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CONFERENCE ON HIGH-SPEED COMPUTING

By the DIRECTOR OF THE METEOROLOGICAL OFFICE

The Director of the Meteorological Office, Dr. O. G. Sutton, accepted an invitation to take part in a conference on the application of high-speed computing to problems of meteorology and oceanography, sponsored jointly by the University of California in Los Angeles and the National Science Foundation of America, on May 13, 14 and 15. The conference brought together some of the leading workers in this subject, and was marked throughout by brisk discussions.

The conference opened with a short statement by Dr. Sutton on the historical background of the meteorological problem, in which he traced briefly the development of mathematical methods in weather forecasting from the early "mechanical models" of Rayleigh, Shaw, Exner and others, to the polar-front analysis of Bjerknes, the courageous but deeply significant attempt of Richardson in 1922 to apply the equations of hydrodynamics to the problem, up to the present stage. Dr. Sutton emphasized his view that the present attack, while not involving the extreme generality of Richardson's approach, was not restricted to any closely defined models of atmospheric systems and therefore appeared more promising, although it must be recognized that the mathematicians had deliberately omitted certain factors, not because they are small, but because they are too complicated to be included at present.

Major P. D. Thompson (United States Air Force Geophysics Research Directorate) followed with an interesting paper on the integration of the equations of hydrodynamics for large-scale non-geostrophic motions. Major Thompson pointed out the importance of Charney's discovery that it is possible to exclude certain classes of unwanted solutions (those corresponding to sound waves and gravity waves) by the judicious use of the hydrostatic equation and the geostrophic balance, without seriously endangering the solutions corresponding to the large-scale disturbances in which the forecaster is most interested. He concluded, however, that, for good predictions of weather, it is necessary to introduce some type of non-geostrophic motion, and he outlined a possible procedure for doing this.

Dr. Jules Charney (Institute for Advanced Study, Princeton), one of the best known workers in numerical forecasting, then gave a lengthy and deeply interesting account of the whole subject and of the progress made so far at the Institute for Advanced Study. As much of this account dealt in detail with the mathematical basis, it is not possible to give an adequate summary of Dr. Charney's lecture here. He pointed out the necessity for including more than two levels in the work and illustrated his theme by showing the calculated pressure field for the famous "Thanksgiving Day storm" of 1950. This occasion is one which is not likely to be forgotten quickly by American meteorologists because of a depression which formed near the northern coast of the Gulf of Mexico, moved up the east coast from Florida, and deepened rapidly as it approached the densely populated areas near New York, finally producing a heavy snowstorm which completely ruined the national holiday in that part of the country. The official forecasters did not foresee this development and public faith in meteorology received a rude shock. Calculations with relatively simple models fail to show any such pronounced cyclogenesis, but with the 3-level model a good approximation to reality was achieved. There seems little doubt that if such a result had been available to the routine forecasters at the time, they would have been forced to reconsider their forecast before publication.

Dr. Charney gave some interesting facts about the effort involved in producing a 3-level 24-hr. forecast for the United States. The solution of the equations necessitates about a million multiplications and divisions, ten million additions and subtractions and some thirty million mathematical "orders" to the machine. These can be done in 45 min. with an existing machine and there is good hope that this period can be reduced to about 15 min. A 5-level model would require not more than three hours to solve the equations for a 24-hr. forecast, and a 3-level 5-day forecast would be completed (as far as the pressure field is concerned) in perhaps 20 hr. of machine time, but of course, the value of such a forecast is problematical. Dr. Charney also discussed the difficult problem of handling the initial data objectively and outlined a possible method of bringing this within the scope of the machine.

Dr. Sutton explained what is being done in the United Kingdom and showed slides comparing the machine forecast with the prebaratics made by Dunstable for the same occasions. The tendency noticed in the Sawyer-Bushby scheme to exaggerate the deepening of depressions or the building-up of anticyclones is not as evident in the American results. On the other hand, there seems to be no case yet examined at the Central Forecasting Office, Dunstable, in which the machine scores a spectacular success over the human forecaster, as in the case of the Thanksgiving Day storm.

Dr. J. Namias (United States Weather Bureau) gave an account of his researches into long-range forecasting and provoked a lively discussion on this subject. Prof. H. A. Panofsky (Pennsylvania State College) gave an interesting talk on his investigations into the spectra of wind turbulence. Other speakers included Dr. H. Wexler (United States Weather Bureau), Prof. Syono (Japan), Dr. W. H. Munk (Scripps Institution of Oceanography) and Prof. J. J. Stoker (New York University). Between them they covered a wide field, ranging from tropical cyclones to tidal theory and river-flood prediction.

One of the high lights of the conference was a public lecture by Prof. J. von Neumann, who covered the whole field in his inimitable manner, quoting masses of figures and speaking without a pause for over an hour without (as far as the writer could see) a single note. Prof. von Neumann has a memory which rivals any electronic device yet devised.

The conference closed with a visit to the Scripps Institution of Oceanography at La Jolla, near the Mexican border, where the visitors experienced the far-famed Californian climate at its best.

The Director subsequently visited the astronomical observatory at Mount Wilson (including a discussion on turbulence in nebulae) and afterwards the

United States Weather Bureau at Washington. Meteorologists will be interested to know that on July 1 it is proposed formally to institute in the United States a Joint Numerical Weather Prediction Unit, which will operate alongside WBAN (the joint aerological analysis unit). The staff, under the general direction of Dr. Wexler, will number about 32 in all, of whom at least half will be professional meteorologists, and the remainder mathematicians, programme experts, punch-card operators, etc. The machine, of advanced design, is expected to be delivered about October 1. Daily charts (and perhaps 2 per day) may be produced early in 1955 for comparison with actual charts, and it is hoped gradually to bring numerical forecasting into routine weather forecasting within the year.

This development will be watched with the greatest interest everywhere, and nowhere more than in the United Kingdom. If the scheme proves successful, 1955 may well mark one of the historic turning points of our science.

In conclusion, this was a highly interesting and successful conference, which brought many of the leading workers into contact with each other and succeeded in putting matters in proper perspective. For this one may thank the University of California in Los Angeles, and the National Science Foundation of America for their generous hospitality, and Dr. F. N. Frenkiel (Johns Hopkins University) in particular for his untiring and skilful administration of the conference.

APPLICATION OF MATHEMATICAL SERIES TO THE FREQUENCY OF WEATHER SPELLS

By E. N. LAWRENCE, B.Sc.

In a recent paper[1] on the frequency of spells of light wind, a formula was obtained for the frequency of light wind spells, in a period of M days, that last for m or more days in terms of the spell length and the average frequency of light winds. The series for the frequencies F_1, F_2, F_3 . . . F_m of spells of at least 1 day, 2 days, . . . m days, respectively, is

$$\frac{M}{\log_e(1/f)}\,(f+f^2+f^3+\ldots+f^{m+1}) \qquad \ldots\ldots (1)$$

where f is the average frequency of light winds in a period of M days. This is a geometric series. In the application of mathematical series to spell frequencies, much attention has been given to the use of the geometric form. In another paper[2], it was shown that the frequency, F_m, of spells of at least m successive like months (wet or dry) is given by:—

$$\log F_m = Rm + S$$

where R and S are station constants. The series for F_1, F_2, . . . F_m becomes:—

$$e^S\,(e^R + e^{2R} + e^{3R} + \ \ldots + e^{mR}\ldots) \qquad \ldots\ldots (2)$$

which, again, is a geometric series.

The use of the geometric series implies a linear relationship between m and the logarithm of the frequency. The data used in both papers[1,2] show that this is true to a fair degree of accuracy but that, to a closer degree of approximation, the graphs of log F against m are really curves.

Gold[3] showed that the number of spells (wet and dry) of length 1 day, 2 days, 3 days, etc. formed a geometric series only if the frequencies were controlled by pure chance. Cochran[4] has shown that before making comparisons with Gold's formula it is necessary to test whether the two events can be regarded as occurring with an equal chance, and that Bilham's data[5,6] for spells of wet and dry months showed that runs of wet and dry months must be kept separate.

An investigation has been carried out in the Meteorological Office[7] in connexion with dry spells (that is sequences of days for which the reported rainfall is nil or trace) for harvesting and drought precautions, using both the geometric series and the logarithmic series. The geometric series was of the form:—

$$N(1 + P + P^2 + P^3 + \ldots) \qquad \ldots\ldots (3)$$

where N is the number of spells lasting at least 3 days, NP the number of spells lasting for at least 4 days and NP^{m-3} the number of spells lasting at least m days, and P is the probability that a spell lasting m days will continue another day, assumed constant for a given month of the year at a particular site. In this investigation, the logarithmic representation for the frequency of dry spells at a particular place was assumed to be of the form:—

$$F_m' = \frac{ar^{m-1}}{m}$$

where F_m' is the frequency of spells lasting only m days, a the frequency of spells lasting only 1 day and r a constant. Thus

$$F_m = ar^{m-1}\left(\frac{1}{m} + \frac{r}{m+1} + \frac{r^2}{m+2} + \frac{r^3}{m+3} + \ldots\right). \qquad \ldots\ldots (4)$$

If n be the average number of dry days during the month,

$$n = \sum_{m=1}^{\infty} m \left[\frac{ar^{m-1}}{m}\right]$$

$$= \frac{a}{1 - r}$$

Thus $$r = 1 - \frac{a}{n}$$

$$= 1 - \frac{\text{Frequency of isolated dry days per month}}{\text{Average number of dry days during month}}.$$

Thus equation (4) may be used to obtain the frequency of dry spells lasting at least m days, in terms of m, a and r.

In practice, charts of the area concerned have been drawn[7] showing for each of the months May to September the isopleths of a and r, and in order to facilitate computation a further set of charts has been drawn showing the isopleths of $\Sigma F_m'$ ($m = 1 \ldots$ infinity) or say, T, the total number of spells. Thus the number of spells of at least m days is given by:—

$$F_m = T - a\left[1 + \frac{r}{2} + \frac{r^2}{3} + \frac{r^3}{4} + \ldots + \frac{r^{m-2}}{m-1}\right]. \qquad \ldots\ldots (5)$$

In a recent study of the length of dry and wet spells at five Canadian cities, Longley[8] concluded "that after a wet day the probability of the following day being wet is constant no matter how long the wet spell has persisted" and that "the same is true for the weather following a dry day, except that there is a slight increase in the probability of dry weather with increasing length of the dry period." The cities were situated in different climatic regions, namely the uniformly moist eastern maritime region, the dry prairie provinces, the arctic zone and the west where wet winters follow dry summers. The length of period examined varied from 50 to 77 years. However, in another recent study[9] it is shown that the frequency distribution of dry and wet spells at Moncton, New Brunswick (for 50 years) conforms very closely to geometric and logarithmic series (i.e. F_m' series) respectively. Furthermore, Williams[10] showed that for certain areas the frequencies of dry spells of increasing lengths could be represented to a fair degree of accuracy by a logarithmic series. It may be concluded that ample evidence exists for the close relationships between the observed series and both the geometric and the logarithmic series but that significant deviations do occur.

Comparison of the geometric and logarithmic series.—In the geometric series, the ratio $F_{m+1} : F_m$ is constant. In the logarithmic series, the ratio $F_{m+1} : F_m$ is $(T - T_m)/(T - T_{m-1})$, where

$$T = a + \frac{ar}{2} + \frac{ar^2}{3} + \frac{ar^3}{4} + \ldots \text{ to infinity}$$

$$T_m = a + \frac{ar}{2} + \frac{ar^2}{3} + \frac{ar^3}{4} + \ldots + \frac{ar^{m-1}}{m}.$$

Thus the ratio $F_{m+1} : F_m$ (which is independent of a) when $r = 0{\cdot}5$, gives

$$\frac{F_2}{F_1} = 28 \text{ per cent.}, \frac{F_3}{F_2} = 36 \text{ per cent.}, \frac{F_4}{F_3} = 40 \text{ per cent., etc.},$$

the value of the ratio increasing with increase of m, i.e. the persistence effect increases the longer the spell lasts. This means that, in the logarithmic-series representation, spells are assumed to have the property (to a certain degree) that the longer a spell lasts the more likely will it continue to last another day. Newnham[11] found that "the chances of continued drought become greater the longer the fine weather lasts, at any rate for spells of a length commonly met with", and Belasco[12] found that the probability that the next day will be anticyclonic after a run of anticyclonic days increases slightly in the range 3 to 20 days and thereafter shows a marked decrease.

