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ANALYSIS OF WINDS AT 40,000 FT. AND 50,000 FT. OVER SINGAPORE

By L. S. CLARKSON, M.Sc.

Summary.—An analysis is presented of all available radar-wind observations at 40,000 ft. and 50,000 ft. over Singapore. Tables showing the monthly mean components from the north and from the east together with the standard deviations are included. The vector mean wind, its constancy, and the standard vector deviation for each month are evaluated. The results of the analysis and some of their implications are discussed.

Observations and analysis.—Some of the observations of winds over Singapore determined by tracking balloons with a manually operated GL. III radar, usually on two or three occasions a week at 0030–0200 G.M.T. from January 1951 to August 1953, have already been discussed by R. F. M. Hay[1]. Since November 1953 radar-wind observations at 0300 G.M.T. have been made by the Malayan Meteorological Service daily, except for a break caused by technical trouble in December 1954. These observations are published[2] at standard heights, with direction to the nearest ten degrees and speed to the nearest knot.

The observations at 40,000 ft. (about 200 mb.) and 50,000 ft. (125 mb.) have been analysed separately for each month, and for each year in most cases. The mean components V_N and V_E for the month and year were obtained, and the standard deviations σ_N and σ_E calculated by summing the squares of the differences from the respective means; combinations of years were normally computed by the method described by Brooks and Carruthers[3].

The vector mean wind $\mathbf{V}_R$ and standard vector deviation σ for each month and year(s) were obtained from the mean components and their standard deviations. The constancy q given by the percentage ratio of the module of the vector mean wind to the scalar mean V_s was also evaluated. Results of all these computations are given in Tables I and II.

Mean meridional component.—The mean meridional components and their probable errors at 40,000 ft. and 50,000 ft. for each month computed from all observations are shown in Fig. 1. The seasonal reversal in meridional flow at both altitudes occurs during the transitional months at around the time of passage through Singapore of the thermal equator. The high-level meridional flow is a maximum from the northern hemisphere at the peak of the S.–SW. surface monsoon in August, and from the southern hemisphere during the N.–NE. winter monsoon. This is consistent with the theory advanced by Sheppard[4] ascribing the associated easterly zonal component to the conservation of momentum in air flowing out at high levels equatorwards from above the low-level intertropical convergence zone.

TABLE I—STATISTICS OF MONTHLY MEAN WINDS AT 40,000 FT. OVER SINGAPORE AT 0300 G.M.T.

		No. of obs.	V_s	V_N	V_E	σ_N	σ_E	V_R		σ	q
				knots				°	kt.	kt.	
January	1951–54	50	22·6	− 6·5	19·9	8·3	10·7	110	21	13·5	93
	1955	15	25·5	− 9·3	21·3	8·6	9·0	110	23	12·5	91
	1951–55	65	23·3	− 7·2	20·2	8·5	10·0	110	21	13·1	92
February	1951–54	50	24·3	− 9·5	18·9	9·3	12·8	120	21	16·0	87
	1955	28	34·7	−12·9	31·3	8·0	14·0	100	34	16·4	98
	1951–55	78	28·0	−10·7	23·3	9·1	14·6	110	26	17·2	92
March	1951–54	56	22·5	− 6·6	18·6	7·8	13·2	110	20	15·4	88
	1955	29	17·6	− 5·9	8·6	9·6	12·4	120	10	15·6	59
	1951–55	85	20·8	− 6·4	15·1	8·4	13·8	110	17	16·2	79
April	1951–54	49	20·0	− 1·8	16·4	9·8	11·5	100	17	15·1	83
	1955	30	18·3	− 2·4	16·1	7·6	9·5	100	16	12·2	89
	1951–55	79	19·4	− 2·0	16·3	9·0	10·8	100	16	14·1	85
May	1951–54	50	22·4	3·4	17·9	11·4	10·8	80	18	15·7	81
June	1951–54	52	34·5	9·9	31·1	10·8	11·7	70	33	15·9	95
July	1951–54	53	39·2	14·1	34·6	10·9	11·2	70	37	15·6	96
August	1951–54	46	44·2	14·4	39·9	11·7	13·1	70	42	17·6	96
Sept.	1951–52, 1954	44	41·4	14·1	37·2	12·2	12·5	70	40	17·5	96
October	1951–52, 1954	51	25·9	3·8	23·9	9·1	12·1	80	24	15·1	93
Nov.	1951–54	67	25·0	− 4·0	23·0	8·0	10·2	100	23	13·0	93
Dec.	1951–54	47	22·3	− 5·6	18·6	9·2	12·2	110	19	15·3	87

Mean zonal component.—Tables I and II show that in all months mean winds at 40,000 ft. and 50,000 ft. over Singapore have an easterly zonal component which is least in the transitional month of March, but which reaches maxima of 40 kt. and 50 kt. respectively at the peak of the summer monsoon in August. There is a suggestion of a secondary maximum in January, but this may be nothing more than an irregularity in the seasonal decrease in V_E from the August maximum to the March minimum; it is certainly much less pronounced than would appear from the more limited set of observations discussed by Hay[1].

Distribution of components.—Geary[6], in an application of Cornu's criterion for normality, has shown that for 50 observations the distribution from which these observations were selected is unlikely to be normal if the ratio of the average deviation from the mean to the standard deviation lies outside the limits 0·75 to 0·85. This ratio for the easterly components of the 51 observations of winds at 50,000 ft. in November 1953 and 1954 was computed to be 0·78. In fact, there seems to be no evidence of abnormality in the distribution of the 40,000-ft. or 50,000-ft. wind components about their respective means.

From Tables I and II it is seen that σ_E is in all months appreciably greater at 50,000 ft. than at 40,000 ft., though there is little difference in the standard deviations of the meridional components at the two heights. Evidently the

TABLE II—STATISTICS OF MONTHLY MEAN WINDS AT 50,000 FT. OVER SINGAPORE AT 0300 G.M.T.

		No. of obs.	V_s	V_N	V_E	σ_N	σ_E	V_R		σ	q
				knots				°	kt.	kt.	
January	1951–53	19	44·3	−6·9	41·5	8·0	20·1	100	42	21·6	95
	1954	31	42·5	−7·6	38·4	16·0	14·3	100	40	21·5	93
	1955	14	27·1	−1·3	24·4	11·1	14·5	90	24	18·2	90
	1951–55	64	39·7	−6·0	36·3	13·6	17·5	100	37	22·1	93
February	1951–53	21	40·3	−6·0	34·5	14·2	28·6	100	35	32·0	87
	1954	27	20·9	4·0	7·1	11·0	22·8	60	08	25·3	38
	1955	27	55·0	−20·8	46·3	16·9	25·3	110	51	30·4	93
	1951–55	75	38·6	−7·7	28·7	14·5	30·7	100	30	33·9	77
March	1951–53	26	23·5	1·4	13·2	9·0	22·7	80	13	24·4	55
	1954	30	28·8	4·0	15·8	9·1	27·6	80	16	29·1	56
	1955	29	19·2	5·5	−0·6	10·9	16·9	350	6	20·1	29
	1951–55	85	23·9	3·7	9·4	9·8	24·1	70	10	26·0	42
April	1951–53	18	16·9	4·7	9·5	9·1	13·2	60	11	16·0	65
	1954	30	28·9	1·6	24·5	9·9	20·5	90	25	22·8	85
	1955	30	23·2	3·2	20·5	8·1	13·2	80	21	15·5	88
	1951–55	78	23·9	2·9	19·5	9·1	17·4	80	20	19·6	82
May	1951–53	19	30·8	10·5	23·2	10·6	16·7	70	26	19·8	83
	1954	29	29·8	9·3	26·6	11·5	12·0	70	28	16·6	94
	1951–54	48	30·2	9·8	25·2	11·2	14·1	70	27	18·0	90
June	1951–53	17	35·4	8·1	27·7	17·2	19·1	80	29	25·7	82
	1954	29	36·6	7·8	33·6	13·2	21·0	80	35	24·8	94
	1951–54	46	36·1	7·9	31·4	14·8	20·5	80	32	25·3	90
July	1951–53	16	51·3	16·6	45·8	17·9	17·5	70	49	25·0	96
	1954	29	36·2	1·2	33·4	11·6	16·2	90	34	19·9	93
	1951–54	45	41·6	6·7	37·8	16·0	17·7	80	39	23·9	93
August	1951–53	13	55·2	13·8	51·0	12·7	19·8	70	53	23·6	96
	1954	22	51·6	11·7	48·7	14·0	21·7	80	50	25·8	97
	1951–54	35	53·0	12·4	49·6	13·5	21·1	80	51	25·0	97
Sept.	1951–52	17	32·9	10·2	28·7	15·2	15·3	70	31	21·6	94
	1954	24	65·7	9·2	63·6	12·2	19·3	80	64	22·8	97
	1951–52, 1954	41	52·1	9·6	49·1	13·5	24·7	80	50	28·2	96
October	1951–52	19	41·1	10·5	38·2	10·8	15·8	80	40	19·2	97
	1954	29	36·6	4·1	34·2	12·2	17·5	80	35	21·4	94
	1951–52, 1954	48	38·4	6·6	35·8	12·2	17·0	80	36	20·9	95
Nov.	1951–52	17	39·7	4·4	38·4	6·2	16·1	90	39	17·3	98
	1953	25	40·4	−3·1	39·6	7·1	13·6	90	40	15·3	98
	1954	26	46·2	−0·7	45·8	8·8	24·3	90	46	25·8	99
	1951–54	68	42·4	−0·3	41·7	8·1	19·0	90	42	20·7	98
Dec.	1951–52	17	36·2	−0·7	34·2	9·6	18·5	90	34	20·8	94
	1953	22	29·6	−4·1	26·0	8·4	21·1	100	26	22·7	88
	1951–53	39	32·5	−2·6	29·6	9·1	20·4	100	30	22·3	91

variability of the zonal but not the meridional component increases from 40,000 ft. to 50,000 ft., and this, as is shown later, leads to an elliptical distribution of the vector winds in most months at 50,000 ft., whereas the distribution at 40,000 ft., where σ_N approximates to σ_E, is roughly circular.

Table III gives, for each month, the computed value of the easterly component which is likely to be equalled or exceeded on 5 per cent. of occasions.

It is evident that at 50,000 ft. over Singapore easterly components equalling or exceeding 80 kt. are likely to occur on at least one or two days in each of the months of February, August and September; at 40,000 ft. there is a similar expectancy of easterly components exceeding 60 kt. in August and September.

Table III also lists the percentage occasions a month when the easterly component may be expected to depart from the appropriate monthly mean value by more than 19 kt. and more than 39 kt. Since the vector mean wind is almost entirely easterly, Table III gives an indication of the frequency of

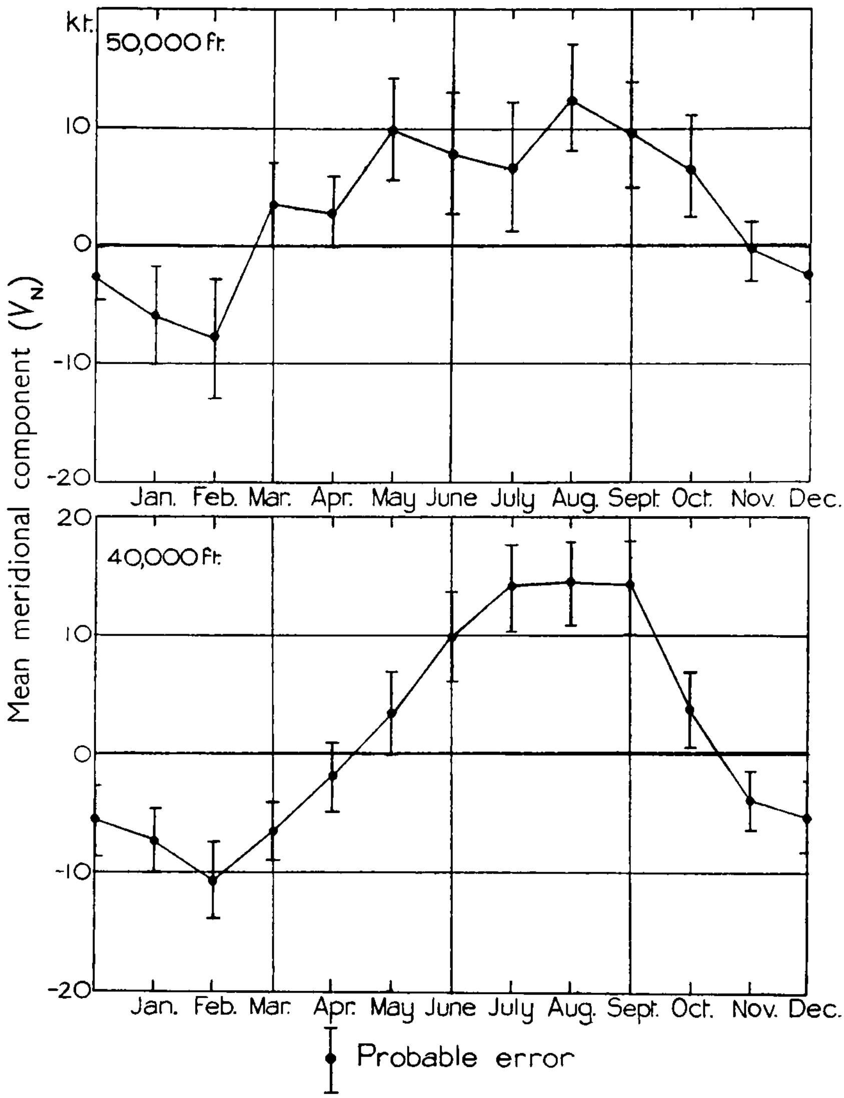

FIG. 1—MEAN MERIDIONAL WIND COMPONENT AT SINGAPORE

errors exceeding 19 kt. and 39 kt. to be expected if the appropriate monthly mean wind is used as a forecast of the wind over Singapore. Comparison of the 40,000-ft. frequencies with the frequency of vector errors of similar magnitude in spot wind forecasts for 24 hr. ahead over England and north-west Europe as given in Table XXIII of Durst's *Geophysical Memoir*[6] is interesting; the forecast error frequencies are generally much larger.

All consecutive daily observations of wind at 50,000 ft. over Singapore at 0300 G.M.T. for the period November 1953 to April 1955, inclusive, have been analysed in Table IV into the number of occasions when the 24-hr. change in the easterly component was less than 10 kt., 10–19 kt., 20–29 kt. and 30 kt. or more. Of the 407 pairs of observations in this period, 56·3 per cent. showed a 24-hr. change in the easterly component of less than 10 kt., and on only 14·7 per cent. of occasions was there a 24-hr. change of 20 kt. or more.

It has been shown in Table III that the distribution of easterly components about their monthly mean values is such that at 50,000 ft. the proportion of daily occasions when the actual easterly component may be expected to differ from the appropriate monthly mean by more than 19 kt. varies from 15 per cent. in May to as much as 52 per cent. in February, but is usually within the range 20–40 per cent. Hence from Table IV the use of an actual 50,000-ft. easterly component as a forecast of that expected 24 hr. later will invoke errors of less than 20 kt. on about 85 per cent. of occasions, whereas use of the mean monthly easterly component as a forecast is likely to be correct to within 20 kt. on only 60–80 per cent. of occasions (depending on the particular month).

TABLE III—HIGH EASTERLY WIND COMPONENTS AND FREQUENCY OF LARGE DEPARTURES FROM THE MONTHLY MEAN EASTERLY WIND COMPONENTS AT SINGAPORE

	Upper limit likely to be exceeded on 5 per cent. of occasions at		Frequency of departures from mean exceeding 19 kt. and 39 kt. at			
			40,000 ft.		50,000 ft.	
	40,000 ft.	50,000 ft.	>19 kt.	>39 kt.	>19 kt.	>39 kt.
	knots		*per cent.*			
January	40	64	5	<1	24	2
February	48	80	18	<1	52	20
March	38	48	15	<1	41	10
April	34	48	7	<1	24	2
May...	36	48	7	<1	15	<1
June...	51	64	9	<1	32	5
July	53	68	7	<1	27	3
August	61	85	13	<1	34	6
September	58	90	13	<1	42	11
October	44	64	9	<1	24	2
November	39	73	5	<1	29	4
December	39	63	9	<1	32	5

Although the preceding paragraphs refer only to the easterly component, in view of the winds at 50,000 ft. over Singapore being predominantly zonal (see Tables I and II), it appears that the temporal variation is appreciably less than over north-west Europe, and that, contrary to what has been found by Durst[6] for that region, the error caused by using a high-level wind over Singapore 24 hr. old as a forecast is likely to be appreciably less than the error made by using the normal wind.

Vector mean winds and constancy.—From Tables I and II it is seen that the direction of the vector mean wind at 40,000 ft. and 50,000 ft. over Singapore in all months is within 20° of 90°. Except in February and March the day-to-day variability in direction of the vector winds, particularly at 50,000 ft., is extraordinarily low. For instance, the values for the constancy q in Tables I and II may be compared with the figure of 90 per cent. for the most steady trade winds and monsoons, and the 97 per cent. reached in some months by the easterly stratospheric "Krakatoa winds" at 30 Km. and Von

TABLE IV—FREQUENCY OF 24-HR. CHANGES OF EASTERLY WIND COMPONENT AT 50,000 FT. OVER SINGAPORE

		<10 kt.	10–19 kt.	20–29 kt.	>29 kt.	Number of pairs
			Number of occasions			
January	1954	16	11	3	0	30
	1955	7	5	1	0	13
February	1954	16	4	4	1	25
	1955	14	9	1	1	25
March	1954	17	8	2	2	29
	1955	16	6	2	2	26
April	1954	14	11	4	0	29
	1955	18	7	4	0	29
May	1954	18	7	1	0	26
June	1954	12	7	7	1	27
July	1954	13	8	4	1	26
August...	1954	7	7	1	2	17
September	1954	10	4	3	3	20
October	1954	16	7	3	0	26
November	1953	14	6	1	0	21
	1954	12	7	1	4	24
December	1953	9	4	0	1	14
Totals		229	118	42	18	407
			percentage frequency			
		56·3	29·0	10·3	4·4	

Berson's westerlies at 17–24 Km. (both discussed by Van Bemmelen[7]), which are characterized as remarkable by Palmer[8]. This observed steadiness of the high-level winds over Singapore contrasts with Palmer's findings for the central Pacific area, which lead him to conclude that the circulation over the equator in the layers 200 mb. to 90 mb. is usually in a state of turmoil, and only occasionally settles down to a state which approximates to the steady.

A comparison of the monthly vector mean winds over Singapore at 40,000 ft. and 50,000 ft. as given in Tables I and II with the corresponding values for 200 mb. and 150 mb. at Nairobi given by Austin and Dewar[9] shows that, although similarly situated with regard to the equator, the high-level wind régimes at the two places are different, easterlies being generally stronger and far more persistent at Singapore, with a constancy at 50,000 ft. greatly exceeding the values ranging from 23 to 75 per cent. at 150 mb. characteristic of Nairobi.

Distribution of vector winds.—The standard deviation of the northerly components of the 40,000-ft. and 50,000-ft. winds is found in all months to be less than that of the corresponding easterly components (Tables I and II). At the lower altitude, however, the differences are small, and the vector distribution is to all intents and purposes circular. But at 50,000 ft. σ_E is in many months about twice as great as σ_N, and this suggests an elliptical distribution of individual 50,000-ft. winds about their vector mean.

Mauchly[10] has described (see also section 12.73 of "Handbook of statistical methods in meteorology"[3]) the application of his statistic

$$L_e = \frac{2\sigma_N\sigma_E}{\sigma_N{}^2 + \sigma_E{}^2}\sqrt{(1 - r_{NE})},$$

where σ_N and σ_E are the standard deviations of the N. and E. components and r_{NE} is the correlation coefficient between these components for N independant observations. For an exactly circular vector distribution, $L_e = 1$. Mauchly has shown that the probability of obtaining a value as small as L_e from a sample of N independent observations drawn from a population with a truly circular distribution is L_e^{N-2}. Now for the 27 observations of wind at 50,000 ft. each separated by at least 48 hr. in November 1953 and 1954, σ_N was evaluated as 8·2 kt., σ_E as 21·7 kt., $\bar{V}_N$ as $-1·2$ kt., $\bar{V}_E$ as $+41·6$ kt. and $\Sigma V_N V_E$ as 2,859, giving a value for L_e of 0·59, and of $L_E{}^{25}$ of $1·52 \times 10^{-7}$. The chance of the November observations having been part of a truly circular distribution is seen on this basis to be almost negligible.

For a normal circular vector distribution, Brooks, Durst and Carruthers[11] have established for particular values of the constancy q an approximate relation between the standard vector deviation and the vector mean wind speed, which is set out in Table LXXIV of the "Handbook of statistical methods in meteorology" and Table II of *Geophysical Memoirs* No. 85[12]. For the 50,000-ft. vector wind distribution in July (which appears approximately circular since in that month σ_E is only a little greater than σ_N) the standard vector deviation calculated from the relation (with q = 93 per cent.) is 20, as compared with the actual value of 24. Similarly for the apparently circular 40,000-ft. vector wind distribution in November, the approximate standard vector deviation calculated from the relation is 12, compared with the actual value of 13. But for the 50,000-ft. wind distribution in November, where q = 98 per cent. the standard vector deviation of a normal circular distribution with $V_R = 41·7$ would be approximately 11, as against the actual value of 21.

It appears therefore that statistical frequencies calculated from vector means and standard vector deviations on the assumption of a circular distribution can be regarded as only approximate in cases where the standard deviations of the components are greatly different. For the 50,000-ft. winds over Singapore in most months, and probably for high-level winds elsewhere near the equator, it is safer to apply the normal frequency curve to the distribution of components rather than to the vector winds.

It is perhaps of some interest that the standard vector deviations in Tables I and II for high-level winds over Singapore are in general much smaller than those indicated in the world maps in *Geophysical Memoirs* No. 85[12].

Table V gives the values of wind speed likely to be exceeded on 5 per cent. of occasions, both as calculated on the assumption of a normal circular distribution and as observed. The maximum observed wind speed is also given.

It is evident that at any time of the year winds over Singapore at 40,000 ft. may exceed 45 kt., and that easterlies greater than 70 kt. may be expected on 1–2 days in each of the months of August and September. At 50,000 ft. an easterly wind of approaching 100 kt. is a possibility in September, and in fact at 50,000 ft. a wind of 80° 108 kt. was observed on September 13, 1954.

TABLE V—WIND SPEED EQUALLED OR EXCEEDED ON 5 PER CENT. OF OCCASIONS

	40,000 ft. Calculated	40,000 ft. Observed	40,000 ft. Max. observed	50,000 ft. Calculated	50,000 ft. Observed	50,000 ft. Max. observed
			knots			
January	43	41	45	75	66	71
February	55	51	58	89	86	88
March	45	40	45	55	54	60
April	40	38	42	55	51	63
May...	46	41	48	58	53	65
June...	61	51	54	77	77	95
July	65	58	62	80	83	84
August	73	65	71	94	84	102
September	71	69	71	98	96	108
October	50	50	54	72	73	77
November	45	38	56	78	78	85
December	45	46	47	70	66	78

If the appropriate monthly vector mean wind were to be used as a forecast of the wind 24 hr. ahead, it is seen from Tables I and II that the standard vector errors of such forecasts would range from 18 to 34 kt. at 50,000 ft. and from 13 to 18 kt. at 40,000 ft. Owing to the smaller variability of high-level winds over Singapore than over Larkhill, it is noteworthy that the errors in simply giving the vector mean as a forecast are appreciably less than the errors of actual forecasts of the 30,000-ft. wind over Larkhill prepared at the Central Forecasting Office, Dunstable for 24–27 hr. ahead. For example, Durst[6] gives the standard vector error of 30,000-ft. winds over Larkhill for July 1951 estimated by the best statistical method as 31 kt. and by orthodox forecasting techniques as 33 kt. For Singapore in the same month the standard error in using the vector mean would be 24 kt. at 50,000 ft. and 16 kt. at 40,000 ft.

The error in using the actual easterly component as a forecast of the easterly component 24 hr. later has previously been shown to be less than the error in using the mean component. It is likely that the latest actual vector wind would similarly show a lesser error than the vector mean. For Singapore, then, the evidence strongly suggests that, owing to its characteristically persistent nature, the latest actual high-level wind used as a forecast is on the average

TABLE VI—EXPECTED FREQUENCY OF LARGE DEPARTURES FROM THE VECTOR MEAN

	40,000 ft. >19 kt.	40,000 ft. >39 kt.	50,000 ft. >19 kt.	50,000 ft. >39 kt.
		per cent.		
January	9	<1	44	4
February	25	<1	71	25
March	21	<1	55	10
April	13	<1	37	2
May...	21	<1	30	1
June...	21	<1	55	10
July	21	<1	50	7
August	30	<1	53	8
September	30	<1	60	13
October	17	<1	41	3
November	9	<1	41	3
December	17	<1	36	5

[To face p. 8

Reproduced by courtesy of W. M. McCrindle

STRATOCUMULUS MAMMATUS AT PRESTWICK
0845 G.M.T. November 2, 1955

To face p. 9]

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STRATOCUMULUS MAMMATUS AT PRESTWICK
0900 G.M.T. November 2, 1955

much more accurate than the best available spot forecasts of 30,000-ft. winds 24 hr. ahead over England.

Conclusion.—Winds at 40,000 ft. and 50,000 ft. over Singapore are in all months predominantly easterly and remarkably constant; they may exceed 70 kt. and 100 kt. in August and September respectively. Their distribution is characterized by the values of the statistical parameters given in Tables I and II.

The actual high-level wind over Singapore is likely to be accurate as a forecast of the wind in 24 hr. more often than the appropriate monthly vector mean wind; the vector mean in turn is accurate more often than the best forecasts for 24 hr. ahead for a particular place or route in north-west Europe.

The usual assumption of a circular distribution of upper winds is probably not valid for the winds at 50,000 ft. over Singapore in certain months.

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PATTERN OF RAINFALL

By R. P. WALDO LEWIS, M.A., M.Sc.

In a recent note[1] Thomson has discussed, for a number of stations, the statistical distribution of tabular hours in which specified amounts of rain fell. If R is the total rainfall during a long period and N_r is the number of hours in which r mm. or more of rain fell, then it appears that

$$\frac{R}{N_r} = C \times 10^{k\sqrt{r}} \qquad \ldots\ldots (1)$$

If r is given, R/N_r is approximately constant over the British Isles, even though R varies considerably, but the figures for Poona differ markedly as might be expected. In Thomson's paper values of C and k were derived for Valentia and Poona.

Some additional data have now been tabulated, including six additional years at Grimsetter (Orkney) and ten years each at the Royal Alfred

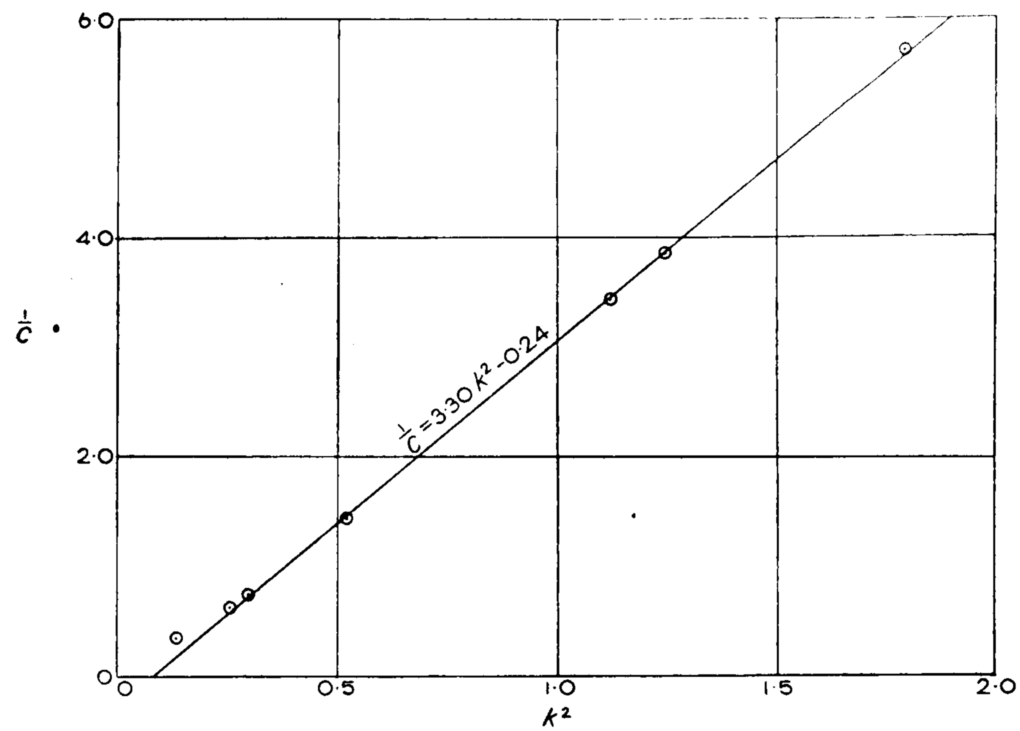

FIG. 1—RELATION BETWEEN $1/C$ AND k^2

Observatory Mauritius*, the Royal Observatory Batavia, and the Observatory at Pola, near Trieste (see Tables I and II). Values of C and k have been fitted to the data for these stations, and also to the data for Leuchars given in Thomson's paper. C and k were also recalculated for Poona, omitting the point for $r = 0{\cdot}01$ in. or more which appeared to be anomalous. These values are summarized below:

	C	k
Grimsetter	0·175	1·34
Leuchars	0·26	1·12
Valentia	0·29	1·06
Pola	0·70	0·72
Mauritius	1·35	0·54
Poona	1·64	0·50
Batavia	3·00	0·36

The Grimsetter figures bear out the suggestion made in Thomson's paper on the basis of one year's data that the rainfall pattern there shows a real difference from that common to most other British stations.

Formula (1) provides an excellent fit for all seven of the widely separated stations considered, and it seems reasonable to assume that it will describe the rainfall pattern at most places in the world. It is clear that C varies in some

*The Mauritius figures call for some comment. The graph of log R/N_r against $\sqrt{r}$ shows that the five points for $r=0{\cdot}1$ mm. up to $r=4$ mm. lie on one straight line, that the next four points up to $r=8$ mm. lie on another line of the same slope but slightly reduced intercept on the log R/N_r axis, and that the next four lie on a third line, again with the same slope but a still further reduced intercept. This suggests that there is some systematic error in the tabulated values connected with the siphoning of the rain-gauge used (a Beckley pluviograph). Siphoning taking place after rather less than 5 mm. of rain instead of after exactly 5 mm. would produce the effect found. Only the points up to $r=4{\cdot}0$ mm. have been used for the determination of C and k.

TABLE I—OBSERVED TOTAL NUMBER OF TABULAR HOURS WITH r OR MORE MILLIMETRES OF RAIN

	Period	r or more millimetres of rain 0·1	1·0	2·0	3·0	4·0	5·0	6·0	7·0	8·0	9·0	10·0	11·0	12·0	13·0	14·0	15·0	Total recorded tainfall
		number of hours																mm.
Grimsetter, Orkney ...	April 1947 –March 1954	11,611	2,200	662	231	81	37	19	...	...	...	...	...	...	...	...	...	7,110
Pola	1902–11	...	2,248	1,180	702	451	301	204	...	...	...	...	...	...	...	...	...	8,640
Mauritius, Royal Alfred Observatory	1921–30	7,109	2,810	1,651	1,157	894	723	527	425	370	313	273	217	182	163	149	136	13,601
Batavia, Royal Observatory ...	1921–30	...	2,494	1,698	1,314	1,049	860	723	643	563	496	443	374	342	317	284	258	16,421

TABLE II—ANNUAL VALUES OF R/N_r

	r or more millimeters of rain 0·1	1·0	2·0	3·0	4·0	5·0	6·0	7·0	8·0	9·0	10·0	11·0	12·0	13·0	14·0	15·0
Grimsetter	0·61	3·23	10·7	30·8	87·8	192	374	...	...	...	...	...	...	...	...	...
Pola	...	3·84	7·32	12·3	19·1	28·7	42·4	...	...	...	...	...	...	...	...	...
Mauritius	1·91	4·84	8·24	11·8	15·2	18·8	25·8	32·0	36·8	43·4	49·8	62·7	74·8	83·5	91·3	100·0
Batavia	...	6·59	9·68	12·5	15·7	19·1	22·8	25·6	29·2	33·1	37·1	43·9	48·1	51·8	57·9	63·7

way with k, and trial (Fig. 1) shows that $1/C$ is a linear function of k^2. The pairs of values $(k^2, 1/C)$ lie almost perfectly on the line

$$\frac{1}{C} = 3\cdot30k^2 - 0\cdot24 \qquad \ldots\ldots (2)$$

for all stations except Batavia. The point for Batavia lies above the curve and suggests that for the small values of k which obtain in equatorial regions the values of C are smaller than those given by the formula. However, for $k > 0\cdot5$, formula (2) provides an excellent fit. Using formula (2), for $k > 0\cdot5$ formula (1) may be rewritten as

$$\frac{R}{N_r} = \frac{10^{k\sqrt{r}}}{3\cdot30k^2 - 0\cdot24}. \qquad \ldots\ldots (3)$$

Formula (3) may be used to determine k, and therefore the rainfall pattern for any suitable station (i.e. such that $k > 0\cdot5$) without a complete analysis of hourly values and consequently with a great saving of time and labour. It seems clear, from the table above, that "suitable stations" are those whose rainfall is not tropical in character.

Taking common logarithms of formula (3) we see that the intersection of

$$y = \log\left(\frac{3\cdot3R}{N_r}\right) \qquad \ldots\ldots (4)$$

$$\text{and } y = k\sqrt{r} - \log(k^2 - 0\cdot073) \qquad \ldots\ldots (5)$$

determines the value of k appropriate to a given value of R/N_r, and it is thus necessary to find R/N_r for only one value of r.

In general, equation (4) intersects equation (5) in two points, for equation (5) tends to $+\infty$ at both $k = \infty$ and $k^2 = 0\cdot073$, with a minimum at

$$k = k_m = \frac{1}{\mu\sqrt{r}}\left\{1 + \sqrt{(1 + 0\cdot073\mu^2 r)}\right\},$$

where $\mu = \log_e 10 = 2\cdot303$. k_m decreases as r increases. To avoid the ambiguity of the double intersection, it is desirable to choose r so that k_m is certainly less than the k we wish to find. So, for non-tropical stations,

$$k_m < 0\cdot6,$$

which leads to

$$r \geqslant 4 \text{ mm.}$$

It is necessary that the intersection should occur not only on the right-hand side of the minimum, but well away from it, as otherwise a small error in R/N_r will cause a large error in the estimated k. This means that the larger r is the better, provided that N_r remains large enough to be an accurate estimate. N_r of course diminishes as r increases, and so does the labour of finding it. Using a well known result in sampling theory, the error made in estimating N_r may be expected to be of the order of $\sqrt{N_r}$ (see 6.4 in "Handbook of statistical methods in meteorology"[2]). Hence the error in $\log N_r$ is of order $\{\log(N_r \pm \sqrt{N_r}) - \log N_r\}$ or $\log(1 \pm 1/\sqrt{N_r})$. For $N_r = 400$, the error of $\log N_r$ is consequently about $0\cdot02$, which is small enough in practice. We may therefore choose the biggest r consistent with N_r remaining not less than several hundred. For about ten years' data a value of r of 4 or 5 mm. is usually satisfactory. For example, R/N_4 for the four extratropical stations considered above yields the following values of k and C:

		N_4	C	k
Grimsetter	... ...	81	0·17	1·35
Leuchars	... ...	202	0·26	1·12
Valentia	... ...	630	0·30	1·04
Pola	... ...	451	0·66	0·73

These values should be compared with those given in the previous table. Even a very small N_4 at Grimsetter gives a good result.

It should be noted that the only complicated part of the above method—the plotting of equation (5)

$$y = k\sqrt{r} - \log (k^2 - 0{\cdot}073)$$

possibly for more than one value of r—needs to be done only once; the graphs are then applicable to any rainfall figures.

For further applications of the method the following table of values of $k\sqrt{r} - \log (k^2 - 0{\cdot}073)$ for $r = 4$ may be useful. It can easily be modified for $r > 4$ by adding a term $(\sqrt{r} - 2)k$.

k ...	0·6	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·5
$2k - \log (k^2 - 0{\cdot}073)$ ...	1·742	1·780	1·846	1·933	2·033	2·144	2·264	2·391	2·524	2·662

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METEOROLOGICAL OFFICE DISCUSSION

Progress in climatological services

The discussion on Monday, October 17, 1955, held at the Royal Society of Arts was opened by Mr. H. C. Shellard who dealt with the provision of climatological services by the British Climatology Branch of the Meteorological Office, with special reference to problems in which progress was being made and to those which were outstanding.

Mr. Shellard began with a brief survey of the scope of climatological services. They could be listed under six main headings: agricultural, hydrological, industrial, medical, legal and educational, and general. It was proposed to confine attention to medical and industrial climatology, although it was expected that later speakers in the discussion would refer to recent progress in hydrological and agricultural services.

Medical climatology was a field in which progress in this country had not been very conspicuous. Some papers on the relation between weather and mortality from certain respiratory diseases had appeared in the 1920's, but each climatic element, e.g. air temperature, rainfall, relative humidity, fogginess, was usually treated separately. Interest had recently revived, chiefly because of the London smog disaster of December 1952, and detailed information on air temperature, vapour pressure and numbers of hours of thick and dense fog covering eight years had been supplied to the Statistical Research Unit of the Medical Research Council who were carrying out a large-scale investigation in which atmospheric pollution data were also being used.

In medical climatology it seemed especially important if progress was to be made that there should be close liaison between the medical specialist and the climatologist. As an example of such liaison a recent inquiry was described which came from a doctor carrying out research on the occurrence of symptoms of respiratory illness, including the common cold, and their relation to weather factors. He asked for advice on the most suitable index of humidity to use, but personal discussion established that what he really wanted was some measure of the rate at which evaporation takes place inside the respiratory apparatus. It was suggested that a relation might be derived giving this in terms of quantities measured directly at a meteorological station. Assuming that exhaled air has a temperature of 95°F. and relative humidity 95 per cent. this relation reduced to

$$W = 216 \cdot 7 \frac{v}{T}(53 \cdot 5 - e) \text{ gm./hr.}$$

where v is the rate at which air is breathed in cubic metres per hour, T is the absolute temperature of the air and e its vapour pressure in millibars. Using values of T and e from a nearby meteorological station this would apply strictly only to people out of doors, but it might give a fair approximation to people indoors if the building was well ventilated and no appreciable evaporation or condensation was taking place inside it. A temperature change of 10°F. would change W by only about 3 per cent., but a similar change in dew point would change W by about 30 per cent. In London W was about 25 per cent. greater on an average winter day than on an average summer day, while on the coldest winter day it was about twice that on the most sultry summer day. The suggestion was that the greater the drying out of the upper respiratory tract the greater the susceptibility to infection; this would account for the greater incidence of respiratory trouble in winter.

Another important aspect of medical climatology was that of advising people where to live. We could give general advice on local climatic factors, based on the work of Sir David Brunt[1] and Dr. C. E. P. Brooks[2], but, apart from a book published as long ago as 1923 by Dr. Edgar Hawkins[3], no work appears to have been done on the types of climate, and hence areas of the country most suitable for sufferers from various common complaints. This appeared to be a field in which considerable progress might be achieved by medical specialists and climatologists working together.

Turning to the subject of industrial climatology a slide (Table I) was shown which indicates the type of problem in which the industrialist or engineer

TABLE I—CLIMATOLOGICAL SERVICES TO INDUSTRY

Building and engineering	Power supply	Transport and communications	Industrial research and development
Heating and ventilating	Consumption of coal, electricity and gas	Roads and railways	Corrosion and moulding
Air conditioning	Transmission lines, insulators	Weather and traffic	Paints, plastics, paper, etc.
Wind pressure	Power from the wind	Telephones, radio, etc.	Lubricants, carburettor icing, etc.
Weathering, frost damage, etc.	Hydro-electric power	Inland waterways	Marketing
Driving rain		Shipping	Storage and packaging of food, etc.
Interruptions to building operations			Electronics

may seek the assistance of the climatologist. It is based on an analysis of inquiries received in the British Climatology Branch over the past few years. Mr. Shellard then dealt with a few specific problems in which progress is currently being made.

In connexion with requests from heating and air-conditioning engineers arrangements were made in 1953 to tabulate hourly values of dry-bulb and wet-bulb temperature at a number of outstations. A good deal of the data relating to the 10-yr. period 1946–55 had now been received and was being analysed, though this work was rather laborious. The results had already proved useful for answering a number of inquiries.

