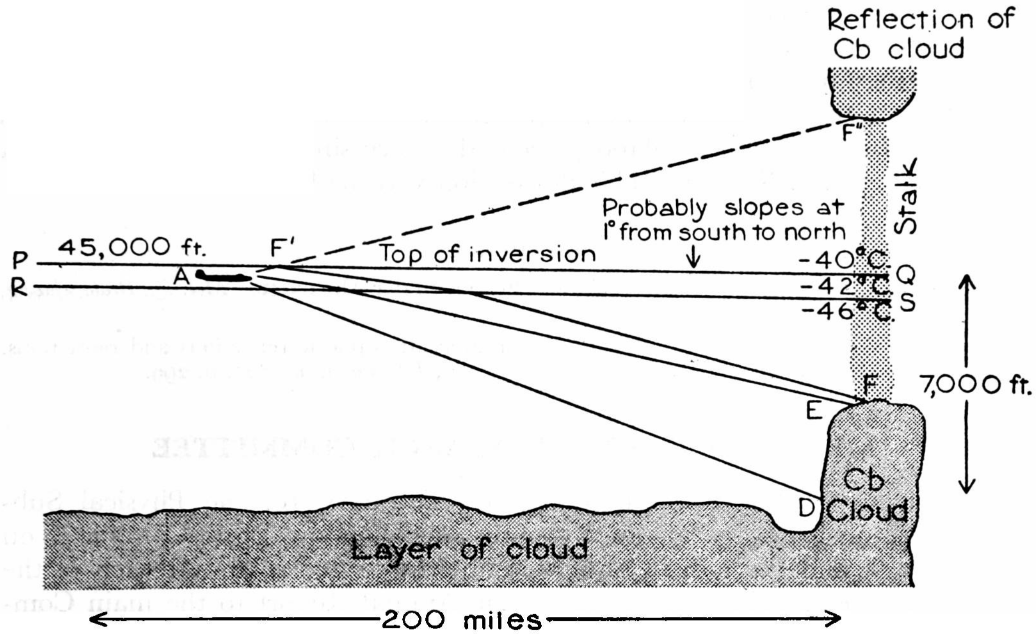


FIG. 4—AIRCRAFT WITHIN THE INVERSION

A. Wegener[1] has explained the drawn-out stalk as being caused by rays from a point reflected at three points on the curved surface of the inversion, which follow the curvature of the earth, and he gives photographs of the Alps with mushroom tops and stalks identical to those seen by F.O. Kortens. Thus the cloud will appear to have grown to a great size in rapid leaps and to an observer at A there will seem to be a mass of cloud extending from D to E with a stalk and an anvil top at F''. During the time of observation the sun was very low and hence the cloud at D was being illuminated with light from the red end of the spectrum giving it first a dirty brown colour and later a glowing red.

The support for the view that this explanation is correct is to be found in the angles subtended by the phenomenon as reported by the pilot. The maximum horizontal development was estimated to subtend an angle of 1°, with the total vertical development two-and-a-half to three times this amount; the stalk and mushroom top appear to have been about a quarter of this, say $\frac{3}{4}$°. The critical angle of reflection for rays impinging on inversions of various magnitudes is given at a pressure of 135 mb. by $\alpha = 4\sqrt{(10^{-7}\delta T)}$, where α is in radians and δT is in degrees Celsius.

If δT is 3°C., α is 0·13°, if δT is 6°C., α is 0·2° and if δT is 10°C., α is 0·25°. The angle subtended by the stalk would be 2α or about $\frac{1}{2}$°.

Figs. 3 and 4 indicate what might have been the temperatures in the various layers if the sharp fluctuation noticed at the time of turn had been really a fall not a rise.

The top of the inversion may have been sloping downwards from south to north as it is drawn in Figs. 3 and 4. The cloud top might then well have been no higher than 25,000 ft. as suggested by Sumner. The image would still have appeared to have been some 5,000 to 7,000 ft. above the top of the real cloud. The slope of the inversion would have been about 1° which is not unreasonable.

Such phenomena as described in this paper do not appear to have been previously reported from aircraft in flight, unless some of the reports of "flying saucers" may have been due to this effect. From ships at sea mirages of this type have been reported and Fig. 5 (facing p. 241) is a copy of an illustration in which the coast of Greenland presented a very similar appearance to that described by F.O. Kortens. This illustration was made by Scoresby[2] in 1820.

REFERENCES

1. WEGENER, A.; Photographien von Luftspiegelungen an der Alpenkette. *Met. Z., Braunschweig*, **53**, 1926, p. 207.
2. SCORESBY, W. JNR; Description of some remarkable atmospheric reflections and refractions, observed in the Greenland Sea. *Trans. roy. Soc., Edinburgh*, **9**, 1821, p. 299.

METEOROLOGICAL RESEARCH COMMITTEE

The Instruments Sub-Committee met on February 10, the Physical Sub-Committee on February 17, the Synoptic and Dynamical Sub-Committee on February 24 and the main Committee on March 22, 1956. At each of the Sub-Committee meetings the terms of the Annual Report to the main Committee were agreed and recommendations made on the items of the Research Programme for 1956–57.

At the 21st meeting of the Instruments Sub-Committee discussion on the fog density indicator[1] led to suggestions of techniques to enable the top of fog to be determined in daylight as well as in darkness. A further report[2] from the Meteorological Research Flight on the speed-correction coefficients of aircraft thermometers was considered. It was generally agreed that the conical thermometer (Model I) described by Mr. Clark[3] would probably solve most of the outstanding difficulties in air temperature measurement on aircraft at high speeds, though it was thought that the standard flat-plate thermometer would meet the requirements of most of the work to be undertaken at subsonic speeds.

The Physical sub-Committee at its 36th meeting considered (at the request of the Synoptic and Dynamical Sub-Committee) the proposals by Mr. Sawyer[4] for the use of an incompressible fluid model for the laboratory investigation of natural air flow over a ridge and recommended that an authority on liquid models should be consulted. Discussion of a report by Mr. P. J. Feteris and Mr. B. J. Mason on radar observations of "coalescence showers" was somewhat critical and indicated that further radar investigation of showers by the Imperial College and the Meteorological Office in co-operation is desirable. In presenting a preliminary report[5] on a method for studying the local diffusion of airborne material released from an elevated source Dr. Pasquill specially mentioned the close association between the vertical distribution of the lycopodium particles (at distances up to a few hundred yards downwards) and the distribution of the inclination of the wind to the horizontal at the place of release.

At the 38th meeting of the Synoptic and Dynamical Sub-Committee, Mr. E. Gold was welcomed to membership. During the discussion of papers by Mr. Johnson[6] and Mr. Durst[7] on the forecasting of upper winds by synoptic and statistical techniques it was suggested that while the statistical method might find application in certain circumstances there is no evidence to justify abandonment of the conventional synoptic procedure, and that close investigation of the reasons for the occurrence of large errors in forecast wind on some occasions should be made. Mr. Bushby described work done[8] with a modified two-parameter model used in the numerical prediction of contour surfaces. There was discussion on the implications of the use of a stream function. It was agreed that the report is a useful addition to experience in this developing field of work.

At its 71st meeting on March 22, the Meteorological Research Committee welcomed Prof. H. S. W. Massey (Chairman of the Gassiot Committee, Royal Society) as a member, received and discussed the annual reports of the three Sub-Committees and the Gust Research Committee (Aeronautical Research Council), approved the revised Research Programme for 1956–57, and the Annual Report to the Secretary of State for Air. After the general business, Dr. F. Pasquill initiated a discussion on the research now in progress at Porton on the medium-range diffusion of particles released from the ground and from an elevated source.