In a comparison test between the use of the geometric series for spells of 3 or more days and the logarithmic series for dry spells, it appears that both series are acceptable to a first degree of approximation and generally satisfy a χ^2 test. Of 21 stations in the south-west of England (see Table I) the logarithmic series was closer than the geometric series in 12 cases, there being 4 cases when the results were of roughly similar accuracy.

An examination of the data for south-west England shows that the logarithmic series tends to over-estimate the number of 3-day spells when the observed number of 1-day spells is high and *vice versa*. This means that in places with a high frequency of showers or intermittent rain, where the frequencies of the shorter spells are increased at the expense of the longer spells, the logarithmic series shows a consistent error. Further, in places which are partly sheltered from this type of rainfall, there is probably also a consistent error, as appears to be the case at Aberdeen[5] which shows a weak persistence effect and therefore does not fit so well into a logarithmic series representation. It may be mentioned here that of the four stations, Greenwich, Aberdeen, Kew and Valentia, examined by Newnham[11], Greenwich and Aberdeen showed only a slight persistence after dry spells of 3–4 days, Kew showed a "levelling" of actual probabilities of continuance of drought after 5, 6 and 7 days (the diagram ending at 8 days) while only Valentia showed a marked persistence in this

TABLE I—COMPARISON TEST

Various stations in south-west England

Period: August 1921–46

	Constants used in calculation of series a^*	r	T^*	P	Type of series	Number of spells in 26 years of length in days equal to 1	2	3	4	5	6	7	8	9	10	>10	Probability of chance occurrence (χ^2 test) %
Ross-on-Wye	...	...	...	...	observed	63	20	9	6	10	5	3	2	2	4	6	...
	22·02	0·863	50·7	...	logarithmic	...	...	14·2	9·2	6·4	4·6	3·4	2·6	2·0	1·5	6·1	0·2–0·3
	...	...	...	0·7874	geometric	...	...	10·0	7·9	6·2	4·8	3·9	3·0	2·4	1·9	6·9	0·5–0·7
Cheltenham	...	...	...	...	observed	49	30	15	12·5	5	5	2	3	1	2	10	...
	22·42	0·874	53·1	...	logarithmic	...	...	14·9	9·7	6·8	5·0	3·7	2·8	2·2	1·7	7·7	0·8–0·9
	...	...	...	0·7715	geometric	...	...	12·7	9·8	7·5	5·8	4·5	3·5	2·7	2·0	7·0	≏0·5
Bishop's Cannings	...	...	...	...	observed	55	22·5	13	11·5	4	3	4	0	2	0·5	10	...
	19·99	0·880	48·2	...	logarithmic	...	...	13·4	8·8	6·2	4·6	3·4	2·7	2·1	1·6	7·9	0·5–0·7
	...	...	...	0·7975	geometric	...	...	9·7	7·8	6·1	4·9	4·0	3·1	2·5	2·0	7·9	≏0·1
Larkhill	...	...	...	...	observed	61	26	13	7	10	4	2	3	3	1	8·5	...
	23·30	0·863	53·6	...	logarithmic	...	...	15·0	9·7	6·7	4·8	3·6	2·7	2·1	1·6	6·7	0·3–0·5
	...	...	...	0·7720	geometric	...	...	11·7	9·1	7·0	5·4	4·2	3·2	2·5	1·9	6·5	≏0·5
Bath	...	...	...	...	observed	69	22	11	10·5	8	1	4	4	1	0	10·5	...
	23·62	0·863	54·3	...	logarithmic	...	...	15·2	9·9	6·8	4·9	3·6	2·7	2·1	1·6	6·7	0·5–0·7
	...	...	...	0·7872	geometric	...	...	10·7	8·3	6·6	5·2	4·1	3·2	2·5	2·0	7·4	0·3–0·5
Bridgwater†	...	...	...	...	observed	54	26·5	16	8	6	4	2	7	0	0	12	...
	21·78	0·880	52·5	...	logarithmic	...	...	14·6	9·7	6·8	5·0	3·8	2·9	2·3	1·8	8·1	0·9–0·95
	...	...	...	0·7843	geometric	...	...	11·9	9·3	7·3	5·7	4·5	3·5	2·8	2·1	7·9	0·5–0·7
Yeovil	...	...	...	...	observed	59	21	14	7	8	4	3	6	1	2	5	...
	22·48	0·857	51·0	...	logarithmic	...	...	14·3	9·2	6·3	4·5	3·3	2·5	1·9	1·5	5·6	0·5–0·7
	...	...	...	0·7597	geometric	...	...	12·0	9·1	7·0	5·2	4·0	3·1	2·3	1·7	5·6	0·7–0·8
Holton Heath‡	...	...	...	...	observed	52	29	17	13	5	7·5	3	2	4	1	8	...
	22·75	0·880	54·8	...	logarithmic	...	...	15·3	10·1	7·1	5·2	3·9	3·0	2·4	1·9	8·4	0·5–0·7
	...	...	...	0·7691	geometric	...	...	14·0	10·8	8·2	6·4	4·8	3·8	2·9	2·2	7·4	0·5–0·7
Weymouth	...	...	...	...	observed	58	24	16	17	6	6·5	1	3·5	2	1·5	8	...
	23·66	0·874	56·1	...	logarithmic	...	...	15·7	10·3	7·2	5·2	3·9	3·0	2·3	1·8	4·4	0·3–0·5
	...	...	...	0·7625	geometric	...	...	14·6	11·2	8·4	6·5	4·9	3·8	2·9	2·2	7·0	0·2–0·3
Barnstaple	...	...	...	...	observed	82	26	16	5	4	5·5	4	1	3	0	3	...
	28·82	0·789	56·6	...	logarithmic	...	...	15·5	9·2	5·8	3·8	2·6	1·8	1·3	0·9	2·7	0·5–0·7
	...	...	...	0·6992	geometric	...	...	12·5	8·7	6·1	4·3	3·0	2·0	1·5	1·0	2·4	0·2–0·3

* for calculating 10-yr. frequencies.
† Period: 1919–44.
‡ Period: 1920–45.

TABLE I—*continued*

	Constants used in calculation of series a*	r	T*	P	Type of series	Number of spells in 26 years of length in days equal to 1	2	3	4	5	6	7	8	9	10	>10	Probability of chance occurrence (χ^2 test) %
Cullompton	...	...	...	...	observed	74	18	15	8	4	6	1	3	2	2	7	...
	24·88	0·841	54·3	...	logarithmic	...	...	15·3	9·6	6·5	4·5	3·3	2·4	1·8	1·4	4·7	0·5–0·7
	...	...	...	0·7612	geometric	...	...	11·5	8·7	6·6	5·1	3·8	3·0	2·2	1·7	5·4	0·3–0·5
Exmouth	...	...	...	...	observed	57	22	15	10	9	5	2	3	1	1·5	9·5	...
	21·63	0·880	52·2	...	logarithmic	...	...	14·5	9·6	6·7	4·9	3·7	2·9	2·2	1·8	8·2	≏0·8
	...	...	...	0·7813	geometric	...	...	12·3	9·5	7·5	5·8	4·6	3·6	2·8	2·1	7·8	0·3–0·5
Plymouth†	...	...	...	...	observed	51	18·5	16	13	8	4	1	5·5	0	0·5	9	...
	20·01	0·874	47·4	...	logarithmic	...	...	13·3	8·7	6·1	4·4	3·3	2·5	2·0	1·5	6·8	≏0·5
	...	...	...	0·7489	geometric	...	...	14·3	10·7	8·1	6·0	4·5	3·3	2·6	1·9	5·6	≏0·5
Princetown‡	...	...	...	...	observed	40	13	10	5	4	4	1	1	1	0	5	...
	20·94	0·848	46·5	...	logarithmic	...	...	9·0	5·7	3·9	2·8	2·0	1·5	1·1	0·9	3·1	0·9–0·95
	...	...	...	0·7417	geometric	...	...	8·0	5·9	4·5	3·2	2·4	1·8	1·3	1·0	2·9	≏0·7
Tavistock	...	...	...	...	observed	74	24·5	9	10	4	4	2	1	1	1·5	6·5	...
	25·38	0·824	53·5	...	logarithmic	...	...	14·9	9·2	6·1	4·2	2·9	2·1	1·6	1·2	3·7	0·1–0·2
	...	...	...	0·7759	geometric	...	...	8·7	6·8	5·3	4·0	3·2	2·5	1·9	1·5	5·1	0·3–0·5
Bude§	...	...	...	...	observed	65	18	17	8	4	5	6	0	1	0·5	6	...
	23·47	0·841	51·3	...	logarithmic	...	...	14·4	9·1	6·1	4·3	3·1	2·3	1·7	1·3	4·4	≏0·7
	...	...	...	0·7474	geometric	...	...	12·0	9·0	6·7	5·0	3·7	2·8	2·1	1·6	4·6	≏0·5
Mere	...	...	...	...	observed	56	19	17	5·5	10	7	3	1·5	1	1	6	...
	22·05	0·856	49·9	...	logarithmic	...	...	14·0	9·0	6·1	4·4	3·2	2·4	1·8	1·4	5·7	0·1–0·2
	...	...	...	0·7400	geometric	...	...	13·5	10·0	7·4	5·5	4·1	3·0	2·2	1·6	4·7	0·2–0·3
Falmouth	...	...	...	...	observed	64	24	17	10	8	4	2	1	1	1	7	...
	19·57	0·874	46·4	...	logarithmic	...	...	13·0	8·5	5·9	4·3	3·2	2·5	1·9	1·5	6·7	0·3–0·5
	...	...	...	0·7316	geometric	...	...	13·7	10·0	7·3	5·4	3·9	2·9	2·1	1·5	4·2	0·3–0·5
Newquay	...	...	...	...	observed	71	23	16	11·5	6	2	1	2	0	1·5	6	...
	25·12	0·824	53·0	...	logarithmic	...	...	14·8	9·1	6·0	4·1	2·9	2·1	1·5	1·1	3·9	0·3–0·5
	...	...	...	0·7161	geometric	...	...	13·1	9·3	6·7	4·8	3·4	2·5	1·8	1·2	3·2	≏0·2
Penzance	...	...	...	...	observed	65	27	14	13	2	5	1	3	1	0·5	9	...
	25·12	0·841	54·9	...	logarithmic	...	...	15·4	9·7	6·5	4·6	3·3	2·4	1·8	1·4	4·9	0·1–0·2
	...	...	...	0·7514	geometric	...	...	12·1	9·0	6·8	5·1	3·9	2·9	2·2	1·6	4·9	0·1–0·2
St. Austell	...	...	...	...	observed	62	25	13	8·5	5	2	1	2	2	1	6	...
	23·07	0·831	49·4	...	logarithmic	...	...	13·8	8·6	5·7	4·0	2·8	2·1	1·5	1·1	3·8	0·5–0·7
	...	...	...	0·7500	geometric	...	...	10·1	7·6	5·7	4·3	3·2	2·4	1·8	1·3	4·1	0·2–0·3

* for calculating 10-yr. frequencies.
† Period: 1916–43, excluding 1929 and 1941.
‡ 18-yr. period: 1929–46.
§ Period: 1920–46, excluding 1924.

range. It is evident that agreement between the logarithmic and observed series is dependent on the locality and the meteorological conditions thereat.