Requests were often received for information about the maximum wind velocities that are to be expected in various parts of the country. These were required in order that the greatest wind pressures to which various structures are likely to be subjected may be calculated and the structures made sufficiently strong to withstand them. The usual procedure had been to supply information based on the highest speeds so far recorded at the nearest stations with anemograph records, adjusting the values as necessary for height above the ground and obvious differences of exposure. Objections to this were that the absolute extreme value tends to increase as the length of record increases (the lengths of anemograph record available vary from less than 10 yr. at some stations to rather more than 40 yr. at others), and also that it is statistically unsound to try to estimate a largest possible value without regard to the time factor. What was required was an estimate of the true probability of recurrence of extreme values based not on one extreme alone but on all the values which are available. Such estimates could be obtained by applying the statistical theory of extreme values which has been developed by E. J. Gumbel[4] and others. The theory was being applied to wind data for this country, and the method was illustrated by slides. The use of a straight line fitted to the annual extreme values plotted on extreme probability paper to obtain estimates of the speeds which may be expected to be reached or exceeded once in 10, 20, 50 or 100 yr. was explained. A map of the British Isles was shown on which the maximum gust speeds reduced to the standard height of 33 ft. and corresponding to a return period of 50 yr. were plotted, and on which tentative isopleths had been drawn. This, it was claimed, gave a much more satisfactory picture than a map which simply showed the highest gusts on record, as does the one published in the "Climatological atlas of the British Isles". Similar maps could be drawn for mean hourly speeds and for other return periods as desired, and, provided that interpolation was done cautiously, it was considered that such maps provided a valuable tool for dealing with wind-pressure problems.

The requirement for accumulated temperature data, or degree-day data as they are frequently called, was next discussed. For the study of heating problems, engineers were interested in monthly values of degree-days below 60°F. for checking fuel consumption month by month, and also in long-period average values so that requirements in different parts of the country could be met. The Gas Council published monthly values for 14 stations in Great Britain, which they computed from daily temperatures provided by the Meteorological Office. Long-period averages of monthly degree-days below 60°F. could be obtained either by laborious calculation from daily temperatures over the required 30-yr. period or by an approximate method using monthly mean temperature. There were objections to most of the approximate methods that had been used, but last year two papers had been published by H. C. S. Thom[5,6] in which he derived by statistical methods a rational relationship between temperature and degree-days and applied it to obtain degree-day averages below various bases for selected stations in the United States. The method used not only the long-period averages of monthly mean temperature but also the standard deviations of the monthly means. It had been decided to apply it for the period 1921–50 to stations in this country and values had so far been computed for a network of 48 stations. The standard deviations of the monthly means had first been computed, and these had been plotted on maps, not only to test the values but also because they were of interest in indicating the variability of temperature in different parts of the country. The maps for the months of greatest and least temperature variability in the recent 30-yr. period, February and May respectively, were shown. The degree-day averages had next been computed for each station. These could be presented in tabular form but publication in map form was also required, e.g. by the Building Research Station. It was found, however, that difficulties arose when the station values were plotted on maps, mainly owing to the considerable effects of altitude. The best solution seemed to be to recompute the degree-day averages for each station after reducing the monthly temperature averages to sea level by adding 1°F. for each 300 ft. of altitude. Maps could then be drawn more easily. They showed the sea-level distribution and could be used directly to interpolate averages for places up to about 200 ft. without serious error. Such a map for the heating season, September to May, was shown and briefly discussed. A means of estimating reasonably accurate averages for higher-level places was suggested, utilizing Thom's result. This would require maps to read off the monthly mean temperatures and their standard deviations, and tables, which could be simply prepared, to obtain the corresponding parameters for use in Thom's expression for monthly degree-day averages. The monthly averages so obtained could be totalled to give seasonal or annual values as required.

Some outstanding problems in industrial climatology were then considered. It was often difficult for the climatologist to discover what could most usefully be done in his field to aid economic development, and the close liaison with the appropriate experts, which was therefore highly desirable, was not always easy to achieve. In practice a certain amount of guidance was obtained either by discussions or correspondence with individual inquirers or by contacts with such bodies as the research stations of the Department of Scientific and Industrial Research. Recent discussions which had taken place with the Building Research Station were mentioned, and a slide was shown listing some of the outstanding problems of the building industry, and of building research, which require climatological information for their study. This indicated, first, that no real progress could be expected with some of the problems until the basic data were made available, e.g. routine measurements of radiation and of soil moisture were required from a network of stations, and secondly, that even where the data were available they had not always been processed in the desired form. This was frequently so where a combined frequency distribution of two or more elements was required, as in the problem of driving rain. Such problems could be tackled economically only by using machine methods.

The possibility of introducing punched-card methods in the Meteorological Office for dealing with surface land data was then considered. Up to now the use of punched cards as routine has been confined in this country to marine and upper air data. A trial has recently been carried out with the aid of the Marine Branch, and suitable card layouts for both hourly and daily observations have been devised. The requirements of agricultural and aviation climatology as well as those of general climatology and hydrology have been borne in mind. Consideration has also been given to the various ways in which the data might be got on to the cards in the required form. It was believed that this could best be done by introducing new climatological forms. These would replace the forms now used at outstations, and would allow the entries to be made in such a way that they could be punched directly on to cards by machine assistants at headquarters. The layout of the proposed forms was described and it had been agreed that a trial of these would shortly be carried out at four selected outstations.

Mr. Lawrence mentioned the limitations of estimating long-term averages from maps of the geographical distribution of an element or of interpolating them from a network of stations. Though usually satisfactory for rainfall or sunshine the map method was frequently unsatisfactory for maximum or minimum temperature which was subject to much local topographical variation.

In connexion with irrigation average values of potential evapotranspiration (based on average values of wind, humidity, temperature and sunshine) were issued by the Agricultural Branch for each county or sub-county at the beginning of each month of spring and summer, while at the end of each month a correction was issued based on the actual sunshine recorded. Thus deviations from average were soon remedied before any serious damage was done.

In dealing with the siting of orchards the Branch was chiefly concerned with the frequencies of very low temperature. It was desirable to estimate the long-term risk before the orchard was established. Because minimum temperature was an element very much influenced by local topography various "visual" methods had been employed. Marks were allocated for various aspects of the site topography and a rather crude and subjective assessment made according to the total marks. Mr. Lawrence then described a technique for the investigation of frost liability which requires that a short period of observations be made[7,8]. This method employs the theory of extreme values developed by Jenkinson[9]. Results suggested that estimates of rare minimum temperatures would tend to be too low if the value of σ_1/σ_2 was assumed to be unity[8,9], i.e. if the graphs of minimum temperature against $y\,[= -\log_e \log_e (1/P)]$ was assumed, following Gumbel, to be a straight line. It was found that σ_1/σ_2 was normally greater than unity which suggested that minimum temperatures were "bounded". This was in direct contrast to maximum rainfall for which σ_1/σ_2 was normally less than unity, suggesting that maximum rainfall amounts were "unbounded". This fitted in with the fact that physical arguments for the non-recurrence of very low air temperatures were more convincing than those for the non-recurrence of very large rainfall amounts. One could feel more confident in forecasting a long-term absolute minimum temperature than in forecasting a long-term maximum rainfall amount based on the same length of record. The curves for maximum flood discharge were also apparently "unbounded", which is what might have been suspected knowing the type of curve given by rainfall amounts. The curves for flood depth were like those of minimum temperature although, according to Jenkinson, some flood-depth curves were almost straight. Mr. Lawrence presumed that these were for areas which might be called "flood hollows" where owing to local orography, soil porosity, etc., flood water could rise much more rapidly than elsewhere.

Mr. Lawrence suggested that climatological probabilities might usefully be modified using current data and knowledge of persistence to form a basis for long-term forecasts.

Finally he mentioned two investigations in medical climatology which he had made. The first was a study of the relation between *migraine* and atmospheric pressure in the Pembroke area, 1942–43, which suggested a connexion between intensity of *migraine* and rate of pressure change. In the second, annual maximum weekly notifications and total annual notifications of poliomyelitis were correlated with annual accumulated temperatures above a base of 60°F. and coefficients of 0·85 and 0·83 respectively obtained. The odds against these occurring by chance were between 20 and 50 to 1.

Mr. H. H. Lamb said that the World Climatology Branch had to deal with most of the same types of inquiry as the British Climatology Branch from persons, industrial firms and government agencies in this country undertaking commitments abroad. Some engineering firms were engaged upon contracts, worth many millions of pounds, in which weather was an important controlling factor. Invalids recommended to health resorts overseas often took the wise precaution of checking the claims of tourist publicity for the places concerned against the records at Harrow. A recent inquiry of special interest revealed the possibly enormous implications of climatic change, and underlined our responsibility for compiling adequate data on climatic trends. The numbers of tropical hurricanes in the North Atlantic and tornadoes in the United States and in Great Britain had markedly increased from a period of minimum in the early years of this century. Insurance rates, based on an average of six hurricanes a year, appropriate enough in 1920, were now proving inadequate; the British insurance market had paid out £30,000,000 in 1954 alone, a sum greatly exceeding the planned risk. Variations in the occurrence of ice around Iceland and in the temperature of the warmest waters of the North Atlantic bore an obvious relation to the trends in the occurrence of tropical storms and of tornadoes over the past half century or more.

Mr. Wadsworth introduced the subject of airfield usability in gusty winds. The use of an airfield was controlled to a certain extent by the wind, for if the cross-component of the wind on the runway exceeded a certain strength it became hazardous for an aircraft to land or take off. The effect of a cross-wind component on an aircraft in flight was to cause drift and a pilot about to land in a cross-wind had to execute a certain manoevre to counteract the drift, otherwise on touching down the aircraft would tend to move sideways across the airfield. A cross-wind also created difficulties in handling an aircraft on the ground during the landing run, and it was here that the gustiness of the wind, which would not materially affect the drift during flight, may need to be taken into account as well. During a gust the speed of the wind increased and the angle of inclination of the wind to the runway might increase at the same time. Both factors caused an increase in the component of wind across the runway.

The maximum cross-wind component to be expected from a wind of speed V blowing at an angle θ to the runway with a gust ratio (ratio of the maximum speed in a gust to the mean hourly wind speed) equal to $1 + \lambda$ was found to be $V(\lambda + \sin \theta)$, and if W was the speed of the greatest cross-wind component that could be tolerated by an aircraft, then the critical value of the wind speed from any direction was equal to $W/(\lambda + \sin \theta)$. When the wind blew along the axis of the runway ($\theta = 0$) this expression became infinite in steady winds ($\lambda = 0$), but remained finite when gusts were taken into account. The effect of introducing gust ratios of different magnitudes was exhibited by means of a wind-rose diagram for London Airport on which were drawn curves indicating critical wind speeds for cross-wind components of 25 kt. in gusts on the east–west runway. The gust ratios adopted were 1 : 2, 1 : 6 and 1 : 9. The diagram showed the progressive decrease in the computed usability of the runway as the gust ratio was increased.

Mr. Bleasdale supplemented Mr. Shellard's account of the work in general climatology by mentioning a few items in which progress was being made on the hydrological side. Problems of drainage and flooding on a river-basin scale were the responsibility, in England and Wales, of River Boards set up as a result of the Act of 1948. The work of these Boards, and Meteorological Office assistance in that work, was still in a stage of development. There had also been in recent years a revived interest in the basic problems of storm-water drainage in urban areas. A special investigation had been started at Cardington using a network of 16 open-scale rainfall recorders over an area of about four square miles, which would provide relevant data, and would probably be of interest in other connexions. In the field of water supply an important item was the estimation of the inevitable loss which occurs through evaporation. The Meteorological Office was represented on the Hydrological Research Group of the Institution of Water Engineers which had arranged with the Metropolitan Water Board to carry out an investigation at the Board's Kempton Park works. The east reservoir of 40 acres, 20 ft. deep, had been set aside for the purpose, and would not be used for water supply except in an emergency. The Meteorological Office had lent instruments to be used by the Board's staff, whose interested co-operation was much appreciated. Data for three months were already available but it was too early to begin speaking of results.

Mr. R. F. M. Hay described some points from the evidence provided by the Marine Division of the Meteorological Office for the Ministry of Transport inquiry into the losses of the trawlers *Lorella* and *Roderigo* recently. These large trawlers were both known to have been lost about 90 miles north-north-east of North Cape, Iceland on the afternoon of January 26, 1955. There was a severe north-easterly gale at the time which had persisted through the previous three days. The loss of both ships was known to have been brought about by a heavy accumulation of ice upon their hulls and superstructures.

The Court of Inquiry wanted meteorological evidence to establish to what extent conditions encountered by the two trawlers in the three days before they were lost were unusual. The Court was also concerned to know the frequency with which NE. gales, lasting as long as three days in the Denmark Strait, occurred in association with subfreezing temperatures. Using data provided by the Icelandic Meteorological Service it had been shown that such prolonged and severe gales from this direction happened about three times a year, but no temperature data were available from these unfrequented waters with which to provide a complete answer. Trawlers were almost the only vessels plying in these waters, and until their skippers agreed to make instrumental observations nothing more could be done.

As regards the ice accumulation, the Court required an explanation of the physical process, and an indication as to whether this would adequately explain an accumulation of ice in a period of about 24 hr. sufficient to capsize the vessels. (There was a skipper who gave evidence that he saw *Roderigo* at a distance of about two miles and apparently free of ice about 24 hr. before the time she capsized.) In reply it was explained that ice accumulation could have been due to three possible causes: the impact of supercooled fog droplets (arctic frost smoke) with or without supercooled drizzle or rain, accumulation of snowfall, and freezing of sea spray upon the hulls and superstructures. A great deal had been written in the Press about the danger of arctic frost smoke ("black frost") in this case. However, it was readily shown that the weight of ice that could have resulted from this cause was quite inadequate to affect the stability of these vessels to a serious extent; the same was true for the weight of snow which could have accumulated though both these factors were likely to have contributed to a small extent to the disaster.

By making reasonable assumptions about the amount of water thrown up by each wave breaking over these trawlers, and using estimates of the air and sea temperatures and wind force which prevailed during the three days preceding the disaster—made with the help of the working charts from the Central Forecasting Office, Dunstable—it was shown that a rate of icing of up to 2 tons/hr. was possible, as a result of the spray thrown up by waves breaking over the ship and freezing before it could run back into the sea. This weight of ice, which it was estimated could have accumulated in the 24 hr. or more before the ships capsized, agreed well with the weight of accumulated ice which an expert witness independently estimated would have been necessary to cause trawlers of this type to capsize.

Mr. Page (Building Research Station) claimed to have been mainly responsible for closer liaison between his Department and the Meteorological Office over the past year or two. He was working on tropical problems and was concerned with losses of heat through walls and windows, radiation on walls and variously orientated surfaces and the use of solar energy. Special attention needed to be paid to radiation measurements as the present lack of information was a serious handicap. The Building Research Station took some observations themselves, but standardization of the instruments was difficult. He thought that the presentation of data reduced to sea level on maps might lead to errors, and suggested that it was better to give the station values because the average user would not bother to apply corrections. In general he felt that there was a tendency for too much statistical technique and insufficient physical study. Thus a lot of information could be obtained by a study of conditions associated with different types of day, i.e. different air masses or synoptic types.

Dr. Robinson taking up the point about lack of radiation data said that measurements of total and diffuse solar radiation on a horizontal surface were made at Kew, Eskdalemuir and Lerwick although they were not fully published. So far as the British Isles were concerned the Building Research Station had been supplied with all the radiation and daylight illumination estimates which it had requested. It was possible to calculate amounts of radiation falling on any sloping surface near to the above three stations with reasonable accuracy. He thought that a closer network of stations was unnecessary because there was a high correlation between solar radiation and amounts of sunshine obtained from a Campbell-Stokes recorder, and claimed that present observations in this country gave solar radiation with sufficient accuracy for any engineering purpose which had been brought to his notice. There was a need for standardization, and he would be glad to compare suitable solar radiation measuring apparatus with the instruments at Kew; the National Physical Laboratory would probably help too. Dr. Robinson then asked Mr. Bleasdale why it was necessary to have a close network of recording rain-gauges at Cardington in view of the fact that it had always been assumed that variations in space would be similar to those in time.

Mr. Bleasdale replied that Dr. Robinson had supplied the answer when he said "it had always been assumed".

Mr. Lacy (Building Research Station) said that in their work he and his colleagues were becoming increasingly aware of the climatic differences which occurred between different parts of the country. One result of recent collaboration with the Meteorological Office was that a leaflet was being planned for issue to builders giving details of the meteorological services available to them. One difficulty that had arisen was that the forecast districts referred to in the morning broadcasts were different from the regions to which the evening forecasts referred. At Garston and also at a more severely exposed site near Glasgow they were trying to estimate the amounts of driving rain on a wall. They were also interested in how the rain was got rid of and thus needed to measure the loss by evaporation. For this purpose special types of evaporation gauges were being developed; these consisted of two vertical plates one kept wet and the other fairly dry.

Mr. Craddock said that some of the problems of long-range forecasting were similar to those of the climatologist, and he was concerned with the application of high-power computing methods for this work. It was not sufficient merely to get the data on to cards, and he wished to point out some of the snags which followed. It was necessary to work a great deal harder to programme the work properly and to deal with the much greater amount of information which was obtained when machine methods were used. For some purposes it might be better to have electronic aids to do complicated calculations; thus the elimination of a climatic trend might be very difficult by punched-card methods. High-speed computing methods might give 1,000 correlation coefficients in a day, and it might be difficult to survey all this information. The punched card seemed to be the best method of storing meteorological data, some of which were at present available only in relatively inaccessible publications. Mr. Lamb's hurricane data raised the important subject of time series, and there was a need for co-ordination between different branches of the Office interested in such questions.

Cmdr Franckom mentioned the problem of the care of cargo in ships' holds. Difficulties arose from the climate in the crates being different from that in the hold and from the mixing of hygroscopic and non-hygroscopic substances. Motor cars were an example. Damage to car upholstery *en route* to Australia had been found to be greatest in insulated holds. It was not easy to measure humidity in the holds, one reason for this being the different types of ventilation employed, but instruments had been put aboard some ships. He endorsed the great value of machine methods for obtaining combined frequencies.

Mr. Jacobs welcomed the proposal to introduce machine methods in surface climatology. He thought that provision ought to be made for duplicate cards to be punched so that they could be used at regional stations for dealing with local inquiries.

The Director recalled an experience of his own with punched cards, and referred to the difficulty of finding storage space for them when they accumulated in large numbers.

Mr. Shellard, in reply, said that he could not agree with Mr. Page's suggestion that maps showing data reduced to sea level were misleading; he thought that it was better for the user to have such a map, with clear instructions on how to adjust interpolated values to site level, than to have one on which straightforward interpolation might give a value which was seriously in error. He was glad that Mr. Craddock had pointed out some of the difficulties which followed the introduction of machine methods and mentioned another one: the need to punch a backlog of at least ten years' data before real use could be made of the installation. In reply to Mr. Jacobs he said that equipment was available by means of which existing Hollerith cards could rapidly be duplicated.

The Director, in closing, thanked the opener and the visitors for their contributions, and said that he had found the discussion a fascinating one, perhaps because the problems discussed were in some ways related to those dealt with in his own subject of micrometeorology.

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ROYAL METEOROLOGICAL SOCIETY

At a meeting of the Society held on November 16, 1955, the President, Dr. R. C. Sutcliffe, in the Chair, the following papers were read:—

*Malkus, J. S.—The effects of a large island upon the trade-wind air stream**

The undisturbed trade winds consist of a uniform stream of cumulus-laden air filling a moist layer which gradually deepens down wind; above this the air subsides slowly and is considerably drier. There is little or no diurnal variation. When this trade-wind air sweeps over an island (Puerto Rico in the example studied by Dr. Malkus) the general effect is as if a fairly symmetrical stationary convection cell were imposed on the general wind distribution. Air ascends in the centre of the island producing large cumulus and even a cumulonimbus and descends over the neighbouring sea so that the island is surrounded by a cloud-free ring some 50 Km. wide. The

* *Quart. J. R. met. Soc., London*, **81**, 1955, p. 538.

convection cell exhibits a diurnal variation, the clear ring shrinking in the late afternoon allowing the trade-wind cumuli to drift in across the coast. Dr. Malkus's conclusions were drawn from four ascents she made in a Catalina aircraft on June 25, 1952, using a psychograph for temperature and humidity and a water-column accelerometer for turbulence; wind was measured by double-drift observations and smoke flow; photographs were taken. Additional information was obtained by calculating moisture budgets for the vertical cross-sections between the ascents.

Among other results it was concluded that the additional heating of the island raised the cloud heights, particularly over the mountainous centre where the cloud base increased from 2,000 to 5,000 ft. and top from 5,000 ft. to a cumulonimbus anvil estimated at 30,000 ft. The subcloud layer, defined where there was no cloud as the region of slight stabilization, decreased in the clear ring on the windward side of the island to a depth of 1,500 ft. near the coast and the stability increased 20 times—all as a result of subsidence. Over the plains the cloud base was extremely variable with a minimum of 3,000 ft.; the lapse rate was superadiabatic up to 1,000 ft. and adiabatic for the next 2,000 ft.; moisture was very irregular.

Mr. Francis described some double-theodolite observations made by himself, Prof. Sheppard and Mr. Charnock at Anegada, a very small island in the trade-wind belt. Again there appeared to be a convection cell centred over the island with net convergence in the lower layers.

*Pearce, R. P.—The calculation of a sea-breeze circulation in terms of the differential heating across the coast line**

From the initial conditions of an isothermal and static atmosphere on both sides of a long straight coast line, Dr. Pearce calculated the resulting motion as the air is heated convectionally by a known amount from the land surface. He made no assumptions other than the neglect of surface drag, and only approximated where subsequent calculation showed it was justified. He separated the resulting motion into a rotational non-divergent component near the coast and a mainly irrotational large-scale tidal motion transferring mass from land to sea.

The equations for the rotational part cannot be linearized, and were solved by numerical methods at a network of points at progressive intervals of time. The results, presented in the form of graphs at 8 intervals up to 12·6 hr. from the beginning of heating, gave potential temperature, a stream function to illustrate the motion in a plan normal to the coast, and isopleths of the wind component parallel to the coast. The calculated sea-breeze showed a tongue of cold air coming in from the sea with speed increasing with time. Inland the onset occurred a few hours after heating commenced. Calculated speeds were too high because of the neglect of surface drag. The wind began to veer almost from the start, and 12·6 hr. from the commencement of heating was almost parallel to the coast (heating was assumed to stop at 6·2 hr. and most of the veering took place after that). Near the coast the drag of the returning current above maintained the direction normal to the coast much longer.

The tidal motion gives small velocities and small changes of pressure but these are spread over a continental scale.

Dr. Malkus compared the numerical analysis to relaxation methods and wondered if the calculation might not be done electronically. Dr. Pearce thought the variations too irregular. Mr. Bushby suggested that a closer mesh and shorter time intervals would overcome these difficulties. Dr. Sutcliffe was sorry about the omission of surface friction since, following Jeffreys, he had always understood the sea-breeze to be a good example of an antitriptic wind.

Smith, R. C.—Theory of air flow over a heated land mass†

In this method of calculating air flow the land mass is assumed to consist of an infinite strip 200 Km. wide. Equations are obtained using the symmetry of the flow and then linearized for solution by neglecting some terms and making other assumptions. The omissions and assumptions were subsequently justified by evaluating by another method to obtain the same answer. The resulting motion besides giving the normal sea-breeze also gave wave-like perturbations moving outwards from the centre of the land mass and some evidence of subsidence at about 2-Km. height whilst the heating is still taking place. Dr. Smith thought this to be caused by a reaction to over-shooting of the initial lifting.

In the discussion Dr. Davies drew attention to the inconsistency between the first paper with rising air in the centre of the island and the third paper with some subsidence. Dr. Malkus pointed out that Puerto Rico was not a flat island and furthermore Dr. Smith had postulated no initial wind. Dr. Smith said moist adiabatic motion, which he had not considered, would swamp the subsidence. Mr. Sawyer thought an overall wind current might be important. Dr. Sutcliffe remarked that with an undisturbed wind from sea to land the sea-breeze might not be as strong as if the undisturbed wind was from land to sea.

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* *Quart. J. R. met. Soc., London*, **81**, 1955, p. 351.

† *Quart. J. R. met. Soc., London*, **81**, 1955, p. 382.

LETTER TO THE EDITOR

Distrail at Laarbruch, Germany

The distrail shown in the photograph opposite was observed just to the south of Laarbruch at 0950 G.M.T. on October 20, 1955. It was estimated that the two darker patches of cloud shown in the photograph just below the distrail were altocumulus at about 16,000 ft. and the light cloud shown on the left-hand side of the photograph was altocumulus with a base in the region of 18,000 ft. in the lower parts, but lifting, breaking and becoming cirrocumulus at about 21,000 ft. towards the top of the photograph.

At the time a depression was centred just off north-east Scotland and was moving east-north-east, with a cold front from the centre through southern Norway and along the western seaboard of Denmark and the Low Countries, with a wave over south-eastern England. There was a moderate south-south-westerly gradient wind over north-west Germany and the Low Countries.

The cloud in which the distrail occurred was estimated to be in the region of 18,000 ft., temperature 0°F., dew point −8°F.

From the De Bilt 1400 G.M.T. upper air ascent, at 16,500 ft. (535 mb.) the temperature was +5°F. and the dew point −2°F., at 21,000 ft. (450 mb.) the temperature was −9°F. and the dew point −18°F., and at 23,500 ft. (400 mb.) the temperature was −20°F. and the dew point −29°F. Below 16,500 ft. the difference between the dry-bulb temperature and the dew point increased, and at 14,000 ft. (600 mb.) the temperature was +17°F. and the dew point +2°F.

No attempt has been made to give an explanation, as details of the type of aircraft and throttle setting are not known.

W. H. IRESON AND R. D. CRAMP

Laarbruch, Germany, November 3, 1955

NOTES AND NEWS

Presentation of barographs to ships' captains

It is customary for the Director of the Meteorological Office to present barographs each year to the Masters of four British "selected" ships who have done consistently meteorological work at sea during a period of at least 15 years. For the year 1955 barographs were awarded to:

Capt. A. B. Fasting, R.D., R.N.R., of the Cunard Company, who has been a voluntary observer since 1924,

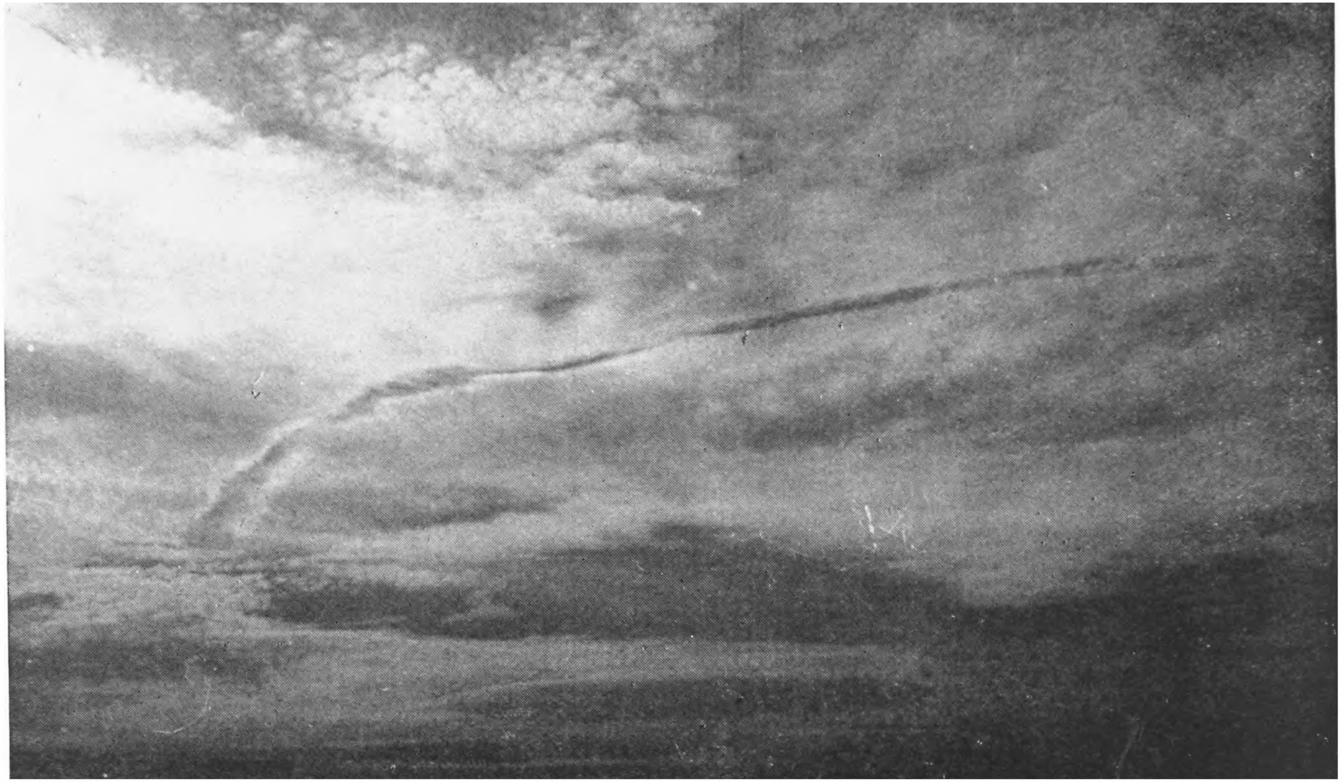
Capt. H. D. Horwood, R.N.R., of the New Zealand Shipping Company, who has been a voluntary observer since 1923,

Capt. S. W. Keay, O.B.E., of the Canadian Pacific Steamship Company, who has been a voluntary observer since 1923,

Capt. J. Trayner of the Union Castle Company, who has been a voluntary observer since 1921.

In recognition of the Centenary of the Meteorological Office and its maritime origin, it was decided that the ceremony should take the form of a celebration and it was accordingly held in the Air Council Room at Whitehall. It was hoped that the Under Secretary of State for Air could have made the presentation but at the last minute he was unable to be present. The Director of the

[To face p. 24



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DISTRAIL AT LAARBRUCH, GERMANY

Reading from left to right: Capt. J. J. Youngs (representing Capt. H. D. Horwood) Marine Superintendent of the New Zealand Shipping Co.; Mrs. Fasting (wife of Capt. A. B. Fasting, Cunard Line); Capt. J. Trayner, Union Castle Mail Steamship Co., with his award; Mrs. Trayner; Sir Graham Sutton, Director of the Meteorological Office; Capt. Sir Gerald Curtis, Deputy Master of Trinity House.

Capt. J. Trayner receives his award from Sir Graham Sutton

PRESENTATION OF BAROGRAPHS TO SHIPS' CAPTAINS

(see p. 24)

Meteorological Office therefore made the presentation himself. Capt. Fasting, Capt. Horwood and Capt. Trayner had accepted invitations to attend in person, but unfortunately Capt. Horwood was eventually unable to attend owing to a severe illness and Capt. Fasting was unavoidably detained on duty. Capt. Keay was at sea so it was arranged that the presentation would be made to him on his ship's return to Liverpool.

Among those who accepted invitations to attend the ceremony in London (see photographs opposite) were the representatives of the management and the marine superintendent of the three shipping companies concerned, the Deputy Master of Trinity House and representatives of the Officers' Unions. Senior Officers of the Meteorological Office were also present.

In making the presentations Sir Graham Sutton mentioned that when the Meteorological Office was born in 1855, under the direction of Admiral FitzRoy, its primary function was to collect meteorological and ocean-current observations over the oceans from British ships. At the end of 1855, over 100 voluntary observing ships had been recruited and this voluntary work by the masters and officers of merchant ships on behalf of the Meteorological Office had gone on continuously—except for gaps during the two world wars—throughout this 100 years. At the same time these British voluntary observing ships play a major part in the wider international scheme in which the merchant ships of most maritime countries take part. Out of a world total of about 2,650 observing ships of all types, 570 are British. Sir Graham suggested that this is a unique example of real international co-operation, which is in keeping with the traditions of the sea and of the shipping industry.

Sir Graham went on to say that the value of these observations from ships is very great; it is the only practical way in which information can be obtained about the meteorology of the oceans. The devastation caused in 1955 by hurricanes on the American coast and typhoons in the China Sea emphasizes the value of ships' observations for safety of life at sea. Similarly they are of value to most meteorological services not only for day-to-day forecasting, for the benefit of shipping, aviation, industry, agriculture and the general public, but also for research and climatological purposes on behalf of many interests.

Sir Graham mentioned the part that meteorology would play in the activities of the International Geophysical Year of 1957–58 and referred in particular to the work being done in Antarctica during that year. Here again observations from ships at sea will form an important part of the programme.

In presenting the barographs Sir Graham congratulated the recipients and thanked them for their good work, but at the same time he mentioned that these awards are a token of recognition of the voluntary meteorological work done at sea by hundreds of ships' masters and officers and radio officers. He was glad to have the opportunity of publicly thanking all voluntary observers aboard British ships, as well as the owners of the ships and their marine superintendents for the work they do on behalf of world meteorology.

The presentation to Capt. Keay was made aboard his ship *The Empress of France* at Liverpool on November 22, 1955, by Mr. S. P. Peters, Deputy Director of Forecasting. Mr. Peters had the opportunity of meeting some of the voluntary observing officers and of seeing the instrumental equipment aboard the ship. He stayed aboard the ship during her passage from the landing stage to the Gladstone Dock and was able to see numerous ships of the Voluntary Observing Fleet.

Retirement of Cmdr C. H. Williams, R.D., R.N.R.

Cmdr C. H. Williams, who has been Port Meteorological Officer in London since 1930, retired from the Meteorological Office on July 16, 1955. During his long period of service in the London docks he has recruited and maintained contact with the masters and officers of an enormous number of voluntary observing ships. His cheerful, easy manner, coupled with a lot of knowledge about the subject, enabled him to carry out this job with considerable success. There is no doubt that Cmdr Williams's efforts have contributed a lot towards the number and quality of reports received from British "selected" ships during recent years.

Cmdr Williams was born in 1892, and began his sea career in 1908 "the hard way" as an apprentice in the four-masted barque *Hougomont.* In 1913 he forsook sailing ships and joined the Union Castle Co. as a junior officer. During the 1914–18 War he served afloat in the Royal Navy, and most of the time he was in command of anti-submarine trawlers. In 1919 he returned to the Union Castle Co., and in 1930, having reached the rank of Chief Officer, he joined the Meteorological Office. He had always been interested in meteorology, and when a 3rd Officer in the Union Castle ships he made what is believed to be the first weather map to be plotted at sea in a merchant ship. In 1940, owing to the severe bombing which had occurred in London docks and frequent diversions of shipping, it was decided to close the Port Meteorological Office in London and Cmdr Williams thereupon volunteered for service with the Royal Navy. After a period of duty with the Admiralty he was appointed Commodore of coastal convoys, and he performed that duty in the North Sea for most of the War. He also took part in the Normandy landings. In 1945 he resumed his duties as Port Meteorological Officer in London, and in 1954 he succeeded Cmdr Hennessy as deputy to the Marine Superintendent at Harrow.

Cmdr Williams is a member of the Honourable Company of Master Mariners and of the Society for Nautical Research. A keen artist, his drawings under the initials C.H.W. must be familiar to all readers of the *Marine Observer.*

On his last day of duty his colleagues made him a presentation as a token of their esteem and affection. We wish him health and happiness in his retirement.

REVIEWS

The meteorology of the Falkland Islands and Dependencies 1944–50. By J. Pepper. $11\frac{1}{2}$ in. $\times 9\frac{1}{2}$ in., pp. vi+250, *Illus.*, Falkland Islands Dependencies Survey, London, 1954. Price: 42*s.*

During the Second World War, 1939–45, it was decided to establish meteorological stations in the Antarctic within the Falkland Islands Sector. Before the end of the war three stations, Port Lockroy, Hope Bay and Deception Island were established and manned by a naval expedition, "Operation Tabarin". With the end of hostilities the Falkland Islands Dependencies Survey came into being and took charge of the stations. During the next five years, 1946–50, Port Lockroy and Hope Bay were closed, but four new stations at Marguerite Bay, Argentine Islands, Admiralty Bay and Signy Island were established. Thus during the period 1944–50 seven fully manned meteorological stations were in action for periods of varying length; during the four years 1947–50 there were always at least four stations in action at the same time, and in the year 1948 seven stations were active for practically the whole year.

All these newly established stations are situated between latitudes 60°S. and 70°S., along the west coast of Graham Land or on the adjacent islands, the whole forming a long narrow group of observing stations extending from Signy Island in the South Orkneys (60°43'S. 45°36'W.) to Marguerite Island (68°11'S. 67°01'W.), the latter base being the only one within the Antarctic Circle. Outside this tightly packed group of stations, and well away to the north, two long-established meteorological stations at Port Stanley (51°42'S. 57°52'W.) in the Falkland Islands, and Grytviken (54°16'S. 36°30'W.) in South Georgia were added, to form the meteorological section of the Falkland Islands Dependencies Survey.

The programme of work was as far as possible the same at all the stations, or bases as they are called in the Falkland Island Dependencies Survey, and included pressure, temperature, wind (direction and force), relative humidity, cloud (height and amount), sunshine, and "weather", all taken by the standard method and instruments of the British Meteorological Service. Pilot-balloon observations were also taken, but are not included in the book under review.

It was clear that the large amount of meteorological data obtained would be lost unless the records were published; the Falkland Islands Dependencies Survey therefore decided in 1950 that the records of the first seven years of the Survey (1944–50) should be collected, summarized and published. The Director of the British Meteorological Office, then Sir Nelson Johnson, offered the facilities of his Office for this work. Dr. J. Pepper of the Climatological Division at Harrow took charge of the preparation of the tables, and personally edited the publication which has recently been published by the Meteorological Service of the Falkland Islands and Dependencies.

The publication is divided into three parts: Part 1—Discussion, Part 2—Gazetteer and Part 3—Tables. It will be convenient to discuss these in the reverse order.

Part 3—Tables.—A uniform scheme of tables has been adopted for the publication of the results of the observations at the individual bases: this consists of seven tables numbered from I to VII, subdivided (a), (b) etc. as necessary. This arrangement of tables, with the same numbers and titles, is used for each base making it easy to extract the corresponding data for the individual bases. Dr. Pepper appears to have solved his problem satisfactorily; all the observations have been used; monthly means have been taken whenever the quantity can be specified numerically, but when it cannot, frequency tables have been given; these latter are very useful.

There is one point which interests me personally. In 1913, when I began to work up the meteorological observations of the Scott Antarctic Expedition, I had to decide what units to use. It was a time of transition; new units, like millibars, had recently come into use in some countries, and there was a strong demand for the exclusive use of metric units and international uniformity, but the British Meteorological Office was still using national units which were not metrical and certainly not international. For practical reasons I decided to follow the British method. In comparing the units I used in 1919 with those used in this up-to-date official publication of 1954 I find the following:

	Pressure	Temperature	Cloud	Wind
1919	inches	degrees Fahrenheit	tenths	miles per hour and compass points
1954	millibars	degrees Fahrenheit	tenths and oktas	knots and degrees from north

Four of the units of these five chief meteorological elements have been changed, but neither the metric scale nor international uniformity have been attained—knots and oktas are not metric (decimal) and degrees Fahrenheit are certainly not international. Thus national use and operational convenience are still proving too strong for pure science.

Part 2—Gazetteer.—This is a very useful description of the bases prepared by Mr. G. A. Howkins, Chief Meteorological Officer of the Falkland Islands Meteorological Service. Again a uniform plan has been used in the description of the individual bases. A brief history of the base, with references to all known meteorological records made there previously, is followed by a description of the general surroundings and site with special reference to features which affect the observations made there, especially the observations of wind. A large-scale map with contours is given for each base. As all the bases are situated on the coast or on off-shore islands of a rugged and mountainous land these descriptions and maps will be of the utmost value to anyone making use of the observations.

Part 1—Discussions.—Written by Dr. Pepper, this is a valuable, one might almost say vital, contribution to the work of the Meteorological Survey, as it examines the dry bones contained in the tables, sorts them out, articulates them and clothes them, producing a presentable young member of the family of polar meteorology. Dr. Pepper begins with a short history of Antarctic meteorology, then describes the origin of the Falkland Islands Meteorological Survey and gives details of the formation of the individual bases, particulars of the observations taken, the instruments used and other technical information necessary for future users of the published data. Then follows the discussion. In this Dr. Pepper takes each meteorological element for which data are contained in the tables, describes in words the numerical information and its significance and interrelation to the other elements. The meteorological conditions in the Falkland Islands Sector are compared with corresponding regions in the Arctic, and a few of the problems which previous investigators have raised are examined. I do not intend to summarize this discussion; in the first place it would be impossible in the space available, and in any case the student of Antarctic meteorology will, or should, go to the original. Sufficient it is to say that Dr. Pepper's discussion is able, valuable and quite adequate.