ABSTRACTS

1. BIBBY, J. R.; Fog density indicator. *Met. Res. Pap., London*, No. 943, S.C. I/108, 1955.

An instrument is described consisting of two layers of photocells sealed between two sheets of perspex. Light from three lamps is scattered into the photocells by fog, generating a current which is proportional to the scattering coefficient of the air. It is mounted on a wire from a radio-sonde balloon and gives the height of base or top of a fog or cloud layer and some indication of density. It can only be used in darkness at least 50 ft. above the ground.

2. DURBIN, W. G.; Some further determinations made by the Meteorological Research Flight of the speed correction coefficients of aircraft thermometers. *Met. Res. Pap., London*, No. 930, S.C. I/103, 1956.

Speed correction coefficients were made of flat-plate and conical-head thermometers, mounted under a wing of an Ashton aircraft and under the nose of a Canberra, at speeds of 108–280 kt. and heights of 5,000–35,000 ft. No evidence was found of systematic variation of the coefficient with height. Values for the Ashton and Canberra aircraft were 1·83 and 1·76 respectively for the flat plate, 2·01 and 1·92 with the conical head. The correction coefficients for existing Meteorological Research Flight thermometers are assessed.

3. CLARK, D. D.; Development of thermometers for high-speed aircraft. *Met. Res. Pap., London*, No. 960, S.C. I/110, 1956.

The principle aimed at was to make the "recovery factor" λ constant. Three designs of flat-plate thermometer were tested in a wind tunnel, and one having a conical shape was selected as the most practicable. In this λ was sensibly constant at 0·881; the temperature error was less than 0·1°C. from Mach 0·2 to 0·8, and only 0·23°C. at 0·9. Protection from radiation was provided by making the outer cover as highly reflecting as possible. The thermometer is mounted on a "sting" protruding from a leading edge.

4. SAWYER, J. S.; Dynamical similarity in an incompressible fluid model of two-dimensional air flow over a ridge. *Met. Res. Pap., London*, No. 935, S.C. III/191 and S.C. II/198, 1955.

This abstract has been given in the May 1956 *Meteorological Magazine*, p. 150, No. 2.

5. HAY, J. S. and PASQUILL, F.; A technique for studying the local atmospheric diffusion of airborne material. *Met. Res. Pap., London*, No. 961, S.C. III/199, 1955.

Spores of lycopodium fall from a hopper through a channel on to the blades of a high-speed fan, the output being 3 gm./min. at 32·5 m. above ground. They are collected on 2-in. lengths of ¼-in. glass cylinders coated with glycerine jelly and exposed vertically on vanes at intervals on the cable of a balloon. The deposit on the tube is scanned with a microscope; collection efficiency is 41–44 per cent. Inclination of wind is measured with a hot-wire anemometer or horizontal vane. Results of four experiments showing distribution of spores up to 40 m. height 50 m. downwind from source, and one up to 150 m. (500 ft.) height 100 m. down wind are discussed.

6. JOHNSON, D. H.; The success achieved in forecasting upper winds by orthodox and statistical techniques. *Met. Res. Pap., London*, No. 953, S.C. II/202, 1955.

7. DURST, C. S.; Comments on statistical and orthodox forecasting. *Met. Res. Pap., London*, No. 955, S.C. II/103, 1956.

Johnson compares 24-hr. forecasts of 700–100-mb. winds over four months by three orthodox methods, Durst's regression equations and persistence, with the actual winds at Liverpool, o.w.s. J and route Shannon–Gander. The root-mean-square errors of each type are broken down into bias and standard deviation, and frequency distributions are tabulated. The statistical forecasts were less accurate than the Central Forecasting Office and London Airport forecasts up to 200 mb. but better than the use of persistence alone. At 100 mb. there was little difference. Durst comments on the paper and gives root-mean-square errors for 500-mb. forecasts for Atlantic and European routes. He concludes that the improvement of orthodox over statistical forecasts is not great, and for winds at high levels is discounted by the greater speed of preparation of the latter.

8. BUSHBY, F. H. and HUCKLE, V. M.; The use of a stream function in the Sawyer-Bushby two parameter model of the atmosphere. *Met. Res. Pap., London*, No. 956, S.C. II/204, 1956.

This paper describes an attempt to improve upon the geostrophic approximation by representing the wind field in an isobaric surface by a stream function which differs from the geopotential. Of three 24-hr. forecasts (made with an electronic computer) two improved on forecasts computed without the stream function.

OFFICIAL PUBLICATION

The following publication has recently been issued:-

GEOPHYSICAL MEMOIRS

No. 98—*Glazed frost of 1940.* By C. E. P. Brooks and C. K. M. Douglas.

The glazed frost which began on January 25 in Great Britain was probably unequalled for persistence and extent. In Part I its development is described and mapped day by day until it disappeared on February 4. The maps show also the areas of rain and snow, the frost forming a broad and fluctuating band between them. This is followed by "eye witness" reports including accounts of the widespread damage. A collection of photographs completes this part.

Part II describes various synoptic developments which combined to produce the severe glazed frost. Two important rain belts came in from the west and were then held up by an increasingly cold south-easterly air stream in which there was a large cross-isobaric wind component. The departures from geostrophic motion are discussed in detail. The upper air soundings do not fit into any simple scheme. A rough cross-section diagram is included, but there were no temperature soundings within the belt of glazed frost. The period January 26–28 is considered in detail, and the following few days in outline. Illustrations include surface and upper air charts and tephigrams.

ROYAL METEOROLOGICAL SOCIETY

At the opening of the Society's meeting on March 21, 1956, the President, Dr. R. C. Sutcliffe in the Chair, reference was made to the death of Dr. J. Patterson, Honorary Member, and tributes were paid by Sir George Simpson and Mr. E. Gold. The award of the Buchan Prize to Mr. F. H. Ludlam, the H. R. Mill Medal and Prize to Mr. J. S. Sawyer and of Darton Prizes to Mr. R. J. Murgatroyd and Mr. S. E. Ashmore was announced. The following papers were read:—

*Bannon, J. K. and Gilchrist, A.—Variation of temperature in the troposphere and lower stratosphere**

This paper (presented by Mr. Bannon) extends the work of W. H. Dines on correlation coefficients between upper air temperatures and pressures and the height of the tropopause further into the stratosphere and to subtropical and polar latitudes. Correlation coefficients were evaluated between the height of the 300-mb. level, pressure at the tropopause and temperatures at 500, 150, 110 and 60 mb. over Arctic Bay (North Canada), Lerwick, Larkhill and Malta. The high "Dines" correlations in the upper troposphere were confirmed for stations in the United Kingdom and for Malta in winter; the correlations with temperature in the stratosphere decreased with height and were only about half at 60 mb. of the values at 150 mb. Over Arctic Bay the correlations were less well marked. Over Malta in summer when the high subtropical tropopause is present the temperate-zone correlations are not found. Data for Aden and some Pacific islands were examined but no correlation could be found. Mr. Bannon concluded that the "Dines" type of correlation applied only to areas affected by travelling depressions and anticyclones. Dr. Sutcliffe asked if this work was important in itself for applications of the correlation coefficients or for suggesting physical relationships; he had not seen a simple explanation of the "Dines" correlations. Dr. Scrase showed slides of soundings to over 30 Km. at Downham Market grouped by tropopause height; the groups were sharply differentiated in the lower stratosphere but became confused at about the 30-mb. level. Dr. Goody said that, whatever may produce the close correlations around the tropopause, radiative effects higher up are all-important. Mr. Gold asked if any attempt had been made to separate

* *Quart. J. R. met. Soc., London*, **82**, 1956, p. 58.

the correlations into classes by wind-stream direction as his own early work showed that a cold westerly stream meant low tropopause; there was a need to evaluate correlation coefficients with surface data. Mr. Sawyer was puzzled by the high correlation between 300-mb. height and 60-mb. temperature in summer compared with the low winter ones. Dr. Scorer thought there might be an effort to explain too much; a coefficient of 0·7 was not very high. Dr. Sutcliffe said the mean geographical distribution agreed with the local correlation, and Mr. Poulter referred to the use of these data in forecasting the likely occurrence of condensation trails. Mr. Bannon in his reply agreed that advection was an important factor in variations of the height of the tropopause and replied to the inquiries.