Further series.—A further application of mathematical series to the frequencies of spells is given by Uttinger[13]. He quotes Poisson's pure-chance distribution, in which the frequencies of spells lasting only 1 day, 2 days, 3 days, etc. are the terms of the following exponential series:—

$$Te^{-h}\left(1 + h + \frac{h^2}{2!} + \frac{h^3}{3!} + \ldots\right)$$

where $(h + 1)$ is the average length of spells and T is the total number of spells. If however the law of frequencies is not governed by pure chance the frequencies, following Polya[14], are the successive terms of the series

$$T\,(P_1 + P_2 + P_3 + \ldots + P_m + \ldots),$$

where $P_1 = (1 + d)^{-h/d}$

and $$\frac{P_{m+1}}{P_m} = \frac{h + md}{(m + 1)\,(1 + d)},$$

where m is the length of spell, $d = \sigma^2/h - 1$, and σ is the standard deviation for the distribution of spells according to length.

It should be emphasized that Poisson's exponential distribution requires that the spell or event be infrequent. In Uttinger's application of Polya's distribution, he found that during the period 1901–40 at Lugano, the frequencies of spells of rain, lasting 1 day, 2 days, 3 days, etc. were

767, 487, 287, 159, 99, 58, 43, 22, 10, 6, 7, 2, 2, 0, 1, 0, 1, 1,

and the corresponding values of "observed minus calculated" frequencies were

−17, +21, +8, −9, −2, −3, +6, 0, −3, −2, +2, −1, 0, −1, 0, 0, +1, +1.

The agreement is particularly good for spells lasting more than 4 days, i.e. for events which occur about 2·5 times a year or less frequently.

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STRATOCUMULUS

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EVENING STRATOCUMULUS WITH HIGHER ALTOCUMULUS NEAR SUNSET

CLIMATOLOGICAL OBSERVATIONS AT GREENWICH

By J. G. GLASSPOOLE, Ph.D.

With the transfer of the Royal Observatory, Greenwich to Herstmonceux Castle climatological records ceased at the Observatory at the end of July 1952. Through the interest of the Director of the National Maritime Museum a climatological station was established there by May 1951, so that overlapping records are available for 15 months. The new site at the Museum is about 700 yd. west-north-west of that at the Observatory, nearer the river and at an altitude of 24 ft. — 125 ft. lower than the Observatory site. The differences in the records show some interesting features which are discussed below. It is desirable, however, to wait until longer records are available for the Museum before finally deciding upon the averages to be adopted for this site, and thus defining the differences between the Museum record and that established at the Observatory as long ago as 1841*. The connecting link will need to be a third record, such as those at East Ham or Bromley, when records covering say 5 or 10 yr. have been maintained at the Museum. As the observers took some time to become accustomed to the observational routine the reliability of the comparison increased after a few months, and more reliance is therefore placed on the overlap during the later period.

Rainfall.—The monthly values at the Museum were consistently smaller, being generally about 93 per cent. of those at the Observatory. The comparison is:—

	May–December 1951	January–July 1952	Total
		inches	
Observatory	18·37	9·39	27·76
Museum	17·01	8·71	25·72

The average annual rainfall 1881–1915 at the Observatory is 23·50 in., and the comparison above gives an estimated average for the Museum of 21·8 in. Records taken at the Museum up to the end of 1953, compared with those at other stations with averages in the district, suggest that an annual average of 22·8 in. may be more appropriate. It is clear therefore that longer records at the Museum are necessary before a definite average can be assigned to this record.

Rain-days and wet-days.—The overlapping records suggest that whereas the Observatory had 169 rain-days annually during 1901–30 the corresponding value for the Museum might well be about 163 rain-days. The number of wet-days is apparently about 4 fewer a year at the Museum, but longer and more precise readings are required before final figures can be given.

Dry-bulb temperature at 0900.—Over the whole period the Maritime Museum was warmer by 0·37°F., which is close to the normal altitude correction of 1°F./300 ft. The mean differences during the seasons are set out in Table I. The Maritime Museum was noticeably warmer at 0900 in the autumn and winter but there was little difference in the spring and summer. On individual days the Museum was up to 3°F. warmer during the winter, while the Observatory was up to 3°F. warmer during the summer, when the Observatory would be expected to be out of morning mist and fog earlier.

* BLEASDALE, A.; Climatological observations at Greenwich. *Met. Mag., London*, **80**, 1951, p. 296.

Mean maximum temperature.—The mean differences during the seasons are given in Table I. There were 28 days during the period when the maximum temperature was higher by 3°F. or more at the Museum than the Observatory and 19 when the Observatory was warmer by this amount. Differences of ±5°F. occurred. The Museum gave the higher maxima in the summer, autumn and winter.

Mean minimum temperature.—The mean differences during the seasons are given in Table I. There were 27 days during the period when the minimum temperature was higher at the Observatory by 3°F. or more and 8 when the Museum was warmer by this amount. Differences of as much as 5°F. occurred. Minima higher by 3°F. or more at the Observatory occurred about equally during the winter and summer half years, but minima higher by 3°F. or more at the Museum were recorded only in the winter. The Museum gave the lower minima in the autumn, winter and spring.

Mean temperature.—The mean monthly differences during the seasons are given in Table I. There was very little difference in the mean temperature at the two sites, although the Museum gave greater extremes than the Observatory.

Sunshine.—The mean monthly differences during the seasons are also given in Table I. The Museum was rather sunnier in the spring and summer and about as sunny in the autumn and winter, the differences being small.

TABLE I—SEASONAL DIFFERENCES IN TEMPERATURE AND SUNSHINE BETWEEN GREENWICH OBSERVATORY AND GREENWICH MUSEUM

(Museum minus Observatory)

Period: June 1951–May 1952

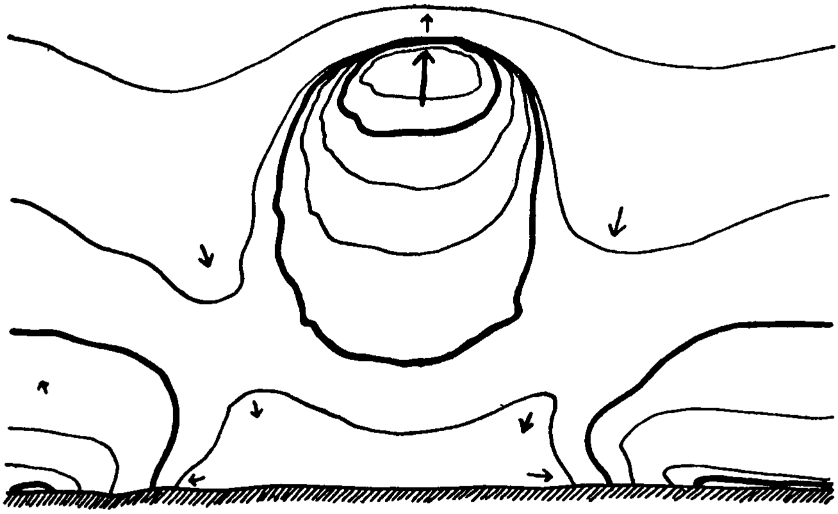
	1951			1952
	Summer	Autumn	Winter	Spring
		degrees Fahrenheit		
Mean temperature at 0900 G.M.T.	+0·1	+0·8	+1·0	0·0
Mean maximum temperature	+0·2	+0·5	+1·2	−0·3
Mean minimum temperature	0·0	−0·6	−0·2	−0·6
Mean temperature [½ (max. + min.)]	+0·1	0·0	+0·5	−0·5
		hours		
Sunshine	+11	−3	0	+8

BUBBLE CONVECTION

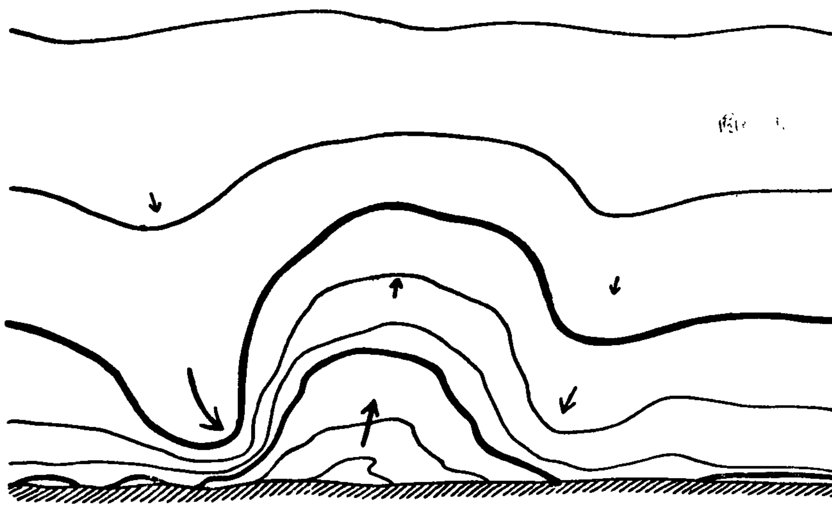
By R. S. SCORER, Ph.D.

Convection in the atmosphere does not always assume the same form. The rate at which the surface temperature changes, the thermal capacity and conductivity of the surface, the water-vapour content of the air, the wind, the shear, the roughness and variety of the surface, and finally the large-scale convergence or divergence, all affect the form it may take. Bubble convection is common over a varied country-side on a sunny day, and it is this kind that we are concerned with here.

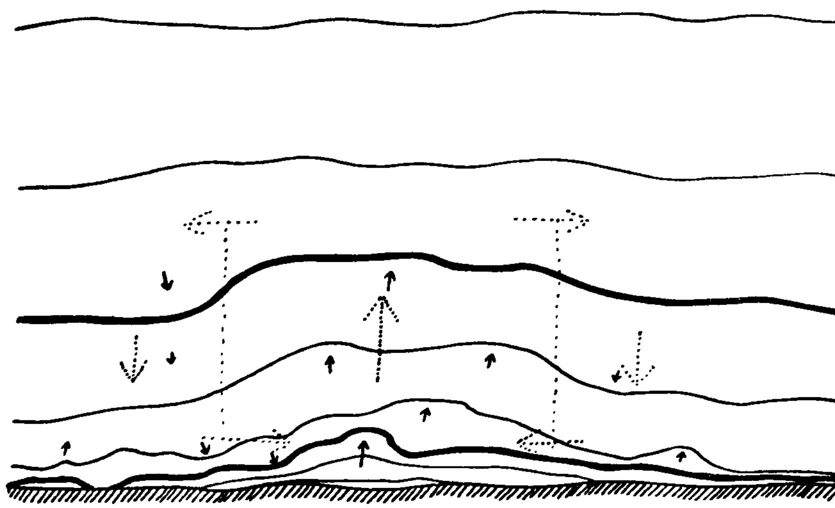
Formation of a bubble.—If a statically unstable layer is formed and it is not horizontally uniform then, in the places where the isotherms bulge upwards and downwards, upward and downward motion begins. This is illustrated in Fig. 1. To begin with, the motion will be somewhat like cellular convection, but soon the cold air descending down the sides of the ascending air cuts off the



(iii) Cold air spreads out over thermal source, bubble becomes detached and forms well defined cap.



(ii) Potentially colder air descends to surface, bubble begins to appear.



(i) Isotherms higher over thermal source, up-motion begins there, organized initially like a convection cell. Depth determines size of bubble.

FIG. 1—RELEASE OF BUBBLE FROM SUPERADIABATIC LAYER

warm air which continues up into the air above. The hottest part of this bubble rises to the top and its boundary forms a sharp discontinuity of temperature at the bubble cap. On the cap and down the sides, the horizontal density gradients cause vorticity to be produced and a turbulent wake is left behind by the bubble. The size of the bubble is determined by the depth of the layer that overturns to form it. The lower boundary of this overturning is usually the ground so that a large bubble is observed only at a greater height.