In conclusion I would like to refer to two points which are not meteorological. One appears at first sight to be very trivial, but I found it irritating. On all the maps the stations are naturally arranged in a geographical sequence from north to south; in all the tables in Part I they are also arranged in a geographical sequence, but from south to north. This is very confusing, especially when studying the latitude variation of a meteorological element. The other point is of a different kind, not even scientific, but human nature. We meteorologists are all grateful to the men who have undergone the difficulties and discomforts of a year or more in the Antarctic to provide us with meteorological information. For each one of these men the experience will be an important episode in his life and career, whether he remains a meteorologist or not. Therefore I should have liked to have seen in this account of their work a list of all the men who manned the bases; it would have served to keep alive friendships formed in the Antarctic and been a way for the Authorities to say "thank you".

G. C. SIMPSON

General atmospheric circulation and weather variations in the Antarctic. By H. H. Lamb and G. P. Britton. *Geogr. J., London,* **121,** 1955, pp. 334–349.

In this paper Mr. Lamb and Cmdr Britton make an important contribution to the synoptic meteorology of the Antarctic. Up to the 1930's it was thought the Antarctic was occupied by a permanent anticyclone with inflow at high levels to balance outflow at low levels. The large pressure changes sometimes taking place were attributed to surges of the anticyclone.

The volume of observations from stations established on the Antarctic continent and neighbouring islands permanently as on Graham Land, or for long periods as at Little America, and from whaling vessels have permitted the drawing of good synoptic charts in recent years. Among these, some of the most important are those drawn at the Naval Investigational Weather Centre, Simonstown. The authors find from these charts that although the pressure distribution is mainly anticyclonic over the continent yet depressions do form there or move inland from the neighbouring seas. The situation over the continent is, they show, anticyclonic for 70–90 per cent. of the time, with anticyclones most frequently centred in eastern longitudes.

Particular interest attaches to their study of the observations made on the high polar plateau about 10,000 ft. above M.S.L. by Shackleton on 34 days in the summer of 1908–09 and by Amundsen and Scott for 44 and 46 days respectively in the summer of 1911–12. The weather there observed by these explorers varied from fair to heavy snowfall, and wind from calm to hurricane. Shackleton experienced winds exceeding force 5 for a third of his period and Amundsen and Scott for about a fifth of their periods on the polar plateau. The wind direction varied greatly, and was often southerly showing no indication of a net inflow of air which is, however, suggested by the direction of movement of higher clouds. The authors of the paper attribute the winds, and changes in them, and weather to the passage of depressions and fronts. The transantarctic expedition now being equipped and the stations to be set up in the International Geophysical Year will throw more light on the meteorology of this fascinating area, and may give results of fundamental importance to the synoptic meteorology of and weather forecasting in the southern hemisphere.

Wind flow is often explicable from the topography. Mr. Lamb has reversed the process and has inferred, from the wind flow observed at shore stations and on ships, the existence of a mountain range or glacier crest over 12,000 ft. high in the largely unknown eastern region of Antarctica about 80°S. 80°E.

G. A. BULL

OBITUARY

Mr. Frank Bispham.—It is with deep regret that we learn of the death, on November 14, of Mr. F. Bispham, Experimental Officer, at the age of 36, as a result of a motoring accident.

Mr. Bispham joined the Office as an Assistant III in March 1939 and was posted to Shoeburyness. At the end of the year he was transferred to Aberporth where he remained until 1941. After a short time at Headquarters and a course at the training school, he was posted in 1942 to an aviation outstation and from then onwards he was mainly concerned with forecasting for the

Royal Air Force. He served as a Meteorological Air Observer from 1944 to 1946 and he also served one tour of duty overseas, at Bahrain, from 1950 to 1952. At the time of his death he was serving at Shawbury.

He is survived by a widow and an infant daughter to whom the sympathy of all who knew him in the office is extended.

METEOROLOGICAL OFFICE NEWS

Acquisition of an electronic computer.—The Director is happy to be able to announce that authority has been given for the purchase of a digital electronic computing machine, and for its installation in the Napier Shaw Research Laboratory, Dunstable. This will allow of a much expanded programme of research into numerical methods of weather forecasting based on hydrodynamical principles, and the computer will also be available for other complicated problems of meteorology where very heavy numerical work is involved.

Courses of training for climatological observers.—Two courses, each lasting four and a half days, were held in October 1955 at the Meteorological Office Training School, Stanmore, and 38 observers attended. The syllabus included talks on the exposure and maintenance of instruments, on the making of observations and on the completion of returns; special attention was given to the work at crop-weather and health-resort stations and talks were given on the various applications of climatological data. Visits were made to the Public Services Branch at Kingsway, and to Harrow where the work of the British Climatological Branch, the procedure for recording climatological readings on punched cards in the Marine Branch, and the testing of instruments were seen and discussed. In addition to giving technical help in the specific field of observing, these courses give the observers a wider perspective of the eventual purpose of their work and a sense of unity among themselves. It is hoped to arrange a similar course in October 1956.

Academic success.—Information has reached us that the following member of the Staff has been successful in a recent examination:

Intermediate B.Sc. Pure Mathematics: G. A. Unwin.

WEATHER OF NOVEMBER 1955

The pressure pattern of the month departed greatly from normal and there was a notable lack of zonal progression of travelling systems. The main centre of low pressure over the North Atlantic was in 50°W. off the coast of Labrador (anomaly −10 mb. at Goose Bay) and a little deeper than normal for November; there was an extension of the low-pressure region towards the Azores, where the mean pressure was also 10 mb. below normal. As the month went on depressions failed more and more to advance into the eastern Atlantic, and from the 12th onwards there was a predominance of anticyclones centred over the British Isles and western Europe. Pressure was 8–9 mb. above normal from Iceland to Scotland. The October low-pressure region near the Arctic coast of Russia and west Siberia continued into November but with some southward shift of the lowest pressure and greatest negative pressure anomaly into north-west Siberia. Pressure was generally above normal in high latitudes (apart from the sector already mentioned) with maximum anomalies of +10 to +11 mb. in the regions north-east Greenland to Spitsbergen and Alaska to the Bering Strait. Below-normal pressures were widespread south of 45–55°N.

The month was colder than normal over the polar regions (anomalies generally −3° to −8°C.) and over North America except Quebec and Labrador, where the excess (up to +6°C.) was attributable to advection of Atlantic air and to more wind than usual. The monthly mean temperature was as much as 11°C. below normal over a wide area in Alberta and the Canadian

Rockies. The month was also 3–5°C. colder than average in Finland. Other parts of the northern hemisphere had only small anomalies, though both western Europe and most of Siberia were generally milder than usual.

Precipitation was excessive (maxima 300 per cent. of the November average or even more) in several areas: the central Rockies and western half of Canada as far as the Rockies, from north-east Greenland to central Norway, in the Azores–Madeira region, Turkey and the eastern Mediterranean, in south-east Asia and in the Hawaiian Islands.

In the British Isles a complex low-pressure system off or over the west of Ireland maintained generally mild unsettled weather from the 2nd to the 11th, but during the remainder of the month, mainly anticyclonic conditions prevailed with cooler, mostly dull, dry weather.

A rather cold sunny day on the 1st was followed by two dull days of widespread rain, which was heavy locally in the south, as troughs and small secondary depressions crossed the country. Temperature rose considerably with the rain, exceeding 60°F. in many places and reaching 65°F. at Huddersfield on the 4th. Fog was widespread during the early morning of the 5th and 6th and persisted throughout the day at some places, but there were good sunny periods elsewhere. Several houses were damaged by lightning as heavy thunderstorms moved northwards across the London area soon after midnight on the 5th–6th, and further north, at Whittlesford, near Cambridge, considerable damage was done by hailstones, 1¼ in. in diameter, during a storm soon afterwards during the same night; a second outbreak of thundery rain with scattered thunderstorms occurred later on the 6th. Depressions and troughs from the region of western Ireland, moving north-eastward across the country, gave another two days of widespread rain on the 9th and 10th. The next day there was a general rise of pressure over the eastern Atlantic and the complex low-pressure system, which had been lying off the west of Ireland since the beginning of the month, moved north-east, and as the southern part of this system crossed the British Isles there was some occasional rain with scattered thunderstorms. On the 12th an anticyclone developed to the west of the Hebrides and drifted over Scotland where it remained until the 15th; weather was cooler and generally rather dull with some slight local drizzle, principally in the east, though there were some good sunny periods on the 12th and 15th. During the next four days the anticyclone was centred over England; fog was widespread and particularly dense in parts of the Midlands and northern England where it persisted throughout the day in many places from the 17th to the 19th; temperature was about normal except in persistently foggy areas, where for example Manchester had a screen temperature of 22°F. and Shawbury 24°F. on the night of the 16th–17th. The anticyclone then moved westwards and was situated in the eastern Atlantic during the next four days, and northerly winds developed over much of the country. The fog cleared slowly and the weather was mainly cloudy and dry with only a few fog patches from the 21st. Although there was some slight rain, particularly in Scotland and eastern England, some places in the west and Midlands had recorded an absolute drought by the 26th. On the 25th and 26th the highest pressure was transferred eastward across the southern part of the British Isles into western Europe; westerly winds in the north brought prolonged rain and drizzle to parts of northern Scotland, Orkney and Shetland. A mild south-westerly air stream became established over most of the country by the end of the month; fairly widespread and locally dense fog formed over England during the night of the 29th–30th and persisted in parts of London and the Home Counties throughout the following day.

Sunshine was above the average in most districts except in parts of eastern England, and the month was mild and also dry since for most of the country there was little rain after the 10th. These relatively mild, dry conditions have enabled cattle to continue feeding on grass, which has been abundant for the time of the year, thus conserving winter fodder supplies. Throughout the month weather has been favourable to farmers for autumn cultivation and sowing. Over England and Wales this has been the fifth consecutive month with rainfall below the average, and so far 1955 has been the driest year in Scotland since records began in 1869.

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 ...	65	16	+1·2	71	−6	96
Scotland	62	19	+2·8	48	−5	95
Northern Ireland ...	58	25	+2·6	64	−6	73

RAINFALL OF NOVEMBER 1955

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	0·57	24	*Glam.*	Cardiff, Penylan ...	4·47	110
Kent	Dover	1·31	41	*Pemb.*	Tenby	3·27	75
,,	Edenbridge, Falconhurst	1·25	35	*Radnor*	Tyrmynydd	4·99	75
Sussex	Compton, Compton Ho.	2·82	74	*Mont.*	Lake Vyrnwy	3·74	65
,,	Worthing, Beach Ho. Pk.	1·09	34	*Mer.*	Blaenau Festiniog ...	3·35	31
Hants.	St. Catherine's L'thouse	1·72	56	,,	Aberdovey	2·17	48
,,	Southampton (East Pk.)	2·77	88	*Carn.*	Llandudno	1·59	55
,,	South Farnborough ...	2·40	90	*Angl.*	Llanerchymedd ...	1·64	39
Herts.	Harpenden, Rothamsted	1·95	74	*I. Man*	Douglas, Borough Cem.	2·39	51
Bucks.	Slough, Upton	2·39	108	*Wigtown*	Newton Stewart ...	3·53	71
Oxford	Oxford, Radcliffe ...	1·39	60	*Dumf.*	Dumfries, Crichton R.I.	2·71	74
N'hants.	Wellingboro' Swanspool	1·30	60	,,	Eskdalemuir Obsy. ...	1·90	33
Essex	Southend, W. W. ...	0·56	25	*Roxb.*	Crailing...	1·10	46
Suffolk	Felixstowe	0·61	30	*Peebles*	Stobo Castle	1·68	51
,,	Lowestoft Sec. School ...	0·59	25	*Berwick*	Marchmont House ...	1·63	54
,,	Bury St. Ed., Westley H.	0·79	34	*E. Loth.*	North Berwick Gas Wks.	0·85	38
Norfolk	Sandringham Ho. Gdns.	1·27	51	*Midl'n.*	Edinburgh, Blackf'd. H.	0·75	33
Wilts.	Aldbourne	2·12	69	*Lanark*	Hamilton W. W., T'nhill	1·76	49
Dorset	Creech Grange... ...	3·09	75	*Ayr*	Prestwick	1·81	56
,,	Beaminster, East St. ...	5·68	143	,,	Glen Afton, Ayr San. ...	3·93	71
Devon	Teignmouth, Den Gdns.	4·04	126	*Renfrew*	Greenock, Prospect Hill	3·01	50
,,	Ilfracombe	3·00	76	*Bute*	Rothesay, Ardencraig ...	3·00	59
,,	Princetown	9·49	107	*Argyll*	Morven, Drimnin ...	2·99	44
Cornwall	Bude, School House ...	2·04	57	,,	Poltalloch	1·75	31
,,	Penzance	2·36	52	,,	Inveraray Castle ...	4·17	49
,,	St. Austell	3·83	78	,,	Islay, Eallabus	2·77	51
,,	Scilly, Tresco Abbey ...	2·14	62	,,	Tiree	1·78	37
Somerset	Taunton	3·61	133	*Kinross*	Loch Leven Sluice ...	1·47	41
Glos.	Cirencester	3·31	107	*Fife*	Leuchars Airfield ...	1·27	56
Salop	Church Stretton ...	3·88	125	*Perth*	Loch Dhu	5·05	58
,,	Shrewsbury, Monkmore	1·38	61	,,	Crieff, Strathearn Hyd.	2·26	52
Worcs.	Malvern, Free Library...	3·66	145	,,	Pitlochry, Fincastle ...	2·15	58
Warwick	Birmingham, Edgbaston	2·89	110	*Angus*	Montrose, Sunnyside ...	2·20	83
Leics.	Thornton Reservoir ...	1·86	82	*Aberd.*	Braemar	1·54	40
Lincs.	Boston, Skirbeck ...	1·24	62	,,	Dyce, Craibstone ...	2·58	79
,,	Skegness, Marine Gdns.	1·19	55	,,	New Deer School House	1·62	48
Notts.	Mansfield, Carr Bank ...	2·24	92	*Moray*	Gordon Castle	0·85	30
Derby	Buxton, Terrace Slopes	3·08	66	*Nairn*	Nairn, Achareidh ...	0·55	24
Ches.	Bidston Observatory ...	1·29	52	*Inverness*	Loch Ness, Garthbeg ...	1·18	28
,,	Manchester, Ringway...	1·53	59	,,	Glenquoich	...	...
Lancs.	Stonyhurst College ...	1·74	39	,,	Fort William, Teviot ...	2·62	32
,,	Squires Gate	1·72	52	,,	Skye, Broadford ...	2·52	29
Yorks.	Wakefield, Clarence Pk.	1·63	77	,,	Skye, Duntuilm ...	3·39	57
,,	Hull, Pearson Park ...	0·85	39	*R. & C.*	Tain, Mayfield... ...	1·16	39
,,	Felixkirk, Mt. St. John...	2·63	107	,,	Inverbroom, Glackour...	1·99	32
,,	York Museum	1·99	95	,,	Achnashellach	3·52	41
,,	Scarborough	1·18	48	*Suth.*	Lochinver, Bank Ho. ...	2·73	54
,,	Middlesbrough... ...	1·77	83	*Caith.*	Wick Airfield	2·31	74
,,	Baldersdale, Hury Res.	2·03	56	*Shetland*	Lerwick Observatory ...	2·26	53
Norl'd.	Newcastle, Leazes Pk....	1·51	64	*Ferm.*	Crom Castle	3·23	93
,,	Bellingham, High Green	1·53	45	*Armagh*	Armagh Observatory ...	2·09	74
,,	Lilburn Tower Gdns. ...	1·80	54	*Down*	Seaforde	3·52	93
Cumb.	Geltsdale	1·38	42	*Antrim*	Aldergrove Airfield ...	1·81	56
,,	Keswick, High Hill ...	2·20	39	,,	Ballymena, Harryville...	2·17	54
,,	Ravenglass, The Grove	2·75	61	*L'derry*	Garvagh, Moneydig ...	2·17	55
Mon.	A'gavenny, Plâs Derwen	6·47	155	,,	Londonderry, Creggan	1·40	34
Glam.	Ystalyfera, Wern House	5·27	80	*Tyrone*	Omagh, Edenfel ...	2·11	56

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INTERNATIONAL GEOPHYSICAL YEAR

By H. W. L. ABSALOM

The normal good international co-operation in astronomy and the sciences of the earth and its atmosphere is enhanced and sharpened by the preparations in progress for the International Geophysical Year, July 1, 1957 to December 31, 1958. During that period some 40 nations acting in concert will engage in an agreed, extended, intensified world-wide programme of concurrent measurements and observations directed to the investigation of selected problems, in the different sciences concerned, which call for maximum practicable international effort widely based. In earlier international years, 1882–83 and 1932–33, attention was specially given to observations in the north-polar regions, whereas the International Geophysical Year programmes, more comprehensive in character, are concerned with all latitudes—so far as resources permit—and indeed place special emphasis on the tropical regions as well as on areas from which systematic geophysical data are not normally obtained. The improvement in techniques of observations in recent decades, especially in ionospheric physics and aerology, and the increased—if still incomplete—understanding of many problems make peculiarly desirable a major general effort only 25 years after the last international year. Moreover, 1957–58 is at or near the next maximum in the sun-spot cycle, whereas 1932–33 was at a minimum, and is therefore of special interest in studies of solar activity, the ionosphere, aurora and geomagnetism.

This notable undertaking is sponsored by the International Council of Scientific Unions which has appointed a Special Committee for the International Geophysical Year consisting of representatives of the international organizations concerned. This Committee has Prof. S. Chapman as Chairman and Prof. M. Nicolet as Secretary-General, and includes Dr. W. J. G. Beynon, Sir Harold Spencer Jones and Mr. J. M. Wordie of the United Kingdom. In the last three years the Special Committee, with the assistance of national proposals and recommendations from international scientific organizations, has developed International Geophysical Year programmes of work in meteorology, geomagnetism, aurora and air glow, ionospheric physics, solar activity, cosmic rays, the determination of longitudes and latitudes, glaciology, oceanography, seismology, gravity, and the exploration of the high atmosphere by rockets. Throughout, the aim is to concentrate effort on main problems. It is for participating nations to comply as fully as practicable with the recommendations of the Special Committee. In most of the countries concerned a special committee has been set up to initiate and co-ordinate their national activities during the International Geophysical Year both within and outside their national boundaries. The

British Royal Society Committee, with Mr. J. M. Wordie as Chairman, includes Sir Graham Sutton and Dr. J. M. Stagg as national correspondents for meteorology and geomagnetism respectively.

In addition to establishing in considerable detail the programmes of work, subject by subject, to be undertaken, the Special Committee has recommended on the distribution of observing stations, and in particular as to the setting up of special stations in places from which observations are needed to provide adequate general coverage, e.g. on ocean islands, in the tropics and subtropics including desert areas, in the Arctic and Antarctic. Two other measures, designed to ensure maximum use of the facilities made available during the International Geophysical Year and of the information obtained, may be mentioned. A plan has been made for World Days of different categories on which there shall be special concentration of effort in the appropriate disciplines. Three or four days each month are specified as Regular World Days; they include days at new moon and quarter moon, days with enhanced meteoric activity, and solar eclipses. Special World Days or Intervals will be announced when, from solar or other indications, a period of solar and geophysical disturbance is expected. World Meteorological Intervals are specified 10-day periods at each equinox and solstice, starting in June 1957. The other and very important measure of co-ordination relates to the form of presentation, exchange and publication of data, and envisages main collecting centres for information obtained during the International Geophysical Year.

In regard to the scientific programmes, it is natural in this article to restrict attention mainly to meteorology, though in doing so it is not implied that meteorologists are not conscious of the interrelations between their science, oceanography and glaciology, and that the increase in knowledge of atmospheric motions and other characteristics above 50 Km. by the use of radio and rockets is of no meteorological interest. Reference may be made to articles by Prof. S. Chapman[1,2] for a survey of the whole field, and (until a later publication is available) to the International Union of Geodesy and Geophysics News Letters No. 9 and No. 11 for more detail on the several subject programmes.

Meteorology.—The Special Committee's plan for meteorology was largely determined by the World Meteorological Organization and the International Association of Meteorology. Briefly stated, the prime objective is the investigation of the large-scale physical, dynamical and thermodynamical processes of the general circulation of the atmosphere the world over. To this end it is proposed that the network of upper air observing stations shall be suitably improved to permit the preparation of aerological cross-sections along the whole or specified major portions of the meridians 10°E., 30°E. (from 30°N. to 30°S.), 75°E., 110°E., 140°E., 180°, 80°W. (north pole to 20°S.) and 70°W. (20°S. to the south pole), 20°W., and also along 5°S., the equator, 5°N., 15°N., 40°N. in North America and a parallel through the Andes. It is recommended, firstly, that all upper air stations (not only those for the vertical sections) shall make two radio-sonde and four radar-wind soundings daily, with an increase to four combined temperature-wind soundings on the 10 consecutive days of the seven World Meteorological Intervals; and secondly, that soundings should attain the 50-mb. level on each day, and that every effort be made to attain the 10-mb. level especially in the tropics and in the four daily ascents on World Meteorological Interval days. Moreover, it is suggested that the World

Meteorological Intervals at the equinoxes shall be extended, as may be necessary, so that the soundings to high levels may cover the occurrence of the directional change in the zonal circulation in the stratosphere at those seasons.

As the thermal economy of the atmosphere is an important item in the central problem of the general circulation there is need for additional stations, preferably aerological stations, to carry out systematic measurements of solar, atmospheric and terrestrial radiation. It is suggested that astronomical observatories shall determine the earth's albedo (and so the total solar energy absorbed by the earth and its atmosphere) by using Danjon's method of observing the earth radiation reflected from the moon. A further requirement is for measurements of atmospheric ozone to be made at certain stations on selected meridians, at points near subtropical anticyclones between 15° and 40°N. and near the subtropical jet stream. Among the subjects of other recommendations are networks of nephoscope observations in areas where upper wind measurements by balloon are impracticable or scarce, accurate measurement of humidity in aerological soundings, good observations of cloud (especially at sea), the importance of upper air observations on ocean islands and whaling or other ships, and representative measurements of temperature at depths below the earth's surface, at the surface, and at heights near the surface.

Participation by the United Kingdom.—The Meteorological Office operates aerological stations at the four ocean weather stations (shared with other countries) A, I, J and K, at 15 stations in the United Kingdom, Mediterranean and Middle East (Lerwick, Stornoway, Leuchars, Aldergrove, Liverpool, Hemsby, Crawley, Camborne, Gibraltar, Malta, Benina, Cyprus, Aden, Bahrain, Habbaniya), and at Stanley (Falkland Islands). The ocean weather stations I, J and K qualify for the 20°W. vertical section, Malta qualifies for the 10°E. and Aden for the 15°N. zonal sections. At almost all these stations two radio-sonde and either two or four radar-wind soundings are made as daily routine. It is intended on ordinary days in the International Geophysical Year to make the normal number of soundings, but that in one of the combined temperature-wind ascents daily a large balloon (perhaps 1,250 gm.) shall be used to attain greater height, and on World Meteorological Interval days to make four combined temperature-wind ascents with large balloons at the three 20°W. ocean weather stations and at three well distributed stations in the United Kingdom, and also to increase the radar-wind ascents (with large balloons) to four daily at stations in the Mediterranean and Middle East.

The current programmes in radiation will be maintained at Kew Observatory, Cambridge, Aberporth, and Eskdalemuir and Lerwick Observatories. Each of these stations will therefore obtain during the International Geophysical Year continuous records of the total and diffuse radiation received on a horizontal surface, while in addition Kew will record the solar intensity normal to the beam, daylight illumination, the vertical flux of total radiation near the ground, and perhaps solar-infra-red radiation. Arrangements are being made to record solar radiation on a horizontal surface and also the vertical flux of total radiation near the earth's surface at Malta, Aden and Port Stanley (Falkland Islands); it is hoped that the vertical-flux measurements at Malta will be made over the sea. A recent study by G. D. Robinson[3] indicates that the international plan for radiation measurements during the International Geophysical Year if carried out with care should make a considerable contribution to the more general meteorological problem, though measurements of the flux of radiation at all attainable heights in the atmosphere are greatly to be desired. It is proposed that the Meteorological Research Flight, in collaboration with Kew, shall measure the flux of long-wave radiation and the albedo of the earth's surface and of cloud at heights up to about 16 Km. over southern England.

In the United Kingdom, measurements of the total amount of atmospheric ozone, using the Dobson spectro-photometer, will be made as at present at the Ozone Commission Centre at Oxford by Prof. G. M. B. Dobson and Sir Charles Normand and at the Meteorological Office upper air stations at Lerwick, Aldergrove, and Camborne. It is hoped that further determinations of the ozone concentration (using a chemical absorption method), together with simultaneous readings of air temperature and humidity, will be made by the Meteorological Research Flight to heights of about 16 Km. To assist the investigation of relationships between ozone amount, the subtropical jet stream, and the occurrence of the double tropopause structure of the atmosphere, it is intended to make ozone measurements at two of the upper air stations maintained at Aden, Bahrain and Habbaniya.

The British sferics network—Leuchars, Irvinestown, Hemsby and Camborne—linked to the Central Forecasting Office, Dunstable, meets several of the international recommendations on the location of thunderstorms by radio direction-finding.

It is scarcely necessary to emphasize that meteorology will be by no means the only field of United Kingdom participation in the International Geophysical Year. Indeed, a significant part is to be taken in the programme of the other subjects.

The usual geomagnetic measurements obtained at the Eskdalemuir and Lerwick Observatories of the Meteorological Office and the Abinger and Hartland Point Observatories of the Royal Greenwich Observatory will contribute to the basis of the international programme in this field. It is intended to operate magnetic recording equipment at two points about 10–15 miles west and north of Lerwick to determine the horizontal space-gradients in the earth's magnetic field in that locality; it is hoped that these and similar measurements at other stations in the auroral region will contribute to knowledge of the intense electric-current systems located at heights of 100 Km. or more. An auroral survey organized by Mr. J. Paton, University of Edinburgh, has operated for some years. In addition, photographic and spectrographic studies of aurora will be made in Scotland by members of the Universities of Edinburgh and St. Andrews, and air glow will be investigated in Northern Ireland in conjunction with members of Queen's University, Belfast. Radio echo recording of aurora, not confined to darkness, will be undertaken at the Jodrell Bank radio astronomical station (University of Manchester). A widespread programme of ionospheric measurements and investigations will be operated by the Radio Research Organization of the Department of Scientific and Industrial Research in the United Kingdom, Falkland Islands, Singapore, and at Ibadan, British West Africa (with the University College); also by the University of Edinburgh, Jodrell Bank, Cavendish Laboratory, University College of Swansea and, it is understood, colleges in east and west Africa. Programmes in various aspects of solar activity will be carried out by the Royal Observatory at Edinburgh, the Cavendish Laboratory, Jodrell Bank, the Royal Greenwich Observatory, and the Royal Observatory at the Cape of Good Hope. Cosmic-ray measurements will be made by the Royal Greenwich Observatory, Imperial College (London), University of Bristol and Makerere College (British East Africa). Preparations are being made for work in glaciology and oceanography. At the time of writing it is too early to say whether British rocket flights to explore the high atmosphere will be made to supplement the series planned by the United States and France.

Arrangements for the International Geophysical Year corresponding to those outlined above are being made by other members of the British Commonwealth, in varying degree according to circumstances. Few of the recommended aerological meridians and parallels listed earlier are everywhere remote from Commonwealth territory. It is to be regretted that other Commonwealth commitments will preclude the setting up of special stations on certain isolated islands in the southern hemisphere from which upper air observations would be very valuable.

Polar regions.—In the past 20 years or so there has been a marked increase in the number of places in the Arctic regions at which meteorological and other geophysical observations are made. Nevertheless, countries bordering or otherwise interested in these regions are preparing to amplify the current programmes, and where practicable to establish additional special stations during the International Geophysical Year.

Probably the most striking feature in the preparations for the International Geophysical Year is the effort being made to develop a good geophysical coverage in the Antarctic. Apart from the permanent British bases in the Falkland Islands Dependencies and bases occupied by Argentina and Chile in that territory, some 20 special geophysical stations, reasonably well distributed, are to be operated on and in the vicinity of the main Antarctic mass by the United Kingdom, Australia, New Zealand, France, Norway, United States, U.S.S.R., Japan and possibly Belgium and Spain. Six stations are planned by the United States (one at the South Pole), three by the U.S.S.R. (probably one at the geomagnetic pole), two by Australia, possibly two by New Zealand, and two by France. An Antarctic Weather Central is to be set up at the main American base in the Ross Sea area for the collection of weather reports from Antarctic stations and neighbouring areas, and the dissemination of reports, analyses and other information. Arrangements for codes and communications are under active discussion between the United States Weather Bureau, the World Meteorological Organization and the countries immediately concerned.

The United Kingdom contribution in the First and Second International Polar Years of an expedition to Fort Rae, north-west Canada, with a party for ionospheric studies at Tromsø in 1932–33, is to be followed by a British (Royal Society) International Geophysical Year expedition to Coats Land (75°36′S. 26°45′W.) in the Weddell Sea to undertake programmes in meteorology, geomagnetism, aurora, ionospheric measurements, glaciology, seismology and, possibly, gravity. The meteorological work will include two radio-sonde and probably radar-wind ascents daily, measurements of atmospheric ozone and the recording of solar radiation on a horizontal surface and of the vertical flux of total radiation. Regular measurements of the components of the earth's magnetic field will be made and continuous photographic records of variations in the geomagnetic field maintained. This base is situated in or very near to the zone of maximum auroral frequency, and the auroral, geomagnetic and ionospheric observations obtained at the station will be of special interest. As is generally known, an advance party of the Royal Society expedition left England for the Weddell Sea in November 1955 to establish the base and to initiate a limited scientific programme of surface meteorological observations, solar radiation and ozone measurements, photographic and visual observations of aurora, ionospheric noise measurements and human physiology. Mr. D. W. S. Limbert of the Meteorological Office is a member of the advance party. The main party, about 18 strong and including five members to deal primarily with meteorology and geomagnetism, will arrive at Coats Land early in 1957 to carry out the extended programme until the end of 1958.

A valuable additional contribution to meteorological knowledge of the Weddell Sea area is expected from the Commonwealth Transantarctic Expedition, led by Dr. V. E. Fuchs. The advance party of this expedition, which also left England in November 1955, plan to carry out surface meteorological observations, radiation measurements and daily radio-sonde ascents at their main base—to be known as "Shackleton"—from as early as possible in 1956 until 1957. Mr. R. H. A. Stewart, formerly of the Meteorological Office, and Mr. P. H. Jeffries, a present member of the staff, are included in this advance party.

At the Argentine Islands base (65°S. 64°W.) of the Falkland Islands Dependencies Survey, the newly inaugurated long-term programme of radio-sonde soundings, and in radiation ozone and geomagnetism, will yield valuable results for International Geophysical Year purposes.

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AN UNUSUALLY SMOOTH WAVE PATTERN IN A CONDENSATION TRAIL

By W. G. HARPER, M.Sc.

An unusually smooth wave pattern was seen in a condensation trail from East Hill near Dunstable just before sunset on March 10, 1955. When the wave pattern was first seen at 1755 G.M.T., about a minute after the passage of the aircraft, the waves were almost uniform in amplitude, but at 1758, when the sketch (Fig. 1) was made, their amplitude showed a definite decrease towards the north-east, the direction in which the aircraft was flying. Waves were not formed outside this zone.

The aircraft was picked up on the East Hill height-range radar, which gave its height as 37,000 ft., track 40° and ground speed 310 kt. The trail itself gave no radar echo. This radar height, and elevation and azimuth measurements made with an 8-in. protractor as an alidade, located the wave pattern in space and gave a value for the wave-length of 1½ miles. The waves were still visible at 1805 G.M.T. but by then had almost dissipated and were in sunset shadow.

Synoptic situation.—An anticyclone of central pressure 1032 mb. was stationary over the British Isles with its centre over southern Scotland, giving

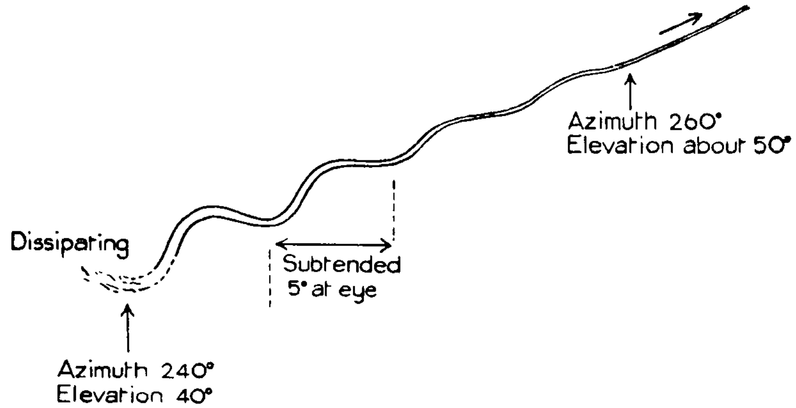

FIG. 1—CONDENSATION-TRAIL PATTERN AS SEEN OBLIQUELY FROM THE GROUND
1758 G.M.T., March 10, 1955

clear skies and cold NE. winds over England. Upper air soundings at Hemsby must on this occasion have been closely representative of conditions along the track of the aircraft. The 1400 G.M.T. temperature sounding (Fig. 2) shows an isothermal layer from 5,000 to 9,000 ft. The tropopause at 35,700 ft. places the aircraft just in the stratosphere. The upper winds, also given in Fig. 2, were north-easterly at all levels up to 50,000 ft. It can be seen that the trail was formed in a region of considerable wind shear in the vertical above a north-easterly jet stream centred at the 32,000-ft. level. The wind at 37,000 ft. was 50° 70 kt.

Cause of wave pattern.—If the wave pattern had been moving with the 70-kt. wind it would have changed in azimuth by more than 20° in the period in which it was observed. This would have been detected readily even though the pattern was not watched continuously, and certainly did not occur. This excludes the possibility that the waves were due to aerobatic motion or to perturbations in the wind field moving with the wind.

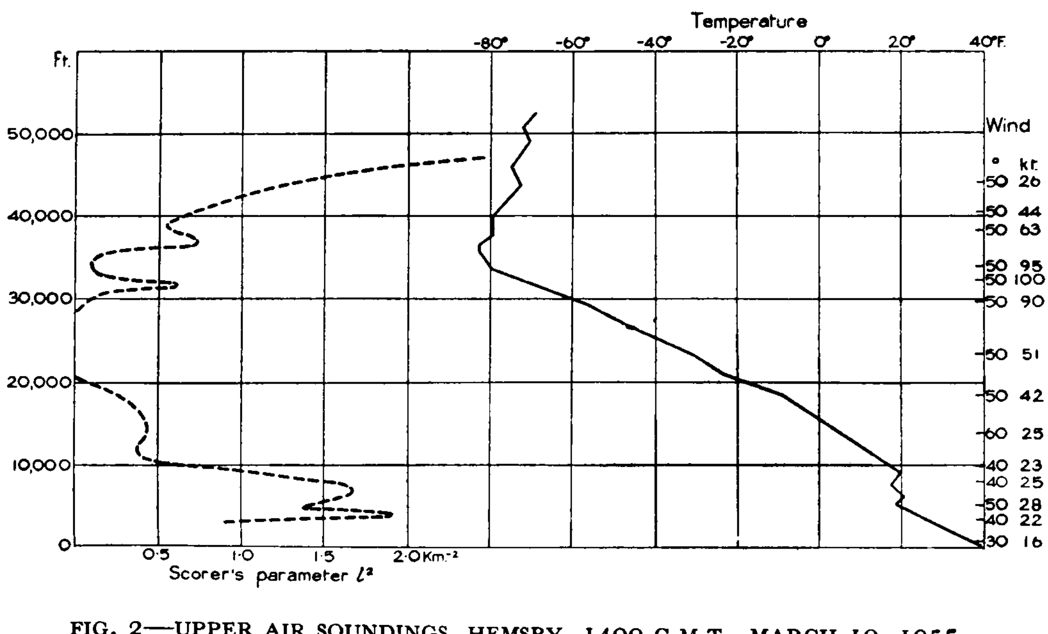

FIG. 2—UPPER AIR SOUNDINGS, HEMSBY, 1400 G.M.T., MARCH 10, 1955
The values of Scorer's parameter l^2 are given on the left-hand side.

There is no certainty that the waves were not due to some sort of horizontal wind shear or formed at an interface between two fluids, but there is some evidence to suggest that they were of standing-wave origin.

Standing waves.—There is increasing evidence that orographic standing-wave effects can occur at considerable heights. They are quite readily demonstrable in the upper troposphere as orographic cirrus. Ludlam[1] has studied orographic cirrus which formed at levels around 30,000 ft. to leeward of the ridges of the Cotswolds and Chilterns, but in the present case the aircraft track was not across the main ridge of the Chilterns, but parallel to it and a short distance to the south-east. It did however cross a well defined spur of the Chilterns rising to 500 ft. above mean sea level which has an obstruction height of 300 ft. (Fig. 3). If orographic cirrus can be formed by the 500–600-ft. obstruction of the Chilterns it cannot be ruled out that in favourable conditions orographic effects from an obstruction of 300 ft. could extend to 37,000 ft.

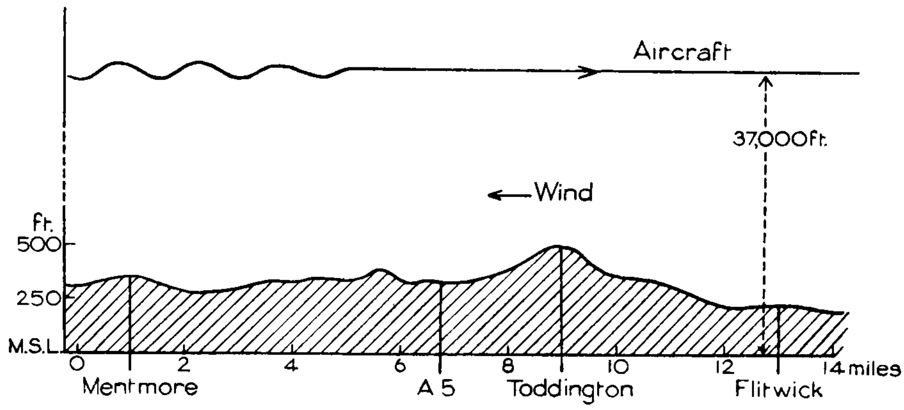

FIG. 3—SURFACE CONTOURS IN RELATION TO WAVE PATTERN

The wave pattern, the height of aircraft and the ground contours are not drawn on the same vertical scale.

Corby[2] quotes the wave-length of hill and ridge waves in Great Britain as being commonly in the range 1–10 miles, and has summarized a study by Turner of aircraft reports of standing waves which indicates that increase of wind with height in the lower layers of the air stream and the presence of a deep isothermal layer are very favourable for their development. These conditions can be seen to be present on March 10 (Fig. 2). It is also of interest to consider the profile of the parameter l^2 which Scorer[3] has shown to be significant in the occurrence of standing waves; l^2 is seen to have a broad maximum between 4,000 and 8,000 ft. In this the amplitude of standing waves should be a maximum, but it should be noted that a subsidiary maximum occurs at 37,000 ft.

In most standing waves the amplitude decreases down wind, and some explanation is desirable for the decrease in amplitude of the wave pattern up wind between 1755 and 1758 G.M.T.

A straight-line condensation trail moving with the wind into a standing-wave zone will of course take up the standing-wave stream-line; but a condensation trail formed in a standing-wave zone will not. Not only is a wave motion imposed on the aircraft itself by the standing waves but each element of the condensation trail is formed in a different stream-line and will move with the wind along that particular stream-line. The effect can be conveniently shown graphically if the standing-wave stream-line is assumed to be sinusoidal and of uniform amplitude, and the horizontal component of the wind equal to the free-air wind speed at every point. Taking wind speed as 75 kt., and ground speed 300 kt., an aircraft heading into wind will traverse one wave-length of the standing wave in exactly 16 sec. for wave-length 1·53 miles. These values are convenient and close to those measured. If the mean horizontal speed of the air in the wave is U, the amplitude (maximum departure from the mean position) of wave-motion a, and wave-length L, the vertical component of air motion in a standing wave of form $z = a \sin (2\pi x/L)$ is $(2\pi a U/L) \cos (2\pi x/L)$.