Kraus, E. B.—Secular changes of tropical rainfall regimes†

Kraus, E. B.—Secular changes of east-coast rainfall regimes‡

These papers were read by Mr. Hoyle. In the first paper Kraus gives curves of the cumulative percentage departure from the mean rainfall for the period 1880–1940 for eight tropical stations from Trinidad to Sierra Leone and Queensland. The curve rises for a year in which rainfall exceeds the mean and falls for a year in which it is less than the mean. The curves all show a decrease in rainfall at the turn of the century; the decrease is especially marked at Sierra Leone and Honolulu. The curves for such places as Aden and Bathurst on the edge of the subtropical arid zone suggest, in comparison with the others, that the decrease was due to the tropical rain belt failing to reach as far from the equator as previously. There was no balancing increase in precipitation in more temperate latitudes so that the reduction in tropical rainfall must have been associated with a decrease in evaporation. Dr. Kraus suggests that the cause of the secular change lies in a decrease of evaporation produced by a decrease in wind speed. The decrease in evaporation reduces the amount of energy transferred to the atmosphere from the ocean which tends to decrease the wind speed further. The ultimate cause may be a change of solar radiation. The second paper shows that a similar decrease in rainfall occurred along the east coasts of North America and Australia. Mr. Schove pointed out the change in rainfall found by Dr. Kraus occurred at the same time as a rise in temperature in high northern latitudes and that there was no sudden change about 1900 in the frequency of sunspots. Mr. H. H. Lamb said that over the eastern part of Argentina there was a substantial increase in rainfall during the 19th century. Prof. Sheppard pointed out it was difficult to explain variations in the general circulation when the general circulation was itself not fully explicable; he was doubtful about Dr. Kraus's theory of wind changes and would like numerical observations of the strength of the trade winds. Mr. Cochrane queried the values of rainfall given for Suva, Fiji by Kraus on the grounds that a fall of 20 per cent. in rainfall is economically disastrous. Further the variation in the levels of Lake Victoria and of the River Volta do not bear out Kraus's theory; he believed the rainfall was correlated with rate of change of sunspot number.

Symons Memorial Lecture

At the meeting of the Royal Meteorological Society on April 11, with the President, Dr. R. C. Sutcliffe, in the Chair, the 1956 Symons Memorial Lecture was delivered by Mr. J. Paton, Lecturer in Natural Philosophy in the University of Edinburgh. The title of the lecture was "The polar aurora".

The lecturer began by pointing out that there was a precedent for the choice of aurora as the subject of a lecture to the Society, for Dr. Chree had selected this topic for his Presidential Address in 1923, prompted no doubt by the recent establishment of a magnetic observatory near the auroral zone at Lerwick. Indeed, the present lecture would be concerned precisely with the lines along which Dr. Chree predicted, in his address, auroral research would proceed, including the influence of aurora on radio communication, which few could have foreseen at that time.

The appearance of a great aurora is so awe-inspiring that it could hardly fail to excite the interest of even the most apathetic observer. The lecturer traced the slow accumulation of knowledge by observations through the centuries to its culmination in the great work of Carl Størmer. It was only when the source of aurora had been traced to the sun and the properties of cathode rays had been investigated that a mathematically based theory became feasible. Stimulated by the remarkable experiments of Birkeland which apparently closely reproduced in the laboratory the large-scale geophysical events causing aurora, Størmer embarked on the formidable task of calculating the trajectories of an electron in the field of a dipole, with the aim of providing explanations of the development of the various auroral forms. As his theoretical work developed, he found it necessary to obtain more information about the height and disposition in space of auroral forms than was then available. The information was obtained by the method of parallactic photography which he then devised.

---

† *Quart. J. R. met. Soc., London*, **81**, 1955, p. 198.

‡ *Quart. J. R. met. Soc., London*, **81**, 1955, p. 430.

Recent developments in auroral research were then surveyed. A means of detecting daylight aurorae and those concealed by cloud by radio-echo methods is being developed, though so far there is no general agreement concerning the interpretation of the echoes. The most direct evidence of the solar connexion is the occurrence of a great aurora about a day after an intense flare has been observed in the central portion of the sun. The accumulating evidence suggests that every great aurora has its origin in an intense flare. It is the great aurora which becomes visible in low latitudes, sometimes within 10° of the equator. Observations made over the period of the last sunspot maximum, 1947, and minimum, 1954, indicate that the much more frequent moderate aurora which usually becomes visible between geomagnetic latitudes 55° and 60° follows, on a smaller scale, the same general pattern as the great aurora. This, along with the fact that it tends to occur when a large sunspot is near the central meridian suggests that the moderate aurora too is caused by a flare of lesser intensity, associated with the sunspot. During the years round sunspot minimum, aurorae appear quite frequently as far south as geomagnetic latitude 58°. These aurorae occur in 27-day sequences and almost invariably take the form of quiet, diffuse arcs. They are thought to be associated with what Bartels has called magnetically active (M) regions in the sun, which continuously emit a corpuscular stream over a long period, but which have never been astronomically identified.

The most striking advance in auroral spectroscopy in recent years has been the identification of emissions of lines by elements present in the incident solar stream. Measurement of the Döppler displacement of the H line in the spectrum of a quiet arc has shown that protons travel into the aural regions with speeds of the order of 3,000 Km./sec. Immediately the arc becomes active and disintegrates into ray bundles, the H emission ceases, so apparently protons play no part in the formation of rays.

The theories of Chapman and Bartels and also of Alfvén, which are each based on a neutral solar stream consisting of ions and electrons, but are otherwise quite unrelated, were then discussed. The problems presented by aurora and the associated magnetic storm are of the utmost difficulty and little progress has been made towards the formulation of a satisfactory theory. Chapman has pointed out the need for a greater knowledge of what he has called auroral morphology. A network of auroral observers on land, in aeroplanes and in ships over the region from Greenland to the English Channel has therefore been organized to provide detailed information of the development of each display. The method of plotting and analysis of the observations of this "Aurora survey" was described.

The lecture concluded with an account of the British plans for auroral work during the International Geophysical Year.

LETTERS TO THE EDITOR

Three aircraft simultaneously struck by lightning

An example of three aircraft being simultaneously struck by lightning in a cumulonimbus cloud with top to only 13,000 ft. is thought to be sufficiently rare to warrant a report on the incident.