Erosion of a bubble.—As it ascends, the bubble is gradually eroded away until after ascending one or two diameters the erosion has penetrated to the middle, and all that remains is the wake which is a mixture of the original bubble with the air through which it has ascended. Fig. 2 is a model of the air movement in and around an eroding bubble. The lines outside the wake indicate the

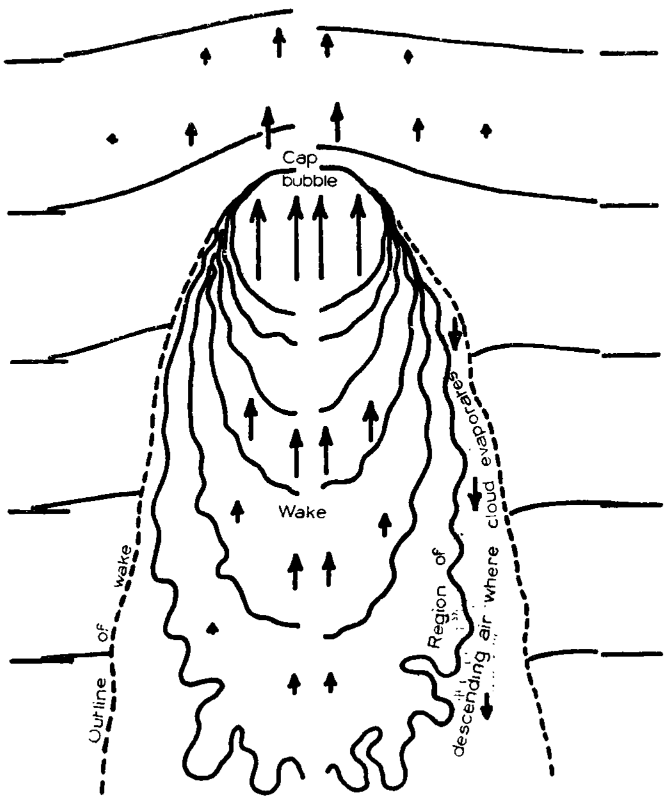


FIG. 2—LONE BUBBLE WITH TURBULENT WAKE

The left-hand half of the diagram refers to a dry bubble, the right-hand half to ascent with condensation, i.e. a cloud bubble.

vertical displacement of the air through which the bubble ascends; their original level is marked at the edge of the diagram. If it is a cloudy bubble ascending through dry air the evaporation of the liquid water in the wake may, and generally does, remove so much heat that the mixture of bubble air and surroundings has a negative buoyancy. The outsides of cumulus towers are therefore seen to be descending.

Growth of large bubbles.—The wake is a region such that if another bubble follows the first soon enough it will not be eroded as quickly as the first because the velocity and temperature differences between the second bubble and the wake of the first are not as great as between the first and the original environment. The second bubble therefore emerges from the top of the wake of the first and builds up a yet larger region in which erosion is less than nearby.

Over places where the supply of heat from the ground is greatest these regions build highest. Every wake is gradually mixed more and more into the environment, and so the effect of the ascent of a few bubbles over a place is to make the isotherms bulge upwards there. The situation is therefore ripe for a deeper layer of air to overturn and form a yet bigger bubble, but this large bubble has a smaller excess temperature because it is formed from the diluted wakes of the small bubbles.

It would be possible for a glider pilot or soaring bird to ascend in one of the small bubbles into the region that a few moments later begins to ascend as a large bubble. This would create the impression, common among glider pilots, that thermals often increase in size as they ascend.

Lapse rate and its effects.—In any dynamical treatment it is necessary to assume that bubbles of all sizes are similar (no reference to actual size has yet been made here). If it is also assumed that the erosion and "form drag" result in bubbles ascending without appreciable acceleration it can be assumed that the velocity of ascent w is determined only by the buoyancy B (defined as the ratio of the difference in density between the bubble and its surroundings to the density of its surroundings) and the size, represented by a linear dimension R. Then it is readily shown (as for example by Malkus and Scorer[1]) that

$$w \propto (gBR)^{\frac{1}{2}}.$$

Following Sutton[2], who assumed that the buoyancy of a convection element was proportional to its size and the excess ε of the average temperature of the layer in which it was formed over the adiabatic lapse rate from the top, if the size of the bubble is proportional to the depth of the overturned layer its buoyancy will be proportional to εR. The vertical velocity will therefore be proportional to $\varepsilon^{\frac{1}{2}}R$. If, at every level, the same fraction of the total area is occupied by up-currents, and if the size of the bubbles mainly responsible for the upward transport of buoyancy is proportional to height, then at height z, the upward transport of buoyancy is proportional to wB, i.e. to $\varepsilon^{3/2}R^2$, i.e. to $\varepsilon^{3/2}z^2$. If, further, the upward transport of buoyancy is constant with height then $\partial\theta/\partial_z \propto z^{-4/3}$ where θ is potential temperature.

The many assumptions made present, admittedly, a very much simplified model of reality but the consequences of different power laws, for instance for the dependence of R upon height, would not affect the result that ε is proportional to a negative power of z. Thus, if the transport of buoyancy through a layer exceeds by far the net transport into the layer (i.e. most of the heat coming in at the bottom goes out at the top) the lapse rate increases greatly towards the ground. This is a condition for the bubbles to be able to become organized into progressively bigger bubbles higher up.

By contrast the down-draughts have their temperature anomaly increased as they descend and they arrive as cold puffs of air at the ground when a large bubble is just leaving. They do not become organized in the process of descent in a manner analogous to the up-currents.

A bubble leaves a wake that is buoyant. The total amount of buoyancy remains the same. Thus $B \propto R^{-3}$ if we regard the wake as a large dilute bubble. In this case, as R increases w decreases. The wakes do not themselves, therefore, constitute the larger bubbles because they have not enough buoyancy. They merely serve to raise the isotherms locally so that the overturning may take place.

Down-draughts on the other hand continuously increase their negative buoyancy as they descend so that an individual down-draught in the super-adiabatic layer may be followed to the ground.

Surface layers.—In order to convey heat from the surface into the lowest layers of air smaller and smaller bubbles could be considered to operate nearer and nearer the surface, with a lapse rate increasing indefinitely towards the surface. In fact various physical properties of the air and of the surface interfere.

When the ground is very hot on a calm sunny day—perhaps it may be 20–30°C. warmer than the air 10 cm. above it—radiation absorption in the lowest 1–3 m. (in those wave-lengths in which it is absorbed at all in the atmosphere) plays a large part in the heat transfer.

The eddies produced mechanically by the wind blowing over roughnesses of the surface convey heat down the gradient of potential temperature and reduce the high lapse rates that would otherwise be built up in the lowest layers. Since these are almost impossible to distinguish from bubbles it is probably only possible to recognize their effect by their size spectrum and how it varies with height, and by how the lapse rate is changed from the calm-air lapse rate.

Over "hot spots", such as bare stone surrounded by grass, there may be converging jets of the kind described by Scorer and Ludlam[3]. These eventually break up into bubbles at a height of perhaps 5–10 m., according to the size and intensity of the hot spot and the calmness of the air.

The term "surface layers" therefore means the layers at the ground in which other mechanisms than the bubble mechanism are operating to an appreciable extent.

Tectonic limit.—When the bubbles have reached a size such that they are capable of effecting the heat transport with no further increase the lapse rate from here upwards will be neutral. This limit, beyond which no building occurs, is called the tectonic limit. From here upwards the main feature of the convection is the erosion of bubbles and the infusion of their wakes into the whole air mass which is thereby warmed. From here upwards warming of the air mass dominates the conveying of heat to higher levels through the air. The tectonic limit will vary from place to place and time to time and will be higher over good thermal sources.

Cloud layer.—At the condensation level a new source of instability appears. Because the lapse rate exceeds the saturated-adiabatic value but is less than the dry-adiabatic one, clouds are a region of instability and therefore of overturning and bubble formation. These bubbles emerge from the cloud tops and, if followed soon enough by others, will extend the clouds upwards to form yet bigger bubbles.

Some bubbles may reach the condensation level without having been completely eroded in the adiabatic layer and will appear as ready-made cloud bubbles. The upward extension of clouds is generally limited by the erosion exceeding the supply of buoyant air through the base, though bubbles may spread out into stratocumulus at a stable layer, or the evaporation may cease if the droplets freeze.

TABLE I—BUBBLE CONVECTION OVER LAND

Layer	Processes	Typical heights* ft.
CLOUD LAYER Dry Stable / Wet Unstable	Spreading out of bubbles into stratocumulus at stable layers Continuous erosion of clouds and solitary bubbles Clouds built upwards by supply of bubbles exceeding erosion Clouds are unstable regions for wet ascent so that bubbles are formed within them and emerge from the tops False cirrus remains while water cloud evaporates Marked sink in evaporating parts of clouds Shear and low humidity destroy bubble wakes and prevent growth of clouds upwards Sinking motion between clouds warms the air without thermals being mixed into it	
CLOUD BASE		3,000
SUB-CLOUD LAYER Stable	Sinking of potentially warmer air into layer below cloud base forms a stable layer. This is most pronounced if no general convergence takes place With a pronounced sub-cloud layer vertical velocities decrease towards cloud base. Bubbles flatten out and lose sharp edges. All cloud bubbles are formed within clouds With a feeble sub-cloud layer many bubbles reach cloud base before complete erosion and fresh small cumulus appear, especially over good thermal sources	
		2,700
ADIABATIC LAYER Neutral	Mainly large sharp-edged bubbles emerge from superadiabatic layer. As they are eroded their wakes diffuse buoyancy into the layer, some transport heat out of the top of the layer	
TECTONIC LIMIT	At this level bubbles are big enough to transport the heat with no further increase in size	1,500
SUPERADIABATIC LAYER Unstable	Lapse rate decreases upwards Temperature fluctuations decrease upwards Bubble wakes very turbulent because whole mass is unstable Newly formed bubbles are sharp edged. Larger ones found higher up because a deeper layer overturns to form them Transport of buoyancy through this layer dominates diffusion of buoyancy into it	
		100
SURFACE LAYERS	Radiation transfers heat from the hot ground into the lowest 1–3 m. Converging jets ascend off hot spots, in calm air; they break up into bubbles at 5–10 m. Mechanical eddies, due to wind, not distinguishable from small bubbles except that they reduce the lapse rate close to the ground (this means that puffs of cold air from above are less evident at the ground)	
HEAT SOURCE		0

*These heights may vary within wide limits.

Sub-cloud layer*.—The clouds warm part of the air mass by direct infusion, but since the mass as a whole is stable the slow sinking, in the dry air, which may be present warms the remainder. If these downward motions are present they may extend down below the cloud base. Thus, between the cloudy areas, potentially warmer air sinks into the adiabatic layer forming a stable sub-cloud layer. This spreads horizontally under the influence of gravity into the cloudy areas where the static stability is partly destroyed by the upward motion and the warming from below. Bubbles arriving at this layer, which may extend to 300 or 400 ft. below the cloud base, lose the sharpness of their caps, spread horizontally, and lose vertical velocity. Accordingly soaring pilots find the up-currents decreasing markedly as the cloud base is approached. This layer may be completely absent if there is general convergence taking place so that no down-motions are present to compensate for the thermals.

These ideas are summarized in Table I, which is intended to describe bubble convection over land. Many other considerations are necessary over the sea or over the hot sandy desert, and these have been briefly discussed by Ludlam and Scorer[5].

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METEOROLOGICAL OFFICE DISCUSSION

Investigations of cumuliform cloud

The discussion on March 15, 1954 dealt with the use of the aircraft of the Meteorological Research Flight for the investigation of cumuliform clouds. Mr. R. J. Murgatroyd was the opening speaker. His general review of this subject included descriptions of instruments used for investigation of the wind, temperature and humidity fields below and around clouds as well as those for measuring the main cloud parameters such as up-currents, water content, temperature and particle sizes. Results of recent experiments were shown, and the mechanisms of shower production were discussed briefly. The main sections of this review are given below.