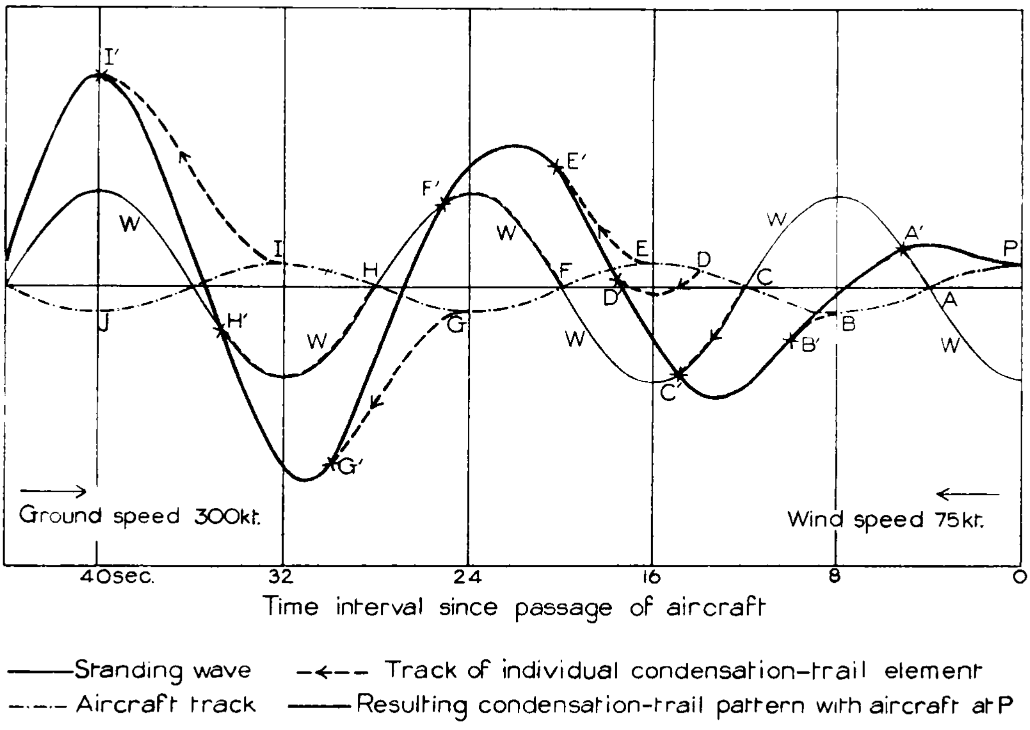

FIG. 4—GRAPHICAL CONSTRUCTION OF CONDENSATION-TRAIL PATTERN

If the attitude of the aircraft relative to the air is unchanged the aircraft will have this vertical component of air motion imparted to it at every point. For an aircraft flying up wind with airspeed V we find, on combining the ground speed $-V+U$ with the vertical component of air motion, that the trajectory of the aircraft is given by

$$z = -\frac{aU}{V-U} \sin \frac{2\pi x}{L}.$$

The track of the aircraft is thus sinusoidal 180° out of phase with the air motion, and for the numerical values of U and V chosen its amplitude is one quarter the amplitude of the standing waves.

In Fig. 4 WWW . . . is the standing-wave stream-line, and JIH . . . the resulting aircraft track. When the aircraft is at P the condensation-trail element formed 16 sec. earlier at E will have been lifted on the standing wave to E′; that at B will in 8 sec. have descended to B′, etc.; so that A′B′C′ . . . . is

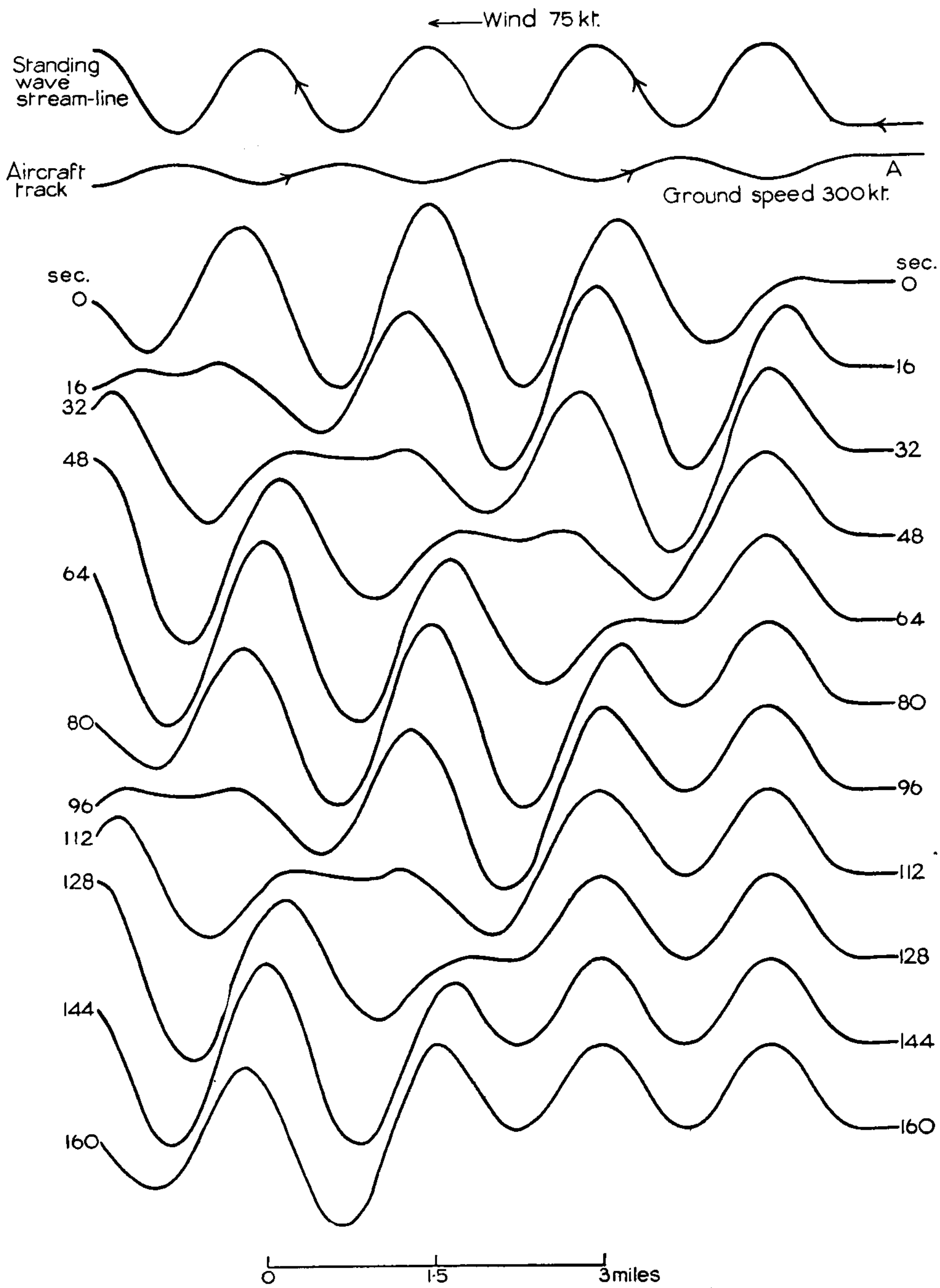

FIG. 5—VARIATION OF CONDENSATION-TRAIL PATTERN FORMED IN A STANDING WAVE

The aircraft is heading into wind. The pattern is illustrated at the times given on the left-hand side since the aircraft left the standing-wave zone at point A.

the condensation-trail pattern at this time. The interesting feature is that a wave with amplitude roughly twice that of the aircraft motion developed within ½ min. of the passage of the aircraft. The changes in the pattern from the time the aircraft leaves the standing-wave zone (Fig. 5) show how the true standing waves gradually take over from the large-amplitude waves. To an observer at the ground the whole pattern would effectively appear stationary although the early stages are not strictly so.

The graphical construction leads readily to the equation of the pattern. For an aircraft of airspeed V passing through the origin at time $t = 0$ the vertical displacement z of the condensation-trail is given by

$$z = a \sin \frac{2\pi x}{L} - \frac{V}{V-U} a \sin \left\{ \frac{2\pi}{L}\left(\frac{V-U}{V}\right)(x + Ut) \right\}.$$

For flight down wind the sign of the wind speed U must be reversed. The first term represents the standing wave, on which is superposed a sine wave with a different amplitude and wave-length moving with the wind. z has a maximum value $(2V-U)a/(V-U)$, from which it can be seen that large-amplitude waves are formed over a wide range of airspeeds for both up-wind and down-wind flight. In the example chosen $V = 375$ kt., $U = 75$ kt., z_{max} is $2 \cdot 25a$. An example of this is I′ in Fig. 4.

The pattern at the time the aircraft leaves the standing-wave zone consists of waves of approximately uniform amplitude and corresponds to the condensation-trail appearance at 1755 G.M.T., while the pattern 144 and 160 sec. later corresponds reasonably to the sketch made at 1758 G.M.T. (Fig. 1). This lends some support to the view that the waves were of standing-wave origin.

The argument above neglects the variation with height in the vertical component and the periodic part of the horizontal component of the air motion in the standing wave. It can be shown that the effects of neglecting these terms are of the second order in the amplitude.

Vertical currents.—The assumption that the wave pattern was in a vertical plane and was due to standing waves leads to a value for the standing-wave amplitude of about 350 ft. As the wind traversed one wave-length in 64 sec. this gives a mean value for the up-draughts and down-draughts of 1,200 ft./min. Bigger vertical currents than this have been reported in standing waves over the Pennines and over Scotland, but none as large over the south of England. It must be remembered however that the amplitude of the aircraft track would have been less than 100 ft., and a pilot would be unlikely to report rate of climb for this type of motion.

It is hoped that, with the steady increase of high-altitude flying, reports from pilots will show clearly whether or not orographic waves can extend to the stratosphere and will throw more light on the frequency of their occurrence.

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LEE WAVES OVER GREEN I AIR ROUTE LONDON TO SOUTH-EAST IRELAND

By E. CHAMBERS, M.A.
(British Overseas Airways Corporation)

B.O.A.C. Stratocruiser GAKGK, under the command of Capt. P. C. Fair, departed from London Airport at 1518 G.M.T. on December 23, 1954 and arrived at Shannon at 1735 G.M.T. on the first leg of a charter flight to Bermuda. The aircraft was flown at a pressure altitude of 10,500 ft. over the Green I Airway and the track is shown in Figs. 1 and 2. The airway extends westwards from Compton, which is 8 miles north of Newbury (Berkshire), and thence to Stockwood, Bristol, Newport, Strumble and Tuskar Rock, which is off Carnsore Point.

The following is an extract from Capt. Fair's voyage report:—

Between Compton beacon and the coast of Ireland a curious phenomenon was observed. A few minutes after passing Compton the airspeed fell back almost 25 kt. from 200 to 175 kt., while the aircraft maintained a constant altitude of 10,500 ft., the altitude control of the gyro-pilot being in use. I flew the aircraft by hand for about 5 min. and was able to get the airspeed back to 200 kt. Shortly afterwards the airspeed fell again. The aircraft was trimmed normally and flew in a stable manner. There was no turbulence. The airspeed again dropped about 25 kt. but gradually returned to normal. All engine instruments gave normal readings and there was no indication of overheating or loss of power. All gills, flaps and undercarriage were checked visually as far as possible and were in normal positions. All doors were checked. This loss of airspeed occurred at least four times between Compton and the Irish coast at Tuskar Rock, and each cycle of loss and build-up lasted about 6 min. There was a strong north-westerly air stream and the temperature at 10,500 ft. was about −6°C. The aircraft was flying in clear air, but all anti-ice heaters were kept on in case the loss of speed was caused by some form of clear ice. There was no indication of any form of icing. The aircraft take-off at London Airport was normal and the landing at Shannon was normal as regards airspeeds for power settings.

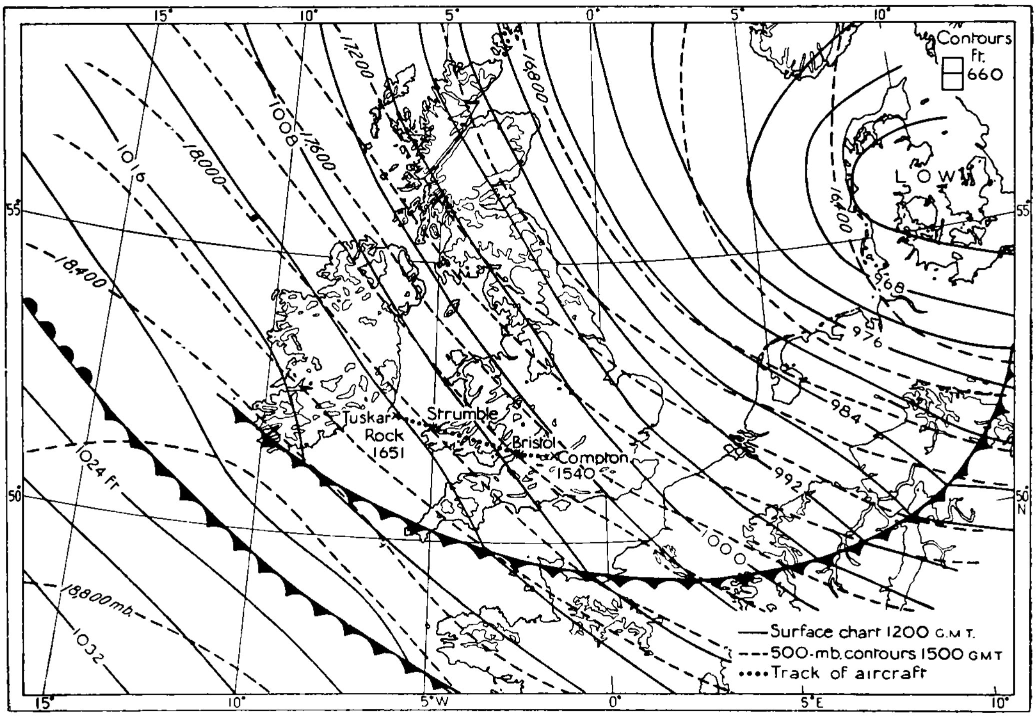


FIG. 1—SYNOPTIC CHART, DECEMBER 23, 1954

The report is interesting in the sense that there were cycles of loss of airspeed with a gradual return to normal but no corresponding increase of airspeed to above normal, and so it was not obvious to the pilots that the effect was due to atmospheric wave motion. It was thought worth while, therefore, to examine the meteorological situation in some detail, and, in particular, to apply Scorer's theory[1,2] to find out if the air-stream characteristics were favourable for the occurrence of lee waves.

Fig. 1 shows the 1200 G.M.T. surface chart and the 1500 G.M.T. contour chart for the 500-mb. level on December 23, 1954 as drawn by the meteorological office at London Airport. Pressure was low over Denmark and high north-east of the Azores and there was a cold north-westerly air stream over the whole of the British Isles. A stream of warm air flowing around the Azores anticyclone was approaching the British Isles from the Atlantic and, as would be expected, there was a well marked jet stream in the north-westerly current ahead of the warm front. Fig. 2 shows a cross-section of the wind and temperature structure of this jet stream normal to the general air flow of 310° true, and was constructed from the 1400 G.M.T. upper air reports obtained from the *Daily aerological record* and other sources.

Strong winds and high values of vertical wind shear, especially in the 750–550-mb. altitude band, were reported at various places and it is unfortunate that the French observations in Table I were restricted to

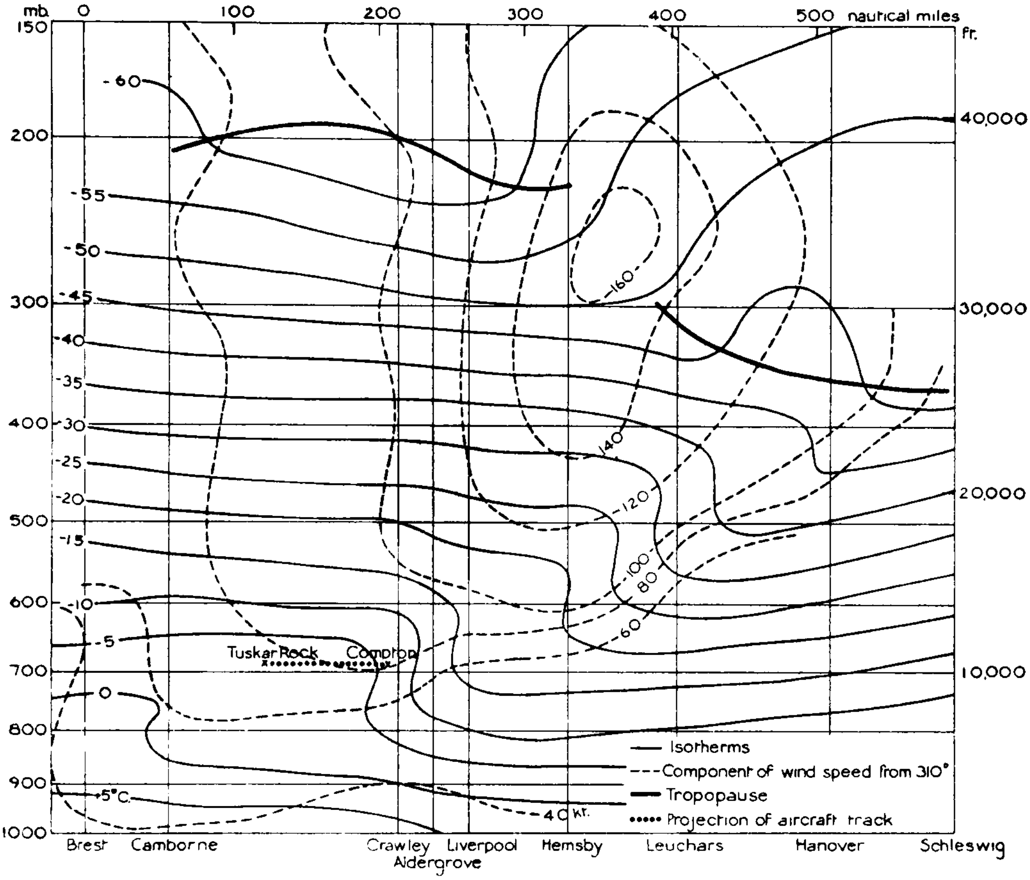


FIG. 2—VERTICAL CROSS-SECTION AT RIGHT ANGLES TO 310°, 1400, DECEMBER 23, 1954

comparatively low altitudes. The flight appears to have been made in the warm air just above the frontal surface of the cold front which is shown in Fig. 1 through Valentia and Cherbourg and it is interesting to note that there was no turbulence.

Wind-speed (component from 310°) and temperature profiles for Aldergrove and Crawley for 1400 G.M.T. are shown in Fig. 3, and it will be seen that these are essentially similar so it seems fair to assume that the Crawley data may be taken as being representative of the air mass in its undisturbed form.

Scorer[1,2] has shown that lee waves can only occur in an air stream if the parameter l^2 has lower values through a fairly deep upper layer than in the

TABLE I—UPPER AIR OBSERVATIONS, 1400 G.M.T., DECEMBER 23, 1954

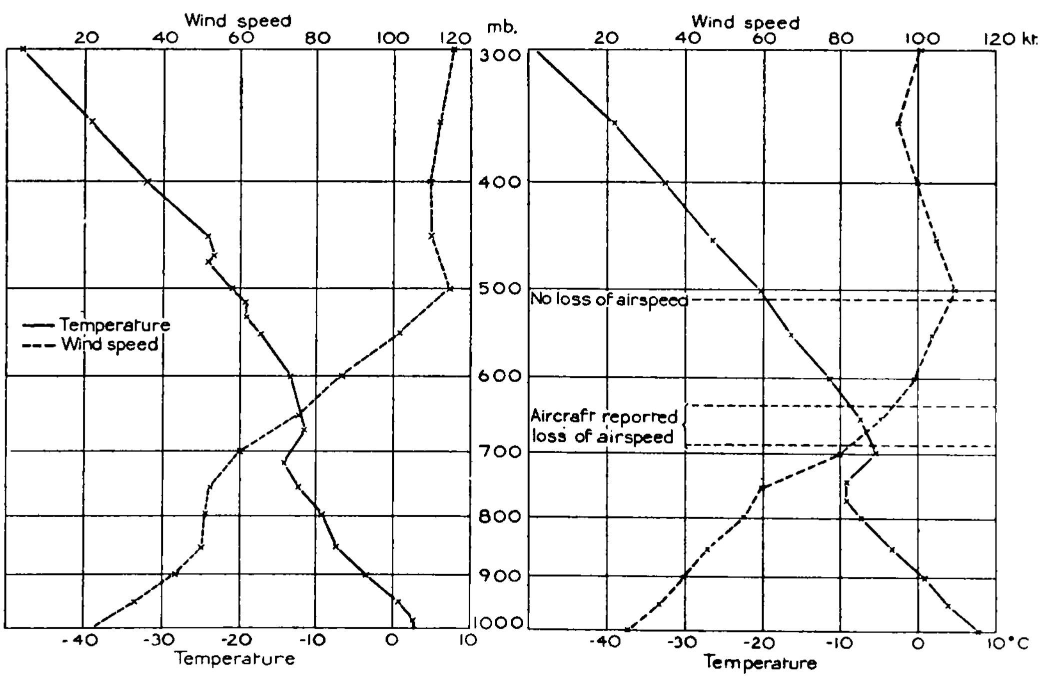
	Brest		Trappes	
mb.	°	kt.	°	kt.
519	290	142	...	...
543	300	130	...	...
553	300	124	...	...
600	300	45	...	...
650	300	41	...	...
671	...	...	300	159
700	300	39	300	124
712	...	...	300	95
750	300	45	300	66

layer below where

$$l^2 = \left(\frac{B}{U}\right)^2 - \frac{1}{U}\frac{\partial^2 U}{\partial z^2}, \quad B^2 = g\beta = \frac{g}{\theta}\frac{\partial \theta}{\partial z},$$

U is the wind speed, z the height, β the static stability and θ the potential temperature. He has also shown that the reduction in l^2 must exceed a critical value for waves to be possible and the greater the reduction of l^2 with height the greater the likelihood of waves.

A first approximation to the value of l^2 has been calculated from the Crawley data for 1400 G.M.T. on December 23, 1954, using the method of Wallington[3] and the results are given in Table II. From the surface to 950 mb. the lapse rate was adiabatic but Scorer[2] has constructed stream-lines to show the occurrence of lee waves for a three-layer model with an adiabatic layer near the surface, a layer with comparatively large l^2 above and an upper layer of small l^2. It will be seen from Table II that the inversion of temperature from 740 to 700 mb. produced large values of l^2 whilst the strong forward wind



Aldergrove Crawley

FIG. 3—WIND-SPEED (COMPONENT FROM 310°) AND TEMPERATURE PROFILES, 1400 G.M.T., DECEMBER 23, 1954

shear was the dominant factor in producing very small values of l^2 above 650 mb.

TABLE II—VALUES USED IN CALCULATION OF SCORER'S PARAMETER l^2

	B	U	B^2/U^2
mb.	hr.$^{-1}$	kt.	Km.$^{-2}$
350	42	95	0·06
400	42	99	0·05
450	35	105	0·03
500	50	110	0·06
550	32	103	0·03
600	32	99	0·03
650	62	90	0·14
700	78	79	0·28
720	110	72	0·68
750	70	59	0·41
770	37	58	0·12
800	42	55	0·17
850	17	45	0·04
900	35	39	0·23

Conditions appeared to be very favourable, therefore, for the occurrence of lee waves, and there seems to be little doubt that the Stratocruiser's loss of airspeed was due to flight at constant altitude in the descending portions of waves set up in the lee of the Welsh Mountains and probably also of the Wicklow Mountains and Cotswold Hills. It would be expected that the waves would attain maximum amplitude somewhere in the layer 750–650 mb. where the value of l^2 was a maximum, and it is interesting to note that an hour or so later two other commercial aircraft, flying at 10,500 ft. and 12,500 ft. respectively, also experienced a loss of airspeed of about 20 kt. in the region of Bristol but with no repetition of the cycle, whilst a third, at 17,500 ft., had nothing to report.

Another case worthy of mention occurred on January 16, 1955 when a B.O.A.C. Constellation aircraft flying at approximately 17,000 ft. along the east coast of Italy on a flight from Beirut to Zurich encountered standing waves continuously throughout the period 2100–2230 G.M.T. The Captain stated that, although he had flown through standing waves on previous occasions, he had never flown for so long a period in waves of such well defined regions of lift and sink. The flight was largely smooth but there were occasional short periods of moderate clear-air turbulence. As in the previous case, the waves occurred in an air stream containing strong forward wind shear on the warm side of a well developed jet stream. Very high values of vertical wind shear were reported at various places near the jet stream; Hemsby at 1400 G.M.T. on January 17, 1955 reported winds of 280° 42 kt. at 500 mb. and 280° 154 kt. at 300 mb., whilst Brindisi reported 20 kt. at 700 mb. and 110 kt. at 300 mb. The flow over Italy was south-westerly, i.e. more or less at right angles to the Apennines.

There now appears to be ample evidence to show that lee waves are very likely to occur in an air stream where the wind speed shows a marked increase with height and where there is a low stable layer, preferably an inversion, so that the parameter l^2 is large in the low layer and small above that layer. Such conditions often exist on the warm-air side of jet streams or perhaps on the cold side if subsidence has occurred in the cold air. Regions of jet streams of high values of wind shear also have a high incidence of clear-air turbulence, and it is not surprising therefore that Jones[4] has suggested a possible connexion between clear-air turbulence and standing waves. The fact remains, however, that the majority of flights in well developed standing waves are quite smooth, and the degeneration of waves into turbulent motion is difficult to substantiate.

Owing to the effect on aircraft performance, it is obviously important that pilots should be warned whenever standing waves are thought to be probable, and Scorer's l^2 criterion might profitably be used by forecasters for the purpose of providing such advice.

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METEOROLOGICAL OFFICE DISCUSSION

Winds in the outer atmosphere

The discussion at the Royal Society of Arts on Monday, November 21, 1955, on winds in the outer atmosphere was opened by Mr. P. Graystone.

Mr. Graystone defined the outer atmosphere, in this instance, as the region above 30 Km., i.e. beyond the normal present limit of radar wind observation. The variation of temperature with height was first briefly discussed. A temperature increase with height has set in by 30 Km. in most latitudes, and a peak value, somewhat above that at the surface, is reached near the top of the ozone layer. Following a temperature lapse to a temperature at 80 Km. similar to that at the tropopause, there is a further rise, possibly to very high values in the ionosphere.

The physical structure of the atmosphere was portrayed, with reference to phenomena relevant to the measurement of upper winds. The E- and F-layers, bases about 100 and 250 Km. respectively, are the principle ionospheric regions, both showing considerable diurnal fluctuation. Other phenomena indicated were sporadic E, or "clouds" of more intense ionization occurring in the lower E-layer, noctilucent clouds, usually about 80 Km., and meteors, visible at heights ranging from 50 to 150 Km.

A few other points of interest were mentioned. The composition of the atmosphere remains roughly constant, apart from minor gases, to great heights, though above 80 Km. oxygen molecules are dissociated into the atomic form, and at higher levels dissociation of nitrogen also occurs. The atmospheric pressure is approximately 10 mb. at 30 Km., 10^{-3} mb. at 100 Km. and 10^{-6} mb. at 400 Km. The mean molecular free path is of the order of 1 cm. at 100 Km. and perhaps 1 Km. at the top of the F-layer.

A fair number of measurements of wind at and just above 30 Km. have been made by the normal radar wind technique, either using very large balloons, or a double-balloon method, the maximum height so far reached being just over

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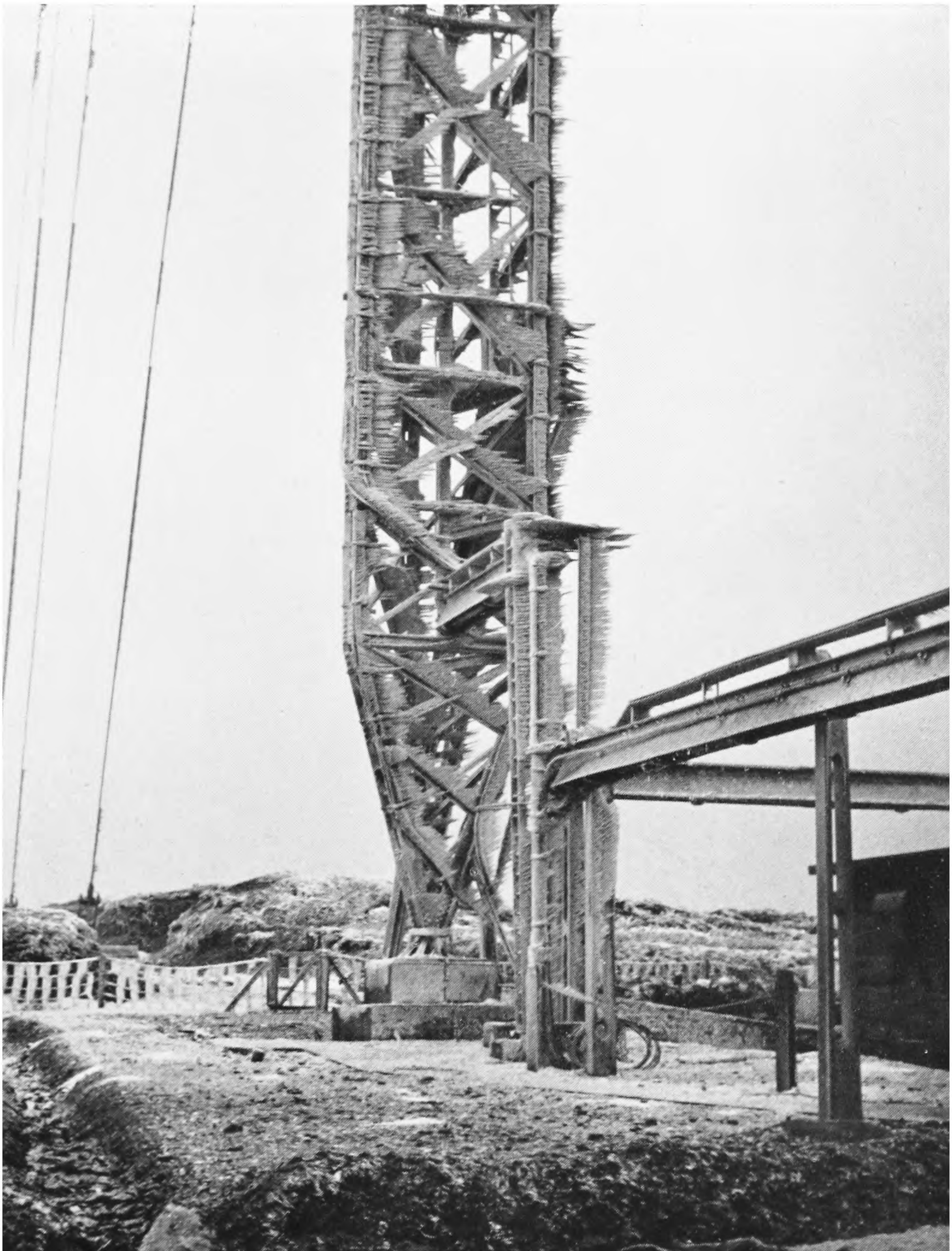

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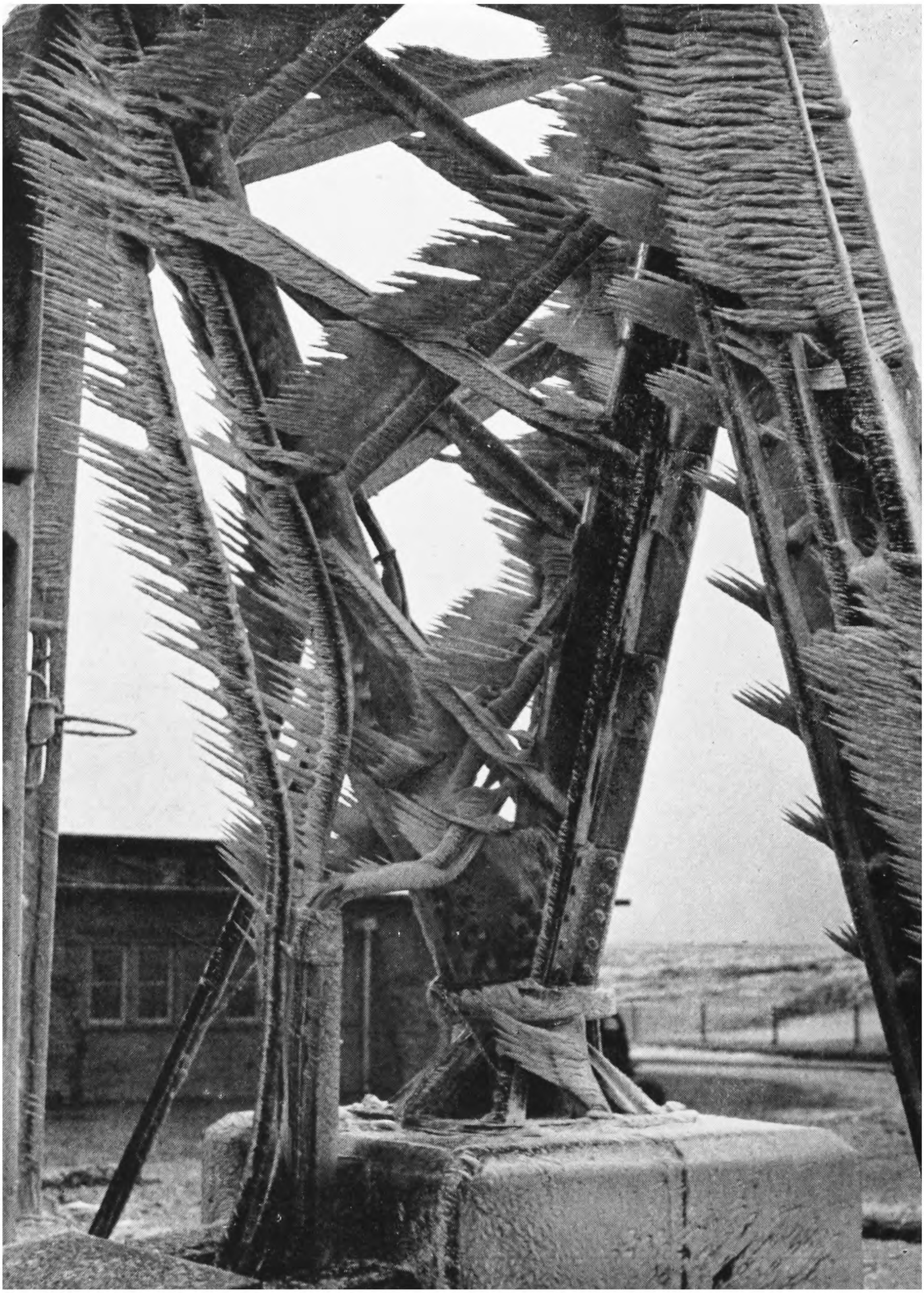
RIME ACCRETION AT B.B.C. TRANSMITTING STATION, HOLME MOSS

Base of main transmitting mast

(see p. 57)



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Base of main transmitting mast

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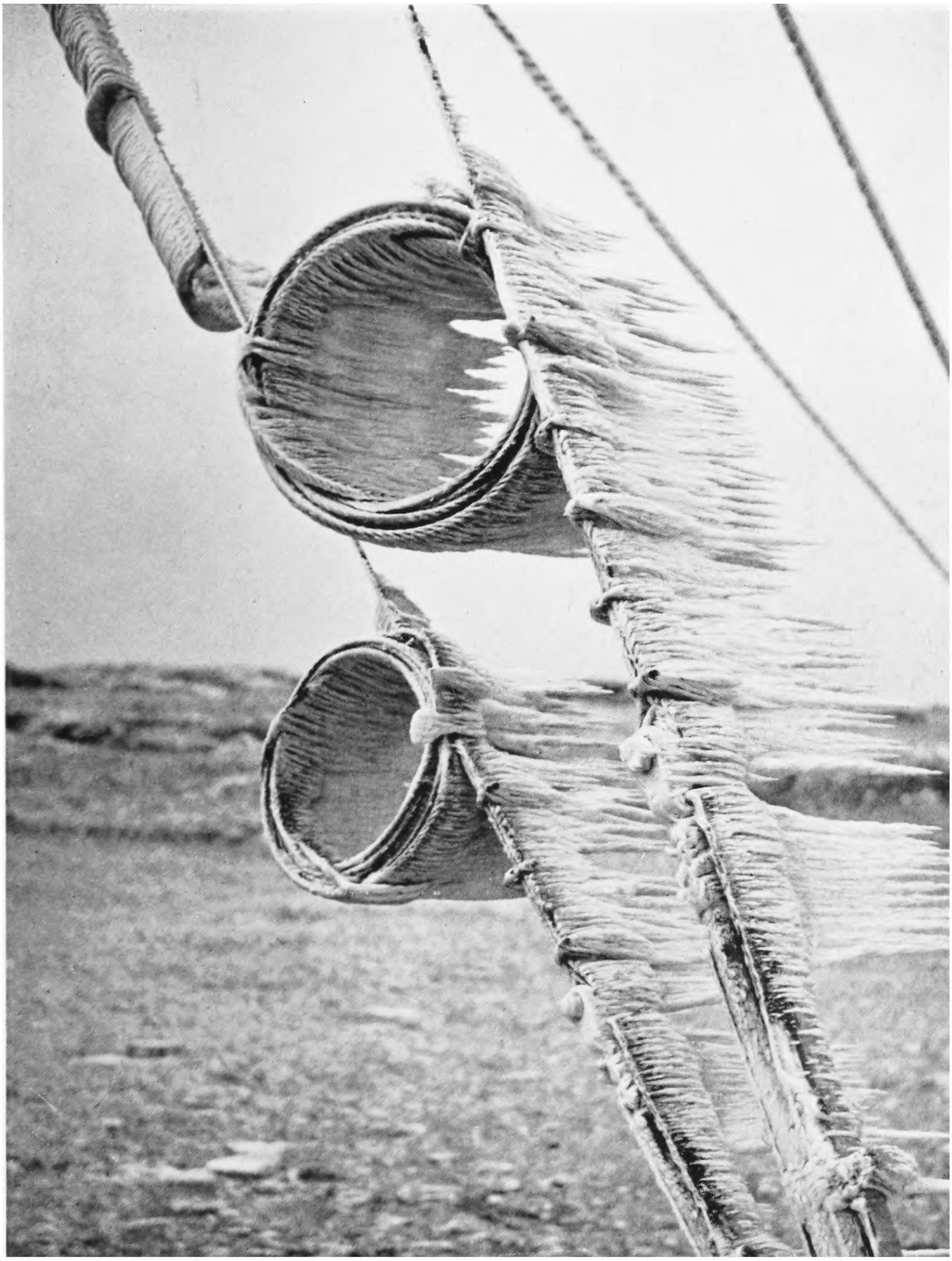

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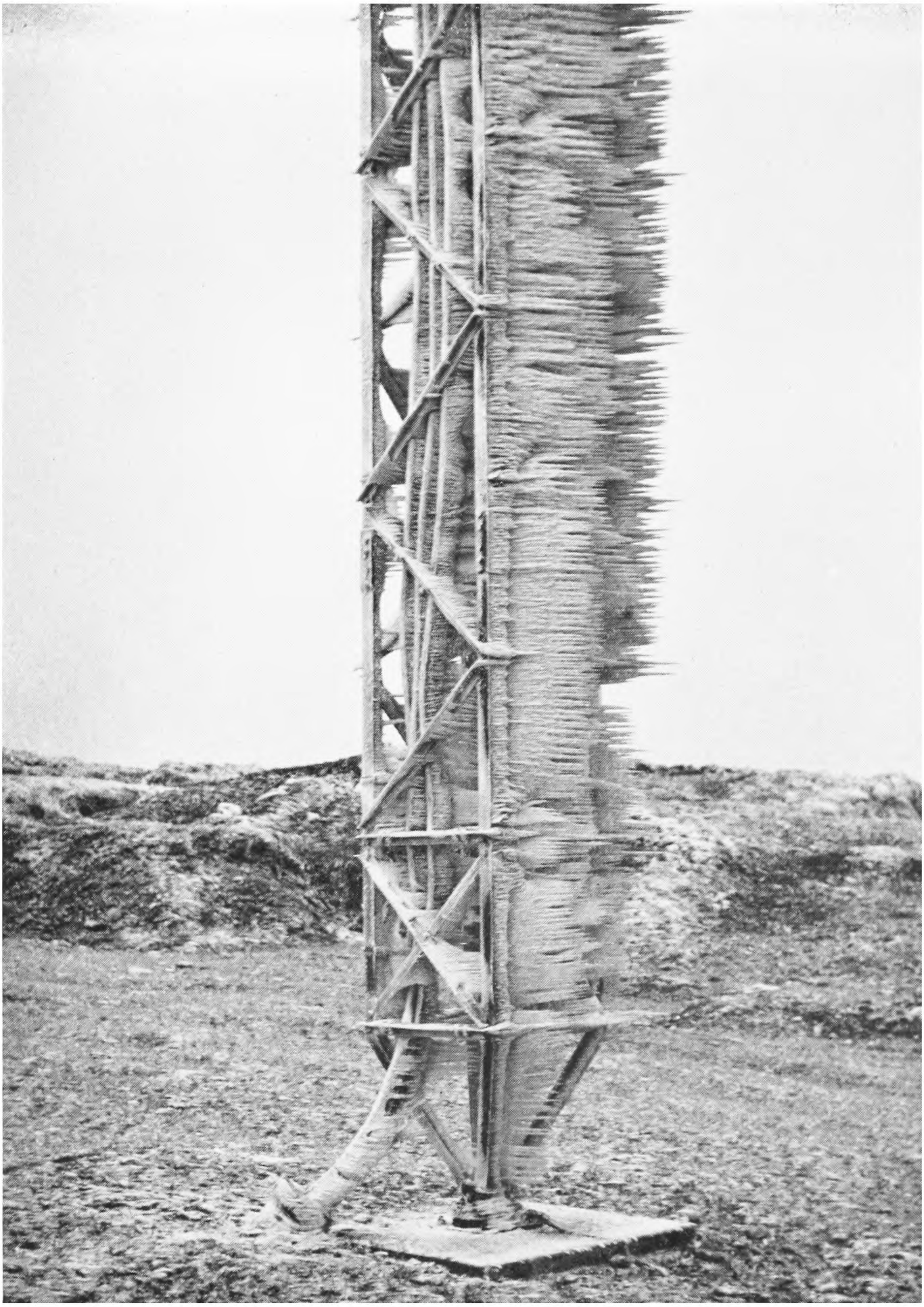

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RIME ACCRETION AT B.B.C. TRANSMITTING STATION, HOLME MOSS

The radio link mast

(see p. 57)

40 Km. Further data at 30 Km. are available from the programme carried out in this country during the last war, when the movements of smoke puffs from high-level shell bursts were recorded[1]. But at higher levels information largely depends on the movements of natural phenomena, observed visually or by radio.