On April 16, 1956, a formation of Valiant aircraft practising low-level formation flying were flying on a track which brought them into the Humber area from the North Sea with the intention of flying southwards to East Anglia. The formation of six aircraft in two waves of three aircraft with about a mile between the waves was flying at 2,000 ft. as it crossed the coast from the sea. Over the sea there was little cloud except for patches of stratus well below the aircraft. As soon as the coast was crossed there was a rapid build up of cumulus cloud which was so widespread that the aircraft could not avoid it. As soon as the cloud was entered, heavy snow was encountered and the formation leader took the formation down to 1,500 ft. in an attempt to clear the base of the cloud. When he found that the cloud extended still lower, the leader ordered the abandonment of the formation and the leading wave separated and climbed, still in the cumulus cloud. At a height of 3,000 ft. all three aircraft in this wave were simultaneously struck by lightning, although by this time there was probably a distance of half a mile between the two outside aircraft. The lightning strike is described as a violent bump accompanied by a vivid flash.

The pilots saw the flash as a horizontal line about the thickness of an arm from the nose of the aircraft while other members of the crew saw the flash as an envelopment of the particular part of the aircraft they could see with a vivid flame. The aircraft continued the climb through cloud till they reached the top at 13,000 ft. The aircraft then had a thin coating of ice on the nose but none on the wings. No damage was sustained by any of the aircraft.

The incident occurred in the Grimsby area at 1625 G.M.T. and is recorded as thunder heard at that time in the observation register at Binbrook (see Table I). There were no other reports of thunderstorms within a very wide area on that day.

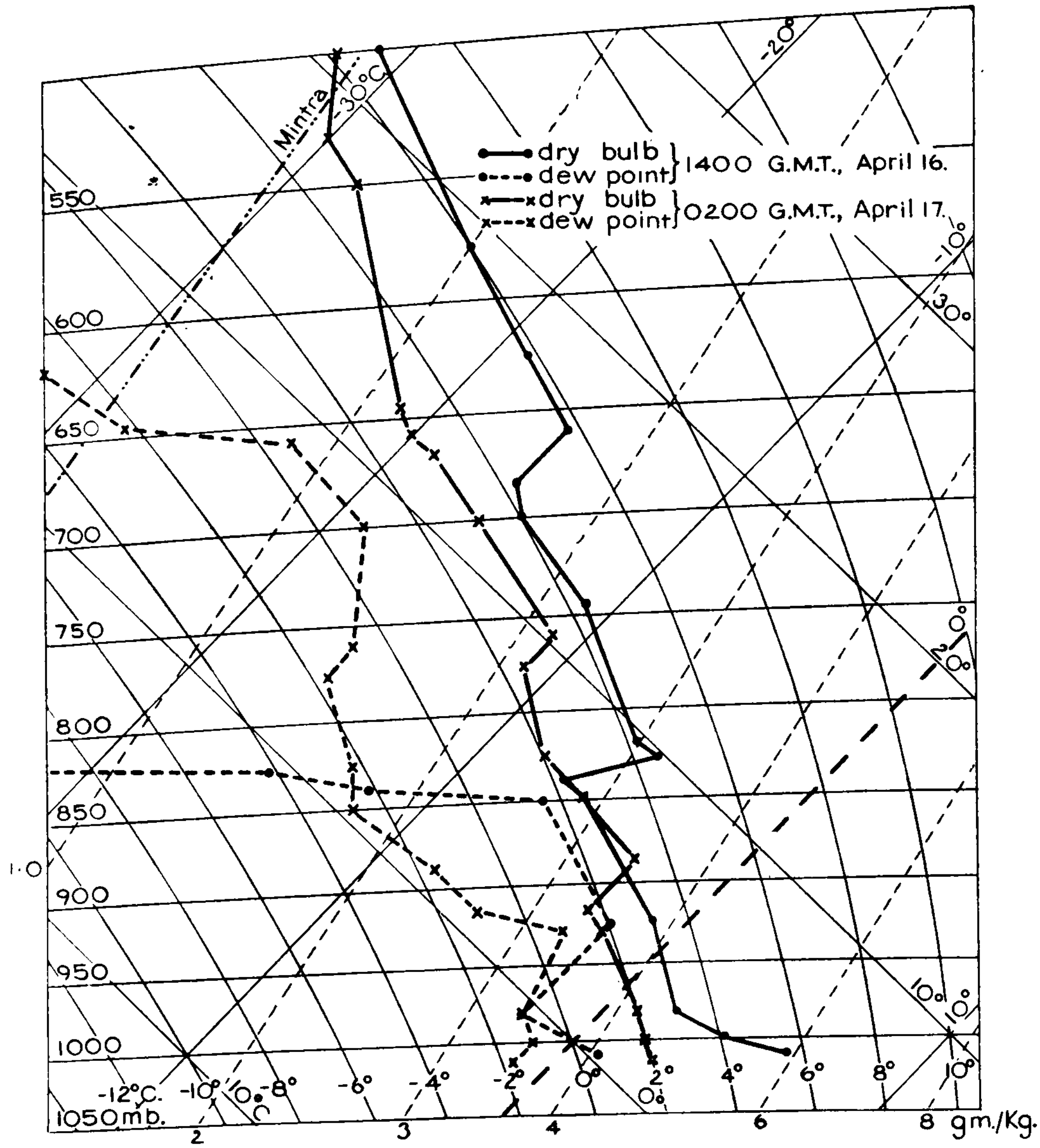


FIG. 1—TEPHIGRAM OF HEMSBY ON APRIL 16 AND 17, 1956

TABLE I—OBSERVATIONS RECORDED AT BINBROOK AT TIME OF INCIDENT

	Surface wind		Visibility	Cloud Amount	Cloud type	Cloud Height	Dry bulb	Dew point	Weather
G.M.T.	°	kt.	*miles*	*oktas*		ft.	°F.	°F.	
1600	90	9	15	2 6	Sc Cb	1,200 1,500	44·1	32·1	
1700	30	9	15	4 7	St Cb	600 800	42·0	33·0	c/tlr$_0$

The winds up to 12,000 ft. over eastern England were between NW. and N. and generally below 10 kt. The Hemsby ascents for 1400 G.M.T. on April 16, and for 0200 G.M.T. on April 17, shown in Fig. 1 describe the state of the air at Hemsby after it had travelled from the area of Grimsby.

Since there were no other thunderstorm reports over a wide area, it is assumed that the excellent conductivity of the three large metal aircraft in the one cell was probably the reason for the flash.

L. L. ALEXANDER

Wittering, April 17, 1956

Aircraft struck by lightning

The photographs facing p. 240 were taken of a Varsity aircraft which was struck by lightning on January 18, 1956. The aircraft, piloted by Flt-Sgt M. Matejski, was flying from Shawbury to Gibraltar, and at 0420 G.M.T. was at a height of 8,000 ft. at a point 50 miles south-south-west of Cape Finisterre (42°N. 10°W.); cloud was 7–8 oktas of cumulus and cumulonimbus.

The incident had been preceded by radio interference and glow discharge from the propellers and sparking along wind-screen frames. The strike itself was described as a zig-zag form of lightning immediately in front of the nose which caused the two members of the crew who saw it 10–15 sec. loss of vision. The magnetic compass and other equipment became unserviceable. The trailing aerial, which had been extended but earthed, was burnt off. The lightning presumably struck the aircraft at the points seen on the upper photograph facing p. 240, three of which were holes a quarter of an inch in diameter through the skin. The buckling shown in the lower photograph facing p. 240 was possibly the result of the path chosen by the strike through the aircraft, or possibly owing to some pressure effect; conditions of turbulence were described as moderate, and sleet had been experienced. Other damage included the tearing away from its mounting bracket of the pitot head.