General considerations in the use of aircraft for cumuliform-cloud research.—In this country large cumulus clouds are often 10–15 miles across and are usually composed of several cells about 3 miles wide. A modern aircraft traverses a single cell in about a minute. Each cell has a fine structure and is very chaotic and turbulent, and usually has an effective life cycle of about 20–30 min. Any experiment designed to investigate the life cycle of a cloud must therefore be completed quickly, and it is found that only 5 or 6 successive traverses at a given level can be made through a cell before it dissipates. Successive traverses at different levels are not so profitable as they involve extra time for manoeuvres and lead to difficulties of both time and space variations in the analysis of the results. The use of several different aircraft

* This term has been used in America to refer to the whole layer between the cloud base and the surface. Here we follow a later usage by Ludlam[4].

simultaneously at different levels would mean a very large effort in manpower and instrumentation.

The requirements for aircraft instruments in this work are that they should have very little lag but at the same time should be sturdy. These are usually opposite requirements. It would be a great advantage for all the instruments which are used to have the same lag. Continuous-recording apparatus or photography of instrument dials should be used, and visual comments by observers should preferably be recorded on tape.

At present most of the work of the Meteorological Research Flight on this subject is instrumental, but, with improvement of instrumentation, the data obtained and analysis required increase enormously. The actual flying time represents only a very small proportion of the effort that is expended.

Clear-air investigations around and below cumuliform clouds.—The object of this part of the work is to investigate the nature of the vertical transfer of heat and moisture from the surface up to the cloud and the interaction of the cloud with its environment.

The instruments available for this purpose are:—

(i) the ultra rapid thermometer[1] which consists of an element of fine platinum wires which can be retracted into the aircraft for protection when not in use and which gives continuous recordings of temperature with a lag of a few milliseconds

(ii) hot-wire anemometers[2] which also have very small lags and give continuous traces of total wind and its vertical component at frequencies where the aircraft can be regarded as a steady platform

(iii) automatic hygrometers[3] which have been further developed by Dr. Brewer and also adapted to give a continuous record of dew or frost point with a lag of a few seconds

(iv) aircraft recording accelerometers.

The picture obtained from flights below cumulus cloud with these instruments is as follows:—

From the surface up to about 1,000 ft. over land the lapse rate is super-adiabatic and decreases with height. In this region there are many rising pulses or bubbles and bumpiness is continuous. These bubbles vary considerably in diameter with an average of about 500 ft. They have a temperature excess over their environment of 1–2°F., a dew-point excess of 5–7°F., and rise at about 10 ft./sec. Both excess temperature and excess humidity contribute to buoyancy but may not occur at the same time. The bubbles are sharp-edged implying that there is little mixing between them and their surroundings.

At about 1,000 ft. this régime changes rather quickly into that of a layer with a dry-adiabatic lapse rate, sporadic burst or showers of bubbles rising at 5–8 ft./sec., and long undisturbed intervals. The mean diameter of the bubbles is about 600 ft. and varies little with height, while the temperature and dew-point excesses are respectively about 0·3°F. and 4°F. The vertical gusts are not as sharp-edged as in the bottom layer but horizontal gusts are frequent.

At 200–400 ft. from the cloud base the lapse rate becomes essentially stable. This region becomes more marked in the afternoon as the convection proceeds. Rising bubbles are infrequent, their speed of ascent is very slow, and their temperature and dew-point excesses smaller than below. Bumpiness is somewhat greater and there are fewer quiet periods. A marked feature is that long-wave (5,000–10,000 ft.) variations of temperature (of amplitude up to 2°F.) and vertical motion are also found. This layer has been noted also by Bunker, Haurwitz, Malkus and Stommel[4] and also explains why glider pilots often find it difficult to ascend into the base of a cumuliform cloud.

The broad subdivision into these three layers is not evident over the sea where there is usually a gradual decrease of turbulence upwards, the general level being much lower than over land. The stable layer just below the cloud, however, is often found.

So far the information on the clear-air region around clouds is sparse. It is a region of mainly slow down-draughts although occasional rising positive pulses have been noticed. The main interest here is the extent of lateral inflow or entrainment into the sides of clouds. This might very well be expected at least in the lower parts of the cloud where up-currents are accelerating and the vertical mass transfer probably exceeds the supply into the cloud base. Some data have been given on this subject by Byers and Hull[5] and Warner and Bowen[6]. The Meteorological Research Flight, in conjunction with the radar station at East Hill, are also attempting measurements by dropping "window"* around the cloud and measuring its subsequent motion by radar. Results so far are inconclusive but work is continuing.

Negative temperature pulses caused by the overlying air being pushed out of the way as the warm air ascends, have been noted when flying over a developing cloud.

Investigations within cumuliform clouds.—*Vertical currents.*—Up- and down-draughts have been measured by noting altitude changes over given time intervals when the aircraft was flying at constant power setting and attitude. This is the method given in "The thunderstorm"[7], and its limitations and attempts to correct for attitude and airspeed changes were outlined by Mr. Murgatroyd. Another method depending on the integration of accelerometer records[8] was discussed.

The results of these measurements show that up-draughts usually consist of a generally ascending mass with some portions rising faster than others. For instance, an up-draught 1½ miles wide may have two or three main sections ½–¾ mile across. These may or may not keep their identity with time and could be regarded as a loose assembly of separate bubbles. Many variations have been noted—sometimes the vertical currents in the cloud are almost entirely upwards sometimes nearly all downwards, and frequently strong up-currents and down-currents may be adjacent in the same cloud.

Vertical currents are usually in the range of 10–20 ft./sec. in cumulus of moderate size, but values up to 40 or 50 ft./sec. have been noted in cumulonimbus in this country. Considerably higher values have been reported elsewhere[7].

Highest values of vertical currents and turbulence are usually found between the middle and three-quarters of the height of the cloud.

Turbulence.—In a Hastings aircraft bumps of $0 \cdot 3g$, as measured by a recording accelerometer, are frequent in large cumuliform clouds, $0 \cdot 5g$ has often been recorded, and $0 \cdot 7g$ was obtained on one occasion in a recent flight.

* The term "window" is a war-time code-word applied to thin metallic strips which produce a radar echo.

Temperature.—It would be very convenient for buoyancy calculations if the temperature difference between the cloud and its surroundings could be measured accurately. Difficulties arise in this on account of kinetic-heating effects, evaporation on the thermometer surface, the necessity of correcting from the vertical movement of the aircraft to a datum level in terms of the lapse rate in the cloud, and the effects of different lags of the airspeed indicator, altimeter, and thermometer on the corrections which have to be applied. The most promising thermometers for this work are vortex thermometers[9,10]. In speed runs in warm stratocumulus clouds both axial and tangential types give readings reasonably independent of airspeed. Icing conditions, however, affect their performance and attempts are being made to produce a de-iced instrument. Other possibilities for this work are the use of sonic thermometers or radiation instruments.

Mr. Murgatroyd suggested that a rough empirical rule relating up-current and temperature excess is $w \simeq 14\sqrt{\Delta T}$, where w is the up-current speed in feet per second and ΔT is the virtual-temperature difference (in degrees Fahrenheit) between the environment curve and the saturated adiabatic curve at any level corrected for the effect of weight of condensed water. It was emphasized that this has been obtained from only a few cases with a large scatter and may give values of w that are too low for large values of ΔT.

Water content.—There are many possible methods of measuring water content[11], and those employed by the Meteorological Research Flight include the use of hot-wire instruments and ice-accretion types. Mr. Murgatroyd showed slides of hot-wire types in which one element is wetted by the cloud and the other is dry but in a similar air stream as regards temperature and wind. A rotating-disc icing meter in which a feeler measures ice accretion during each revolution of a thin disc was also described. This particular instrument has its disc refrigerated to overcome heating by latent-heat effects[12]. These instruments are developed in co-operation with the Icing Research Section of the Royal Aircraft Establishment, Farnborough.

The theoretical water content of a cumulus cloud can be calculated by subtracting the saturation specific humidity at the level in question from that at the base of the cloud, the assumption being that all the condensed water is carried up in the up-draught. The result is usually converted to grams per cubic metre, and it was shown that, with high cloud-base temperatures, water contents up to 7 gm./m.^{3} can be realized, whereas only about 2 gm./m.^{3} can be realized when the cloud-base temperature is low. Very few instruments have been made so far which are capable of measuring more than about 2 gm./m.^{3} and the lack of measurements of higher values has led to some doubt whether they exist. If not, a good deal of entrainment would be necessary to explain the dilution.

The measurements of water content made by the Meteorological Research Flight have attained the theoretical value in cold-base clouds and the meters have gone off the scale for considerable periods in the warmer-base clouds. By calculating the percentage of the theoretical value at different parts of a number of traverses and combining them into a non-dimensional model cloud, it was argued that during the growing stage the theoretical value is likely to be attained in a central core up to about 70 per cent. of the total cloud height and covering about one-quarter of its width. Dilution is uniformly greater from this core towards the sides and tops. One result of this is that entrainment ideas based on the assumption of uniform mixing across a cloud cannot be validly applied to cloud-growth calculations. If this model is re-applied to a large summer cloud over England, maximum water contents up to 5 gm./m.^{3} should be common in the top part of the central core during the last 5 min. or so of the growing stage before precipitation commences. The water-content distributions in these clouds are very similar in form to those shown by Zaitsev[13].

Cloud particles.—A knowledge of cloud-particle development is fundamental to the understanding of the rainfall mechanism. Measurement techniques are complicated because of the necessity to deal with size ranges from droplets and crystals to raindrops, snow-flakes and hail. The larger particles present the most difficulty on account of the force of their impact with the measuring apparatus and the likelihood that it will cause them to break up. Reference was made, by Mr. Murgatroyd, in this connexion to sooted screens, raindrop microphones, raindrop cameras and light-scattering systems. In the range of small particles impaction methods using magnesium oxide and oil collectors were described. The Meteorological Research Flight is at present using the oil system exclusively, utilizing a six-cylinder pneumatic impactor and micro-photography of the samples in flight. It has been demonstrated recently by Mr. G. Abel of the Civil-Aircraft Test Group at Boscombe Down, that this system can be used to catch ice crystals and also that, in mixed cloud, by photographing a mixture of crystals and water drops, allowing the crystals to melt and re-photographing the sample, it is possible to determine the relative proportions of the two constituents. Attempts have also been made to obtain crystal samples in cloud by a replica method due to Schaefer[14].

The information obtained on cloud-droplet sizes was outlined by Mr. Murgatroyd.

Near the cloud base, droplet diameters are usually less than 10μ but occasionally up to 25μ is found. The number of droplets is between 200 and 600 per cubic centimetre and varies from day to day presumably with the condensation nuclei available.

By about 300 ft. above the cloud base most of the condensation on nuclei will have taken place, and from then upwards, the further condensation will be on droplets already formed. The number of droplets per cubic centimetre then decreases with height due to coalescence.

The mean volume diameter of the droplets doubles itself within the first 4,000–5,000 ft. and the number and size of large droplets increases with height. By about 1,000 ft. above the cloud base drops 50μ diameter are found, and at medium heights below the freezing level drops with diameters of 100μ or even 200μ are often found. These are probably associated with giant salt nuclei and the fact that usually the air over the British Isles has had a recent maritime track[15].

Shower production.—The Bergeron mechanism and the coalescence mechanism by which cloud droplets with a diameter of a few microns could be converted to raindrops of diameter of a few millimetres were outlined by the speaker. Evidence was given that the latter mechanism is much more important than has been commonly supposed in our rainfall. It was shown from observations made by the Meteorological Research Flight that ice crystals may usually be expected in cumulus-cloud tops not seeded from above at temperatures below about 0°F. and droplets above 10°F. These results are in line with other icing studies[16,17,18] and figures given by Ludlam[19] showing the relative frequencies of reports of cumulus and cumulonimbus tops in various temperature groups in a study of war-time reconnaisance flights.