The principal visual method is the observation of meteor trails. Some of these give a luminosity persisting for several seconds, and in rare cases a few hours, and observations of long-persisting trails, dating back over many years, have been tabulated by Olivier[2,3] and others. Though this is a chance method, observations compiled over a long period could be very useful, and it is unfortunate that there is doubt as to the accuracy of some of the observations. A modern variation on this method is the photography of meteor trails at intervals of a second or two. The other visual method is the observation of movements of noctilucent clouds, rather uncommon phenomena chiefly seen in summer in high latitudes when the sun is just below the horizon.

Radio techniques, however, provide the principal tool for wind measurement on a regular basis. Two quite distinct ones have been developed during the past few years. The first uses the fact that meteor trails are highly ionized, and hence that their movements at right angles to their orientation can be recorded, either by the Doppler technique, or by the variation in range. Since meteor trails can be tracked at the rate of a hundred an hour or more, a continuous record can be maintained of the mean wind over a wide area.

The other radio method uses the fact that irregularities of electron density exist throughout the ionosphere and can be recorded at ground receivers, both by reflection from the E and lower F regions, and in the upper F region by recording the "scintillation" of radio stars. Three receivers located at the corners of a right-angled triangle are used, and the "fading pattern" is normally found to be similar at each, with a time-lag of a second or two. This is taken as a measure of the velocity of the irregularity pattern, and the use of three receivers enables two wind components to be evaluated. There are doubts as to the reliability of these wind-measurement methods. The height of the irregularities recorded is uncertain, casting doubt on the F-layer velocities, and there is also the question of whether a true air movement is being recorded. Two other possibilities exist—there may be a form of redistribution of ionization occurring, or there may be a separation of the motion of ionized and neutral air. The ionized air is subject to electric and magnetic forces, and in a very rarified gas there could be a separation of velocities. This effect, unlikely in the E-layer, is a distinct possibility in the F-layer.

Sporadic E affords another method of wind measurement, principally used by Gerson[4] assisted by a large body of radio amateurs in North America. Over a period of four years, they have carried out experiments in tracking sporadic E by observing when radio contact was established and broken off between two amateurs. Lack of knowledge as to the origin and nature of sporadic E, however, make it uncertain whether true air movements can be measured in this way.

The method of acoustical propagation is one other way of recording high-level winds on a systematic basis. The marked temperature inversion in the ozonosphere assists the refraction of sound waves, so that sound waves from an explosive source can be recorded at the surface at ranges of 100–200 miles.

Observations of the time of travel of the sound wave, and of the orientation of the wave front at the receivers, enable estimates to be made of the temperature and wind structure to the top of the ozonosphere. Despite the technical difficulties involved, the fact that temperature and wind effects have to be separated and that some form of variation with height has to be postulated, the results are basically reliable, and are the only ones available for this level.

Fig. 1 illustrates the normal heights over which these methods of wind measurement are operative. It will be seen that there is a gap between 60 and 80 Km., with little information available—all the information above about 120 Km. is doubtful, if considered as air movements.

Results for the level 30–60 Km. fit into a coherent pattern, and the estimated zonal flow for summer and winter is illustrated in Fig. 2. The outstanding feature is the reversal in nearly all latitudes from westerly in winter to easterly in summer. The position of the westerly maximum in winter is uncertain—it may extend down to much lower latitudes than those indicated in the diagram. In summer there is some slight evidence that the easterly winds decrease, or even become westerly in the upper ozonosphere in high latitudes.

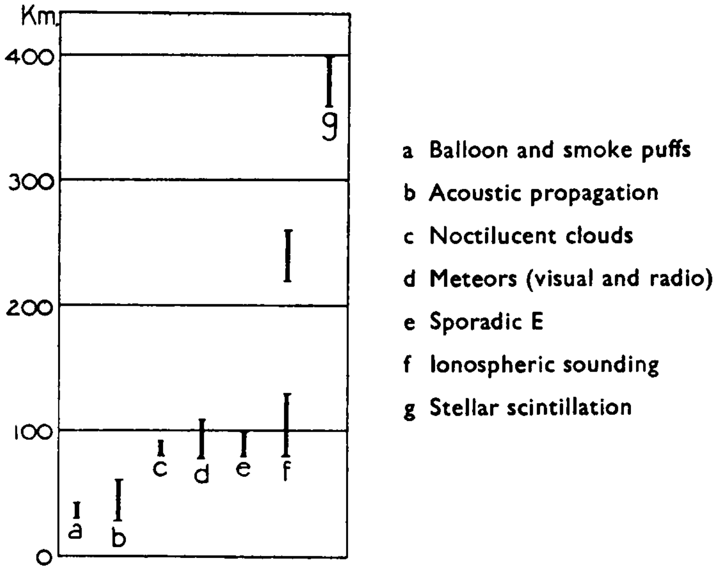
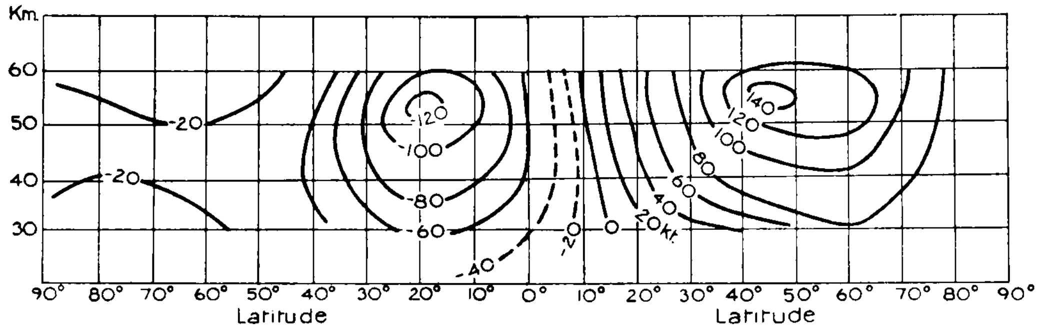


FIG. 1—HEIGHTS FOR WHICH WIND ESTIMATES ARE AVAILABLE

At higher levels no definite flow pattern has yet emerged. In and below the E-layer, there is agreement on the order of magnitude of the velocities, which has a modal value of 100–150 kt. and occasionally reaches 400–600 kt. Seasonal trends have been identified by individual workers, but it would be unrealistic at this stage to attempt to deduce a circulation pattern. Similar considerations apply to the F-layer, where velocities are similar in magnitude but occasionally reach very high values, these being apparently highly correlated with the intensity of geomagnetic activity.

Several observers have noted the existence of periodic oscillations at or near the E level, the most pronounced being a semi-diurnal variation of large amplitude representable by a wind vector rotating through 360° twice in 24 hr. Such an oscillation at the surface is readily explicable in terms of the surface semi-diurnal pressure wave; by applying the equations of motion for small perturbations, and using an empirical formula for the pressure variation, it can be shown that this entails a wind component, rotating every 12 hr., in a clockwise direction in the northern hemisphere and counter-clockwise in the southern, with an amplitude in middle latitudes of around 1 kt. On the resonance theory of the surface pressure wave, Taylor[5] and Pekeris[6] have shown that for an idealized atmosphere possessing a temperature structure similar to that now known to exist, a free period of oscillation of 12 hr. is possible, and that the resulting wind variation would undergo a 180° change of phase at 30 Km. and subsequently increase rapidly in amplitude. The observed results for the ionosphere fit the theory quite well, though the change in phase differs somewhat. Results obtained by Johnson[7] at 100 mb. fit the theory well, showing a rotation of about 1 kt. amplitude in phase with the surface oscillation.

The radio methods of wind measurement are capable of yielding much information about the spatial and temporal variations of wind in the ionosphere. The radio-fading technique usually shows rapid velocity fluctuations over a minute or two, but the interpretation of these is open to doubt. Meteor trails likewise indicate rapid velocity fluctuations, the vertical shear apparently predominating. Visual observations and the photography of meteor trails illustrate this vividly. Results in general indicate that wind variability with height and time are as great as, if not greater than, in the troposphere.



Summer hemisphere Winter hemisphere

FIG. 2—ISOPLETHS OF WESTERLY WIND COMPONENT

In conclusion, Mr. Graystone mentioned the possibility of connexions between high-level phenomena and meteorological conditions near the surface. No relation has been noticed as far as upper level winds are concerned, apart from the diurnal oscillation, but claims have been made of the existence of relationships between ionospheric intensity and various surface parameters.

Mr. Waldo Lewis, opening the general discussion, described the relation of the transient small-scale fluctuations of the earth's magnetic field to winds in the high atmosphere. During a magnetic "quiet" period, the fluctuations are regular and of small amplitude, and have components periodic in the solar and lunar day. By analysing the distribution of these fluctuations over the earth's surface, it is possible to construct a hypothetical current sheet at about 100 Km., which in turn can be explained by the dynamo action of the solar and lunar atmospheric tides, a current being induced in the conducting air by the earth's magnetic field. The currents deduced from the observed tidal flow agree reasonably well with those deduced from the magnetic observations, and direct evidence of the existence of a current sheet has now been derived from rocket observations. The magnetic variation in disturbed conditions cannot as yet be closely linked with high-level winds.

Mr. Murgatroyd described briefly an attempt he had made to explain the temperature structure below 100 Km. in terms of the absorption of solar ultra-violet radiation by oxygen and ozone. It is possible to calculate the heating if the solar spectrum outside the earth's atmosphere, the concentration of oxygen and ozone, and the absorption coefficients of these gases are known, a good deal of data about them now being available from American rocket experiments. Some preliminary unpublished calculations by Dr. R. M. Goody, Department of Meteorology, Imperial College, have been extended to all zenith angles, and hence to different seasons and latitudes, assuming constant oxygen and ozone conditions at any given height. Calculated heating rates for different solar zenith angles, and the corresponding values for summer and winter for different latitudes are given in Tables I and II. There is a

TABLE I—HEATING RATES FOR DIFFERENT SOLAR ZENITH ANGLES

Zenith angle	Height (kilometres) 30	40	45	50	60	70	80	90	100
°	*degrees Celsius per day*								
0	5	21	26	21	8	3	2	6	40
40	5	16	23	21	8	3	2	4	31
60	4	10	18	18	8	3	2	3	21
80	3	4	6	10	7	3	2	1	6

TABLE II—HEATING RATES FOR DIFFERENT LATITUDES

Latitude	Height (kilometres) 30	40	50	60	70	80	90	100
°	*degrees Celsius per day*							
	SUMMER							
0	2	6	8	3	1	1	2	10
20	2	6	9	4	2	1	3	13
40	2	7	11	3	2	1	4	15
60	3	7	12	4	2	1	3	15
80	2	8	17	8	4	1	3	16
	WINTER							
0	2	6	9	4	2	1	2	11
20	2	4	8	4	2	1	1	8
40	1	2	5	3	1	0	1	4
60	0	1	1	1	0	0	0	1
80	0	0	0	0	0	0	0	0

reversal of temperature gradient with season in the ozonosphere, the maximum heating in the hemisphere occurring at 50 Km. near the pole in summer and at 48 Km. near the equator in winter. This would produce westerly winds in winter and easterly in summer, the winter type including both mid-seasonal months, March and September. At 100 Km. there is a positive gradient of heating rate from pole to equator in winter, but an irregular one in summer, though the results here are less reliable than for the ozonosphere. Similar calculations can be made for temperature from the formula $\partial T/\partial t = KT^4$, where K, a constant of assumed grey-body radiation, is obtained from a single assumed temperature structure and then taken as constant at a given altitude. Results from this indicate a much greater gradient of "solar radiation temperature", and hence stronger thermal winds, in winter than in summer.

Mr. Bannon queried the sensitivity of these calculations to variations in ozone distribution. Mr. Murgatroyd replying considered that these were not very critical; Pressman[8], who has recently published calculations giving results similar in form though with slightly differing magnitudes, found that the variation of ozone distribution with latitude was comparatively unimportant compared with the effect of the sun's changing declination.

Mr. Graystone observed that the computed seasonal variations of temperature in the ozonosphere would result in winds many times stronger than those reported. Mr. Murgatroyd emphasized that estimations of wind and temperature gradients were qualitative at this stage. When more was known about the long-wave components of radiation and about the detailed composition of the upper atmosphere, we should have a circulation problem in terms of unequally heated air masses.

Mr. Gold referring to the relation between the surface pressure wave and upper wind variations, asked if the lag in phase of the pressure variation at high-level stations was consistent with theory. Mr. Graystone replied that the surface pressure oscillation itself differed in phase from that resulting from a solar tide, the difference presumably being attributable to thermal effects. He thought that variations in the latter might explain the phase lag with height, pointing out, however, that the observed lag might not occur in the free atmosphere. Replying to another question from Mr. Gold, Mr. Waldo Lewis said that the phase of magnetic variations agreed as well as could be expected with that of the wind variations.

Mr. G. M. Brown (University College of Swansea) spoke of ionospheric research carried out under Dr. Beynon at the University College of Swansea. There is now considerable evidence suggesting that the currents responsible for the solar "quiet day" magnetic variations flow in the E region of the ionosphere. The electrodynamics of this "dynamo" region is complicated, but it appears that vertical transport of ionization is important. Except at latitude 30–40°, corresponding to the foci of these current systems, there is an east–west component of current overhead at all stations. This current, acting across the horizontal south–north force of the earth's magnetic field, results in a vertical force, directed upwards for places on the equator side of the foci, and downwards for places on the polar side. This vertical force may be expected to lead to a distortion of the ionization in the dynamo region. From E-region studies at Swansea it had been concluded that the so-called anomalies of this region can be attributed to the influence of this vertical drift. It was possible to locate the foci along a line of longitude, while at a given station the varying influence of drift over the day could be detected, showing a maximum east–west current at about 1100 G.M.T., and a minimum about 1500 G.M.T. Mr. Brown also referred to the difference in length observed between the two cycles of wind variation, the day cycle being completed in 9 hr. and the night in 15 hr. Mr. Graystone said that this variation had been noticed by two or three observers; it did not fit the resonance theory, and if real, it would indicate that some other effect is operating. Referring to Mr. Brown's references to vertical transport of ionization, he pointed out that this would affect the validity of wind observation by the ionospheric reflection method.

Dr. Stagg inquired to what extent we were justified in talking of "winds" at all, in the ionosphere.

Mr. G. M. Brown said that ionospheric workers were concerned only with the ions and electrons, and preferred to speak of "motions" rather than winds.

Mr. Absalom said that movements of meteor trails were generally considered to represent true air movements.

Mr. Graystone thought that the frequency of collisions at 100 Km. was sufficient to talk of real "winds".

The Director doubted whether hydrodynamicists could deal with motion when the mean free path became too great, and drew attention to the importance of momentum, rather than wind velocity.

Mr. H. H. Lamb asked if the decrease in wind velocity indicated at the top of the ozonosphere was real, pointing out that this meant a reversal of temperature gradient. Mr. Graystone said it was unfortunate that information for the very interesting levels 60–80 Km. was almost totally lacking. If the results obtained from meteor-trail observations at 80–90 Km. were accepted, it would certainly mean a reversal of thermal gradient at some level below 80 Km.

Mr. Beimers, on the question of a relation between the ionosphere and surface parameters, suggested a connexion between sporadic E and thunderstorms, adding that this might mean that the movements of the two are related. Mr. Murgatroyd argued that the directions and velocities of sporadic E movements recorded by Gerson were against this.

Mr. Gold considered that the upper wind might be related to the movement of areas of thundery activity rather than of individual storms.

Dr. Sutcliffe suggested that thunderstorms could initiate sporadic E, which would then move with the wind.

Another speaker referred to the work of Fr Gherzi in relating ionospheric intensity to surface parameters.

Dr. Scrase, in answer to a question of the possibility of more accurate wind measurements at very high levels, considered that 35–40 Km. was about the limit we could reach by radar wind sounding, and thought that rockets offered the only prospect of readings at higher levels.

Mr. Oddie asked what forces were available for the maintenance of large velocity gradients at very high levels. Mr. Graystone said that there was no difficulty about the forces responsible for high velocities; the energy available from the ionization and dissociation processes had been shown to be greater than from the evaporation and condensation of water vapour at low levels. The magnitudes of the velocity gradients were however surprising.

Dr. Sutcliffe wondered what had occasioned the interest shown in very high-level winds, and asked whether it was envisaged that they would have practical importance for the Meteorological Office.

Mr. Murgatroyd argued forcibly that the whole of the atmosphere was the concern of the meteorologist. In particular he expressed his disappointment that the high-level rocket research programme should be the responsibility of the Gassiot Committee, rather than of the Meteorological Office.

Mr. Graystone drew attention to the over-statistical approach adopted by ionospheric physicists in dealing with upper winds, and called for a more synoptic investigation. He also regretted the lack of co-ordination of different methods of wind measurement.

Mr. Gold likewise held that meteorologists should not restrict themselves to that part of the atmosphere attainable by radio-soundings, and thought that ionospheric workers might expect the Meteorological Office to give information on high-level winds.

Dr. Stagg, reverting to the validity of wind observations at high levels, drew attention to the fact that aurora "pencils" extending out to about 1,000 Km. remained straight, while meteor trails were rapidly distorted. Mr. Graystone thought the two phenomena were of quite a different nature; insufficient was known about the aurora to explain the mechanism of the auroral rays. The bodily motions of these rays had been measured, and had, mistakenly he thought, been classified as winds.

Mr. G. M. Brown referred to the complexity of the problem of motions in the ionosphere, where we were concerned with electrodynamics rather than hydrodynamics.

The Director, in conclusion, agreed that the Meteorological Office need not consider itself restricted to the lower atmosphere. In thanking the visitors for their contributions to the discussion, he referred in particular to Mr. Gold's pioneer work on radiation in the high atmosphere.

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OFFICIAL PUBLICATION

The following publication has recently been issued:—

METEOROLOGICAL REPORTS

No. 16—Winds between 300 and 100 mb. in the tropics and subtropics. By A. Gilchrist, M.A.

Charts showing the mean winds at 300, 200, 150 and 100 mb. for stations in the tropics and subtropics and mean atmospheric cross-sections at 80°W., 45°E., 140°E. and 165°E. are presented for January, April, July and October 1951. A strong westerly wind belt, which is strongest in winter, exists near latitude 30° in winter and at higher latitudes in summer. This belt may be distinct from the polar jet stream; cross-sections at 80°W. for individual occasions indicate its structure. The easterly winds on the equatorial side of the westerlies reach their maximum extent in summer when a strong easterly current stretches from the Pacific across southern Asia to Africa.

ROYAL ASTRONOMICAL SOCIETY

A discussion held by the Royal Astronomical Society on Friday, November 25, 1955, on the subject of irregularities and horizontal movements of electrons in the upper atmosphere, was attended by several prominent ionospheric physicists.

The chairman, Mr. J. A. Ratcliffe, F.R.S., opened with a brief survey of existing knowledge of ionospheric irregularities and their movements, and suggested several problems for general discussion. Dr. Briggs and Dr. Greenhow presented observations of mean flow obtained by radio reflection from the E-layer and by meteor-trail operations respectively, while Dr. Beynon and Mr. Dagg illustrated results for the F-layer, using ionospheric reflection and the stellar-scintillation techniques. Mr. Jones gave results indicating an advance of phase and an increase of amplitude with height in the E-layer semi-diurnal wind rotation. Dr. Weekes considered these to be consistent with theory, but the large reported seasonal variation in phase could not be explained. A mean velocity gradient of 2 kt./Km. was found by Dr. Beynon for the F-layer.

Dr. Clemmow discussed the relation of the electron movements to air movements, and it was generally agreed that, in the case of ionized meteor trails at least, true air movements were being recorded. No simultaneous observations, using different methods at the same height, had yet been made, and Dr. Scorer urged the use of visual observations of noctilucent clouds which could be correlated with meteor-trail movements.

The nature of ionospheric irregularities was discussed, particularly interesting being the F-layer "ripples", 100–200 miles across, which moved over considerable horizontal distances. The small-scale F-layer irregularities had been found to have a similar diurnal variation over widely separated geographical locations, though this was not considered to be due to the maintenance of the irregularity pattern over long distances.

LETTER TO THE EDITOR

Use of Esperanto by meteorologists

In the course of his article, "Second Congress of the World Meteorological Organization" in the September 1955 number of this Magazine, Mr. Durward writes "It will be appreciated that one source of difficulty is that of language—translation too often alters the sense". In this connexion I should like to draw attention to a Resolution passed by the General Conference of UNESCO in December 1954, which reads as follows: The General Conference

(i) takes note of the results attained by Esperanto in the field of international intellectual relations and in the *rapprochement* of the peoples of the world

(ii) recognizes that these results correspond with the aims and ideals of UNESCO

(iii) authorizes the Director-General to follow current developments in the use of Esperanto in education, science and culture, and to this end to co-operate with the Universal Esperanto Association in matters concerning both organizations

(iv) takes note that several Member States have announced their readiness to introduce, or expand, the teaching of Esperanto in their schools and higher educational establishments, and requests these Member States to keep the Director-General informed of the results attained in this field.

In meteorological circles we have been living with the difficulty mentioned by Mr. Durward for at least a quarter of a century, and it is strange that, whilst great advances have been made in finding solutions to scientific problems connected with the weather, as far as I am aware, no serious attempts have been made even to encourage the younger generation of meteorologists to familiarize themselves with a universal language. Opinions, often based on hearsay, that Esperanto is not practicable or that something else, like basic English, would probably be better, are only too familiar but lead nowhere. I suggest the World Meteorological Organization could give a lead in this matter by following up the UNESCO resolution and fostering the use of Esperanto for a trial period of, say, 3 or 5 yr. It is in line with the best scientific traditions to conduct such an experiment, and arrive at a conclusion, either to continue or abandon the project, in the light of results. For instance, a page in the *WMO Bulletin* devoted to letters on meteorological topics and written in Esperanto would stimulate interest.

Esperanto cannot be said to be a perfect international language, but if we wait for perfection we may wait for ever. As far back as 1907 it was the most widely known and used of its numerous competitors, and the fact that it has survived 50 yr., and is now the subject of a UNESCO resolution, indicates that it is the most reasonable and practical artificial language that has yet appeared. To the meteorologist it can perhaps best be regarded as a code language, and to any one who masters the international codes contained in the World Meteorological Organization Publication No. 9, Volume A, and who also has a knowledge of French, the acquisition of a working knowledge of Esperanto is a relatively simple matter and can be a fascinating relaxation. It is entirely phonetic, and according to the "Encyclopaedia Britannica" the grammar can be learned in half an hour. In 1929, Mr. Gold, then President of the International Meteorological Organization Commission for Synoptic Information, wrote:* "I have been frequently concerned by the difficulties which are experienced in our Commission owing to differences of language . . . I do not think it is practicable for the difficulty to be satisfactorily resolved in our generation; it can only be met by the adoption of one standard language for our discussions, and this language ought to be one which is taught as part of the education of youth". The Conference of Directors in the same year adopted a resolution* which recommended "that the League of Nations should be notified of the importance for the work of the Conference and all its Commissions of an international agreement on a standard language to be used generally for international meetings and eventually taught to the youth of all nations".

Doubtless there are many readers who share the belief that the use of a universal language would be of great benefit to the science of meteorology, the advancement of which depends so much on international co-operation, but who have thought it too idealistic, or too difficult, or not worth-while. This has been the view of the majority of nationals up to now, but the minority of "pioneers" who urge otherwise and consider it is a practical proposition may, after all, be proved to be correct.

Dunstable, October 18, 1955. C. V. OCKENDEN

[The Report of the Tateno Aerological Observatory, Japan, was published wholly in Esperanto from 1926 to 1939.—Ed. *M.M.*]

NOTES AND NEWS

Rime at Holme Moss

The photographs in the centre of this magazine were taken on March 17, 1954, at Holme Moss the site of the B.B.C. television transmitter nine miles south-south-west of Huddersfield. They illustrate the formation of rime in an easterly wind during the previous few days. Holme Moss is at a height of 1,750 ft. above sea level and the main mast of the transmitter extends 750 ft. above that.

A large anticyclone covered the whole of Russia and southern Siberia on March 11, 1954, and began to spread westwards, a separate circulation splitting off the main anticyclone and settling over Scandinavia on the 12th. This new anticyclone then spread further west and became persistent over the region

* Secrétariat du Comité Météorologique International No. 3. Procès-verbaux des séances de la conférence internationale des Directeurs du Comité Météorologique International et de diverses commissions à Copenhague Septembre 1929. Utrecht 1929.

from Iceland to Scotland on the 15th; it finally retreated eastwards on the 18th. During the period from the 12th the wind at low-level stations in Yorkshire was persistently easterly or east-north-easterly with a strength between 5 and 15 kt. During the same period over Liverpool radar wind measurements at 950 mb. (about the height of Holme Moss) gave east-south-easterly winds with speed decreasing from 25–30 kt. on the 12th–13th to 10–15 kt. on the 18th.

Air temperature on the Yorkshire coast was almost constant at 37–40°F. and at Huddersfield (Oaks), at a height of 762 ft., the temperature never rose above 38°F. until the 17th when a maximum temperature of 41°F. was recorded; the mean of the temperatures at 950 mb. over Leuchars and Hemsby varied between 28½° and 31½°F. from the afternoon of the 13th until the morning of the 17th; the temperature at Holme Moss was continuously below freezing for at least four days before the photographs were taken (the temperature at 950 mb. over Liverpool was sometimes above freezing but there, in the lee of the hills, there would be a föhn effect).

The air mass was typically polar continental with an inversion of 10–15°F. extending from 2,500–3,000 ft. to about 4,500 ft. where the temperature was 38–40°F.—warmer than at sea level. Beneath this inversion was a continuous sheet of North Sea stratus with base normally at about 800 ft. but occasionally lifting during the day to 1,000–1,200 ft. Not until the 16th did the cloud lift to 2,000 ft. or higher when it began to break in the afternoon.

At Holme Moss the cloud was down to the surface until the 17th, and with temperature a few degrees below freezing rime formed on all surfaces exposed to the wind. Rime builds up into the wind as each supercooled cloud particle strikes and freezes on to any exposed object. The characteristic horizontal feathery "icicles" illustrated in the photographs are then formed, each pointing into the local wind direction. In this connexion the "icicles" near the base of the large transmitter mast (on the north-north-west side of the buildings) are particularly interesting because they show a consistent down-draught in the lee of the buildings almost free from eddies. The smaller radio-link mast, illustrated in the photograph facing p. 49, is clear of the buildings (north-east of the main mast) and only shows horizontal "icicles"; close to the ground these "icicles" are shorter as would be expected with the lower wind speed (and therefore lower number of passing cloud particles) at that level. The ground itself shows only slight accumulations of ice for the same reason, but moorland grass was reported to be exhibiting the "icicles" in miniature. These would be more pronounced on the crests of hillocks as can be seen by the increased whiteness on some of the photographs.

There was no snow during this period, and therefore the "icicles" are not smothered and concealed as was the ice on the radio-telephone towers on Great Dun Fell, Cumberland, illustrated in the October 1951 *Meteorological Magazine.*

During March 17 (maximum temperature of 41°F. at Huddersfield), the stratus cloud lifted and the air became warmer. Whilst the photographs were being taken some of the "icicles" broke off and fell in great masses, deluging the photographer in a rain of ice.

Despite the accumulation of ice on the transmitting aerials there was no effect on transmission from Holme Moss.

P. B. SARSON

Extension of area forecasts for shipping and a new service for ships sailing from London

From November 1, the Atlantic weather bulletin for shipping transmitted from Portishead Radio Station has included forecasts for the areas "Denmark Strait" and "North Iceland" covering a period of 24 hr. from the time of issue.

Forecasts for these two areas give surface-wind force and direction with the addition of air temperature when this is expected to be below freezing. The importance of these additional forecasts to the large number of trawlers which fish in this area is considerable. The British trawlers *Lorella* and *Roderigo* were both lost on January 26, 1955, with no survivors, within a few miles of each other in an approximate position 67½°N. 21°W. The court of inquiry, which held an investigation into this disaster, found that "the vessels capsized and foundered due to the unusual and unpredictable combination of a heavy gale, high seas and the loss of stability due to the heavy accumulation of ice on the upper structures", and stress was laid on the fact that the disaster occurred, not as a result of a prolonged north-easterly gale alone but because it was associated with persistent low temperatures. Thus for the benefit of trawlers operating in this area the importance of including air temperature when this is expected to be below freezing, as well as wind force and direction, becomes obvious.

The "Denmark Strait" area extends to the middle of that Strait (about 100 miles from the Icelandic coast); its southern limit is the parallel of 65°N. extending from the Icelandic coast to the meridian of 30°W., and its eastern limit the meridian of 19° W. extending from the Icelandic shore to 68°N.

The "North Iceland" area also embraces an area about 100 miles off the coast. Its western limit will be the meridian of 19°W. extending from the Icelandic shore to 68°N. and its south-eastern limit will be along the northern limit of the "South-East Iceland" area extending from the Icelandic shore to the position 64°N. 10°W.

Another new service provided by the Meteorological Office for shipping with the co-operation of the Elder Brethren of Trinity House and British Railways began on November 21; ships sailing from London are now provided with a prebaratic chart which is taken aboard by the pilot when he joins the ship at Gravesend. The chart is prepared at the Meteorological Office in Victory House, London, in sufficient time to catch the 9 a.m. train to Gravesend, and it is thus available to the pilots by about 11 a.m. each day, Sundays included. The information on the chart includes a brief statement about the general synoptic situation, a forecast (prebaratic) chart for "midnight tonight" showing the North Sea, Iceland, Greenland and the Atlantic as far as 40°W., and a statement of the sea-area forecasts for 24 hr. from 0600 G.M.T. for the "Thames estuary", "North Sea", "south coast" and "south-west approaches to the English Channel".

Charts of standard vector deviation of wind

It was stated in the *Meteorological Magazine* for May 1955, that a limited number of charts of average vector wind distribution over the world at 500, 300, 200 and 100 mb. for the four seasons were available for purchase.

Corresponding charts of standard vector deviation of wind at 300, 200 and 100 mb. have now been reproduced, representing revisions of those published in *Geophysical Memoirs* No. 85 (which gives values at 130 mb. not 100 mb.).

Combined sets of the two charts (16 average vector wind and 12 standard vector deviation) size approximately 13 in. × 16 in. are now available for purchase, price £1 8*s.* 0*d.* plus postage (6½*d.* in the United Kingdom) on application to the Director, Meteorological Office, Kingsway, London, W.C.2.

REVIEWS

Theoretische Hydromechanik. Band II. By N. J. Kotschin, I. A. Kibel and N. W. Rose. Translated from the Russian and technically edited by K. Krienes. 9½ in. × 6¾ in., pp. viii + 569, *Illus.*, Akademie-Verlag, Berlin, 1955. Price: *DM* 48.

The first volume of this work, dealing with inviscid fluids, was reviewed in the *Meteorological Magazine**. The present volume, which presumably completes the work, is devoted to the study of gas dynamics (compressible flow), viscous fluids and turbulence.

"Gas dynamics" is not a very happy term, and here it is taken, as usual, to imply the study of fluids of relatively small volume moving at high speed. It thus embraces those aspects of fluid dynamics that are of importance in ballistics, turbine design, rocket construction, etc., and as such does not often concern the meteorologist. Much of the text also relates to problems arising in high-speed flight and, as might be expected, there is considerable use of the method of characteristics which has found application also in the meteorological field. This section of the book, written by Kibel and occupying the first 240 pages, is a very good and clear account of the main features of compressible flow that have yielded to analysis.

The second chapter deals with viscous flow. This takes up about 260 pages and is mainly written by Kotschin. It covers the ground adequately, beginning with a full discussion of the Navier-Stokes equations in their various forms (rectilinear, cylindrical and spherical co-ordinates), the vorticity equation, similarity relations (Reynolds and Froude numbers), and the conduction of heat. After this come the various well known applications, such as Poiseuille's law and the diffusion of vorticity. The two limiting cases of small Reynolds number (influence of viscosity dominant as in Stokes law for a sphere) and of large Reynolds number are then discussed. The case of small friction (large Reynolds number) introduces the boundary-layer theory, which is also dealt with thoroughly.

The final section of the book, written by Kibel, deals with turbulence. It is refreshing to find that at last there is a textbook which is prepared to devote some space to a mathematical discussion of Reynolds's rules for forming mean values and the conditions under which these are valid. The subsequent discussion of technical problems is somewhat brief, but most of the techniques that have proved fruitful, such as the mixing-length concept and the statistical-mechanics approach of Taylor, are included, and there is a mention of the work of Kolmogoroff. Meteorological applications do not receive much attention, but this is not unexpected in a book that is intended to cover fluid mechanics in general.

The impression left on the reviewer is that this volume, like the first, is a very workmanlike job, and can be thoroughly recommended. It is to be doubted if there is a book of similar length in English that covers the ground as well, and

* *Met. Mag., London,* **84,** 1955, p. 27.

one is filled with admiration for the way in which the topics have been selected and discussed. Anyone who seeks to become proficient in this difficult field of mathematical physics could hardly do better than to study this treatise. Finally, the text, possibly because it is a translation, is written in a style that offers few difficulties even to those who (like the present reviewer) learned to read scientific German rather late in life. In this respect it is a welcome relief from the average *Handbuch.*

O. G. SUTTON

Degree of wintriness. By B. D. Kyriazopoulos. *Meteorologica* No. 1. $9\frac{1}{2}$ in. $\times 6\frac{1}{2}$ in., pp. 25, *Illus.*, University of Salonika, 1954.

This little paper, written in English, contains a reasoned presentation of an index of wintriness in Thessaloniki (Salonika) obtained by adding together

(i) the sum of all minimum temperatures $\leqslant$ 0°C.

(ii) the sum of all minimum temperatures $\leqslant$ −4°C.

(iii) the number of observations with temperature $\leqslant$ +3°C. at the observation hour

(iv) the number of days with average cloud cover at the three observations $\geqslant$ 8 tenths

(v) the number of days with precipitation (> 0·0 mm.)

(vi) twice the number of days with snow-cover

In 45 winters (1891–1910, 1928–1954) the resulting index varied from 98 in 1901–02 ("mild") to 457 in 1941–42 ("severe"). The temperature contribution, items (i)–(iii), ranged from 9·5 to 367·5; the contribution due to cloudiness, rain and snow-cover, items (iv)–(vi), was always between 50 and 176.

The severer two thirds of the winters were all so rated mainly on account of high values of the low-temperature contribution; only one of these winters (1953–54) had a "humidity" contribution higher than in the mild winters. The winter of 1953–54 seems to have been of a highly unusual type in this respect, dull, wet, snowy and severe. Other severe winters were generally dry, though the numbers of cloudy days were subject to a good deal of variation; the average winter rainfall in the 16 milder winters was 176 mm. as against 143 mm. in the remaining (normal and severe) winters.

In the reviewer's opinion this paper is chiefly of interest for its statement of the different make-up of different winters, whereas an index which adds up, and purports to measure, all these unlike characteristics on a single scale is meaningless.

H. H. LAMB

Meteorologia por correspondencia. Nos. 3 and 4. $9\frac{1}{4}$ in. $\times$ $5\frac{1}{4}$ in., pp. 4, *Illus.*, Instituto de Estudios Superior, Sociedad Meteorológica, Montevideo, 1954.

The Meteorological Society of Uruguay is publishing a series of folders entitled "Meteorologia por correspondencia" giving elementary lessons in meteorology. Nos. 3 and 4 have been sent to us. The first of these contains short articles on the qualities needed in a meteorological observer, on the questions he should ask himself when making an observation, and on the sun. Accompanying them are sheets giving graphical methods of recording observations and a climatological record form for the month.

G. A. BULL

Fish rain in Western Macedonia. By G. C. Livadas. 9½ in. × 6¾ in., pp. 12, *Illus.*, University of Salonica, Meteorological Institute, Salonica, 1954.

This publication of the Meteorological Institute of the University of Salonica describes the circumstances attending the fall of a large number of fish at the village of Alona in northern Greece (about 90 miles west of Salonica).

The fish were found on the morning of October 15, 1951, scattered in groups on the ground and in trees over an area of about ½ square mile. Samples examined by an ichthyologist showed that some at least of the fish came from a lake about 25 miles to the east of Alona. A strong NE. wind blew during the night with showers. The author concludes that a waterspout formed over the lake sucking up the fish which were then dropped to the westward.

G. A. BULL

ERRATA

September 1955, PAGE 295, line 29; *for* "On the islands and coasts of north and west Scotland sea fog and low cloud kept temperatures in the fifties for most of the month." *read* "Over north and west Scotland there were many gloriously sunny days on which temperature rose to over 70°F. but fog and low cloud restricted bright sunshine on some days in coastal districts, especially in the mornings."

November 1955, PAGE 349, equation (3) and both parts of equation (4); *for* "U_{gr}" *read* "U_{gs}".

METEOROLOGICAL OFFICE NEWS

Retirement.—Mr. E. D. Dent, Experimental Officer, retired on December 31, 1955. He joined the Office in January 1927 and during his service has worked both at Headquarters and outstations. Since 1948 he has served in three branches at Harrow. Mr. Dent saw military service during the whole of the First World War, 1914–18, and during the latter part he served with the Royal Air Force.

Ocean weather ships.—The following is an extract from the report of the Meteorological Officer-in-Charge aboard the *Weather Recorder* during voyage 64 (October 27 to November 30, 1955) when the ship was on duty at Station A.

"A fund was inaugurated this voyage whereby the staff filling balloons were fined ½*d.*/ft. by which the rate of ascent was outside the required limits, the proceeds to go towards a pre-sailing Christmas party for the meteorological staff. An interesting result was the fact that no improvement in rate of ascent evolved, hard as the staff tried! Dinner and a visit to a show in Glasgow are now envisaged, the night before sailing."

WEATHER OF DECEMBER 1955

The main Atlantic depression track was further south than normal and the depressions largely travelled due east between 50° and 60°N., passing across or near to the British Isles and over Europe, though there were also some deep centres off the coast of north Norway. One depression from the Atlantic became rejuvenated and had a depth of 976 mb. over central Russia on the 14th. The Azores and continental anticyclones were both weaker and farther from Europe than usual. As in recent months the anticyclone over the polar ice was again prominent and unusually intense (monthly mean pressures 6–10 mb. above normal on the Arctic coasts of north-east Siberia and Alaska, monthly mean pressure 1028 mb. north of the New Siberian Islands at approximately 77°N. 160°E.). Maximum pressure anomalies in the Atlantic–European sector were −13 mb. off the Norwegian coast in 65°N. 5°E., −12 mb. near Stockholm and −10 mb. in mid ocean at about 45–50°N. 35–40°W.