The situation on January 18 was that of an active low centred just west of Portugal moving very slowly eastwards. Neither the 0300 G.M.T. ascent at Portella (Lisbon) nor that at Madrid were conspicuously unstable, but the track of the air, both at low levels and up to 20,000 ft. was from over the high ground of north-west Spain so that the storms which developed in this area would be carried out to sea. High ground in the area is up to 6,000 ft. or more.

The aircraft was patched up at Gibraltar and demagnetization was carried out to a considerable extent; a strong residual area remained however, on the starboard side of the bomb bay. The aircraft was allowed to return to

Shawbury a couple of days later in formation with other aircraft. The damage sustained appeared rather abnormal.

G. W. HURST

North Front, Gibraltar, February 20, 1956

NOTES AND NEWS

Distrails

On Thursday, May 24, 1956 a very weak, warm front, followed by a stronger cold front, moved across the country from the west. The warm front crossed the London area about midday and gave broken cloud without rain. At about 1100 G.M.T. a layer of cirrocumulus, between 20,000 and 25,000 ft., with some cirrus, was spreading over North and West London, a jet aircraft flew into this cloud sheet over the Harrow area where there was about half cover and continued in a straight flight towards London. A distrail was formed and was most marked for some 15–20 min.

The first photograph in the centre of the magazine, between 5 and 10 min. after the formation, was taken at 1105 G.M.T. looking south-west. The second, 5 min later, was nearly overhead. The circular discontinuity in the first photograph was independent of the distrail and, as there were no trails leading into or away from it, it seems probable that it was formed some time previously by an aircraft entering the cloud from below or above.

The second photograph in particular shows very well the ice-crystal trails described by F. H. Ludlam*.

D. T. TRIBBLE

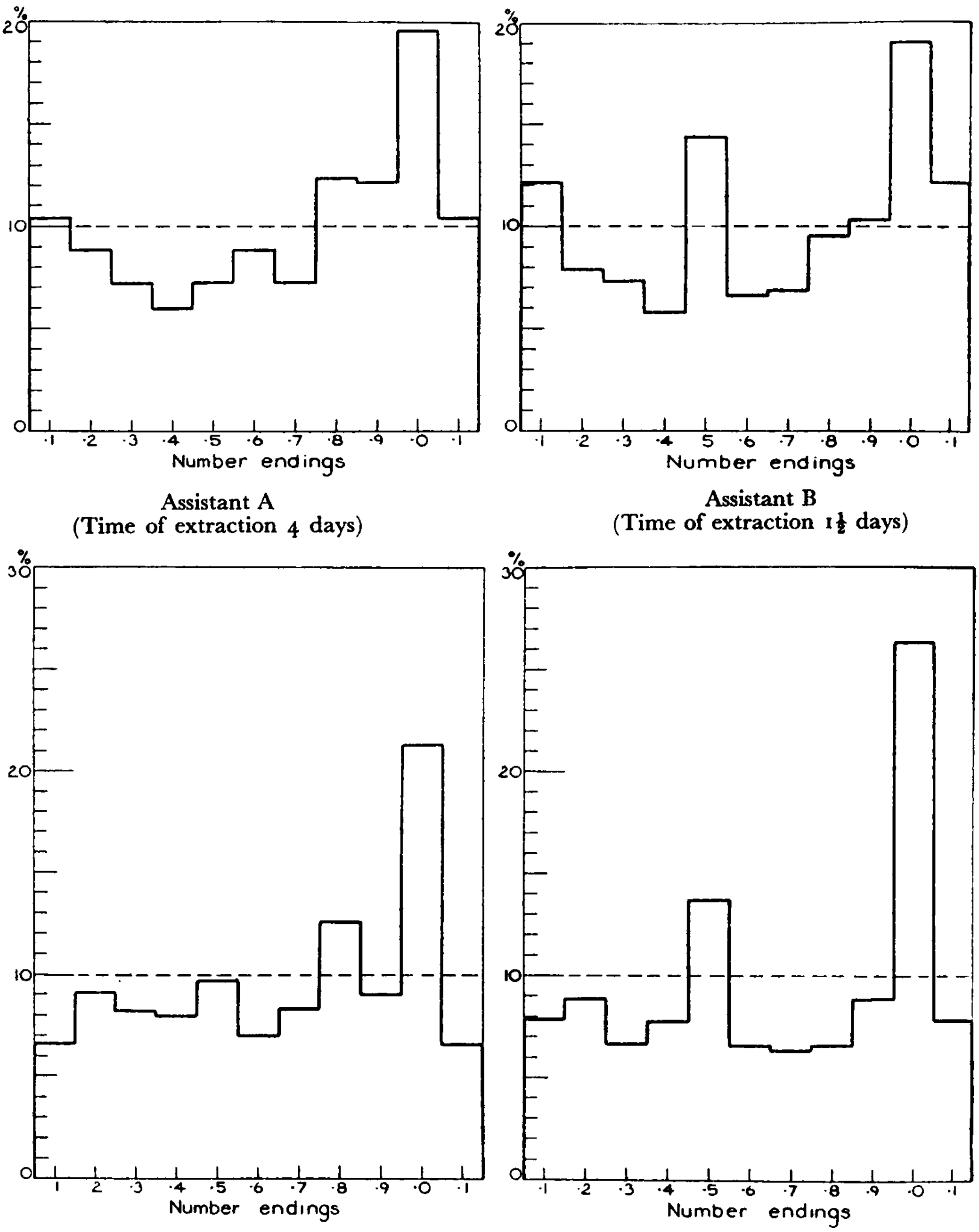
Personal bias introduced during interpolation

Chapter 8 of the "Observer's handbook" deals with temperature and humidity and in paragraph 8.1.1. observers are warned against introducing personal bias when reading a thermometer to one tenth of a degree. The following analysis, conceived whilst reading "Number: The language of science" by Tobias Dantzig[1], shows the tendency of four people to favour certain numbers, with the partial exclusion of others. This example illustrates the danger referred to in the "Observer's handbook" and may be of interest to many who have never seen a case analysed.

In the World Climatology Branch of the Meteorological Office, assistants were given the task of extracting values of vapour pressure, which were to be estimated to one tenth of a millibar, by interpolation from world maps of vapour pressure at mean sea level for January, April, July and October, one assistant being assigned to each map. These maps were 2 ft. by 3 ft. 9 in. and were on Mercator's projection. Values for 980 stations were required, each station having accurate co-ordinates and each assistant having the use of dividers and magnifying glass. The isobars were drawn at 0·5-mb., 1-mb. and 2-mb. intervals, and in some places were very close together making interpolation difficult. At the end of the project all the maps were interchanged and the extractions repeated, so that all the extracted values were checked.

After extracting approximately 350 values, assistant A realized his preference for the figures 8 and 0. A quick analysis resulted in the percentage frequency

* LUDLAM, F. H.; Fall-streak holes. *Weather, London*, **11**, 1956, p. 89.