On the other hand observations by Petterssen and others[20] showed that a 50 per cent. probability of rainfall existed in England in convective clouds with temperatures of 20°F. at the cloud tops and also with a cloud thickness of about 7,000 ft. It was suggested, therefore, that this higher temperature for rainfall production compared to that required for the phase change to ice crystals indicated that a good deal of convective rainfall in England may be due to coalescence. Applying these figures to the Larkhill average upper air temperature, zones of convective-cloud heights, in which the two different rainfall mechanisms were likely to be separately more important, were suggested. These gave good agreement with the theoretical results of Ludlam[19,21]. Rainfall from clouds entirely below the freezing level is occasionally possible in summer in the British Isles.

If these arguments are correct the possibility of artificial stimulation of rainfall here is considerably affected because rainfall may be produced in many cases by means of the coalescence mechanism alone, and any attempt to accelerate the Bergeron process, e.g. by the use of solid carbon dioxide or silver iodide, would not then necessarily produce more precipitation or even advance its appearance. Also, if the coalescence mechanism is operating reasonably efficiently, methods based on inducing coalescence, e.g. by salt nuclei or water droplets, may be largely redundant.

Other data were also presented by Mr. Murgatroyd suggesting the importance of the coalescence mechanism, including a flight example in which precipitation, clear icing and a radar echo were present in a cloud with hard tops several minutes before any crystals were first sampled. These ideas are in agreement with those expressed by Battan[22].

Conclusion.—In conclusion Mr. Murgatroyd said that work was continuing at the Meteorological Research Flight on the above lines, and from it and the work of the various collaborators and other agencies in this field there was hope for further progress. However, in both cumuliform and layer clouds the difficulty in applying any cloud-physics results to forecasting, was that of knowing the height of low-cloud tops and the distribution of medium and high clouds. In his opinion a good deal of effort was now called for in this border-line area between synoptic meteorology and cloud physics.

Dr. Scorer then presented a short paper on bubble convection which is reproduced in this issue.

Mr. Veryard thought that the type of convection described was only applicable to conditions similar to those found in the British Isles. Sand devils for instance could not be described by a bubble mechanism. He also asked for more information on the life-cycle time of cumulus clouds. Dr. Scorer agreed that over desert surfaces with small thermal capacity, bubble building of the form described would not occur. Mr. Murgatroyd said that the figure of 20–30 min. for a life-cycle was based on observations made by the Meteorological Research Flight. The mean value given in the American thunderstorm report[7] was 23 min.

Mr. Ludlam referred to the difficulty of predicting the height of cumulus-cloud tops and considered that arrangements should be made for the routine collection and dissemination of cloud observations by aircraft over this country. With regard to the question of forecasting showers the depth of cloud was of first importance, and a case in the joint field work between Imperial College and the Meteorological Research Flight at Cranfield in August 1951 was recalled, in which showers occurred when the cloud depth was 6,000 ft. but not when it was 5,000 ft. on an apparently similar day.

The Director envisaged difficulties in cloud reports in plain language and thought a simple code would be necessary. He wondered whether, in practice, reports of cloud location, height and type from aircrew would be of sufficient accuracy for current forecasting use. Referring to the general scope of the discussion he remarked that other investigations on the subject of convection in the atmosphere were at present also being carried out in this country, including work on the mathematical theory, and laboratory investigations at the Military College of Science, Shrivenham and the Cavendish Laboratory, Cambridge. He hoped it would soon prove possible to link these up with the investigations in the atmosphere itself.

Gp Capt. Hughes welcomed the idea of the introduction of a simple code for general aircraft reports of cloud tops and considered routine reports of this type would be invaluable if they were disseminated rapidly and made available to all forecasting officers in this country. He also suggested that in addition to the cumulus-clouds investigations in the British Isles and the Thunderstorm Project in the United States[7], data were also needed for different parts of the Commonwealth, and there was a need for this type of work to be carried out at various overseas locations.

Wg Cmdr Finch agreed with the view that cloud data reported from aircraft are extremely valuable and stressed that on account of the great speed of modern aircraft VHF channels must be used for passing back reports. It would be desirable for the pilots to pass them in plain language and for any coding to be done on the ground.

Dr. Farquharson confirmed that aircraft reports of cloud tops are very useful in general forecasting work within the Meteorological Office. Both he and *Mr. Peters* agreed, however, that owing to the large volume of teleprinter traffic it would be difficult to disseminate all the reports that could be received and that there would have to be a good deal more traffic selection at the Central Forecasting Office to satisfy the needs of all recipients with regard to the transmission space available.

Mr. Durward inquired what were the prospects of fitting the various research instruments described, such as icing meters, water-content meters, vortex thermometers and accelerometers, on commercial aircraft to accumulate statistical data.

Mr. Rendel said that this type of work was being done to some extent both in this country and in the United States of America. Some of the instruments could be and were being used in this way, such as accelerometers, hot-wire icing detectors, and modified versions of the Smith's icing detector. Others presented more difficulties depending on their stage of development. Vortex thermometers at present are considered to be too bulky and too unreliable in icing conditions for this purpose.

Dr. James gave more details of the nature of the convection process over land and over sea which he hoped to describe in a report in the near future.

Mr. Durbin described the next stages of instrument recording projected by the Meteorological Research Flight.

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ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on February 17, 1954, a Vice-President, Prof. P. A. Sheppard, in the Chair, the papers read were:—

*Gibbs, W. J.—A comparison of hemispheric circulations with particular reference to the western Pacific**

Mr. Gibbs's paper was read by Mr. J. M. Craddock. The paper discusses the distribution of high-pressure and low-pressure centres in the two hemispheres in January and July 1949, the variation with latitude of the frequency and intensity of high- and low-pressure centres, and vertical cross-sections of temperature and the mean zonal winds. The distribution of high-pressure and low-pressure centres is much more symmetrical round the pole in the southern

Quart. J. R. met. Soc., London*, **79, 1953, p. 121.

than in the northern hemisphere and the centres occur on the whole within a narrower band of latitude in the southern hemisphere. The vertical cross-sections show stronger zonal upper winds in the "winter" hemisphere and an appreciably stronger maximum of the mean zonal wind (at about 200 mb. in lat. 30°) in the northern hemisphere in January than in the southern hemisphere in July.

*Smagorinsky, J.—The dynamical influence of large-scale heat sources and sinks on the quasi-stationary mean motions of the atmosphere**

Dr. Smagorinsky's paper is on the dynamical theory of disturbances of the zonal air flow across cold continents and warm oceans. The air tends to move north and ascend over the cold parts of the track and move south and descend over the warm parts. His theory provides a more rational explanation of the distribution of mean high-pressure and low-pressure centres such as the Siberian high in relation to the temperature distribution over the northern hemisphere in winter.

Smith, C. V. and Forsdyke, A. G.—Some down-stream effects associated with large-amplitude troughs in upper flow patterns†

Mr. Smith and Dr. Forsdyke are concerned with forecasting for four days ahead and with the suggestion that the formation over North America of a trough of low pressure at the 500-mb. level is followed by the formation of troughs to the east over the Atlantic which might be important for the weather over Britain. From a statistical examination they found that it was only when the primary trough lasted for over two days that a trough was likely to form over the Atlantic, and that the more persistent the primary trough the more likely the formation of the down-stream one. The paper was followed by a lively discussion, in which Professor Rossby took part on the possibilities of numerical forecasting.

At the meeting of the Society on March, 17, 1954, the President, Dr. O. G. Sutton, in the Chair, the following papers were read:—

Goody, R. M. and Walshaw, C. D.—The origin of atmospheric nitrous oxide‡

Dr. Goody had measured the mixing ratio of nitrous oxide between 3 and 8 Km. from observations of the absorption of solar radiation by nitrous oxide. The measurements show the mixing ratio is constant, and from its value the total destruction rate of nitrous oxide by photo-chemical dissociation can be calculated. The destruction rate agrees to the right order of magnitude with the rate of release of nitrous oxide to the air from the soil as measured by Dr. P. Arnold of the Cavendish Laboratory. The work confirms the hypothesis of Dr. A. Adel (Arizona) the discoverer of the existence of nitrous oxide in the atmosphere.

Scorer, R. S.—The nature of convection as revealed by soaring birds and dragonflies§

Dr. Scorer took the observations of the flight of large soaring birds and of dragon-flies and related them to the theory of convection bubbles suggested by himself and Mr. Ludlam. The birds show that convection develops upwards

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Quart. J. R. met. Soc., London,* **79, 1953, p. 342.
†*Quart. J. R. met. Soc., London,* **79**, 1953, p. 414.
‡*Quart. J. R. met. Soc., London,* **79**, 1953, p. 496.
§*Quart. J. R. met. Soc., London,* **80**, 1954, p. 68.

[To face p. 216

ALTOCUMULUS CASTELLATUS FROM 18,400 FT.

This photograph was taken at 0730 G.M.T. in about 37°N.13°W. from a meteorological reconnaissance aircraft on its return journey to Gibraltar.

(see p. 219)

To face p. 217]

STRATOCUMULUS OFF CAPE ST. VINCENT
(see p. 219)

as the heavier birds, which soar to the greatest heights, take to the air after the lighter ones. As a convection bubble leaves the lowest layers and birds begin soaring in it it is replaced by a puff of cold air in which dragon-flies, which ascend only a few metres, are unable to soar. The air flowing in towards a thunderstorm was very favourable for soaring, whereas the colder outspreading air dragged down by the rain was unfavourable. In the discussion reference was made to the importance of thermal convection in the migration of locusts, and glider pilots described their observations of birds soaring in the same thermal current as themselves.

Symons Memorial Lecture

At a meeting of the Royal Meteorological Society on April 7, 1954, the President, Dr. O. G. Sutton, in the Chair, Dr. G. K. Batchelor delivered the Symons Memorial Lecture on heat convection and buoyancy effects in fluids.

Dr. Batchelor began by stating that there had been little fundamental research so far into free convection. In convection the distribution of velocity and temperature were interdependent in the sense that the temperature distribution was modified as soon as motion began. Consequently mathematical analysis was difficult and few exact solutions were known; it was necessary to seek aid from experimental evidence rather than rely exclusively on mathematical theory. The main theoretical weapons were dimensional analysis and dynamical similarity.

After a mathematical description of some of the variables and parameters in use, such as the Reynolds number, Prandtl number, Rayleigh number, Nusselt number, and Richardson number, Dr. Batchelor discussed a number of specific problems. The first was that of a maintained point source of heat in a fluid of constant temperature, such as that of the smoke or plume rising from a cigarette-end which becomes turbulent at a distance of 1–2 ft. from the source. Such a plume was found to be conical (semi-vertical angle about 11°) with mean sideways inflow or entrainment.

An extension of this problem to a maintained line source of heat gave a similar plume (wedge-shaped) with a semi-vertical angle about 14°. An application of this was the two line sources of heat used in the artificial dispersal of fog over an airfield (FIDO). In this the plumes do not act singly because of the limited quantity of air between the sources; and, except quite close to the ground, the plumes unite to form a single plume which appears to come from a line source midway between the two actual line sources. With a cross-wind the plume is only slightly disturbed from the vertical unless the cross-wind exceeds the entrainment speed when the plume lies down-wind along the ground.

A most important problem, meteorologically, for which no laboratory experiments are available, was that of a maintained point source in stratified air. If the air is unstable the plume accelerates, but if stable there is a distinct limit to the height of the plume. In order that the flux of heat shall be finite (in an unstable fluid) theory leads directly to a zero value of heat flux, which means that the development of a convective plume in unstable air does not need a point source. In other words, a plume could begin at any point in an unstable fluid provided there is some slight initial disturbance.

Dr. Batchelor went on to describe the motion, found by dimensional arguments, of an instantaneous point source in stable and unstable atmospheres;

in an unstable atmosphere the motion was the same as that of a maintained point source (where flux of heat is zero), and therefore can be applied to conditions over the sea where there are no discrete sources.