The distribution of temperature anomalies was very similar to the previous month with cold areas dominating the Canadian Rockies (greatest anomaly −8°C.) and the broadest part of North America south-east thereof, also a less extensive but even bigger negative anomaly over northern Europe (−10°C. over central Finland). Europe south of 55°N. was a little milder than usual thanks to the prevailing westerly winds. Northern Siberia, north of about 55°N., was colder than usual in December. After a relatively mild November, most stations around the fringe of the polar ice again registered negative anomalies of 1° or 2°C.

The month had above-normal precipitation over most of northern, central and south-western Europe but was dry in the Balkans and most of the Mediterranean. Two or three times the normal precipitation was measured in western Spain, the eastern Alps, eastern Germany, Sweden and central Norway.

In the British Isles the main feature of the month was the large variations of temperature due to the frequent incursion of polar or arctic air from the north. This affected much of the country during the 7th, 10th–12th, 17th–22nd and 30th–31st, but otherwise the weather was mild and changeable.

During the first week the weather was of a mild westerly type, though slight air frost occurred in places at night. Fog was fairly frequent night and morning, and persisted locally until late afternoon on the 2nd. There were occasional rain and showers, heavy at times, in the north and west, with thunder on the 2nd and 3rd in north Scotland and the Hebrides. On the 7th, an anticyclone over Greenland intensified, and cold arctic air subsequently swept southward to the English Channel, but on the 9th a large and complex depression crossed Scotland bringing mild air back over the country; there was widespread rain preceded in the north by snow; 1½ in. fell at Leuchars in the 24 hr. ending 0900 on the 10th. Arctic air again broke through to much of the British Isles on the 10th, and the following day a ridge of high pressure developed south-eastwards from Greenland giving a south-easterly air stream over England. Fronts, which were held quasi-stationary by this air stream, gave considerable rain and sleet over the south and south-west of the country; at 2100 on the 11th Aberporth measured over 1 in. of rain which had fallen in 12 hr. A deep depression on the Atlantic brought mild cloudy weather slowly back over the country on the 13th, the warm air being preceded by fog and rather prolonged rain and snow; there was widespread rain, heavy at times, also on the 14th and 15th. On the 16th, the near freezing temperatures, which had persisted in the Shetlands since the 10th, began to spread southwards as a ridge from the Greenland anticyclone developed over the British Isles, and early on the 19th there was keen or hard frost over most of the country; Elmdon recorded a screen temperature of 16°F. with 5°F. on the grass. For several nights very low temperatures were reported from parts of Scotland including 8°F. at Dyce on the 21st–22nd with 2°F. on the grass. A depression moved across southern England on the 20th giving widespread rain or sleet in the south and snow further north; there were prolonged and heavy falls east of the Pennines, and in many parts of Yorkshire snow lay to a depth of more than 12 in. It was not until the 22nd that the weather reverted to a mild westerly type which, once established, persisted until after Christmas. Christmas-day was generally fine in the east but rain spread to western districts during the afternoon, and thereafter troughs from a complex depression near Iceland maintained widespread and locally heavy rain over the country for the next two days with a gradually rising temperature. Temperature did not fall below 50°F. over most of England and Wales on the night of the 27th–28th, and 55°F. at Ross-on-Wye was a record high minimum for a December night. On the 28th temperature reached 59°F. in East Anglia and in Yorkshire, and the maximum, 58°F., recorded on the Air Ministry roof at Kingsway London had not been exceeded in late December since records began there in 1940. On the night of the 29th–30th there was heavy rain over south England and south Wales as a secondary depression moved along the English Channel, but thereafter weather became progressively colder as squally north-westerly winds with occasional showers became established over the country.

Mean temperature varied from 4°F. above the average in the south to 4°F. below average in the north, and while sunshine was about average over the country as a whole there was an excess in Scotland and eastern England and a deficit in the west. Rainfall was above average in Scotland and northern England but was below in much of East Anglia, the Midlands, north Wales and Northern Ireland. In spite of the rain, some of the heaviest land is still not ploughing easily, but most seed beds have been good with quick germination. Farm work has gone on without hindrance and is more forward than it has been at this date for a considerable number of years. Most winter cereals look well and the sugar-beet harvest is virtually complete. Supplies of winter fodder remain good and seem adequate to withstand a hard winter.

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 ...	60	9	+2·3	109	+2	104
Scotland	58	−4	−0·8	146	+2	120
Northern Ireland ...	57	18	+1·0	117	−1	83

RAINFALL OF DECEMBER 1955

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·03	85	*Glam.*	Cardiff, Penylan ...	5·96	119
Kent	Dover	2·36	77	*Pemb.*	Tenby	6·43	129
„	Edenbridge, Falconhurst	3·12	95	*Radnor*	Tyrmynydd	7·37	90
Sussex	Compton, Compton Ho.	4·88	116	*Mont.*	Lake Vyrnwy	8·58	122
„	Worthing, Beach Ho. Pk.	3·67	122	*Mer.*	Blaenau Festiniog ...	14·64	116
Hants.	St. Catherine's L'thouse	5·23	165	„	Aberdovey	4·49	94
„	Southampton (East Pk.)	4·20	115	*Carn.*	Llandudno	3·52	121
„	South Farnborough ...	2·58	89	*Angl.*	Llanerchymedd ...	4·56	104
Herts.	Harpenden, Rothamsted	2·44	86	*I. Man*	Douglas, Borough Cem.	6·34	128
Bucks.	Slough, Upton	2·13	85	*Wigtown*	Newton Stewart ...	5·70	105
Oxford	Oxford, Radcliffe ...	3·09	126	*Dumf.*	Dumfries, Crichton R.I.	5·56	130
N'hants.	Wellingboro' Swanspool	2·01	86	„	Eskdalemuir Obsy. ...	8·07	115
Essex	Southend, W. W. ...	1·43	72	*Roxb.*	Crailing...	3·69	137
Suffolk	Felixstowe	1·48	71	*Peebles*	Stobo Castle	5·15	136
„	Lowestoft Sec. School ...	1·24	53	*Berwick*	Marchmont House ...	3·95	141
„	Bury St. Ed., Westley H.	1·48	61	*E. Loth.*	North Berwick Gas Wks.	3·55	166
Norfolk	Sandringham Ho. Gdns.	1·87	74	*Midl'n.*	Edinburgh, Blackf'd. H.	4·02	172
Wilts.	Aldbourne	3·51	109	*Lanark*	Hamilton W. W., T'nhill	5·95	138
Dorset	Creech Grange... ...	6·48	147	*Ayr*	Prestwick	4·34	124
„	Beaminster, East St. ...	6·08	127	„	Glen Afton, Ayr San. ...	9·41	147
Devon	Teignmouth, Den Gdns.	5·27	125	*Renfrew*	Greenock, Prospect Hill	9·19	123
„	Ilfracombe	5·99	124	*Bute*	Rothesay, Ardencraig ...	8·11	149
„	Princetown	13·89	120	*Argyll*	Morven, Drimnin ...	8·34	106
Cornwall	Bude, School House ...	5·68	130	„	Poltalloch	8·39	132
„	Penzance	8·19	144	„	Inveraray Castle ...	14·03	141
„	St. Austell	6·95	114	„	Islay, Eallabus	7·02	118
„	Scilly, Tresco Abbey ...	4·46	95	„	Tiree	6·29	120
Somerset	Taunton	5·17	156	*Kinross*	Loch Leven Sluice ...	6·60	168
Glos.	Cirencester	3·86	111	*Fife*	Leuchars Airfield ...	4·35	176
Salop	Church Stretton ...	3·49	99	*Perth*	Loch Dhu	14·81	147
„	Shrewsbury, Monkmore	2·20	90	„	Crieff, Strathearn Hyd.	6·98	156
Worcs.	Malvern, Free Library...	2·35	85	„	Pitlochry, Fincastle ...	6·09	151
Warwick	Birmingham, Edgbaston	2·36	80	*Angus*	Montrose, Sunnyside ...	5·01	180
Leics.	Thornton Reservoir ...	1·60	60	*Aberd.*	Braemar	5·79	163
Lincs.	Boston, Skirbeck ...	1·63	76	„	Dyce, Craibstone ...	5·69	168
„	Skegness, Marine Gdns.	1·54	70	„	New Deer School House	6·01	176
Notts.	Mansfield, Carr Bank ...	2·20	76	*Moray*	Gordon Castle	5·35	199
Derby	Buxton, Terrace Slopes	5·89	104	*Nairn*	Nairn, Achareidh ...	4·51	220
Ches.	Bidston Observatory ...	3·00	113	*Inverness*	Loch Ness, Garthbeg ...	7·08	154
„	Manchester, Ringway...	3·35	110	„	Glenquoich	...	...
Lancs.	Stonyhurst College ...	7·05	145	„	Fort William, Teviot ...	11·99	118
„	Squires Gate	3·31	106	„	Skye, Broadford ...	12·13	135
Yorks.	Wakefield, Clarence Pk.	2·78	114	„	Skye, Duntuilm ...	7·38	118
„	Hull, Pearson Park ...	2·90	120	*R. & C.*	Tain, Mayfield... ...	5·03	177
„	Felixkirk, Mt. St. John...	2·51	104	„	Inverbroom, Glackour...	9·79	133
„	York Museum	2·69	120	„	Achnashellach	13·22	139
„	Scarborough	3·96	166	*Suth.*	Lochinver, Bank Ho. ...	5·70	102
„	Middlesbrough... ...	2·12	109	*Caith.*	Wick Airfield	4·86	158
„	Baldersdale, Hury Res.	7·35	191	*Shetland*	Lerwick Observatory ...	4·86	101
Norl'd.	Newcastle, Leazes Pk....	2·82	120	*Ferm.*	Crom Castle	3·92	95
„	Bellingham, High Green	4·29	118	*Armagh*	Armagh Observatory ...	4·13	132
„	Lilburn Tower Gdns. ...	4·54	173	*Down*	Seaforde	6·16	150
Cumb.	Geltsdale	4·03	105	*Antrim*	Aldergrove Airfield ...	3·93	115
„	Keswick, High Hill ...	8·28	124	„	Ballymena, Harryville...	4·34	98
„	Ravenglass, The Grove	5·05	110	*L'derry*	Garvagh, Moneydig ...	5·07	126
Mon.	A'gavenny, Plâs Derwen	7·47	152	„	Londonderry, Creggan	3·98	91
Glam.	Ystalyfera, Wern House	8·88	106	*Tyrone*	Omagh, Edenfel ...	5·47	129

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METEOROLOGICAL OFFICE

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APPLICATION OF RADIATION AND LAG CORRECTIONS TO TEMPERATURES MEASURED WITH THE METEOROLOGICAL OFFICE RADIO-SONDE

By F. J. SCRASE, Sc.D.

In a previous paper[1] the writer described a method of deriving the radiation errors of the Meteorological Office radio-sonde from the rates of absorption of radiation and loss of heat by forced convection by the temperature element and its shield. The purpose of the present paper is to describe the practical application of the method to the routine measurements of the upper air temperature.

The simplified expression for the temperature error is

$$S - T = \frac{Q}{q} - k\frac{dS}{dt}, \qquad \ldots\ldots (1)$$

where T is the true air temperature, S the observed temperature, Q the radiation absorption rate, q the heat transfer coefficient and k the lag coefficient or time constant (which is equal to C/q, where C is the heat capacity of the thermometer). The expression is simplified since each of the terms on the right-hand side should represent the separate effects of the thermometer element and its radiation shield. There are a number of factors which affect Q, q and k, and therefore the temperature errors, but which do not vary systematically. These are the absorption factors of the temperature element and its shield, the albedo of the earth, clouds and air below the radio-sonde, the rate of ascent and the swinging of the radio-sonde. All these may vary from one sounding to another but it is impracticable in routine work to take full account of the variations. The best that can be done is to adopt values which are representative of average conditions.

Variable factors affecting the errors.—*Absorption factors.*—The value of the absorption factors used in the previous paper[1] were obtained from laboratory measurements of random samples of the temperature elements and shields. So long as the materials and surface finish at present specified for their components remain unchanged the values for individual radio-sondes will not differ much from these values.

Albedo.—The radiation absorbed by the temperature unit after reflection from earth and cloud surfaces is roughly 25 per cent. of the total absorption. Variations in the albedo may therefore be quite significant. For example, a change of 0·1 in the albedo alters the radiation error by about 7 per cent., except at low solar altitudes where the effect is smaller. It is not practicable to estimate the albedo for individual soundings since, quite apart from the difficulty of estimating the amount of cloud visible from a radio-sonde, the measured albedos of apparently similar clouds are known to vary greatly.

The problem of the best value of the albedo to adopt has been facilitated by making estimates of the average albedos for each of the Meteorological Office radio-sonde stations. These estimates were obtained by taking the following average albedos of cloud, atmosphere and surface, based on the work of Fritz[2]:

Cloud ...	0·53	Air over cloudless area ...	0·11
Land ...	0·15	Air over clouded area ...	0·05
Water ...	0·09		

The relative contributions were then assessed from the annual mean cloud amounts and the proportions of land and sea visible from a radio-sonde at a height of 20 Km. and a distance of 50 Km. from its station in the prevailing wind direction. The results are given in Table I. They fall into two groups, the higher-latitude stations with an average albedo of 0·48 and the lower-latitude stations with 0·34. It is satisfactory to note that G. D. Robinson[3], using an independent method based on the surface measurement of radiation at Kew, obtained an average of 0·455 for south-east England, which may be compared with the figure 0·47 for Crawley in Table I. In view of the wide variations in cloud amount from day to day it is not considered worth while adopting different values for the two groups of stations. A single value of 0·40, instead of the 0·35 of the previous paper[1], has therefore been adopted for Meteorological Office stations.

TABLE I—ESTIMATES OF ALBEDO AT METEOROLOGICAL OFFICE RADIO-SONDE STATIONS

			Relative area "seen" from 20 Km. height			Contributions to albedo				Total albedo
			Cloud	Land	Sea	Cloud	Land	Sea	Air	
Camborne...	50·2°N.	5·3°W.	0·70	0·18	0·12	0·37	0·03	0·01	0·07	0·48
Crawley ...	51·1°N.	0·1°W.	0·68	0·22	0·10	0·36	0·03	0·01	0·07	0·47
Hemsby ...	52·6°N.	1·7°E.	0·71	0·15	0·14	0·38	0·02	0·01	0·07	0·48
Fazakerley	53·5°N.	2·9°W.	0·70	0·24	0·06	0·37	0·04	0·01	0·07	0·49
Aldergrove	54·7°N.	6·2°W.	0·70	0·18	0·12	0·37	0·03	0·01	0·07	0·48
Leuchars ...	56·4°N.	2·9°W.	0·67	0·10	0·23	0·35	0·01	0·02	0·07	0·45
Stornoway	58·2°N.	6·3°W.	0·77	0·09	0·14	0·41	0·01	0·01	0·06	0·49
Lerwick ...	60·1°N.	1·2°W.	0·78	0·07	0·15	0·41	0·01	0·01	0·06	0·49
o.w.s. I ...	59·0°N.	19·0°W.	0·79	0·00	0·21	0·42	0·00	0·02	0·06	0·50
o.w.s. J ...	52·5°N.	20·0°W.	0·77	0·00	0·23	0·41	0·00	0·02	0·06	0·49
Mean ...	... ...	...	0·73	0·12	0·15	0·38	0·02	0·01	0·07	0·48
Aden ...	12·8°N.	45·0°E.	0·30	0·49	0·21	0·16	0·07	0·02	0·09	0·34
Bahrain ...	26·3°N.	50·6°E.	0·20	0·48	0·32	0·11	0·07	0·03	0·09	0·30
Benina ...	32·1°N.	20·3°E.	0·35	0·39	0·26	0·19	0·06	0·02	0·09	0·36
Habbaniya	33·4°N.	43·6°E.	0·23	0·77	0·00	0·12	0·11	0·00	0·09	0·32
Malta ...	33·8°N.	14·5°E.	0·39	0·24	0·37	0·21	0·04	0·03	0·08	0·36
Nicosia ...	35·1°N.	33·3°E.	0·30	0·42	0·28	0·16	0·06	0·03	0·09	0·34
Gibraltar ...	36·1°N.	5·3°W.	0·41	0·35	0·24	0·22	0·05	0·02	0·08	0·37
Mean ...	... ...	...	0·31	0·45	0·24	0·17	0·06	0·02	0·09	0·34

Rate of ascent.—The radiation error varies inversely as the square root of the rate of ascent of the radio-sonde, except in the lower levels where the error is, in any case, small. The rate of ascent normally used at present averages 6 m./sec. (1,200 ft./min.), but there is a standard deviation of 7 per cent. which therefore gives a corresponding variation in the radiation error of 3·5 per cent. There is generally, also, a systematic change with height with a maximum at the tropopause which may be 15 per cent. greater than near the ground or high in the stratosphere. For the purpose of computing the radiation and lag corrections the rate of ascent of 6 m./sec. has been adopted, but if for special purposes a very different rate is used the appropriate corrections can be obtained by multiplying the standard corrections by the square root of the ratio of the standard rate of ascent to the actual rate.

Swinging of radio-sonde.—In the previous paper[1] it was assumed that the average half-amplitude of swing of a radio-sonde from the vertical is 30°, and graphs were given showing the effect of this on the amounts of direct solar radiation absorbed by the thermometer element and its shield for solar altitudes between 0° and 90°. No allowance was made, however, for the fact that at solar altitudes below 30° the swinging of the radio-sonde allows some direct radiation to enter the bottom of the shield where it is reflected on to the thermometer element. The effect of this, which is relatively large at solar altitudes below 20°, has now been taken into account in calculating the total radiation absorbed, the revised figures for which are given in Table II and supersede those of Table 4 of the previous paper.

TABLE II—RATE OF ABSORPTION OF RADIATION

	Solar altitude (h)										
	−5°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
	10^{-3} × *calories per second*										
Shield											
Direct solar (Q_h) ...	447	489	543	575	597	594	543	470	422	405	415
Reflected from below (Q_m)	0	0	37	72	106	137	161	182	198	205	211
Emitted from below (Q_1)	8	8	8	8	8	8	8	8	8	8	8
Total (Q_s)	455	497	588	655	711	739	712	660	628	618	634
Element											
Direct solar (Q_h) ...	6·0	5·3	4·5	4·3	4·1	6·4	7·8	8·1	9·4	11·1	12·2
Reflected from below (Q_m)	0·0	0·0	0·8	1·5	2·3	2·9	3·4	3·8	4·2	4·4	4·6
Emitted from below (Q_1)	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5
Total (Q_e)	6·5	5·8	5·8	6·3	6·9	9·8	11·7	12·4	14·1	16·0	17·3

The intensity of solar radiation is taken to be 0·032 cal. cm.$^{-2}$sec.$^{-1}$

The figures for the reflected radiation are for an albedo of 0·40 and those for long-wave radiation emitted from below refer to a surface at 288°K. with the radio-sonde at 220°K.

Revised values of radiation errors.—In re-evaluating the radiation errors the following values of the various factors were adopted:

Absorption factor of temperature element for short waves ...	0·67
Absorption factor of temperature element for long waves ...	0·18
Absorption factor of radiation shield for short waves	0·33
Absorption factor of radiation shield for long waves	0·03
Albedo of earth, cloud and air	0·40
Rate of ascent	6 m./sec.
Half-amplitude of swing of radio-sonde	30°
Intensity of solar radiation at the top of the atmosphere...	0·032 cal./cm.^{2}/sec.

Apart from the albedo these values are the same as were used in the previous paper[1]. The heat-transfer coefficients, q of equation (1), are also the same as in Table 3 of that paper. For the reasons already given the rates of absorption Q differ from the earlier estimates, and the new values given in Table II for the thermometer element and the shield have been used in obtaining the revised values of the radiation errors from Q/q. Since the values of Q assume the intensity of solar radiation to be that at the top of the atmosphere, use has again been made of a diagram provided by Väisälä[4] to allow for depletion of the solar radiation by absorption and scattering before it reaches the radio-sonde. This

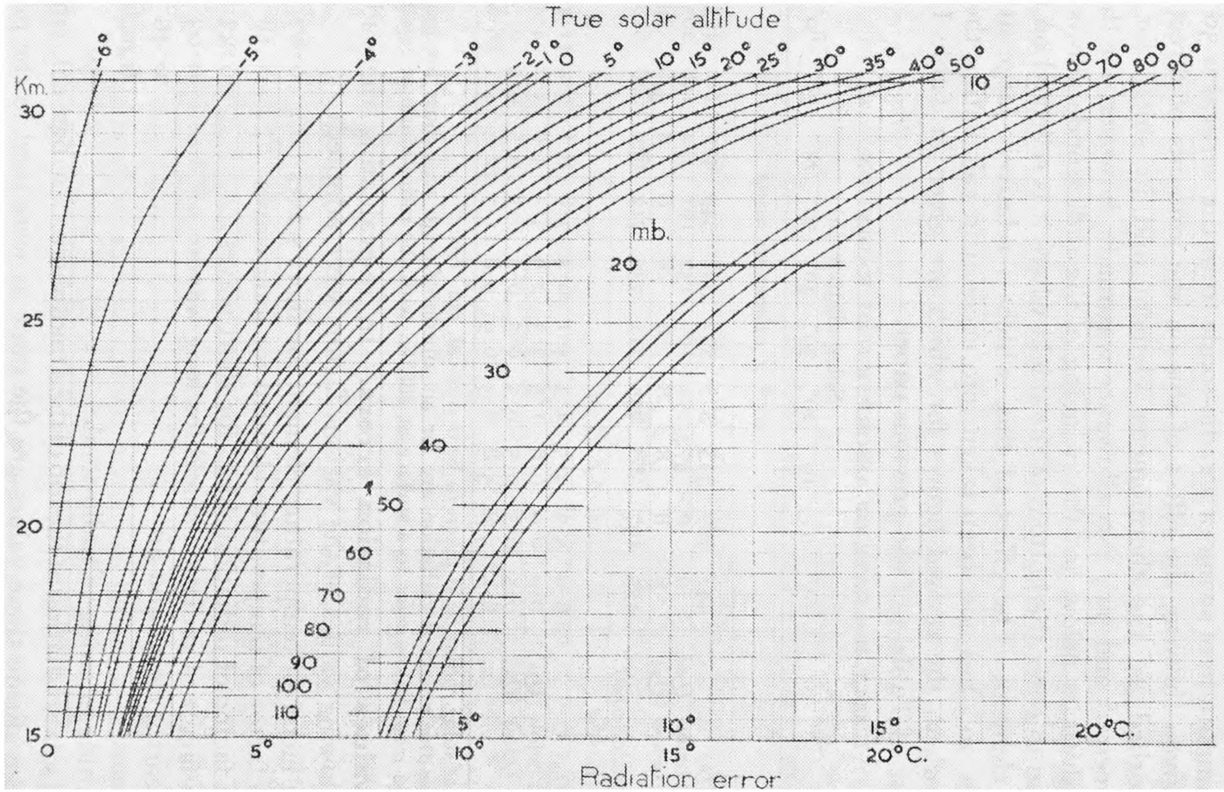

FIG. 1(*a*)—RADIATION CORRECTIONS (15–30 KM.)

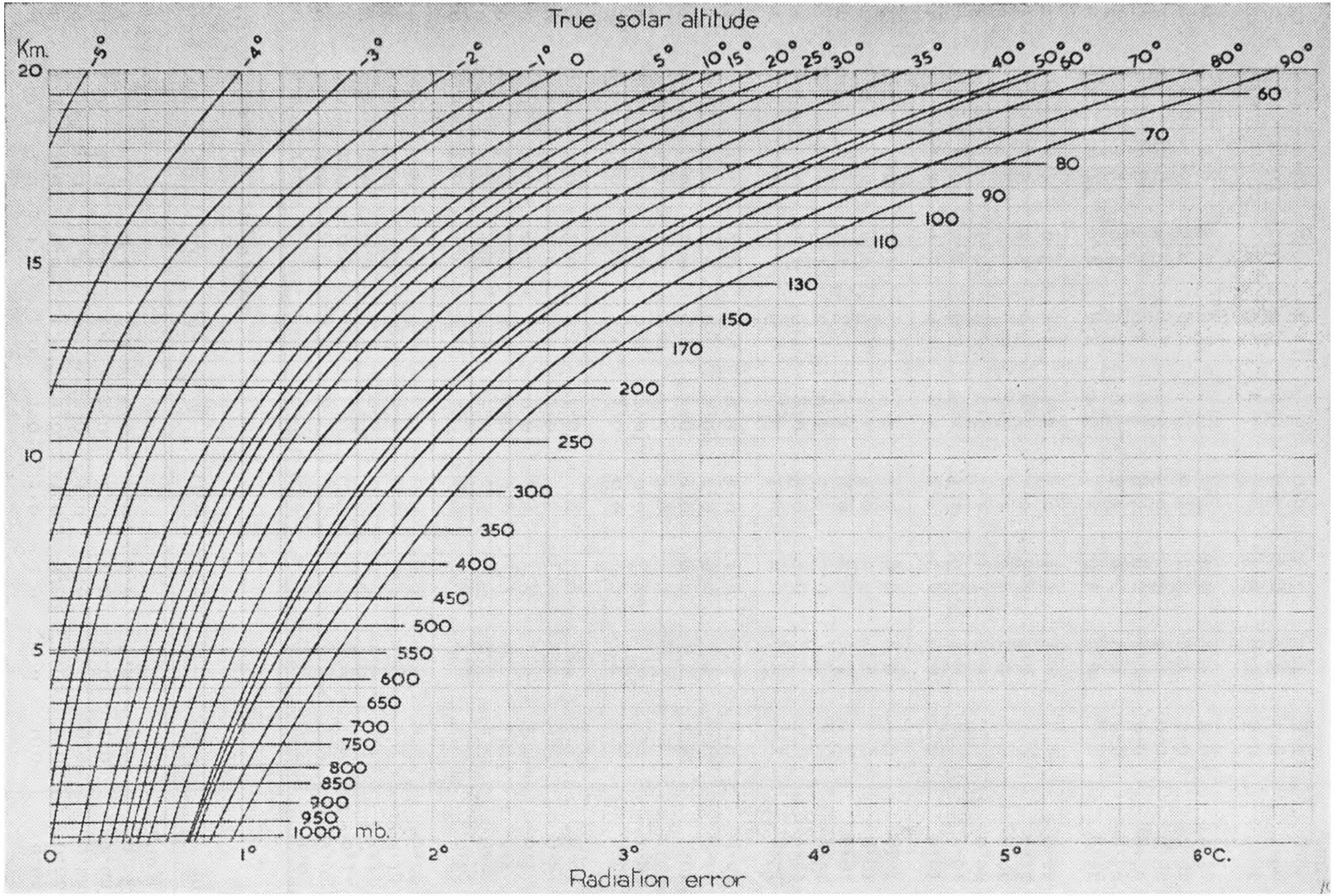

FIG. 1 (*b*)—RADIATION CORRECTIONS (BELOW 20 KM.)

TABLE III—RADIATION

True solar

Height		−6°	−5°	−4°	−3°	−2°	−1°	0°	5°	10°	15°
mb.	Km.*									*degrees*	*Celsius*
10	30·8	1·1	4·5	7·3	9·6	10·9	11·3	11·7	13·0	14·2	15·0
12	29·4	0·7	3·4	6·0	7·9	9·0	9·4	9·7	10·8	11·6	12·2
14	28·5	0·5	2·8	5·3	6·9	7·8	8·3	8·6	9·6	10·3	10·8
17	27·4	0·3	2·2	4·4	5·8	6·7	7·2	7·5	8·3	8·9	9·4
20	26·4	0·1	1·7	3·7	4·9	5·7	6·2	6·5	7·3	7·8	8·2
23	25·6	0·0	1·4	3·2	4·3	5·2	5·6	5·9	6·6	7·0	7·5
26	24·8	0·0	1·2	2·8	3·8	4·6	5·0	5·3	6·0	6·4	6·7
30	23·8	0·0	0·9	2·3	3·2	4·0	4·3	4·6	5·2	5·6	5·9
35	22·8	...	0·7	1·9	2·7	3·4	3·8	4·0	4·6	4·9	5·2
40	22·0	...	0·5	1·5	2·3	3·0	3·4	3·6	4·1	4·5	4·6
45	21·2	...	0·4	1·3	2·1	2·6	3·0	3·2	3·7	4·0	4·2
50	20·6	...	0·3	1·2	1·8	2·4	2·7	3·0	3·4	3·7	3·8
55	20·0	...	0·2	1·1	1·7	2·2	2·5	2·7	3·1	3·4	3·6
60	19·4	...	0·1	0·9	1·4	1·9	2·2	2·5	2·8	3·1	3·2
70	18·4	...	0·0	0·7	1·2	1·6	1·9	2·1	2·4	2·7	2·8
80	17·6	...	0·0	0·6	1·1	1·4	1·7	1·8	2·2	2·4	2·5
90	16·8	...	...	0·5	0·9	1·2	1·5	1·6	2·0	2·2	2·3
100	16·2	...	...	0·4	0·8	1·1	1·3	1·5	1·8	2·0	2·1
110	15·6	...	...	0·3	0·7	1·0	1·2	1·3	1·6	1·8	1·9
130	14·5	...	...	0·2	0·5	0·8	1·0	1·1	1·4	1·6	1·7
150	13·6	...	...	0·2	0·4	0·7	0·9	0·9	1·3	1·4	1·5
170	12·8	...	...	0·1	0·3	0·6	0·7	0·8	1·1	1·3	1·4
200	11·8	...	...	0·0	0·2	0·5	0·6	0·7	1·0	1·1	1·2
250	10·4	...	...	0·0	0·1	0·3	0·5	0·5	0·8	0·9	1·0
300	9·2	...	...	...	0·1	0·2	0·4	0·4	0·7	0·8	0·9
350	8·1	...	...	...	0·0	0·2	0·3	0·3	0·6	0·7	0·8
400	7·2	...	...	...	0·0	0·1	0·3	0·3	0·5	0·6	0·7
450	6·3	...	...	...	...	0·1	0·2	0·3	0·5	0·6	0·6
500	5·6	...	...	...	...	0·1	0·2	0·2	0·4	0·5	0·6
550	4·9	...	...	...	...	0·0	0·1	0·2	0·4	0·5	0·5
600	4·2	...	...	...	...	0·0	0·1	0·2	0·3	0·4	0·5
650	3·6	...	...	...	...	...	0·1	0·1	0·3	0·4	0·5
700	3·0	...	...	...	...	...	0·1	0·1	0·3	0·4	0·4
750	2·5	...	...	...	...	...	0·0	0·1	0·2	0·3	0·4
800	1·9	...	...	...	...	...	0·0	0·1	0·2	0·3	0·4
850	1·5	...	...	...	...	...	...	0·0	0·2	0·3	0·4
900	1·0	...	...	...	...	...	...	0·0	0·2	0·3	0·3
950	0·5	...	...	...	...	...	...	...	0·1	0·2	0·3
1000	0·1	...	...	...	...	...	...	...	0·1	0·2	0·3

TABLE IV—LAG CORRECTIONS

True solar

Height		−6°	−5°	−4°	−3°	−2°	−1°	0°	5°	10°	15°
mb.	Km.*									*degrees*	*Celsius*
10	30·8	0·2	0·5	0·7	0·8	0·9	1·0	1·0	1·1	1·2	1·4
20	26·4	0·1	0·2	0·2	0·3	0·3	0·3	0·3	0·3	0·4	0·4
30	23·8	0·0	0·1	0·1	0·1	0·2	0·2	0·2	0·2	0·2	0·2
40	22·0	0·0	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1
50	20·6	0·0	0·0	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1
60	19·4	0·0	0·0	0·0	0·1	0·1	0·1	0·1	0·1	0·1	0·1
70	18·4	0·0	0·0	0·0	0·0	0·0	0·1	0·1	0·1	0·1	0·1
80	17·6	0·0	0·0	0·0	0·0	0·0	0·0	0·1	0·1	0·1	0·1
90	16·8	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·1
100	16·2	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
110	15·6	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0

* International standard atmosphere.

CORRECTIONS

altitude 20°	25°	30°	35°	40°	50°	60°	70°	80°	90°	Height Km.	mb.
(to be subtracted)											
15·7	16·6	17·7	18·8	20·1	20·7	19·0	19·4	20·1	21·1	30·8	10
12·8	13·5	14·0	14·9	15·9	16·6	16·3	16·8	17·6	18·3	29·4	12
11·4	11·9	12·5	13·2	14·0	14·7	14·6	15·2	15·9	16·6	28·5	14
9·9	10·4	10·8	11·6	12·2	12·8	12·8	13·4	14·1	14·7	27·4	17
8·6	9·1	9·5	10·1	10·8	11·3	11·3	11·6	12·4	13·0	26·4	20
7·8	8·2	8·6	9·2	9·8	10·3	10·4	10·8	11·5	12·0	25·6	23
7·0	7·4	7·8	8·3	8·9	9·3	9·5	9·9	10·5	11·0	24·8	26
6·2	6·5	6·8	7·3	7·9	8·3	8·4	8·7	9·3	9·7	23·8	30
5·4	5·7	5·9	6·5	6·9	7·3	7·5	7·9	8·4	8·8	22·8	35
4·9	5·1	5·3	5·8	6·3	6·6	6·7	7·1	7·6	8·0	22·0	40
4·4	4·6	4·8	5·3	5·7	6·0	6·1	6·6	7·0	7·4	21·2	45
4·0	4·2	4·4	4·9	5·3	5·6	5·6	6·0	6·5	6·9	20·6	50
3·7	3·9	4·0	4·5	4·9	5·2	5·3	5·7	6·1	6·5	20·0	55
3·4	3·5	3·7	4·2	4·5	4·8	4·9	5·2	5·6	6·0	19·4	60
3·0	3·1	3·3	3·7	4·0	4·3	4·4	4·6	5·0	5·4	18·4	70
2·7	2·8	3·0	3·3	3·6	3·9	4·0	4·2	4·6	4·9	17·6	80
2·4	2·5	2·7	3·0	3·3	3·6	3·7	3·9	4·2	4·5	16·8	90
2·2	2·3	2·5	2·8	3·0	3·3	3·4	3·6	3·9	4·2	16·2	100
2·0	2·1	2·3	2·5	2·8	3·1	3·1	3·3	3·6	3·9	15·6	110
1·8	1·9	2·0	2·2	2·5	2·7	2·8	3·0	3·2	3·5	14·5	130
1·6	1·7	1·8	2·0	2·2	2·5	2·5	2·7	3·0	3·2	13·6	150
1·4	1·5	1·6	1·8	2·0	2·3	2·3	2·5	2·7	2·9	12·8	170
1·3	1·4	1·5	1·6	1·8	2·0	2·1	2·3	2·5	2·6	11·8	200
1·1	1·2	1·3	1·4	1·6	1·8	1·8	2·0	2·2	2·3	10·4	250
0·9	1·0	1·1	1·2	1·4	1·6	1·6	1·8	2·0	2·1	9·2	300
0·8	0·9	1·0	1·1	1·3	1·4	1·5	1·6	1·8	1·9	8·1	350
0·8	0·8	0·9	1·0	1·2	1·3	1·4	1·5	1·7	1·8	7·2	400
0·7	0·8	0·8	0·9	1·1	1·2	1·3	1·3	1·5	1·7	6·3	450
0·6	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·6	5·6	500
0·6	0·7	0·7	0·8	1·0	1·1	1·1	1·2	1·4	1·5	4·9	550
0·6	0·6	0·7	0·8	0·9	1·0	1·0	1·1	1·3	1·4	4·2	600
0·5	0·6	0·6	0·7	0·8	1·0	1·0	1·0	1·2	1·3	3·6	650
0·5	0·5	0·6	0·7	0·8	0·9	0·9	1·0	1·1	1·2	3·0	700
0·5	0·5	0·6	0·6	0·8	0·9	0·9	0·9	1·1	1·2	2·5	750
0·4	0·5	0·5	0·6	0·7	0·8	0·8	0·9	1·0	1·1	1·9	800
0·4	0·5	0·5	0·6	0·7	0·8	0·8	0·9	1·0	1·1	1·5	850
0·4	0·4	0·5	0·5	0·7	0·8	0·8	0·8	0·9	1·0	1·0	900
0·4	0·4	0·4	0·5	0·6	0·7	0·7	0·8	0·9	1·0	0·5	950
0·4	0·4	0·4	0·5	0·6	0·7	0·7	0·7	0·8	0·9	0·1	1000

TO RADIATION ERRORS

altitude 20°	25°	30°	35°	40°	50°	60°	70°	80°	90°	Height Km.	mb.
(to be subtracted from radiation errors of Fig. 1)											
1·5	1·6	1·7	1·9	2·0	2·0	1·6	1·6	1·5	1·6	30·8	10
0·4	0·4	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	26·4	20
0·2	0·2	0·3	0·3	0·3	0·3	0·3	0·3	0·3	0·3	23·8	30
0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	22·0	40
0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·2	0·2	20·6	50
0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	19·4	60
0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	18·4	70
0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	17·6	80
0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	16·8	90
0·0	0·0	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	16·2	100
0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·1	0·1	0·1	15·6	110

diagram gives the radiation intensity in terms of true solar altitude, and height as a percentage of the intensity at the top of the atmosphere, and it takes into account refraction of the sun's rays. Different factors should be applied to the direct radiation Q_h at the height of the radio-sonde and to the reflected radiation Q_m at the height of the reflecting surface, which in most cases will be partly cloud and partly the earth's surface. It has not, however, been thought worth while attempting to make this differentiation and the radiation errors have, therefore, been reduced by the factor corresponding to the height of the radio-sonde. The effect of this simplification is generally to increase the errors by about 4 per cent. but it is offset by errors of opposite sign caused by the effect of downward-scattered sky radiation which has not been taken into account.

The radiation errors have been computed in this manner for every 5 Km. height and for true solar altitudes (measured above the horizontal plane) at one-degree intervals from $-5°$ to 0°C., at five-degree intervals from 0° to 40°C. and at ten-degree intervals from 40° to 90°C. The results are plotted in Figs. 1(*a*) and 1(*b*) and the international standard pressure levels are indicated on the graphs. Table III gives corrections derived from the graphs at these pressure levels. It should be emphasized that since these errors relate only to the first term of the right-hand side of equation (1) they do not take account of the fact that the full radiation effect is reduced by the lag of the thermometer unit in responding to it.

Effect of thermometer lag.—The error arising from the lag of the thermometer unit is represented by the last term of equation (1). The rate of change of indicated temperature, dS/dt, on which it depends may arise partly from the change due to the radiational heating, if the sounding is in daylight, and partly from the change of air temperature with height. Since, in general, kdS/dt is small compared with the full radiation error Q/q, equation (1) approximates to

$$S - T = R - k\left(\frac{dR}{dt} + \frac{dT}{dt}\right), \qquad \ldots\ldots (2)$$

where R is substituted for Q/q. The term kdR/dt is the lag in the response to radiational heating whereas kdT/dt is the lag associated with the change in air temperature.

Since kdR/dt can be written as $kVdR/dz$, where z is the height and V the rate of ascent, it can be readily evaluated from the slopes of the curves of Fig. 1 and the values of k appropriate to the standard rate of ascent of 6 m./sec. and the height. The values of k given in the previous paper have been used; they are as follows:

Height (Km.) ...	0	5	10	15	20	25	30
k (sec.)	7·4	9·5	12·9	20	33	54	97

The values so obtained for the lag corrections to the radiation errors are given in Table IV. They are less than 0·1°C. at levels below 110 mb., but at 10 mb. they are large enough to reduce the radiation errors by about 10 per cent.

The last term in equation (2), which may be written as $kVdT/dz$, represents the ordinary lag error of a thermometer following a uniform change of air temperature. Table V gives corrections for this error when the change results from the radio-sonde ascending at 6 m./sec. in temperature gradients of -6°C./Km. in the troposphere and 1°C./Km. in the stratosphere. Corrections for other gradients are in proportion to their magnitude. These lag corrections, unlike those for the radiation errors, apply by night as well as by day.

It should be noted from equation (1) that combined lag corrections for the radiation effect and for changes in air temperature at any part of a sounding can be evaluated as the product of the lag coefficient and the rate of change of indicated temperature. It is preferable to adopt this procedure for correcting observations in the stratosphere, but for the troposphere, in which the lag in radiation error is negligible and in which a lapse rate of 6°C./Km. is sufficiently representative of nearly all conditions, the use of Table V(*a*) is to be preferred.

TABLE V—LAG CORRECTIONS FOR CHANGES IN TRUE AIR TEMPERATURE WITH HEIGHT

Height	(*a*) Troposphere Correction for assumed* lapse rate of 6°C./Km. at a rate of ascent of 6 m./sec.	Height	(*b*) Stratosphere Correction for assumed* inversion of 1°C./Km.
mb.	°C.	mb.	°C.
95–109	−0·8	10	0·7
110–139	−0·7	20	0·4
140–189	−0·6	30	0·3
190–289	−0·5	40–80	0·2
290–509	−0·4	90–200	0·1
510–1050	−0·3		

* Corrections for other temperature gradients are in proportion to their magnitude. The sign of the corrections is negative for temperature lapse and positive for inversion.