Assistant A
(Time of extraction 4 days)

Assistant B
(Time of extraction 1½ days)

Assistant C
(Time of extraction 8 days)

Assistant D
(Time of extraction 8 days)

FIG. 1 FREQUENCY OF READINGS OF LAST FIGURE OF INTERPOLATION

shown in Fig. 1 (Assistant A) which verified his assumption, and indicated that more care was required. Assistant B worked at great speed, which resulted in a large number of errors and emphasis on the centre and extremes of the range of digits. Assistants C and D approached the work in a deliberate manner but an analysis of their results still indicated definite bias in their choice of number. With such a large sample of stations, it would be expected that extracted values ending 0 to 9 would all fall about the 10 per cent. frequency line. The closeness of the isobars in some places appeared not to justify any estimate closer than to the nearest millibar, but the number of cases does not seem to warrant the high frequency of 0.

Before checking each other's work, all the assistants were shown the results of this analysis and were consequently more alert.

An interesting comparison is afforded by the results found by E. Gold[2], when he analysed reported wind-speed observations. Similar examples of the preference of individuals for certain digits are given by G. U. Yule and M. G. Kendall[3].

L. FLETCHER

REFERENCES

1. DANTZIG, T.; Number: The language of science, 2nd edn., London, 1940.

2. GOLD, E.; Frequency distribution of wind speed in synoptic reports. *Met. Mag., London*, 79, 1950, p. 22.

3. YULE, G. U. and KENDALL, M. G.; An introduction to the theory of statistics. 3rd edn, London, 1947, p. 86.

REVIEWS

Principals of meteorological analysis. By W. J. Saucier. $9\frac{1}{2}$ in. × 7 in., xvi + 438, *Illus.*, Chicago University Press, Cambridge University Press, 1955. Price: 75*s*.
The author began writing this book when he was Instructor in Meteorology at the University of Chicago and completed the work after he had been appointed Associate Professor of Meteorology at the Agricultural and Mechanical College of Texas. His experiences led him to believe that the teaching of meteorological analysis had not been sufficiently linked with courses in the more academic but kindred subjects of statics, thermodynamics and the physical processes occurring in the atmosphere, and that the practice of surface analysis was still not sufficiently integrated with the routine co-ordinated analyses of the overlying free atmosphere which had become possible during the last few decades. This book is an attempt to strengthen the links between theory and practical analysis and between analyses of data at the surface and in the free atmosphere. The student is required to have an elementary knowledge of meteorology and a working knowledge of calculus and vector algebra. In no part of the book do the mathematics become involved and the student should find no difficulty in following the treatment.

The opening chapters contain a simple review of atmospheric variables and of meteorological charts and diagrams. General properties of the various thermodynamic diagrams are given, and there is a useful section on several map projections used in meteorological analysis. In the third chapter Prof. Saucier covers familiar ground in hydrostatics and static stability. In his treatment of the parcel theory of convection he includes a section on the effect of entrainment of air from the environment in the moving parcel.

The next two chapters are devoted to scalar analysis and graphical analysis. From his treatment of scalar analysis the author leads up to the concept of gradients in the scalar field, to vectors, and to their resolution into components along suitable axes. He derives theoretically the relations between topographic and horizontal fields of various meteorological quantities and then discusses the procedures for drawing isopleths from data plotted on charts. This leads on naturally to the general relationship between the accuracy of analysis and the density of data and to a discussion of interpolation and extrapolation. An explanation is given of the gridding technique for graphical addition or subtraction of two families of curves. The usual formulae are developed for the evaluation of approximate values of various first- and second-order space derivatives by finite differences from values at selected points on a rectangular grid.

At this stage the author has included a long chapter on cross-section analysis He describes the construction of many types of cross-sections and includes numerous diagrams illustrating various types of cross-section. These cross-sections are constructed for the same instant of time and depict the state of the atmosphere over North America. Although these diagrams can be directly compared some of their instructive value has been lost owing to the smallness of the scale employed. After developing the concept of solenoids and baroclinity, the author includes another series of cross-sections covering North America which are discussed at considerable length to describe the polar air mass, the polar-front region, and the tropical air mass. There is undoubtedly a great deal of valuable material in this chapter but there are so many types of cross-section that the reader suffers from a form of "cross-sectional indigestion" before the end of the chapter is reached. The student would derive greater benefit from illustrations of fewer types of cross-section but of more adequate size and clarity.

The following chapter on isobaric analysis follows conventional lines. Thermal winds are discussed and a number of values are quoted relating the variation of wind and the tilt of various pressure systems with height to the relative locations of warm and cold air. Formulae are included for the movements and development of pressure systems in terms of their isallobaric fields as developed by Petterssen in "Weather analysis and forecasting" and by Byers in "General meteorology". The author sounds the usual notes of warning regarding the numerical application of these formulae. This chapter is also marred by illustrative charts of inadequate size. A considerable number of charts are included showing many relative thicknesses, total contours, isotherms, pressures at the tropopause, and other isopleths. Not all of these charts are necessary to the understanding of the chapter. Many of these charts extend over North America from the Pacific to the Atlantic coasts and from north of 70°N. to south of 25°N. Some contain two families of curves. As each illustration is reduced to a size of $2\frac{1}{2}$ in. $\times$ 2 in. approximately the various isopleths on the charts are particularly difficult to follow whenever two families of curves are included on one illustration. Fewer illustrations on a larger scale would also have improved this section.

The analysis of the surface chart is well treated and is characterized by bold clear illustrations. This is followed by a long chapter on kinematic analysis. The difference between stream-lines and air trajectories is clearly brought out and divergence and convergence are adequately treated. Vorticity and constant-absolute-vorticity trajectories are fully discussed. Practical methods for evaluating divergence, vorticity and deformation are clearly explained.

In the remaining sections of the book the author includes a very limited treatment of broad-scale analysis over substantial portions of the northern hemisphere. This is followed by a very different kind of analysis, namely, local analysis with an open time scale. The final chapter surveys analysis in the tropics in a very general and limited manner.

The book is well and clearly printed and very few errors were noted. The index is quite comprehensive and a number of useful tables are included in the appendix. At the ends of several chapters are some problems and exercises but solutions and answers are not provided. Throughout the book the standard of treatment of the chapters varies considerably. Some are full and self-contained, others give just an outline. The author explains that this was intentional because the book is intended for study in parallel with other texts—adequate general references to which are given in a list of "reading references at the end of each chapter"—yet these variations in standard and thoroughness were disconcerting to the reviewer. The book has also been designed so that the various chapters may be studied in a somewhat flexible order. The net result is that the reviewer felt that he was being led through the subject in a series of disconnected lessons of varying degrees of complexity, and that the student would find it difficult to comprehend that unity between theory and practice and a fully co-ordinated analysis of the atmosphere which the author set out to achieve. In spite of these shortcomings practical and experienced analysts will find much in Prof. Saucier's book which is both stimulating and illuminating.

N. BRADBURY

A study of fifty years' rainfall of Mangalore. By K. P. Ramakrishnan and J. Narayanan. *Mem. India Met. Dep., Delhi,* **30**, Pt. III. $12\frac{1}{2}$ in. × 10 in., pp. 52, *Illus.*, Manager of Publications, Delhi. Price: *Rs* 6–14 or 11*s*.