Analysis of motion in fluids caused by sources of heat distributed over large areas brought out the importance of the Rayleigh number. Between two horizontal plates, maintained at different temperatures, when the Rayleigh number begins to exceed 50,000 the motion begins to change from laminar to turbulent; between 50,000 and 10^6 many different modes resembling the Bénard-cell type of motion are possible but no one steady state is possible; when the Rayleigh number exceeds 10^6 individual elements can become turbulent before reaching the upper boundary. The problem of one heated horizontal boundary was very difficult since no steady state is reached in a finite time, although after a time a quasi-steady state of thermal convection is reached. Experimental evidence (Dr. Batchelor's illustration was a photograph of steam rising from a heated plate) showed random convective bubbles moving with the wind; movement occurred at values of the Rayleigh number below that calculated as necessary for bubble convection. Single plumes occurred because they do not need a finite source but, when formed, they can have an independent existence and can move about.

In conclusion, Dr. Batchelor stressed that dimensional analysis based on singularity methods can provide useful solutions and that it was possible to conduct experiments to verify the solutions.

ROYAL SOCIETY OF ARTS

Meteorological Office and the Commonwealth

On April 8, 1954, the Director of the Meteorological Office, Dr. O. G. Sutton, read a paper to the Royal Society of Arts on the Meteorological Office and the Commonwealth.

He pointed out in particular that for the planning of air routes and the provision of meteorological information to aircraft close collaboration between the meteorological services of the Commonwealth countries was essential. The United Kingdom meteorological service at the end of the war maintained offices in many Commonwealth countries. To effect a smooth transition to peacetime requirements United Kingdom staff continued to be loaned until locally or other recruited staff could be trained to take over the work. The British Caribbean meteorological service is still almost wholly manned by forecasters on loan from the Meteorological Office. Many of the locally recruited staff of Commonwealth services have also received training at the Meteorological Office Training School. Besides assistance with staff the Meteorological Office has also lent or given advice about instruments for the measurement of upper air conditions, such as radar wind-measuring sets and facsimile equipment for the transmission of meteorological charts.

The Director's address will be published in full in the *Journal of the Royal Society of Arts.*

ADDENDUM

To the record, in the October 1953 number of the *Meteorological Magazine*, of the career of Sir Nelson K. Johnson should be added his Vice-Presidency in 1939 and 1940 of the Royal Meteorological Society.

NOTES AND NEWS

Altocumulus castellatus from above

The photograph facing p. 216 shows altocumulus castellatus as observed from a Halifax aircraft on meteorological reconnaissance from Gibraltar on June 8, 1944. The aircraft was at a height of 18,400 ft. about 350 nautical miles from Gibraltar in the direction of 280° true. Immediately after the photograph was taken the aircraft began its descent to near sea level through the cloud, temperature and other observations being made as it did so. These observations are recorded in the tephigram in Fig. 1, the details of cloud, as they appeared to the observer at the time, being indicated at the appropriate levels to the right of the temperature curve.

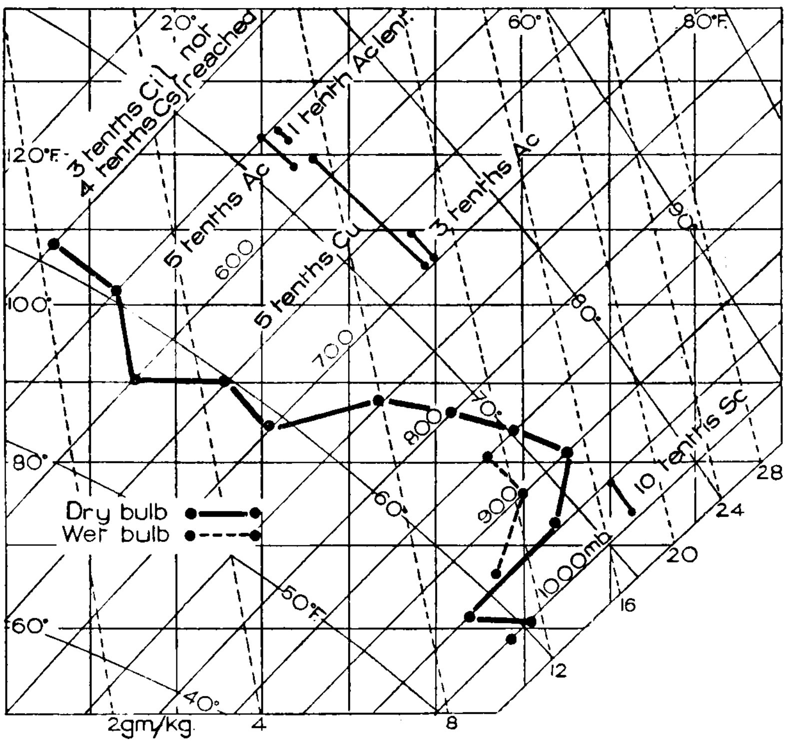

FIG. 1—TEPHIGRAM OF TEMPERATURE OBSERVATIONS MADE BY AIRCRAFT IN DESCENT THROUGH ALTOCUMULUS CASTELLATUS

The surface chart at the time of observation showed a low-pressure area over Portugal sandwiched between a shallow high over the Bay of Biscay and a ridge extending north-eastwards from the Azores. It is probable that some of the air in which the cloud was formed had been over the Iberian peninsula a day or two earlier.

Stratocumulus cloud off Cape St. Vincent

The stratocumulus cloud shown in the photographs facing p. 217 was seen from a Catalina flying boat on meteorological reconnaissance from Gibraltar on July 26, 1944. The aircraft was flying on a course of 280° in warm air drifting southwards ahead of a cold front moving from the north-west. Whilst in the lee of the Portuguese coast the air was free from cloud and there was not more than a tenth of cumulus or stratocumulus near Gibraltar, in air over the open ocean there was this almost complete covering of stratocumulus. The cloud had a sharp edge running north–south off Cape St. Vincent.

The cold front, which was giving a narrow belt of rain was met some 150 nautical miles further west. Details of the flight are shown in the cross-section illustrated in Fig. 1.

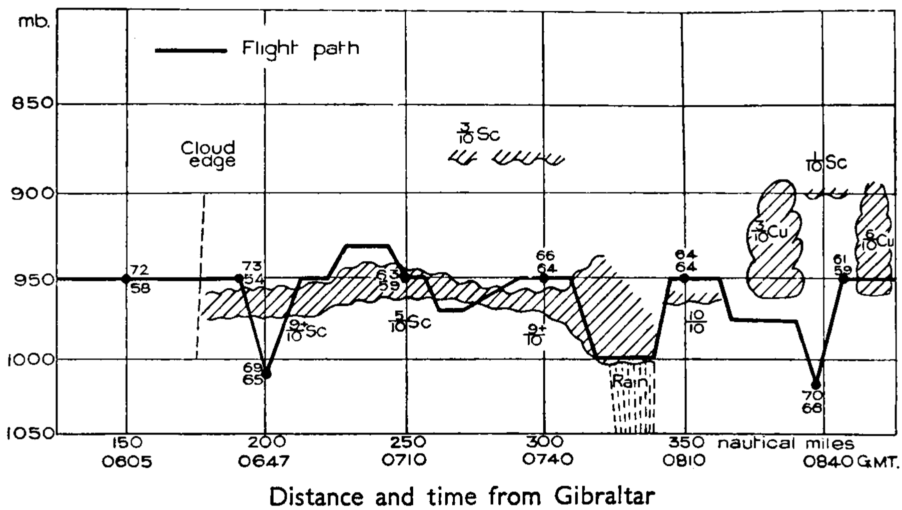

FIG. 1—CROSS-SECTION OF METEOROLOGICAL RECONNAISSANCE FLIGHT

OBITUARIES

Cmdr. John Hennessy, M.B.E., R.D., R.N.R.—With deep regret we announce the death, in his 69th year, of Cmdr. Hennessy, which took place at his home at Sidcup, Kent, on Saturday, May 22, 1954, following an illness.

Jack Hennessy was Deputy Marine Superintendent of the Meteorological Office and had worked in the Marine Branch since 1919. In association with the late Capt. Brooke-Smith he played a prominent part in the building up and development of the modern "selected ship" system, whereby weather reports are received by radio from merchant ships all over the world, and in the statistical treatment of the data by modern machine methods. The Marine Branch adopted the Hollerith system of "punch cards" as early as 1921, and nobody had a more intimate knowledge of the capabilities and limitations of that system than he had. The change from the old climatological logbook to the modern synoptic logbook for use aboard voluntary observing merchant ships, as well as the rather frequent but unavoidable changes in meteorological codes, caused many complications and changes in the form of the cards, and Cmdr. Hennessy's experience and sound advice about such problems were invaluable. Without the "punch-card" system the compilation of world-wide climatological statistics in all oceans and the preparation of comprehensive meteorological atlases covering a large number of years would be an almost impossible task, and tribute is due to Hennessy for his good work in this connexion. He contributed numerous articles to the *Marine Observer* in the years before the war—the subjects including "Winter gales in the North Atlantic 1930–1938"; "Fog and atmospheric obscurity in the Western Approaches, English Channel, Thames Estuary and mouth of the Humber"; "Ice in the western North Atlantic" and "Recorded extremes of meteorological elements".

During the Second World War, 1939–45, the Marine Branch was moved to Stonehouse in Gloucestershire. Hennessy will be remembered for his tactful and efficient work as Billeting Officer in the early days of that move. There is little doubt that the happy atmosphere among meteorological staff throughout their sojourn in Gloucestershire owed much to his efforts. In the absence of the Marine Superintendent, who was called up for service in the Royal Navy, Cmdr. Hennessy was in sole charge of the Marine Branch from 1940 till 1945, and was responsible for the preparation of the comprehensive ocean atlases of marine climatology, surface currents and ice which were produced for naval purposes during the war. In the course of this work, Hennessy worked closely and harmoniously with the various naval authorities. These atlases are probably the most accurate of their type in existence. In 1945, the Marine Branch returned to the London district, at Harrow, and Hennessy resumed the post of Deputy Marine Superintendent. The many unavoidable absences of the Marine Superintendent at international conferences and on other duties brought much responsibility to Hennessy, especially in connexion with the initial fitting out of the British and Norwegian weather ships which coincided with the conferences of the International Meteorological Organization in Toronto and Washington which the Marine Superintendent had to attend. The subsequent successful operation of the weather ships, both British and Norwegian, is a measure of the efficient way in which Hennessy dealt with this job.

Cmdr. Hennessy was a member of the Commission for Maritime Meteorology and at the meeting of that Commission in London in 1952 his knowledge and experience proved very valuable. He was awarded the M.B.E. in the New Year's Honours List in 1953.

His journey from his home at Sidcup to Harrow and back took about four hours daily, but he never complained, and was always bright and cheerful and extremely conscientious in his work. He had great charm of manner and considerable ability in getting the best out of his staff and there is no doubt that all who worked with him loved him.

He had an intense sense of loyalty and considerable religious conviction; he was very generous, an agreeable companion, had a fine sense of humour and a never-failing fund of anecdotes. His knowledge of maritime meteorology was unique—not only because of his long experience in the Marine Branch and the great interest he had in this work but also because he was a very experienced seaman and had done much voluntary meteorological work at sea before joining the Office.

Cmdr. Hennessy was born at Tenby in 1885, his father being an Engineer Captain in the Royal Navy. He served his apprenticeship in deep-water sailing ships, aboard the Barques *Ancon* and *Serena* and was subsequently Second Mate and Mate of the Barque *Miniven*. He then transferred to steamships as a Junior Officer in the P. & O. Company and later joined the North West Transport Company. He was in command of s.s. *Uranium* when war broke out in 1914. As a Lieutenant, R.N.R., he was mobilized and appointed Navigator of the Armed Merchant Cruiser *Carmania* and took part in the famous battle with the German Armed Merchant Cruiser *Cap Trafalgar* in the South Atlantic. He then served in H.M.S. *Hussar* at the Dardanelles landings; and commanded her during the subsequent operations in the Adriatic. At the end of the war he served ashore in the Second Sea Lord's office at the Admiralty, before joining the Meteorological Office.