Lag errors at discontinuities.—The errors, due to lag, in determining the height and temperature at a discontinuity can be evaluated in the following way. Let the true air temperature at a discontinuity where there is a sudden change of temperature gradient dT/dz from A to B be T_d, so that air temperatures below and above the discontinuity are given by $(T_d + Az)$ and $(T_d + Bz)$, where z is height measured from the discontinuity and is therefore negative below, and A and B are negative for lapses. Then, in accordance with the last section, the temperature indicated by the radio-sonde at the true height of the discontinuity is $(T_d - kVA)$. Above that height it is governed by the relation

$$kV\frac{dS}{dz} = T_d + Bz - S, \qquad \ldots\ldots (3)$$

the solution of which is

$$S = T_d + Bz - BkV + kV(B - A)\,e^{-z/kV}. \qquad \ldots\ldots (4)$$

When, as in (*a*) of Fig. 2, there is a change of sign of temperature gradient at the discontinuity, the latter can best be recognized in the graph of the observed temperatures as the point, at z_1 say, where dS/dz is zero. Differentiation of equation (4) then shows that the error in the indicated height is given by

$$z_1 = kV\log_e(1 - A/B). \qquad \ldots\ldots (5)$$

At the indicated height the radio-sonde temperature S_1 and the air temperature are the same, i.e. $T_d + Bz_1$. The difference, Bz_1, between this temperature and the air temperature T_d at the true height of the discontinuity is, therefore, $BkV\log_e(1 - A/B)$.

For a tropopause at 10 Km. at which, for example, there is a change from a lapse rate of 6°C./Km. to an inversion of 1°C./Km. the height error for $V = 6$ m./sec. and $k = 13$ sec. is + 150 m. and the temperature error is + 0·15°C. For a sharper tropopause with an inversion of 6°C./Km. the corresponding errors are + 54 m. and + 0·3°C. At inversions near the ground, where k is about 7 sec., the errors are roughly half these values.

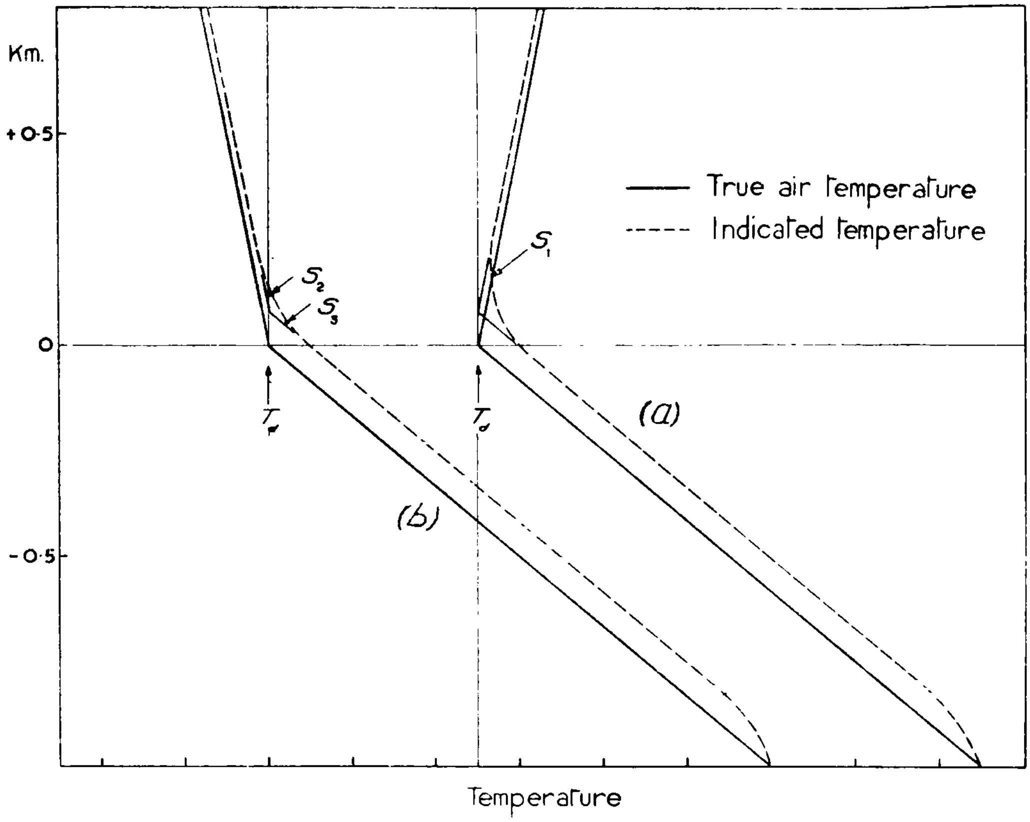

FIG. 2—ERRORS DUE TO LAG, IN HEIGHT AND TEMPERATURE OF A DISCONTINUITY

At a discontinuity, such as that illustrated in (*b*) of Fig. 2, where there is no change in sign of the temperature gradient the fact that dS/dz does not pass through zero, together with the smoothing effect of the lag, makes it difficult to determine precisely the observed height of the discontinuity. It could be specified in terms of a particular value, D, of dS/dz, such as a lapse rate of 2°C./Km. In that case by differentiation of equation (4)

$$D = B - (B - A)\, e^{-z/kV}, \qquad \ldots\ldots (6)$$

giving the height error

$$z_1 = kV \log_e (A - B)/(D - B). \qquad \ldots\ldots (7)$$

For a tropopause at 10 Km. separating lapse rates of 6° and 1°C./Km. this amounts to + 125 m. and the temperature, S_2 in Fig. 2(*b*), exceeds the true tropopause temperature by + 0·03°C. Such a discontinuity, however, is probably more readily recognized in the observations as the point S_3 where the gradient is the mean of A and B. In this case equation (6) shows the height error to be $kV \log_e 2$, which for the above example amounts to + 54 m., the temperature error being + 0·22°C.

It follows from the expressions for the straight portions of the graphs o indicated temperatures in Fig. 2, where the exponential changes have become negligible, that they intersect at the true temperature of the discontinuity and at a height kV above it. It is doubtful, however, whether in practice the temperature gradient remains constant long enough to make this procedure practicable.

The temperature and height errors at discontinuities, though systematic, are not very important in individual cases since with radio-sonde readings at intervals of about 150 m. the discontinuities can hardly be determined to a higher accuracy than this.

Application of corrections to Meteorological Office observations.—In 1953 the World Meteorological Organization recommended that all radio-sonde observations should be corrected for radiation errors on the basis of the best information available. In accordance with this recommendation the radiation corrections of Table III, adjusted if necessary for departures from the standard rate of ascent, are being applied to upper air temperatures observed at Meteorological Office radio-sonde stations at home from February 1 and overseas from March 1, 1956. For climatological purposes the observations made in January will also be corrected. In addition the lag corrections of Table V(*a*) are being applied as standard corrections to all observations in the troposphere. For observations in the stratosphere corrections derived from the rate of change of indicated temperature and the appropriate lag coefficient are applied when a temperature gradient departing from isothermal is maintained over a sufficient depth to render the corrections significant in the computation of the heights of pressure levels.

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METEOROLOGICAL OFFICE PRACTICE FOR THE APPLICATION OF RADIATION AND LAG CORRECTIONS TO TEMPERATURES MEASURED BY RADIO-SONDE MK IIB

By C. L. HAWSON, B.A.

Methods have been devised by Scrase[1,2] for evaluating the temperature errors of the Meteorological Office radio-sonde Mk IIB arising from the effects of solar radiation and of thermometer lag. Corrections for these errors are now being applied at all Meteorological Office radio-sonde stations. For synoptic messages the corrections were introduced from February 1, 1956 at home stations and in ocean weather ships, and from March 1, 1956 at Meteorological Office stations overseas. For climatological purposes the corrections were applied from January 1, 1956 at all stations. The purpose of this note is to outline the methods adopted for applying the corrections on a routine basis. These methods, which have been evolved by the staff of the Upper Air Observations Branch of the Meteorological Office, effect a balance between the conflicting requirements for a minimum increase of computation time, and for as high an accuracy as practicable in the determination of the heights of the standard pressure surfaces.

Basic radio-sonde observations.—In the Meteorological Office radio-sonde system the frequency of an audio modulation of a radio carrier is measured and plotted against time. The frequency of this audio modulation is controlled successively by the pressure, temperature, and humidity elements of the airborne transmitter. Thus at the ground station the initial record consists of a series of observations of frequency plotted against time, which fall naturally into three separate curves corresponding to the variations of the three atmospheric parameters. Time is recorded to the nearest 3 sec. and frequency to the nearest $\frac{1}{2}$ c./sec., corresponding in the case of temperature to approximately $\frac{1}{4}$°C. The combined lag and radiation corrections, determined for each computed temperature observation as described below, are rounded off to the nearest $\frac{1}{4}$°C. before they are applied.

Radiation corrections.—Before the ascent the times at which the sun will pass through certain chosen values of true solar altitude at the particular station, during the flight, are derived by means of the tables given in "Sight reduction tables for air navigation"[3] and *The abridged nautical almanac*[4]. The values of true solar altitude chosen for this purpose are those intermediate to the values given in the heading of Table III of Dr. Scrase's paper on pp. 70–1. A series of time intervals during each of which a particular column of Table III is applicable is thus obtained, and can be readily related to the time used in the frequency/time plot, i.e. to the time of any part of the ascent. No adjustment of the solar altitude to allow for the down-wind drift of the radio-sonde during the flight is attempted. This drift can readily introduce solar-altitude errors of the order of $\frac{1}{2}$° but the corresponding radiation errors are less than 0·2°C., except in a few instances, principally when small negative values of solar altitude are experienced at altitudes above about the 100-mb. level.

The radiation correction for each computed temperature observation is initially determined from Table III. The times at which the temperature observations are made are used to determine both the appropriate pressure lines and the appropriate solar-altitude columns of Table III. The values of the radiation corrections are read directly without interpolation. When the departure of the actual rate of ascent from that assumed in computing the table would introduce a change of more than 0·2°C. in the value of the radiation correction, each correction is adjusted using the formula given by Scrase. For this purpose rates of ascent determined by measuring the times taken to ascend through 3-Km. layers are normally employed. The methods of selecting the 3-Km. layers and applying the adjustment are both graphical, but introduce no significant inaccuracy beyond that inherent in the basic pressure observations[5].

Lag corrections.—Lag corrections depend directly on the lag coefficient of the thermometer and upon the rate of change of temperature experienced with time. The former increases fivefold as the pressure decreases from 1000 to 50 mb. The latter is unique for each sounding, changing frequently in magnitude and less frequently in sign. It is indicated, to the first order by the rate of change of temperature frequency with time. To apply lag corrections based upon all the detailed rates of change of temperature observed on each individual sounding would involve a considerable increase in the time required to compute the sounding. Therefore, in order to expedite computation, the sounding is divided into broad sections or régimes, each naturally defined by the general slope of the observed temperature-frequency/time plot, and the mean value of this slope over each section is taken as a common value for all temperature observations in the section.

The first section chosen normally extends from the ground to the first tropopause. In this régime the lag coefficients are so small that a standard lapse of

6°C./Km. coupled with a standard rate of ascent of 6 m./sec. is assumed instead of the observed lapse. The consequent inaccuracy introduced into the lag corrections, when meaned over the section, rarely exceeds 0·1°C. In this first régime, therefore, the standard lag corrections of the appropriate pressure ranges of Table V(*a*) on p. 73 are used for each temperature observation, no adjustment for the observed lapse rate being attempted. The extent of the first section is occasionally varied as to its upper limit, either when the first tropopause is not readily apparent, or has not been encountered up to a height corresponding to 95 mb.

Sections subsequent to the first are normally in the stratosphere. Here the lag coefficients are larger than in the first section, and although the overall lapse rate approximates to isothermal, local departures occur which can be maintained over a sufficient depth to render the lag correction significant in the computation of the heights of the standard pressure levels. In each of these subsequent sections therefore, the observed mean slope of the temperature-frequency/time plot and the appropriate pressure value are used to determine the lag correction for each temperature observation. The actual determination is carried out graphically, assuming a constant factor for the conversion of temperature-frequency changes to degrees Celsius. Actual values of this factor have a standard deviation of approximately 11 per cent. of the assumed constant value, and the errors involved in the assumption are directly reflected in the derived corrections. Thus the lag corrections employed embody an error with a standard deviation of approximately 11 per cent. of the value of the correction. In practice this error rarely reaches 0·2°C. except in very shallow layers and introduces inaccuracies of the order of 1 m. in the computation of the heights of the standard pressure surfaces above the first tropopause.

The routine methods of application of the lag corrections, although rarely introducing significant inaccuracies into the computed heights of the standard pressure surfaces, can introduce appreciable error in the temperature at individual levels, e.g. in a tropospheric inversion. In the troposphere these errors in any particular case can be assessed by the user if required. The lapse rates as reported are representative of the true rates of change of temperature to the first order and corrections appropriate to these lapse rates can be derived from Table V(*a*) on p. 73 by applying the ratio

$$\frac{\text{actual change}}{\text{standard assumed change (6°C./Km.)}}$$

and choosing the appropriate sign. These can then be compared with the standard corrections. For example at 400 mb., for a temperature observed in a region of lapse rate 7°C./Km., the appropriate correction is −0·5°C., whilst for a temperature observed in an inversion of 6°C./Km. the appropriate correction is +0·4°C. The standard correction is −0·4°C. Thus the temperature corrected by the routine method is 0·1°C. too warm or 0·8°C. too cold respectively. In the stratosphere similar errors occur when the rate of change of temperature departs from the mean employed for the particular section, these errors however cannot be readily determined without reference to the original computation.

The temperature errors at individual levels arising from the simplified application of lag corrections are normally unimportant[6], and although they could be eliminated at the radio-sonde stations to do so would incur a delay to the reported message quite disproportionate to the gain in accuracy.

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TRANS-ANTARCTIC EXPEDITION, 1955–58

By R. H. A. STEWART, B.Sc.(Tech.)

The aim of this expedition, under the leadership of Dr. V. E. Fuchs, is to cross the Antarctic continent from the Weddell Sea to the Ross Sea and to carry out a full programme of geophysical research, including meteorology and glaciology. Articles by Dr. Fuchs and by the leader of the New Zealand Party, Sir Edmund Hillary, describing the expedition are appearing exclusively in *The Times.*

The main base was set up at Vahsel Bay (78°S. 35°W.) in January 1956, and a full meteorological programme will start as soon as the base is established. Surface observations will be made at all the synoptic hours and more frequently when air operations are in progress. It is expected that the observations will be transmitted to Stanley, Falkland Isles, for inclusion in collective broadcasts, and possibly to Cape Town also. The base will have a radio-sonde station and a daily ascent will be attempted. This will yield measurements of temperature, pressure and humidity up to perhaps 10 miles. Upper winds will be measured by pilot balloon whenever conditions are favourable. In addition a programme of radiation and glaciological measurements has been planned. The radiation work will consist of obtaining continuous records, by a bimetallic recorder, of short-wave radiation received on a horizontal surface together with the measurement, on selected occasions, of the vertical flux of total short-wave and long-wave radiation.

In March 1957, an additional station will be established 300 miles inland from Vahsel Bay at an altitude of about 8,000 ft. This will be manned until November 1957, and during this time synoptic observations and possibly pilot-balloon ascents will be carried out.

Most of the equipment will be of standard Meteorological Office pattern, but the low temperatures likely to be encountered have raised a number of problems of instrument design and operation, many of which will only be solved by experience. Screen temperatures down to −80°F. may be experienced and low-range thermometers, including mercury/thallium maximum thermometers, will be used. Wind-driven snow frequently makes it almost impossible to maintain proper ventilation through a Stevenson screen, and although many devices have been tried, a satisfactory answer has not yet been found. The expedition will be testing a new type of screen designed by the Meteorological Office in yet a further attempt to solve this problem.

Hydrogen generation for balloons is another question which has been given much consideration. Hydrogen in cylinders cannot be taken as the amount of useless weight is too great. Some types of chemical generator have also been ruled out owing to the volume of water that they require. Water in its liquid form is a rare and valuable item in the Antarctic, and can only be produced by the expenditure of much valuable fuel. It is intended to try both low-pressure and high-pressure generators, using ferro-silicon and caustic soda, and requiring not more than five gallons of water for each charge.

Weather conditions in winter are frequently such as to make outdoor observation both difficult and dangerous. With this in mind distant-reading instruments for wind, temperature and humidity are being provided at the coastal station, and for wind and temperature at the inland station.

The expedition will initially include three meteorologists, one former member of the staff of the Meteorological Office (Mr. R. H. A. Stewart), one South African meteorologist (Mr. J. J. Le Grange), and one present member of the staff of the Meteorological Office (Mr. P. H. Jeffries).

It is hoped that at least one meteorologist will be a member of the party which, between November 1957 and March 1958, will attempt the continental crossing.

Reprinted, except for omission of less technical material, from *The Times*.

MINIMUM TEMPERATURES AND TOPOGRAPHY IN A HEREFORDSHIRE VALLEY

By E. N. LAWRENCE, B.Sc.

Introduction.—One of the chief methods of minimizing frost damage to fruit crops is by means of careful siting of orchards. In April and May 1954 an attempt to assess the frost risk[1,2] of a site at Long Orchard, which is about half a mile to the south-south-west of Much Birch, near Hereford (see photographs in the centre of this magazine) has produced some interesting microclimatological data relating minimum temperature to topography, mainly surface contours.

Data.—Eight minimum thermometers (of the sheathed spirit type) with white painted shields, attached to vertical posts at a height of 4 ft. above the ground, were distributed as shown in Fig. 1. Four of these thermometers (numbers 5, 6, 7 and 8) were placed at height intervals of 10 ft. along a "trough" line, i.e. in a valley at points of approximately maximum curvature of contours, while the other four thermometers (numbers 1, 2, 3 and 4) were placed along a roughly parallel line on the side of the valley, where the contours were approximately straight, and so that thermometers 2, 3 and 4 were at the same heights as thermometers 8, 7 and 6 respectively.

All readings quoted are actual readings, but to compare with screen minimum temperatures it is estimated that 0·9°F. must be added to the readings of weeks 1–4 (April 2–29) and 0·8°F. to the readings of weeks 5–8 (April 30–May 27) to allow for instrumental differences. The field under consideration was sown with crops as shown in Fig. 1. The progress of crop growth is given in Table I.

During the month of May the change in height of the crop and percentage ground cover made analysis difficult, but during April the percentage ground cover, even at the end of the month, did not exceed 15 per cent. Thus the analysis refers primarily to April readings. April 1954 was an anticyclonic month. The average pressure (April 2–29) was about 1024 mb. as compared with a long-term mean of 1013–1014 mb., and the rainfall in the area was only

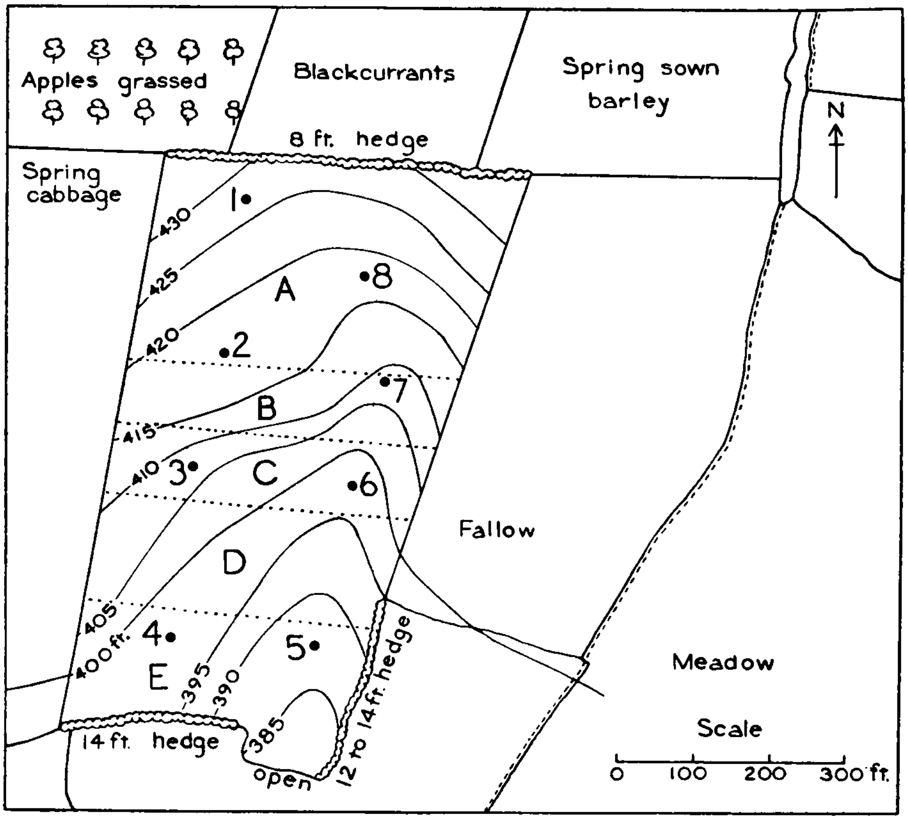

FIG. 1—CONTOURS, LAYOUT AND SURROUNDINGS OF EXPERIMENTAL FIELD

A First sowing peas B Third sowing peas
C Second sowing peas D Potatoes
E Fourth sowing peas

The positions of the thermometers are indicated by numbers

0·2 in., so that night minimum temperatures below average might have been expected. The differences between the 1954 value of the average minimum temperature and the long-term average, together with the corresponding "anomalies" in the weekly spread coefficient (i.e. average weekly minimum temperature minus extreme weekly minimum temperature), are given in Table II.

TABLE I—STATE OF CROP GROWTH ON THE EXPERIMENTAL FIELD

	1st sowing peas Thermometers 1, 2, 8		3rd sowing peas Thermometer 7		2nd sowing peas Thermometers 3, 6		4th sowing peas Thermometers 4, 5		Potatoes	
	Height of crop	Ground cover	Height of crop	Ground cover	Height of crop	Ground cover	Height of crop	Ground cover	Height of crop	Ground cover
	in.	%	in.	%	in.	%	in.	%	in.	%
April 2	1	Negligible	Bare soil		Bare soil		Bare soil		Bare soil	
April 9	2	Negligible	Bare soil		Bare soil		Bare soil		Bare soil	
May 2	8	15	1	Negligible	4	5	1	Negligible	Just appearing	Negligible
May 8	—	—	—	Peas (2–9 in.)	—	—	—	—	Negligible	Negligible
May 22	12	75	4	10	12	50	9	40	4–6	7
May 31	18	90	5	30	18	70	15	60	6–18	13

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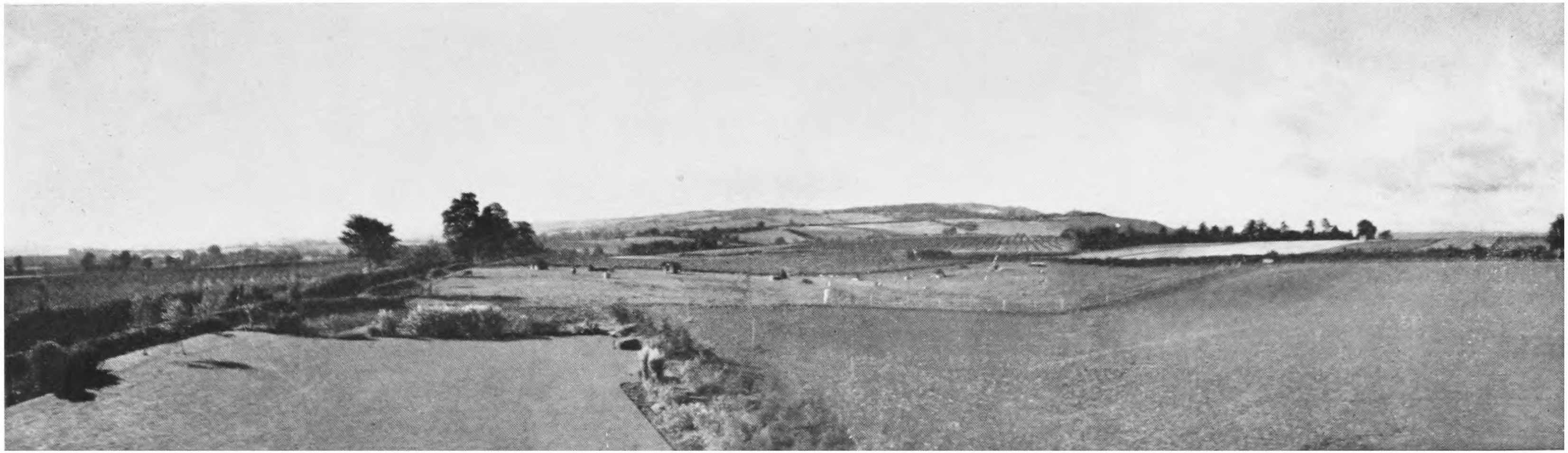
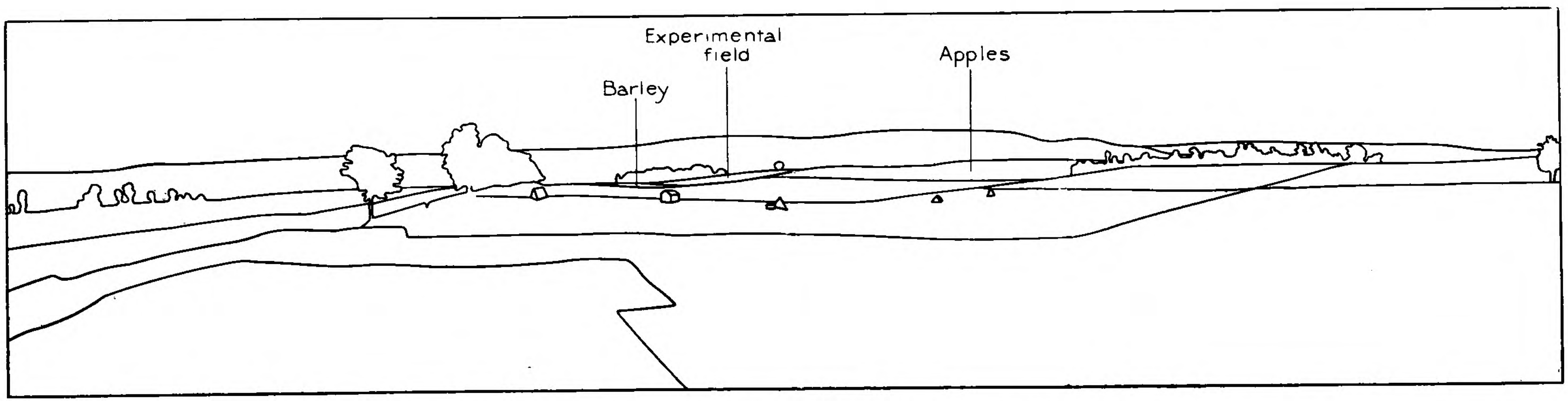


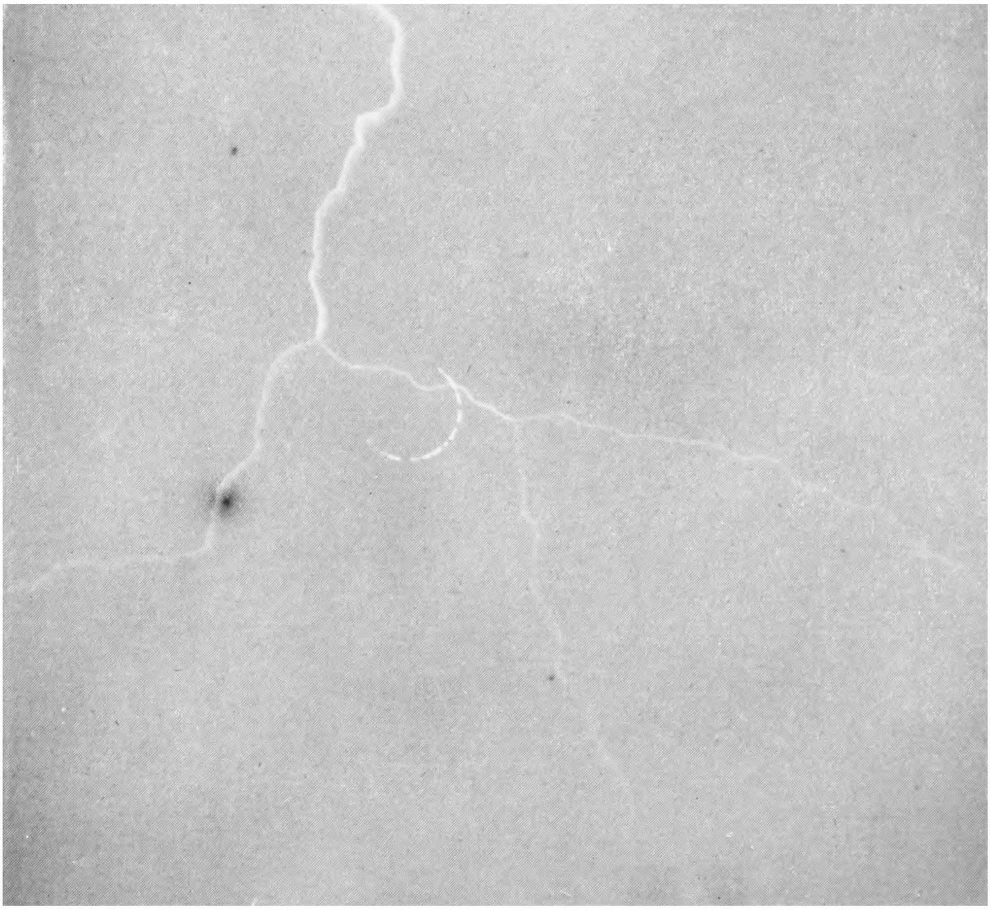


POSITION OF EXPERIMENTAL FIELD, LONG ORCHARD, MUCH BIRCH
Looking south (see p. 79)

FROST EXPERIMENTAL FIELD, LONG ORCHARD, MUCH BIRCH
North-east corner looking south (see p. 79)

FROST EXPERIMENTAL FIELD, LONG ORCHARD, MUCH BIRCH
South-east corner looking north-west (see p. 79)

To face p. 81]



LIGHTNING RECORDED BY NIGHT-SKY CAMERA

This photograph of a lightning flash was recorded on the film of the night-sky camera at Stornoway on the night of December 2–3 during normal operation. The trace made by the Pole Star may also be seen in the picture, indicating that the cloud during the night was very broken. Frequent thunderstorms were reported from Stornoway and other stations in the Hebrides that evening and throughout the night the photograph was taken.

It is extremely rare to find a flash so recorded. Night-sky cameras have been in operation more or less continuously since 1947 or 1948 at about a dozen stations in different parts of the country, but the only other known record of such a flash occurred at Porton, Wiltshire, during the development of the prototype night-sky camera in the late 1920's.

R. E. BOOTH

TABLE II—ANOMALIES OF MEAN TEMPERATURE AND SPREAD COEFFICIENT IN APRIL 1954

	1954 average minus long-term average Minimum temperature	Weekly spread coefficient
	degrees Fahrenheit	
Ross-on-Wye	−2·1	−0·9
Parkend	−3·0	−1·3
Malvern	−2·2	−0·1
Droitwich	−3·8	−1·5
Stratford-on-Avon	−4·1	−0·9

To assess the frost liability of the site at Long Orchard, these values were plotted on a map in order to obtain a measure of the April 1954 anomaly at Long Orchard, there being no single "standard" meteorological site in the same climatological régime as the site being assessed. This measure was used to "adjust" the Long Orchard observations, which were then smoothed (as described in an earlier paper[2]) to obtain the long-term average minimum temperature and long-term average spread coefficient for Long Orchard, and hence the frost frequency[2].

Results.—The temperature measurements are shown in Table III.

TABLE III—AVERAGE WEEKLY AND EXTREME WEEKLY MINIMUM TEMPERATURES

	Minimum temperature	Thermometers 1 (427 ft.)	2 (417 ft.)	3 (407 ft.)	4 (397 ft.)	5 (387 ft.)	6 (397 ft.)	7 (407 ft.)	8 (417 ft.)
1954		*degrees Fahrenheit*							
Week 1	Average ...	36·8	37·7	37·3	37·5	36·5	37·6	37·6	36·9
Apr. 2–8 ...	Extreme ...	30·8	32·0	31·8	30·1	28·2	30·4	30·5	30·4
Week 2	Average ...	35·0	36·8	36·9	35·9	34·8	35·1	35·6	34·6
Apr. 9–15 ...	Extreme ...	30·8	33·0	32·8	33·1	30·2	29·9	30·5	29·4
Week 3	Average ...	35·8	36·6	36·8	36·6	35·4	35·6	36·2	35·8
Apr. 16–22 ...	Extreme ...	31·8	32·5	32·8	32·1	30·2	31·4	32·5	31·4
Week 4	Average ...	35·2	35·9	35·8	35·8	34·8	34·7	35·3	35·1
Apr. 23–29 ...	Extreme ...	29·3	30·0	30·3	30·1	29·7	28·9	29·0	29·4
Week 5	Average ...	37·9	38·6	38·7	39·0	37·8	37·2	38·9	37·8
Apr. 30–May 6	Extreme ...	32·8	33·0	32·8	33·1	32·2	31·4	32·0	31·9
Week 6	Average ...	39·8	41·0	42·0	41·3	38·7	38·5	39·7	39·5
May 7–13	Extreme ...	33·3	35·0	34·8	34·6	32·2	31·9	33·0	32·4
Week 7	Average ...	42·2	42·3	42·9	43·1	42·3	40·8	42·5	42·4
May 14–20 ...	Extreme ...	35·8	36·0	36·3	36·6	36·2	34·4	36·0	35·9
Week 8	Average ...	44·5	45·3	45·2	45·4	44·1	42·5	44·1	44·3
May 21–27 ...	Extreme ...	40·3	42·5	42·9	43·1	40·2	38·4	40·0	39·9
Week 1–4	Average ...	35·7	36·7	36·7	36·5	35·4	35·7	36·2	35·6
Apr. 2–29 ...	Extreme ...	30·7	31·9	31·9	31·3	29·6	30·1	30·6	30·1
Week 5–8	Average ...	41·1	41·8	42·2	42·2	40·7	39·7	41·3	41·0
Apr. 30–May 27	Extreme ...	35·5	36·6	36·7	36·9	35·2	34·0	35·3	35·0

Consider the period April 2–29 (i.e. weeks 1–4) and the three pairs of thermometers:—

Thermometers 2 and 8 at 417 ft., both on first sowing of peas.

Thermometers 3 and 7 at 407 ft., on the second and third sowing of peas, respectively.

Thermometers 4 and 6 at 397 ft., on the fourth and second sowing of peas, respectively.

The three "bank" sites at 2, 3 and 4 were warmer than the corresponding "trough" sites at 8, 7 and 6 respectively. The average excess temperature was 0·8°F., but 1·1°F. for the anticyclonic nights of April 7, 8, 9, 10, 14, 16, 21, 24, 25, 27 and 29, 1954. The three "trough" sites had greater weekly spread coefficients (weekly average minus weekly extreme) than the corresponding "bank" sites. The average excess temperature was 0·6°F.

These results suggest that points on concave contours have lower average minimum temperatures and higher average spread coefficients (and hence are frostier) than points on straight contours, other things being equal. A similar result at 40 cm. above the ground was obtained by Geslin[3], who examined the period April 12–20 (which did not include any typical radiation nights) and the frosty night of April 29–30, 1951, in Champagne vineyards. He found that broadly speaking the isopleths of minimum temperature followed the contours, but that for places at the same level the minima were higher on "crest" lines than on "trough" lines. This phenomenon may be explained by the thicker or deeper cold air flow in the trough due to convergence and canalization of the katabatic flow. If the flow were generally a shallow one, convergence and canalization could lead to stronger wind velocities in the trough than on the bank[4], and hence to greater mixing of the shallow cold-air layer with that at thermometer level.

It may be noted here that the generally steeper and more southerly and sheltered aspect of the thermometers 8, 7 and 6 would normally produce a higher day temperature. Furthermore, the smaller night wind (on radiation nights) over thermometers 2, 3 and 4, would encourage inversion conditions. Both these factors would tend to give lower minimum temperatures on the bank sites, which is contrary to observation.

The thermometer at point 1 appears to give a reading lower than might have been expected from considerations of height and shape of contour. This may be due to the proximity of the upslope field of blackcurrants (height 3 ft. 6 in. to 3 ft. 9 in., cover 35 per cent.) which would tend to form a radiating surface immediately upslope at about the same height as the thermometers (i.e. 4 ft.). The grassed bush apple (see Fig. 1) may have had a similar effect, possibly emphasized by the grass. Also, both these crops may have encouraged inversion conditions (low minimum temperatures) by acting as an obstruction to wind. All three thermometers (1, 2 and 8) on the first sowing appear to give temperatures a little lower than might have been expected from considerations of height. This could be due to the slightly higher radiating surface and its slightly greater frictional reduction of wind.

Ignoring the three thermometers on the first sowing, the remaining ones give an average-minimum-temperature increase with height of 1°F./30 ft. and an average-weekly-spread-coefficient decrease with height of about 1°F./50 ft. For the previously mentioned 11 radiation nights, the rate of increase in average minimum temperature with height was 1°F./20 ft. On a particular night, the rate may vary considerably from point to point, and from his results Geslin suggested that the accumulation of cold air in frost hollows tends to equalize temperatures below the level of the surface of the "lake" of cold air.

The data obtained by Geslin were supplemented by observations of damage to vines, and he found that for a given night minimum temperature, the damage was less on hills than in valleys. This, he explains, could be due to the longer duration of the minimum temperature in valleys. Another important contributing factor could be the greater speed of air flow in the valleys during radiation conditions.

Acknowledgement.—I am indebted to the County Horticultural Staff of the National Agricultural Advisory Service at Hereford for their help in arranging the experiment, and to the grower, Mr. Acheson of Much Birch, Hereford, without whose observations the work would not have been possible.

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METEOROLOGICAL OFFICE DISCUSSION

Three-front model

The Discussion on Monday, December 19, 1955, held at the Royal Society of Arts, was opened by Mr. B. W. Boville of the Canadian Central Analysis Office. He described the procedure at that Office and in particular the three-front model that had been developed there.

When the Central Analysis Office was established in 1951 six meteorologists, all with 10–15 years of synoptic experience in various parts of Canada, were assigned to work out an organization on both the theoretical and administrative side. This analysis and short-range prognosis centre was to meet the requirements of the whole country. To eliminate duplication of work transmission was to be by facsimile. An extended-period forecast centre was to be developed simultaneously.

The status of surface fronts was rather chaotic; coded analyses exchanged among major forecast centres in Canada and abroad indicated, in many cases, areas of agreement arising by chance rather than by science. It was clear that an approach based on detailed study of surface hourly and synoptic reports would not solve the problem.

Differential analysis was reasonable up to 500 mb. although investigation of some forecast failures over the North Atlantic showed that this method had failed to preserve essential details of the flow required for synoptic developments. Although 300-mb. and 200-mb. charts were being drawn it was clear that knowledge of the jet-stream structure and behaviour was rather superficial.

In some parts of the meteorological world fronts were tending to be regarded as transient surface phenomena largely dependent on frictional convergence. In contrast jet streams, which are associated with strong baroclinity and support the idea of three-dimensional fronts, were gaining prominence. It was necessary to devise a new system of analysis which could be applied uniformly by a group and would be acceptable to forecasting centres spread out over a distance of 3,000 nautical miles.

The experiment covered a period of about two years before the method became operational. All standard charts up to 300 mb. were analysed for an area stretching from Japan to eastern Europe; tephigrams were plotted for all temperature ascents (about 150 stations) and hodographs drawn for upper wind data (about 99 stations) for the area from the central Pacific to the central Atlantic. A number of detailed cross-sections from the surface to 100 mb. were also constructed each day.

Frontal-contour analysis seemed the most promising approach. Initially wet-bulb potential temperature and saturated wet-bulb temperature were plotted at all significant first-order discontinuities in vertical temperature and wind shear. Wet-bulb potential temperature was used as the major identifier but density was the fundamental parameter of discontinuity. It became clear that the three-dimensional picture of the fronts provided a sound relationship between surface fronts, upper westerlies and jet streams. Surface analyses became to a large extent unique with excellent continuity. Jet-stream analysis could be extended into areas of sparse data.