This is a straightforward piece of descriptive meteorology of Mangalore (12°52′N. 14°51′E.). Daily rainfall observations for the period 1901–50 are analysed to give daily, 3-day, 3-day-moving, half-monthly and monthly means; also monthly extremes and the mean intensity (more correctly mean amount) per "rainy" day, i.e. on which some rain fell. In addition, frequencies have been computed of the raininess (more correctly, the occurrence of rain) for each calendar date, of different 24-hr. intensities (more correctly, different daily amounts) for each month, rainy spells (consecutive days with some rain) and dry spells. Data are also given of the composition of the total 50-yr. rainfall in each month in terms of amounts and percentages for different ranges of falls per day. Finally, there are sections and tables dealing with spells of heavy rain and exceptionally heavy rain defined as one or more consecutive days with specified amounts, i.e. ranging from 4 in. in one day to 22 in. or more in 10 days for heavy falls and from 5 in. in one day up to 32 in. or more in 10 days for exceptional falls.

The analysis does not reveal anything startling. It is shown that the "normal" rainy season is from June 1 to September 1, i.e. during the SW. monsoon, nearly 80 per cent. of the average annual rainfall total falling in that period. It is interesting to learn that at least some rain fell on four dates in July in every one of the 50 years and that 78 dates during June to September had rain in 45–49 years. The highest rainfall for June to August was 149 in. and for the year 182·7 in., both in 1946.

Had there been a rainfall recorder we might have been told a little more about the intensity and duration of the rainfall but we do learn that there were only two spells of consecutive days with rain exceeding 100 days, both commencing in May, and that the highest fall in a single day was 14·21 in., i.e.

over 3 in. more than the highest fall in 24 hr. in the British Isles. The wettest spell on record appears to have been in 1933 when 43·44 in. fell in the 10 days from June 30 to July 9. The wealth of information provided will be of great use to water engineers and hydrologists.

R. G. VERYARD

METEOROLOGICAL OFFICE NEWS

Retirement.—Mr. C. F. J. Jestico, Experimental Officer, retired on June 17, 1956, after 44 years' service. He joined the Office in December 1912 as a Probationer in the Forecast Division. From February 1917 to November 1919 he served in the Meteorological Section, Royal Engineers. From 1919 until 1941 he served successively at a number of aviation outstations, including a tour of duty in Iraq. Since 1941 he has worked at Headquarters in Kingsway and at Harrow. For the last four years he has served in the Marine Division.

At a ceremony at Harrow on June 15, Cmdr C. E. N. Frankcom made a presentation to Mr. Jestico on behalf of his colleagues.

Ocean weather ships.—The following note has been received from the British Ship Adoption Society:

The Master and Ship's Company of *Weather Observer*, which is this school's* adopted ship, have presented to the school a cheque for £4 in order to provide a prize or prizes to the pupils. This year four *Weather Observer* prizes have therefore been awarded to the school for school service and patriotism.

The British Ship Adoption Society, by bringing ships and schools together in this way makes a very useful contribution towards the education of young people, and we are glad that the weather ships are thus associated with this movement. *Weather Recorder* and *Weather Watcher* have also been adopted by schools in the Clyde area.

Sports activities.—The Air Ministry Annual Sports were held at the White City Stadium on June 20, and marked the end of the year for the competition for the Bishop Shield. The Meteorological Office retained the Bishop Shield for the eighth consecutive year. The Shield is presented to the department gaining the highest number of points in all the Air Ministry sports competitions held throughout the year. The Office also won the W. S. Jones Memorial Cup for the sixth successive year. This cup is awarded to the department gaining most points at the Annual Sports. Miss K. N. Newman won the Ladies' 100 yards Championship for the fifth successive year. The Office also won the Ladies' High Jump and the Ladies' Long Jump, and both the Men's and Ladies' Inter-Divisional Relay Championships, and were runners-up in the Tug-of-War Championship.

WEATHER OF JUNE 1956

In June as in May the main anticyclones in the North Atlantic and North Pacific were both above normal intensity, the greatest pressure anomaly being in the north-east sector (in June +6 mb. between the Azores and 50°N. 20°W.). Nevertheless the weather in western and middle Europe underwent a radical change about the beginning of June, associated with the in-break of north-westerly winds. The lowest pressure in May had been near Iceland, but shifted in June to three centres, the deepest off north-west Norway (mean pressure for the month 1009 mb., maximum anomaly −4 mb.) and the others over southern Scandinavia and off south-west Greenland. A corresponding feature was seen in the Pacific sector, an unusual centre over central Alaska (1009 mb., anomaly −3 to −4 mb.) with the lowest pressure anywhere in that sector. As in May the monsoonal low pressure was rather more pronounced than usual over Siberia.

This circulation pattern made all Europe cold for June, except Russia and the lands east and north of the Baltic and small areas in south Portugal and Greece. Anomalies reached

* Hillhead High School, Glasgow.

$-3°C.$ in central Europe and $+3°$ to $+4°C.$ near the White Sea. Mean temperatures for the month were above the normal over most of North America, anomalies reaching $+4°C.$ in places, though the extreme north-west and north-east were both cold (anomalies $-2°$ to $-4°C.$). There were negative anomalies around most of the polar basin.

Rainfall was excessive in the path of the northerly and north-westerly winds everywhere from the Norwegian Sea to the eastern Alps, exceeding three times the normal at one place in Germany and over twice the normal in many places from Sweden to the Riviera and Greece. Considerable excesses were also noted in west Mexico and over most of India and Pakistan. Cherrapunji in Assam, noted as the world's wettest place, had over 180 in., making this the wettest June at least since 1890. On the 4th, 37·5 in. of rain fell in 24 hr., exceeding the highest previously recorded total for this place. There was serious flooding in this region and also in the Yangtze valley and southern China.

In the British Isles unsettled weather during the first half of June, with rainfall in many places more than twice the average, brought to an end a period of drought which in a great many districts had lasted for nearly four months. For most of the second half of the month a changeable type of anticyclonic weather predominated and did much to bring rainfall and temperature nearer the normal June levels after a wet and cool beginning.

Weather was generally cool, dull and rather stormy during the first week as a series of depressions from the Atlantic passed over or near Scotland. Winds became fresh to strong on the 5th reaching gale force in the north where 55 kt. was recorded at Tynemouth. A depression became almost stationary over north-western districts on the 6th and the following day moved slowly south-east to the southern North Sea, accompanied by widespread thunderstorms with some exceptionally heavy rain in Yorkshire during the evening; more than 1 in. fell at Scarborough. The depression persisted in the southern North Sea for 4–5 days, and the wet weather continued into the second week particularly over the eastern half of the country, with thundery rain or showers and with winds mainly from between N. and NW. Thunderstorms were again widespread on the 11th; over 1 in. of rain was recorded at many places and more than 1½ in. fell at Lake Vyrnwy (north Wales). The last day of general rainfall of any note during the month was the 16th when a depression from the Atlantic increased in intensity over Ireland as it moved across the country. As this depression passed on to the Continent the Azores anticyclone moved nearer to the British Isles. High pressure to the west and south-west dominated the weather from the 18th to the 27th, and although slight rain fell in many places amounts were mostly small except during thunderstorms which occurred mainly in western districts from the 23rd to the 25th. Temperatures during these ten anticyclonic days were mainly above normal and in many places rose progressively during that time reaching 78°F. at Southampton on the 26th; Scotland was at times the warmest part of the British Isles, notably on the 23rd when afternoon temperature at Renfrew reached 76°F. A large complex depression to the west of Ireland on the 29th was associated with a return to less settled and rather cool weather during the last two or three days of the month.