He is survived by a widow and two sons.

C. E. N. FRANKCOM

Prof. Antoni Boleslaw Dobrowolski.—We regret to record the death of Professor Dobrowolski, the Polish meteorologist and explorer, at the age of 81. He took part in the "Belgica" Antarctic expedition in 1897–99 and he published a number of scientific works and a history of polar explorations. He was Director of the Polish National Meteorological Institute from 1924 to 1929.

HONOURS

The following awards were announced in the Birthday Honours List, 1954:—

C.B.E.

Instr. Capt. P. Bracelin, R.N., Director, Naval Weather Service

Dr. G. E. R. Deacon, Director, National Institute of Oceanography

O.B.E.

Instr. Cmdr. F. L. Westwater, R.N.

M.B.E.

Mr. F. M. Dean, Senior Experimental Officer, Meteorological Office

BOOKS RECEIVED

Hydrometeorology of the Damodar Catchment. By S. K. Pramanik and K. N. Rao. *Mem. India met. Dep., Delhi,* **29,** pp. iv + 153. *Illus.* Manager of Publications, Delhi, 1953. Price: *Rs*13/2/- or 20*s.* 6*d.*

New relations between the mean monthly air temperatures. By J. Xanthakis. 9½ in. × 6¾ in., pp. 48. *Illus.* University of Thessaloniki, Department of Astronomy, Thessaloniki, 1953. Price: 21*s.* 0*d.*

Harmonic analysis of Tides at Bakar. By M. Kasumović. *Rad. geofiz. Inst., Zagreb,* Ser. III. Br. 1, University of Zagreb, 1952.

WEATHER OF MAY 1954

Pressure was above normal northward of about 55°N., from Greenland eastward at least as far as Finland. It was mostly 8–10 mb. above normal between northern Norway and north-east Greenland, averaging from 1021 to 1025 mb.

Associated with this area of high pressure there was a warm area which included Scandinavia, Finland, Scotland, most of Asia Minor and northern India. Temperature was as much as 4–8°F. above normal over most of Scandinavia and Finland. Over North America deviations of pressure and temperature from normal were generally rather small.

In the British Isles the weather was very changeable. The first six days were cool and unsettled. A short warm spell followed but was succeeded about the 14th by a cool northerly type which lasted until the 23rd. Temperature then rose but there were outbreaks of rain and thunderstorms in many places.

The month started with a cool cyclonic type of weather, a depression developing to the south of Ireland on the 1st and bringing rain to all parts of the country, thus ending the drought which had prevailed in parts of southern England for the last three weeks of April. This depression moved north-east across the British Isles and was followed by another which maintained the cyclonic type until the 6th. There was heavy rain in places during this period (1·30 in. at Princetown on the 2nd and 1·38 in. at Alston and 1·42 in. at Dyce on the 5th) and thunderstorms occurred in England from the 1st to the 4th. Snow or sleet fell in Scotland on the 1st and 2nd and snow showers occurred on high ground in parts of England as far south as the Chilterns on the 2nd. There were gales on parts of our southern and western coasts from the 2nd to the 6th. An anticyclone which was centred over northern France on the 7th intensified and drifted north-east across the North Sea, bringing a warm southerly air stream over the British Isles. By the 10th temperatures had risen into the seventies and from the 11th to the 13th reached the eighties in southern and eastern England, the highest recorded temperature being 82°F. at Kensington Palace on the 11th and 12th. Some good sunshine records were obtained during this period. Thunderstorms broke out in east Scotland and east England on the 10th and occurred also from the 11th to the 14th. They were rather widespread on the 12th and 13th and local flooding and some deaths due to lightning in the Midlands were reported. Among the heavier falls were 2·29 in. at Ilkley on the 12th and 1·30 in. at Eskdalemuir on the 13th. Sea fog occurred around our coasts from the 10th to the 12th notably in south-western districts. Between the 12th and 15th a cold front moved slowly eastwards across the country and a ridge developed from the Azores anticyclone to the west of Ireland, giving a cool and cloudy, mainly northerly, air stream over the British Isles which lasted from the 14th to the 23rd with some slight falls of rain in eastern England and Scotland, but mainly dry weather elsewhere. During this period, however, western districts from the Hebrides to Cornwall had some sunny days with over 14 hr. recorded locally. In eastern districts temperature was low and on the 22nd maxima of only 46°F. at Cleethorpes and Mildenhall and 45°F. at Lindholme were recorded. Parts of south-west England and Wales were without rain from the 6th to the 23rd. From the 24th to the 28th pressure was low to the west of Ireland and troughs moved across the country in a southerly air stream, giving outbreaks of rain, especially in Wales and the south and west of England, with gradually rising temperatures. The eighties were again reached on the 27th when the highest recorded temperature was 84°F. at Camden Square, London. Thunderstorms occurred from the 25th to the 30th and were widespread on the 27th and 28th. Among the heavier falls during this period were 2·28 in. at Princetown and 2·84 in. at Ystalyfera, Glamorganshire, on the 24th and 2·29 in. at Birdsall Gardens, Yorkshire, on the 28th. On the 29th a depression formed over north-east England and moved slowly west then south, causing further outbreaks of rain. By the 31st this depression had filled up and an anticyclone had developed to the north of Scotland. This gave warm, mainly fine weather in the west, though with a few scattered thunderstorms, but rather cool and mostly cloudy weather in the east.

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 ...	84	25	+0·1	130	+1	81
Scotland	76	26	+1·2	160	−1	88
Northern Ireland ...	75	28	+0·5	163	−1	86

RAINFALL OF MAY 1954

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·64	93	*Glam.*	Cardiff, Penylan ...	2·20	90
Kent	Dover	1·67	101	*Pemb.*	Tenby	2·88	125
„	Edenbridge, Falconhurst	2·99	161	*Radnor*	Tyrmynydd	4·08	119
Sussex	Compton, Compton Ho.	3·05	137	*Mont.*	Lake Vyrnwy	4·84	150
„	Worthing, Beach Ho. Pk.	1·60	97	*Mer.*	Blaenau Festiniog ...	5·48	97
Hants.	Ventnor Park	2·01	116	„	Aberdovey	3·06	122
„	Southampton, East Pk.	2·08	104	*Carn.*	Llandudno	2·18	122
„	South Farnborough ...	3·17	181	*Angl.*	Llanerchymedd ...	3·02	129
Herts.	Royston, Therfield Rec.	2·73	141	*I. Man*	Douglas, Borough Cem.	2·71	108
Bucks.	Slough, Upton... ...	2·78	165	*Wigtown*	Newton Stewart ...	2·53	96
Oxford	Oxford, Radcliffe ...	2·09	112	*Dumf.*	Dumfries, Crichton R.I.	4·33	157
N'hants.	Wellingboro' Swanspool	2·98	154	„	Eskdalemuir Obsy. ...	7·03	213
Essex	Shoeburyness	1·71	132	*Roxb.*	Crailing...	4·65	231
„	Dovercourt	1·09	78	*Peebles*	Stobo Castle	5·48	241
Suffolk	Lowestoft Sec. School...	1·61	100	*Berwick*	Marchmont House ...	4·87	197
„	Bury St. Ed., Westley H.	2·23	123	*E. Loth.*	North Berwick Res. ...	3·75	188
Norfolk	Sandringham Ho. Gdns.	2·43	133	*Midl'n.*	Edinburgh, Blackf'd. H.	4·53	221
Wilts.	Aldbourne	2·52	128	*Lanark*	Hamilton W. W., T'nhill	3·69	154
Dorset	Creech Grange... ...	1·31	64	*Ayr*	Colmonell, Knockdolian	2·40	94
„	Beaminster, East St. ...	2·24	109	„	Glen Afton, Ayr San. ...	6·09	203
Devon	Teignmouth, Den Gdns.	1·84	101	*Renfrew.*	Greenock, Prospect Hill	3·87	119
„	Ilfracombe	2·36	115	*Bute*	Rothesay, Ardencraig...	3·58	117
„	Princetown	8·14	190	*Argyll*	Morven, Drimnin ...	4·68	145
Cornwall	Bude, School House ...	2·10	114	„	Poltalloch	4·04	140
„	Penzance, Morrab Gdns.	4·04	183	„	Inveraray Castle ...	4·23	108
„	St. Austell	4·18	173	„	Islay, Eallabus... ...	3·89	147
„	Scilly, Tresco Abbey ...	2·98	176	„	Tiree	4·09	164
Somerset	Taunton	1·47	86	*Kinross*	Loch Leven Sluice ...	5·61	230
Glos.	Cirencester	1·76	85	*Fife*	Leuchars Airfield ...	3·10	159
Salop	Church Stretton ...	3·76	148	*Perth*	Loch Dhu	5·92	132
„	Shrewsbury, Monkmore	2·99	153	„	Crieff, Strathearn Hyd.	6·10	245
Worcs.	Malvern, Free Library...	2·10	97	„	Pitlochry, Fincastle ...	5·56	262
Warwick	Birmingham, Edgbaston	2·88	135	*Angus*	Montrose, Sunnyside ...	3·32	163
Leics.	Thornton Reservoir ...	2·32	115	*Aberd.*	Braemar	4·73	199
Lincs.	Boston, Skirbeck ...	2·87	163	„	Dyce, Craibstone ...	3·83	150
„	Skegness, Marine Gdns.	1·80	106	„	New Deer School House	3·64	167
Notts.	Mansfield, Carr Bank...	3·30	156	*Moray*	Gordon Castle	5·08	240
Derby	Buxton, Terrace Slopes	3·65	118	*Nairn*	Nairn, Achareidh ...	3·29	185
Ches.	Bidston Observatory ...	2·46	129	*Inverness*	Loch Ness, Garthbeg ...	4·52	182
„	Manchester, Ringway...	2·79	131	„	Glenquoich	4·83	88
Lancs.	Stonyhurst College ...	2·45	86	„	Fort William, Teviot ...	4·10	104
„	Squires Gate	2·51	121	„	Skye, Broadford ...	...	...
Yorks.	Wakefield, Clarence Pk.	2·62	133	„	Skye, Duntuilm ...	3·43	120
„	Hull, Pearson Park ...	2·68	139	*R. & C.*	Tain, Mayfield... ...	3·55	172
„	Felixkirk, Mt. St. John...	2·96	157	„	Inverbroom, Glackour...	5·46	182
„	York Museum	2·53	127	„	Achnashellach	4·61	109
„	Scarborough	1·82	95	*Suth.*	Lochinver, Bank Ho. ...	2·29	130
„	Middlesbrough... ...	2·33	121	*Caith.*	Wick Airfield	2·73	132
„	Baldersdale, Hury Res.	4·99	201	*Shetland*	Lerwick Observatory ...	1·41	67
Norl'd.	Newcastle, Leazes Pk....	3·33	168	*Ferm.*	Crom Castle	3·28	118
„	Bellingham, High Green	4·41	184	*Armagh*	Armagh Observatory ...	3·95	166
„	Lilburn Tower Gdns. ...	4·38	190	*Down*	Seaforde	4·57	174
Cumb.	Geltsdale	3·45	134	*Antrim*	Aldergrove Airfield ...	3·27	144
„	Keswick, High Hill ...	4·23	133	„	Ballymena, Harryville...	4·36	152
„	Ravenglass, The Grove	3·42	122	*L'derry*	Garvagh, Moneydig ...	5·11	200
Mon.	A'gavenny, Plâs Derwen	3·08	104	„	Londonderry, Creggan	4·50	172
Glam.	Ystalyfera, Wern House	6·64	190	*Tyrone*	Omagh, Edenfel ...	4·53	175

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