Heaviest rainfall occurred in Yorkshire, Lincolnshire, Nottinghamshire and Derbyshire where over 3 in. was recorded during the month. During the week ending June 9 Rothamsted and Dumfries had four times their normal amount of rain while Scarborough and Cranwell had about four and a half times as much as usual. In most midland and eastern counties it was one of the dullest Junes of the century, with large areas having 40–80 hr. below the normal sunshine totals. Mean temperature was only slightly below average in Scotland, but over most of England it was 2 or 3 degrees below. In London and Birmingham the average day maximum was 4 degrees below average and below the May figure. It was the coldest June for 10 yr. at Kew and the coldest since records began at Sprowston in 1924. Recovery in crops suffering a set-back caused by the drought of previous months has on the whole been good. Gales on the 5th caused damage to several acres of cabbages in the Durham area while reports from Northampton tell of severe damage caused to growing crops during heavy thunderstorms on the 11th.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	80	29	−2·0	109	+3	76
Scotland	81	26	−1·2	117	+2	102
Northern Ireland ...	76	30	−1·5	119	+3	109

RAINFALL OF JUNE 1956

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·34	116	*Glam.*	Cardiff, Penylan ...	2·23	89
Kent	Dover	2·60	135	*Pemb.*	Tenby	2·46	103
,,	Edenbridge, Falconhurst	3·54	161	*Radnor*	Tyrmynydd	2·98	91
Sussex	Compton, Compton Ho.	3·23	130	*Mont.*	Lake Vyrnwy	4·09	127
,,	Worthing, Beach Ho. Pk.	1·93	110	*Mer.*	Blaenau Festiniog ...	5·64	87
Hants.	St. Catherine's L'thouse	1·93	108	,,	Aberdovey	3·22	118
,,	Southampton (East Pk.)	2·05	102	*Carn.*	Llandudno	1·22	64
,,	South Farnborough ...	1·99	103	*Angl.*	Llanerchymedd ...	2·03	86
Herts.	Harpenden, Rothamsted	3·75	167	*I. Man*	Douglas, Borough Cem.	2·46	102
Bucks.	Slough, Upton	1·79	87	*Wigtown*	Newton Stewart ...	2·88	109
Oxford	Oxford, Radcliffe ...	2·47	110	*Dumf.*	Dumfries, Crichton R.I.	2·59	102
N'hants.	Wellingboro' Swanspool	2·82	134	,,	Eskdalemuir Obsy. ...	3·62	115
Essex	Southend, W. W. ...	1·71	92	*Roxb.*	Crailing...	2·86	129
Suffolk	Felixstowe	1·66	97	*Peebles*	Stobo Castle	2·72	116
,,	Lowestoft Sec. School ...	1·47	81	*Berwick*	Marchmont House ...	2·59	112
,,	Bury St. Ed., Westley H.	2·21	105	*E. Loth.*	North Berwick Gas Wks.	2·20	134
Norfolk	Sandringham Ho. Gdns.	3·36	155	*Midl'n.*	Edinburgh, Blackf'd. H.	2·29	115
Wilts.	Aldbourne	2·15	87	*Lanark*	Hamilton W. W., T'nhill	2·85	130
Dorset	Creech Grange... ...	2·50	109	*Ayr*	Prestwick	1·94	101
,,	Beaminster, East St. ...	2·73	121	,,	Glen Afton, Ayr San. ...	4·18	139
Devon	Teignmouth, Den Gdns.	1·33	69	*Renfrew*	Greenock, Prospect Hill	3·13	100
,,	Ilfracombe	2·22	102	*Bute*	Rothesay, Ardencraig ...	2·97	97
,,	Princetown	5·39	134	*Argyll*	Morven, Drimnin ...	3·82	123
Cornwall	Bude, School House ...	0·00	000	,,	Poltalloch	2·64	87
,,	Penzance	2·82	127	,,	Inveraray Castle ...	3·85	97
,,	St. Austell	3·21	124	,,	Islay, Eallabus	3·34	127
,,	Scilly, Tresco Abbey ...	1·94	112	,,	Tiree	2·47	97
Somerset	Taunton	·99	56	*Kinross*	Loch Leven Sluice ...	3·30	151
Glos.	Cirencester	2·22	89	*Fife*	Leuchars Airfield ...	2·81	168
Salop	Church Stretton ...	1·92	76	*Perth*	Loch Dhu	4·41	106
,,	Shrewsbury, Monkmore	1·73	83	,,	Crieff, Strathearn Hyd.	3·82	145
Worcs.	Malvern, Free Library...	1·72	74	,,	Pitlochry, Fincastle ...	2·87	137
Warwick	Birmingham, Edgbaston	2·09	82	*Angus*	Montrose, Sunnyside ...	2·52	152
Leics.	Thornton Reservoir ...	3·18	147	*Aberd.*	Braemar	2·21	113
Lincs.	Boston, Skirbeck ...	2·72	150	,,	Dyce, Craibstone ...	1·79	96
,,	Skegness, Marine Gdns.	2·91	162	,,	New Deer School House	1·90	95
Notts.	Mansfield, Carr Bank ...	4·15	184	*Moray*	Gordon Castle	2·47	121
Derby	Buxton, Terrace Slopes	3·26	101	*Nairn*	Nairn, Achareidh ...	2·39	135
Ches.	Bidston Observatory ...	1·56	71	*Inverness*	Loch Ness, Garthbeg ...	3·01	132
,,	Manchester, Ringway...	2·33	96	,,	Loch Hourn, Kinlochourn	4·66	94
Lancs.	Stonyhurst College ...	2·42	79	,,	Fort William, Teviot ...	3·41	96
,,	Squires Gate	1·78	86	,,	Skye, Broadford ...	2·90	74
Yorks.	Wakefield, Clarence Pk.	2·60	121	,,	Skye, Duntulm ...	3·10	119
,,	Hull, Pearson Park ...	2·71	132	*R. & C.*	Tain, Mayfield... ...	2·05	111
,,	Felixkirk, Mt. St. John...	4·13	189	,,	Inverbroom, Glackour...	3·04	108
,,	York Museum	2·43	117	,,	Achnashellach	3·05	81
,,	Scarborough	2·97	161	*Suth.*	Lochinver, Bank Ho. ...	3·29	154
,,	Middlesbrough... ...	3·45	183	*Caith.*	Wick Airfield	2·39	133
,,	Baldersdale, Hury Res.	2·44	111	*Shetland*	Lerwick Observatory ...	2·45	137
Norl'd.	Newcastle, Leazes Pk....	2·63	125	*Ferm.*	Crom Castle	3·19	118
,,	Bellingham, High Green	3·08	134	*Armagh*	Armagh Observatory ...	2·50	99
,,	Lilburn Tower Gdns. ...	2·35	114	*Down*	Seaforde	3·33	121
Cumb.	Geltsdale	3·43	127	*Antrim*	Aldergrove Airfield ...	2·49	103
,,	Keswick, High Hill ...	2·24	77	,,	Ballymena, Harryville...	3·47	119
,,	Ravenglass, The Grove	3·10	119	*L'derry*	Garvagh, Moneydig ...	3·34	131
Mon.	A'gavenny, Plâs Derwen	2·47	92	,,	Londonderry, Creggan	3·73	132
Glam.	Ystalyfera, Wern House	4·57	121	*Tyrone*	Omagh, Edenfel ...	3·91	139

Printed in Great Britain under the authority of Her Majesty's Stationery Office
By Geo. Gibbons Ltd., Leicester

Wt-34. K16.