It became evident that there were three major frontal zones, at least in the two-thirds of the hemisphere covered by the analysis. These were named:

Polar front, separating tropical-maritime air and polar-maritime air (mT/mP).

Maritime front, separating polar-maritime air and arctic-maritime air (mP/mA).

Arctic front, separating arctic-maritime air and arctic-continental air (mA/cA).

Several other charts were tested. Charts of particular wet-bulb potential temperature proved difficult to define by a single surface and history, and continuity were not satisfactory. Charts of three-dimensional zones of maximum wind shear were quite interesting in relation to fronts but were somewhat discontinuous and transitory. Tropopause contour charts verified the general relationship with broad air masses and fronts.

Only the three-dimensional "density" discontinuity fronts had the desirable properties of continuity in space and time. They are of course subject to frontolysis and frontogenesis at all levels, but usually on a broad enough scale to handle synoptically.

A method of charting frontal intensity has not yet been found because of the difficulty of varying slope. Even if the gradient of temperature normal to the front remains constant the horizontal and vertical gradients of temperature can change relatively as the slope of the front changes. Both horizontal and vertical temperature gradients can, of course, decrease together with the front eventually disappearing.

It was found in the experiment that occlusions rarely occurred. The major feature was a trough of warm air aloft which had been given the name "trowal". The trowal moved with the wind field and was significant for both weather and development.

Mapping of jet streams by drawing isotachs at the level of the maximum wind was tried. This proved interesting but was difficult to interpret. The major features and details of the jet streams and maxima could be charted by isotach analysis at 300 mb. One method, very useful experimentally, was to grid shear isotachs on to isotachs at 500 mb. on the assumption of constant wind direction. The jet-stream analysis proved very satisfactory; a jet-stream maximum could be traced from an area of sparse data to an area of good data (Canada) and into an area of abundant data (central United States). Even in such a dense network of wind observations as that over the United States the maximum wind strength can miss the observing stations for thousands of miles; however, the sloping baroclinic zone will intersect the stations.

Mr. Boville illustrated the Canadian technique with two series of charts and diagrams. The first series* showed how a cross-section can be drawn and the winds calculated using the thermal wind equation

$$\frac{\partial V_H}{\partial z} = -\frac{g}{fT}\frac{\partial T}{\partial n}$$

where V_H is the horizontal wind component, f the Coriolis parameter, T the temperature, z the height and $\partial T/\partial n$ the temperature gradient perpendicular to the wind component. Cross-sections were drawn approximately normal to the wind flow, and two fronts were clearly marked from the tephigrams. The first cross-section showed the wind field as calculated up to the 50-mb. level using all the temperature data and only the wind observations from the ground to 700 mb. The second cross-section was drawn from the actual wind observations. The similarity between the wind fields was striking, both cross-sections showing a jet stream of more than 140 kt. just below the tropopause and a possible secondary jet stream at 100 mb. well above the tropopause. The main jet stream had an observed wind speed of more than 160 kt. Further discrepancies between the two wind fields could possibly be explained by neglect of anticyclonic curvature of the stream-lines in the calculated wind field and partly by the depth over which the observed winds are averaged to obtain the wind at a specific level.

The second series† showed the situation over Canada, the United States and Greenland on January 11 and 12, 1954, and illustrated the different features shown by the surface synoptic map, the frontal-contour chart, and the 500-mb. and 300-mb. contour charts. The frontal contour chart shows where each of the three fronts cuts the 850-mb., 700-mb. and 500-mb. surfaces. Trowals were marked along some of the isobaric troughs on the surface chart; they appeared as kinks or waves on the frontal contour chart. On these two days the western coast was affected by the arctic and maritime fronts and also—as shown by the frontal-contour chart alone—by the polar front at higher levels. Except in the extreme south and along the east coast the maritime front did not reach the land surface on the 11th; the frontal-contour chart showed that it was present aloft as far north as 70°N. but was occluded out in these latitudes during the day. The arctic front extended from northern British Columbia to the Middle West of North America eventually being gathered up with the maritime and polar fronts into one very strong front over the eastern states. There was marked confluence over this strong front which formed a typical deepening polar-front depression during the 11th (the central pressure fell from 1004 to 976 mb. in 24 hr.).

Isotachs were drawn every 20 kt. above 60 kt. on the 300-mb. charts and jet-stream positions were clearly visible. On the 11th there were two jet streams of 110–130 kt. (associated with the maritime front) meandering across the country to combine into one jet stream of 200 kt. (associated with the combined front over the eastern States). On the 12th the jet stream associated

* BOVILLE, B. W., CRESWICK, W. S. and GILLIS, J. J. A frontal-jet stream cross-section. *Tellus, Stockholm*, **7**, 1955, p. 314 (Figs. 1–3).

† ANDERSON, R., BOVILLE, B. W. and MCCLENNAN, D. E.; An operational frontal contour-analysis model. *Quart. J. R. met. Soc., London*, **81**, 1955, p. 588.

with the occluded maritime front had almost disappeared; the jet stream associated with the polar front had strengthened in all parts reaching 210 kt. over the cold-front part of the combined front of the deepening depression centred over Nova Scotia.

Mr. Murray was not convinced of the forecasting value of frontal contour charts. What did they give that could not be obtained from thickness charts? How objective was the analysis from upper air soundings? Mr. Boville said that major prognostic problems reduce to placing the frontal analysis and thermal structure and in getting the upper flow (at 500 and 300 mb.) right. The frontal-contour charts gave a good outline and define more clearly the frontal analysis to begin with. With advection of vorticity aloft and good frontal contrast development would occur. He also described how waves on the polar front go round a block in middle latitudes; only waves on the arctic front would go round a block in high latitudes, vigorous waves on the maritime and polar fronts travelling to the south.

To a question on how he placed a jet-stream maximum wind velocity which had not appeared in any station reports, Mr. Boville replied that jet streams were not transient and the analysis was based on a model where observations were few.

Mr. Illsley drew attention to the similarity between what was called a trowal in Canada and an occlusion in the United Kingdom; an occlusion does not necessarily mean a discontinuity at the surface. Would not a strong front and vorticity be the same as a strong thickness gradient? Do the frontal-contour charts help in forecasting? Mr. Boville though the difference between trowal and such an occlusion might simply be of nomenclature. However, an occlusion, by definition, should not be drawn if not supported by a surface thermal discontinuity. In 1951 there were wide discrepancies in analysis in forecasting offices in Canada; the frontal-contour analysis method has largely eliminated this. In the Central Analysis Office there is analysis and prognosis not forecasting of the weather. A "prognostician" does not analyse. The aim was to get the front right to begin with. He did not believe in the simple concept of upsliding motion on a front; he rather thought that vertical motion should be related to convergence and divergence. He had done no forecasting for four years but outstation forecasters seemed happy with the method.

Mr. Starr asked in what way did a trowal differ from a ridge of warm air aloft. Mr. Boville said they could be the same.

Mr. H. H. Lamb described an X-structure of fronts once used by the United States Weather Bureau with a valley line in continuation of either warm or cold front where the occlusion follows the line of the other front. If the valley line could be equated with Mr. Boville's trowal was the surface part of the occlusion not important in Canada? Mr. Boville said the surface part would be called another front not an occlusion if it had a temperature difference. Mr. Lamb asked if the following of trowals—not associated with a main surface front—settled many forecasting difficulties. Mr. Boville said it did. Mr. Lamb also asked if there were still rain areas not associated with front or trowal. Mr. Boville said not all rain areas were associated with fronts.

Dr. Tucker asked if there was a difference of analysis or merely a difference of nomenclature. Mr. Boville said there was no fundamental difference in the dynamical problem but a difference of approach.

Mr. McNaughton said he was trained as a forecaster in Canada 12 years ago and he had been taught there that the back-bent occlusion did not exist. Now the occlusion itself seemed to be disappearing. He asked for an indication of the density of the network necessary to carry out the three-dimensional analysis. Mr. Boville said the radio-sonde network in the United States and Canada was adequate, the North Atlantic grid of ocean weather ships was fairly adequate and the Pacific Ocean with but one ocean weather ship is quite inadequate. For small details even the United States network is inadequate; the upper-wind network was not so good.

To a question of what is the connexion with thickness-pattern work, Mr. Boville said the 1000–500-mb. thickness was mainly used to study advection. A wave develops with vorticity advection aloft over a strong low-level discontinuity. In the year no serious new development had been missed using these methods. The thickness chart was too gross to give the frontal structure adequately; fronts show up clearly as a shear orientation on wind hodographs over ocean weather stations; the thickness lines mask much of the detail.

Mr. Boyden found the last statement hard to understand. The frontal-contour analysis simply gave the intersection of the front with, say, the 500-mb. surface. Could that not equally come from a horizontal discontinuity in the mean temperature and thermal wind field.

Mr. Graystone thought Mr. Boyden was assuming a constant slope with height; some of Mr. Boville's charts showed it was not so.

Mr. Hawson asked what the evidence was for changing the slope between two stations. Mr. Boville pointed out that the temperature change from the tephigram combined with the wind shear from the hodograph could be used with the thermal-wind equation to calculate the slope and orientation of the front at any point from one radio-sonde and radar-wind ascent.

Mr. Veryard asked what Mr. Boville meant by a front. Mr. Boville said a front satisfied three criteria:

(i) it is a three-dimensional hyperbaroclinic zone with a first-order discontinuity in the temperature and wind fields

(ii) it is a quasi-substantial surface which moves with the wind flow

(iii) it is a reasonably continuous feature of the chart both in space and time.

If these conditions are not satisfied the front is not drawn.

Dr. Sutcliffe remarked that Mr. Boville had used a definition of a front which was both clear and communicable. A front was originally defined as a first-order discontinuity in density, but has since got muddled by the idea of it as a line of cloud and rain—being liable to be dropped if there is no rain. Mr. Boville's definition was more consistent with physical ideas. Meteorologists were partly responsible for the muddle, and would have to un-educate people who now associated a front with rain. Dr. Sutcliffe asked what staff were necessary at the analysis centre; the Central Forecasting Office, Dunstable, had to issue forecasts as well as analyses. Mr. Boville said that in Canada many outstations do no analysis work and receive only local data; all outstations receive facsimile broadcasts of all the charts and prognoses. The Central Analysis Office has two men on each shift for actual analysis and two for prognosis, plus ancillary staff.

Dr. Farquharson asked how long after the data were the charts received. Mr. Boville said that the surface chart was broadcast 4½ hr. after the data to which it referred; the first upper air chart was 5 hr. after the data and the experimental prognostic chart 10 hr. after the data on which they were based. Dr. Farquharson also said fronts could not often be identified above 10,000–12,000 ft. Mr. Boville said the hodograph and tephigram analysis together gave the answer.

Mr. Illsley asked who did the forecasting of the actual weather—the analysis charts shown were uncomplicated. Mr. Boville said the forecasting was done in the field offices. He thought it essential to abandon the simple model relation between surface fronts and rain and cloud and to make more use of fundamental parameters.

Mr. Pothecary said that Meteorological Research Flight data had shown that the humidity field was much more complicated than the temperature field. The upper levels of fronts could be recognized quite easily at 18,000 ft. from the temperature field but the humidity structure depended much more on past history; in some frontal zones the humidity had been found as dry as 5 per cent. even as low as 700 mb.

Mr. Tse Yu-Wai talked about the apparent difference in viewpoint between Canada and the Central Forecasting Office, Dunstable, over the existence of occlusions; he thought that unless we could prove the occlusion does not exist we should assume it does.

Mr. Wallington wondered how much of the difference in idea was due to difference in geography and climate. Perhaps the British Isles would be only a detail to the Canadians. How much of the Canadian work was a change in fashion? Mr. Boville said that size was not the only point of difference; the frontal-contour chart was an important part of the analysis.

Mr. Gold was glad to see the Canadians tackling the problem of analysis in a three-dimensional way and was relieved to hear Mr. Boville speaking about air masses. It was surprising and most encouraging to hear that no major development had been missed; if the prognosis agreed with events (no comparison charts had been shown) then the method was justified. Mr. Gold stressed the trinity of an occlusion (three air masses) and the duality of an ordinary front (two air masses); he thought an occlusion had a reality in the physical constitution of the atmosphere. He was, however, shocked at the disbelief in upsliding motion, an idea which had enabled a forecaster to understand the progressive formation of cirrostratus, altostratus and nimbostratus. He thought the frontal-contour chart an important part of the forecaster's armoury which made clear some of the details of a frontal surface.

Dr. Stagg, in closing the discussion, said that it was not just a comparison of techniques in which Canadian practice differed from United Kingdom practice. It was right to hear from Mr. Boville how other meteorologists think.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

PROFESSIONAL NOTES

No. 116—Variations of the measured heights of pressure surfaces. By D. H. Johnson, M.Sc.

The 6-hr. and 12-hr. apparent diurnal variations of the measured heights of standard pressure surfaces have been evaluated for levels up to 100 mb. at Larkhill, Lerwick, Malta and Nicosia. Calculated values of the apparent diurnal variation, based on estimates of the radiation errors made by Scrase, tend to underestimate the observed variation, but nevertheless provide a reasonable first approximation to the diurnal changes, except for the 2100–0300 G.M.T. variation, when both ascents are made whilst the sun is low in the sky. Tables are given which enable heights of pressure surfaces computed from radio-sonde observations made by stations in the British Isles, Malta and Nicosia to be corrected for diurnal variation.

Handbook of weather messages, Part I, 2nd edn

The new edition of Part I of the Handbook of weather messages contains schedules of reports, forecasts, warnings and analyses broadcast by radio in the United Kingdom, from ocean station vessels and from certain British centres overseas. Times of issue and the frequencies and power used in these broadcasts are given, together with a note of the code forms, and amplifying remarks on the significance of the terms used in the case of plain-language messages, such as gale warnings. Internationally approved numbers, names and co-ordinates of all observing stations used in these broadcasts are listed in numerical order, and a section has been allotted to facsimile transmissions from Dunstable for the first time.

To accord with the practice adopted in Volume A of Publication No. 9 of the World Meteorological Organization station heights for synoptic purposes which have hitherto been the height of the rain-gauge, or the ground upon which the thermometer screen stands for stations without a rain-gauge, are now defined as the height of the barometer cistern above mean sea level.

Part I of the Handbook, like Parts II and III which have already been published, is printed in loose-leaf form to facilitate periodical amendments.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society on December 21, 1955, with the President, Dr. R. C. Sutcliffe, in the Chair, papers were read on convection and on frontal contour analysis.

*Priestley, C. H. B.—Free and forced convection in the atmosphere near the ground.**

This paper was read by Sir Graham Sutton. Sir Graham explained that the paper set out to examine the differences in heat flux between free convection in which the buoyancy force was predominant and forced convection in which convection was produced by the dynamic turbulence of the flow of air over surface obstacles. Using dimensional arguments Priestley had earlier established a formula relating the vertical convective heat flux in free convection to the air density, specific heat at constant pressure, potential temperature, lapse-rate of potential temperature and height. In this paper he postulated that in purely forced convection the heat flux was a function of the Richardson number (R_i) alone and again by a dimensional argument found the form of the function. To examine the validity of this formula he studied a number of observations of heat-flux lapse rate of potential temperature and vertical wind gradient at 1·5 m. made by Swinbank. Plotting heat flux against Richardson number he found that at values of $-R_i$ less than about 0·02 the heat flux was a function of R_i satisfying the theoretical relation for forced convection, and for large values of $-R_i$ the assumption of fully free convection satisfied the values of heat flux better than any other existing law. The transition between the two appeared to be wholly within the range 0·02 to 0·05 for $-R_i$.

In the discussion Dr. Scorer objected to the form of the functions chosen for the dimensional analysis, considering temperature should be used instead of potential temperature. Mr. Charnock spoke on the general applicability of dimensional analysis, and Mr. Craddock described observations on two days at Mauripur, near Karachi, of the entirely different convection patterns occurring on a calm day and on a windy day showing the great difference between forced and free convection.

Anderson, R., Boville, B. W., and McClellan, D. E.—An operational frontal contour-analysis model.†

This paper was read by Mr. Boville of the Central Analysis Office, Montreal, Canada. He explained that it became apparent soon after the Central Analysis Office was founded three years ago that more rigorous methods of frontal analysis than current ones were necessary. The definition of a frontal surface adopted was that it was (i) a three dimensional hyperbaroclinic zone with first-order discontinuities in the temperature and wind fields, (ii) a quasi-substantial surface moving with the wind flow, and (iii) a reasonably continuous feature of the chart both in space and time. The tools used for analysis were charts of contours of the lines in which the fronts intersected the surface, 850-, 700-, 500- and 300-mb. surfaces; and surface, and 700-, 500- and 300-mb. contour charts with, on the upper charts, isotachs at 20-kt. intervals, and vertical cross-sections. The best parameters for representing a front were found to be the orientation given by the hodograph of vertical wind shear, the wet-bulb potential temperature and the saturated wet-bulb potential temperature. In analysis during winter three fronts were recognizable, in roughly south-to-north order, the polar front with tropical maritime air

* *Quart. J. R. met. Soc., London*, **81**, 1955, p. 139.
† *Quart. J. R. met. Soc., London*, **81**, 1955, p. 588.

above and to the south of the front, the maritime front with polar maritime air to the south, and the arctic front north of which was arctic continental air. Some examples of the charts were shown by lantern slides.

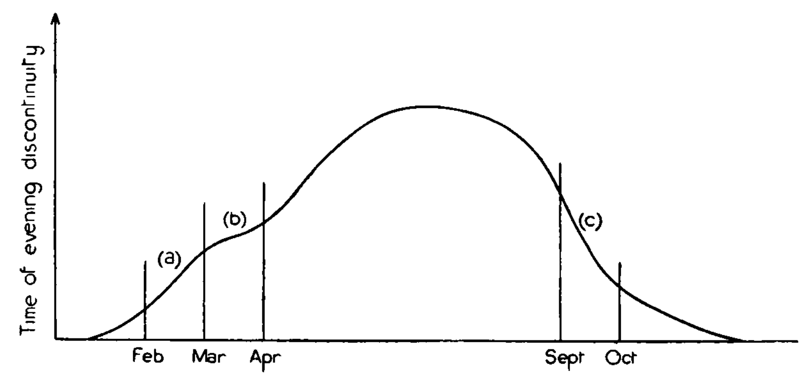
In reply to Dr. Sutcliffe, Mr. Boville said the upper part of the frontal zone was plotted as the front. Mr. H. H. Lamb said the charts showed the amplitude of the frontal "wave" as increasing with height which Mr. Boville said was characteristic of frontal waves. Mr. Boyden thought frontal contour charts showed no more than did the changes of gradient on a thickness chart. Mr. Sawyer inquired as to where the frontal analysis broke down to allow the necessary transformation of air masses, and Dr. Stagg asked on what basis the decision to adopt the frontal-contour method was taken.

LETTER TO THE EDITOR

Night cooling under clear skies

W. E. Richardson's[1] recent paper "Night cooling under clear skies at high-level stations in Cumberland" has been read with interest. It is agreed that owing to the scarcity of observations, the drawing of the 1953 cooling curve for Wahn[2] over the months of May and June is open to doubt. However the 1952 curve[2] confirms a significant change in the slope of the curve of annual variation of the time of discontinuity in evening cooling during the end of March and the first three weeks of April. Parry[3] found an identical change of slope over the years 1949–53 for Shawbury. Recently a night cooling curve was produced for London Airport, and this curve re-affirmed the levelling out of the change of slope during March and April. In view of this it is felt that the significant change of slope during spring cannot be ruled out.

W. E. Richardson's[1] curve for Riverside appears to show a flattening out of the curve during April. It is suggested that the following symbolic curve of annual variation could be drawn showing three stages associated with changes in soil moisture and in vegetation:



(*a*) Drying out of soil

(*b*) Delaying of the progressive change of time of discontinuity caused by transpiration of moisture from surface vegetation

(*c*) Moistening of soil with onset of winter.

W. J. BRUCE

London Airport, November 8, 1955.

[There appears to be an attempt at compromise in W. J. Bruce's letter between the relative significance of the "early spring late time bulge" and the "late spring early time bulge". Under the circumstance of insufficient suitable data this may be the best approach, but until such data are produced some consideration about the implications of such a compromise may provide valuable discussion.

(a) (b) (c) (d)

The conflict of ideas expressed in mine and Mr. Bruce's papers may be summarized by Figs. (*a*) and (*b*) where the curve represents the expected variation in the time of discontinuity, and the shaded areas show the disputed positions of the spring anomaly. Fig. (*c*) demonstrates the casual implication of the compromise, and Fig. (*d*) shows the possible distribution of areas of anomaly if the following argument is acceptable.

Attention has been drawn[1] to the importance of the spring low-humidity factor. It was considered to be both contributory to the drying out of soil, and significant in itself as an aspect of this subject. The attainment of dew point at 4 ft. above the ground is the relevant issue, and although ground effects will influence this, they need not be dominant as has hitherto been assumed. However if the resultant drying of soil is added to this low-humidity factor then the weight of influence seems strongly in favour of the "early spring late time bulge", but in view of the suggestions of Bruce a minor late spring anomaly may very well exist. This distribution is symbolized in Fig. (*d*).

Perhaps I may be allowed to take advantage of this opportunity to expand upon the idea in my paper[1] that minimum temperatures below about 15°F. appear to be impossible when no snow is lying. In the first place I am indebted to J. Glasspoole for examining the point in the light of observations from other British stations taken during certain recent severe spells. So far he has found no evidence to contradict the statement. Further, the events of March 5, 1953, at Alston are most revealing, for the minimum readings for that night were 16°F. at all three stations (Nether Park, Riverside and Samuel King's School). This was the only occasion in the record when a good radiation night produced no inversion. No snow lay at any height in the district.—W. E. RICHARDSON.]

REFERENCES

1. RICHARDSON, W. E.; Night cooling under clear skies at high-level stations in Cumberland. *Met. Mag., London,* **84,** 1955, p. 301.
2. BRUCE, W. J.; Night cooling curves for Wahn, Germany. *Met. Mag., London,* **84,** 1955, p. 105.
3. PARRY, T. H.; Night cooling under clear skies at Shawbury. *Met. Mag., London,* **82,** 1953, p. 368.

NOTES AND NEWS

Snow rollers at Grimsetter

During the heavy snow-falls last winter in Orkney a rather unusual occurrence was observed by several people in Orphir, a district about 15 miles to the west of Grimsetter. At dusk on February 22, 1955 a very heavy snow shower fell in which the snow-flakes were exceptionally large. They were described as being "as big as cigarette cards". There was a light westerly wind at the time. By 2100 G.M.T. the snow shower had died out, the wind became calm and the sky cleared. These conditions continued throughout the night and there was a keen frost.

The following morning lumps of snow were seen lying on the slopes of two small hills. They were very numerous and irregular in size and shape, and on close inspection they appeared flattened as if they had spread out on coming into contact with the surface snow. Some of the lumps were larger than a football, and they were confined entirely to the hill slopes, covering an area of roughly half a square mile. Towards the sea there was an abrupt change from the disturbed snow to the smooth undisturbed snow.

J. C. HAY

Publication of data on solar radiation and intensity of daylight

From January 1956 it is intended to make provision for the publication in the *Monthly weather report* of an extended table of radiation data (Table IIIb). At the same time the table of night-sky observations (Table IIIa) will be discontinued.

The new Table IIIb will permit the entry of mean, maximum and minimum daily values of total radiation on a horizontal surface and diffuse radiation on a horizontal surface for Kew, Eskdalemuir, Lerwick, London (Kingsway), Aberporth and Cambridge. It will also allow the entry of mean, maximum and minimum daily values of integrated illumination on a horizontal surface at the first four of these stations. The table will not be complete at first because the radiation recorders for Kingsway and the illumination recorders for Eskdalemuir and Lerwick are not yet available, and it may be some time in 1957 before they are all installed.

Values of maximum and mean direct solar radiation on a surface normal to the sun at Kew will no longer be published. Direct solar radiation can be obtained from the difference between total and diffuse radiation on a horizontal surface, and, as indicated above, mean values of both these quantities will be published.

It is hoped that this additional information will be of assistance to research workers in the agricultural, horticultural, building and engineering industries.

REVIEW

Report on experiments on artificial control of rainfall at Amboseli, Kenya, and Dodoma, Tanganyika, 1953–54. By D. A. Davies, H. W. Sansom, and G. Singh Rana. *Mem. East African Met. Dep., Nairobi,* **3,** No. 3. 10½ in. × 7½ in., pp. 21, *Illus.*, Nairobi, 1955. Price: 4*s*.

Tropical cumulus clouds were seeded at Amboseli and Dodoma in east Africa, using finely ground sodium chloride (50–75 μ) as the seeding agent. Dispersal within clouds was effected by releasing hydrogen balloons carrying charges of hygroscopic salt into each selected cloud and exploding the charges slightly above the cloud base. The experiments were conducted at Amboseli from October 15 to December 15, 1953 and at Dodoma from January 1 to March 31, 1954, at both places on all occasions whenever conditions appeared suitable. It was not possible to install a satisfactory control grid of rain-gauges, and assessment of the results of the experiments was based mainly on the visual observations of subsequent development of the seeded cloud.

The total number of seedings at the two places was 73, of which 57 succeeded in reaching the target cloud. Of these 57 seedings, it was observed that on 42 occasions rain fell within 13–38 min. after the explosion of the charges.

The rain was light or very light on 36 occasions, moderate on 3 occasions and heavy on 3 occasions, and the duration of the rain varied from 3 to 55 min. The results appear to prove conclusively that the release of these hygroscopic particles into a suitably large cumulus cloud would generally be followed by a light shower.

In discussing what adjustment might be made to the technique to increase amounts of rain the authors suggest an increase in amount of seeding substance and a decrease in particle size to, say, 25 μ; from theoretical considerations they suggest that the total quantity of rain might be about eight times as great with particle size 25 μ as with particle size 100 μ.

We look forward with great interest to learning the results of future experiments which it is hoped may be conducted with a smaller-size hygroscopic particle, and we congratulate the British East African Meteorological Department on the excellence of the work so far carried out.

A. F. JENKINSON

OBITUARIES

Charles William Heinemann.—We regret to report the death of Mr. C. W. Heinemann, formerly Staff Clerk in the Meteorological Office which occurred at the age of 90 years, on November 19, 1955. This removes from the roll of Office pensioners one of its Victorian characters. Mr. Heinemann joined the staff at the Victoria Street Office in October 1880 and resigned on account of ill health in November 1922. For the greater part of his career he assisted in the preparation of the *Weekly weather report* and *Monthly weather report.* He spent the last few months of his service in the British Rainfall Organization.

He is remembered by those who knew him as a cheerful likeable man and a very conscientious worker who was never known to make an error in the computing work. In many respects an individualist, he was an ardent vegetarian and the first man on the Office staff to own a motor vehicle—a tricycle. His hobbies included astronomy and the construction of clocks from spare parts; at one time he owned several good telescopes. Mr. A. T. Bench records that at about the age of 83 Mr. Heinemann cycled several times across London to visit him. In March 1955, to the gratification of his old colleagues, Mr. Heinemann attended the centenary dinner. Mr. Heinemann was unmarried and lived with a sister to whom we express our sympathy at her loss.

Professor W. M. H. Greaves, F.R.S.—We regret to learn of the sudden death on December 24, 1955, of Prof. Greaves, Astronomer Royal for Scotland and a member of the Meteorological Committee.

David H. Owen.—The death of Mr. D. H. Owen of Sparkhill, Birmingham, in November 1955 at the age of 84, brought to a sudden close a long and enthusiastic devotion to meteorology in this country. Mr. Owen was one of the now dwindling company of amateur meteorologists whose meticulous care and faithful service as an observer co-operating voluntarily with the Meteorological Office extended over a period of nearly half a century. His climatological returns began in 1907 and are a valuable contribution to local climatology and in recognition of this he received, in 1954, a presentation aneroid barometer from the Office. His interest in weather commenced at an early age and he had maintained weather notes since 1892 at the same place, contributing daily rainfall observations to the British Rainfall Organization from 1905.

Albert Roy Hosker.—It is with deep regret that we learn of the death, on January 30, 1956, of Mr. Hosker, Scientific Assistant, at the age of 25. Mr. Hosker joined the Office as a Meteorological Assistant in April 1947. He served at several aviation outstations and in o.w.s. *Weather Observer.* At the time of his death he was serving at Ronaldsway. Mr. Hosker has been a member of the Meteorological Office swimming team on several occasions when they have won the Air Ministry Championship. He was also a runner-up in the Civil Service Plunging Championship. He is survived by a widow and an infant daughter to whom the sympathy of all who knew him in the Office is extended.

METEOROLOGICAL OFFICE NEWS

Academic successes.—Information has reached us that the following members of the Staff have been successful in recent examinations:

General Certificate of Education (Advanced Level): physics, D. Gibbons; pure mathematics, B. Stapleton and G. A. Unwin.

Ocean weather ships.—The following are extracts from the Master's report of Voyage 67 of the *Weather Observer* when the ship was on duty at Station I.

December 22, 1955. Neptune aircraft from Topcliffe circled the ship using a television camera for the British Broadcasting Corporation, Independent Television Authority and the *Daily Mail*, and dropped five canisters containing mail and a Christmas tree. This was a very welcome thrill and cheered everybody up greatly. We are all most grateful to everyone who made this possible. A padre gave us a 15-min. Christmas message whilst the aircraft was circling.

December 25, 1955. Everybody seemed to enjoy their Christmas at sea; the Christmas dinner was excellent and was a great credit to the catering staff. It must have been good as both the crews told the chief steward how much they enjoyed it.

Social activities.—The staff of the London Airport meteorological office held a dance at the Master Robert Hotel, Hounslow on November 30, 1955. The dance was well attended despite the fact that the 30th was the only occasion during November on which fog had persisted at the airport all day. Headquarters and meteorological offices in the London area were well represented, and a highly successful evening was enjoyed by all.

WEATHER OF JANUARY 1956

The average state of the atmospheric circulation over the northern hemisphere during January was similar to that of the month before. The North American anticyclone was generally very large and strong and centred rather further east than usual, the highest mean pressure being 1029 mb. near Hudson's Bay and the greatest anomaly about +15 mb. over northern Labrador and Quebec. The Azores anticyclone was weak and small, and its usual January extension over Spain into central Europe was very feeble. The Siberian anticyclone was large and strong, but lacked its usual extension towards Europe.

Both in the Atlantic and Pacific the cyclonic activity was concentrated in two widely separate regions over the north-eastern and western, or south-western, parts of the oceans. There were several very deep centres early and late in the month over the sea areas between east Greenland and Novaya Zemlya. A very unusual feature was a low which deepened to about 984 mb. near Bermuda on the 5th with pressure remaining very low in that area for the ensuing three weeks; temperature had previously become unusually low over the eastern United States and this depression drove the very cold air on south into Florida.

Most of the month the pressure and thermal patterns were so abnormal over North America that normal patterns and sequences could hardly be expected to the eastward over the Atlantic and Europe. However, for a week or so from the 22nd to the 27th a former Alaskan anticyclone became quasi-stationary over the central United States, near 90°W.—itself a rare event—and the prolonged southerly advection over the great plains and prairies on the western flank of this system removed the pronounced negative temperature anomaly which had covered the region since autumn. East of this same American anticyclone, the complex of Atlantic lows began to coalesce and shift bodily eastwards. On the 27th the prolonged high-pressure régime over northern Greenland was dislodged and shifted to Scandinavia. This train of events brought a radical change in the character of the winter.

In the British Isles the weather during the first week over most of England had been dominated by extensive and persistent fog; elsewhere it was mild and dry. A wet cold period, with considerable snow in the north, followed, but the third week was milder and changeable and ended with widespread rain and gales. Mild rainy weather continued for most of the rest of the month, but on the 31st cold easterly winds spread from the continent over most of the country.

The year began with widespread north-westerly gales—a gust of 73 kt. was recorded at Tynemouth—as a depression moved south-eastwards from Iceland to Germany; there was also widespread rain or showers with scattered thunderstorms. An anticyclone from the Azores began to move north-eastwards on the 2nd and became centred over southern England on the 4th; and that night frost and fog developed extensively in east and south-east England and the Midlands. The fog was dense locally and persisted throughout the day in many areas from the 4th to the 6th; on the 5th it covered most of England south-east of an approximate line from the Bristol Channel to Whitby. There were good sunny periods however, especially on the 2nd and 5th, and weather was mild, except in foggy areas, with afternoon temperatures exceeding 50°F. at times in Scotland. Arctic air on the western flank of a depression north of Scandinavia, swept southwards bringing snow to many parts of eastern Great Britain on the 7th, and falls became substantial the following day as a depression formed over the North Sea. Another depression, which deepened unusually quickly as it moved south-east toward Ireland on the 9th, absorbed the North Sea depression into its circulation on the 10th as a belt of snow, heavy in places, spread eastwards. Temperature, which had fallen to 10°F. at Dyce early on the 10th, rose to 40°F. during the day. Heavy continuous snow fell for about 11 hr. in parts of Lincolnshire and lay to a depth of about 15 in., but in southern England it turned to rain, and thunderstorms developed. Thundery showers of rain, sleet or snow continued daily until the 12th. A slight earth tremor was felt in some Midland counties on the 10th. The first substantial rainfall of the year occurred on the 13th ahead of a depression which approached from the south-west; both Plymouth and St. Mawgan had more than 1 in. of rain in 12 hr. Throughout the third week a series of depressions moved eastwards over, or to the north of, Scotland on tracks which became progressively further south. Weather during the first part of the week was changeable, though fairly dry and often sunny in England and Wales, particularly on the 18th when many places recorded more than 6 hr. sunshine, but a depression north of Scotland deepened and gave severe gales on nearby coasts—wind reached 83 kt. in a gust at Lerwick on the 21st—as it moved slowly eastward on the 20th and 21st, and there was widespread and locally heavy rain over most of the country. Considerable rain and snow fell on the 23rd as a depression crossed southern England while in its rear cold air spread southwards to give a fall of temperature of 10–15°F. Frost was widespread on the night of the 24th–25th; at Eskdalemuir temperature fell to 12°F. and did not rise above 26°F. the following day, but milder air, preceded by rain and snow, returned from the south-west on the 25th and spread very slowly northward. The thaw caused extensive floods in counties adjacent to the Severn on the 27th as the melting snow and recent widespread rain caused the river to overflow its banks. Weather was dull and wet from the 26th to the 30th with widespread and heavy rain in places as troughs, associated with a large low-pressure system between Iceland and Greenland, crossed the country; but on the last day of the month a well developed anticyclone over northern Scandinavia started to move south-westward and very cold easterly winds spread across the British Isles.

This changeable month produced the rather unusual combination of high rainfall and an excess of sunshine, but temperature was about normal, except in the extreme north of Scotland, where it was 3–4°F. below average. In Scotland the rather severe weather presented many farming difficulties, though hill sheep have suffered more from the cold high winds and lack of shelter than from lack of grazing. Elsewhere maintenance work on farms and market gardens continued with little interruption, and was so well forward that farmers were able to plan to catch up with arrears from previous years. Cattle, even in the north of England, have been left in pasture longer than usual, thus conserving fodder. Ploughing for spring sowing has continued.

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 ...	58	12	−0·6	167	+3	118
Scotland	56	2	−1·9	106	+2	119
Northern Ireland ...	53	18	−2·1	111	+1	96

RAINFALL OF JANUARY 1956

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	3·60	194	*Glam.*	Cardiff, Penylan ...	5·02	136
Kent	Dover	5·80	271	*Pemb.*	Tenby	6·03	161
,,	Edenbridge, Falconhurst	5·08	207	*Radnor*	Tyrmynydd	8·92	141
Sussex	Compton, Compton Ho.	5·55	175	*Mont.*	Lake Vyrnwy	9·37	162
,,	Worthing, Beach Ho. Pk.	5·07	218	*Mer.*	Blaenau Festiniog ...	8·35	82
Hants.	St. Catherine's L'thouse	5·12	207	,,	Aberdovey	5·16	133
,,	Southampton (East Pk.)	4·81	180	*Carn.*	Llandudno	2·71	112
,,	South Farnborough ...	3·94	189	*Angl.*	Llanerchymedd ...	3·67	116
Herts.	Harpenden, Rothamsted	4·51	218	*I. Man*	Douglas, Borough Cem.	4·28	128
Bucks.	Slough, Upton	3·29	177	*Wigtown*	Newton Stewart ...	3·79	92
Oxford	Oxford, Radcliffe ...	3·91	216	*Dumf.*	Dumfries, Crichton R.I.	3·53	110
N'hants.	Wellingboro' Swanspool	3·80	205	,,	Eskdalemuir Obsy. ...	4·43	82
Essex	Southend, W. W. ...	3·58	245	*Roxb.*	Crailing...	1·81	94
Suffolk	Felixstowe	3·45	227	*Peebles*	Stobo Castle	2·83	94
,,	Lowestoft Sec. School ...	3·37	202	*Berwick*	Marchmont House ...	2·42	108
,,	Bury St. Ed., Westley H.	3·24	181	*E. Loth.*	North Berwick Gas Wks.	2·13	125
Norfolk	Sandringham Ho. Gdns.	3·34	172	*Midl'n.*	Edinburgh, Blackf'd. H.	1·44	82
Wilts.	Aldbourne	4·86	195	*Lanark*	Hamilton W. W., T'nhill	2·21	67
Dorset	Creech Grange... ...	5·03	154	*Ayr*	Prestwick	2·50	88
,,	Beaminster, East St. ...	5·34	153	,,	Glen Afton, Ayr San. ...	3·66	72
Devon	Teignmouth, Den Gdns.	3·99	137	*Renfrew*	Greenock, Prospect Hill	...	...
,,	Ilfracombe	5·26	160	*Bute*	Rothesay, Ardencraig ...	3·89	86
,,	Princetown	8·97	112	*Argyll*	Morven, Drimnin ...	4·69	74
Cornwall	Bude, School House ...	3·35	110	,,	Poltalloch	4·24	84
,,	Penzance	6·20	164	,,	Inveraray Castle ...	...	...
,,	St. Austell	5·49	128	,,	Islay, Eallabus	5·54	118
,,	Scilly, Tresco Abbey ...	4·21	134	,,	Tiree	3·79	89
Somerset	Taunton	2·98	125	*Kinross*	Loch Leven Sluice ...	3·89	123
Glos.	Cirencester	3·60	138	*Fife*	Leuchars Airfield ...	2·27	125
Salop	Church Stretton ...	4·14	159	*Perth*	Loch Dhu	6·09	67
,,	Shrewsbury, Monkmore	3·07	157	,,	Crieff, Strathearn Hyd.	3·19	79
Worcs.	Malvern, Free Library...	3·92	177	,,	Pitlochry, Fincastle ...	2·80	80
Warwick	Birmingham, Edgbaston	3·61	162	*Angus*	Montrose, Sunnyside ...	3·40	171
Leics.	Thornton Reservoir ...	3·59	181	*Aberd.*	Braemar	3·79	119
Lincs.	Boston, Skirbeck ...	...	...	,,	Dyce, Craibstone ...	3·59	152
,,	Skegness, Marine Gdns.	3·99	231	,,	New Deer School House	4·66	200
Notts.	Mansfield, Carr Bank ...	3·80	177	*Moray*	Gordon Castle	3·27	162
Derby	Buxton, Terrace Slopes	9·02	202	*Nairn*	Nairn, Achareidh ...	1·37	76
Ches.	Bidston Observatory ...	2·94	139	*Inverness*	Loch Ness, Garthbeg ...	...	...
,,	Manchester, Ringway...	4·31	180	,,	Loch Hourn, Kinl'hourn	7·45	59
Lancs.	Stonyhurst College ...	4·59	107	,,	Fort William, Teviot ...	7·15	74
,,	Squires Gate	3·69	142	,,	Skye, Broadford ...	6·11	81
Yorks.	Wakefield, Clarence Pk.	3·50	182	,,	Skye, Duntuilm ...	4·25	80
,,	Hull, Pearson Park ...	4·99	277	*R. & C.*	Tain, Mayfield... ...	3·09	127
,,	Felixkirk, Mt. St. John...	4·80	240	,,	Inverbroom, Glackour...	7·36	137
,,	York Museum	4·11	232	,,	Achnashellach	10·50	115
,,	Scarborough	3·57	179	*Suth.*	Lochinver, Bank Ho. ...	5·38	127
,,	Middlesbrough... ...	2·69	168	*Caith.*	Wick Airfield	5·44	221
,,	Baldersdale, Hury Res.	4·06	121	*Shetland*	Lerwick Observatory ...	5·21	122
Norl'd.	Newcastle, Leazes Pk....	3·67	185	*Ferm.*	Crom Castle	2·86	86
,,	Bellingham, High Green	3·09	108	*Armagh*	Armagh Observatory ...	2·09	83
,,	Lilburn Tower Gdns. ...	4·00	193	*Down*	Seaforde	3·68	117
Cumb.	Geltsdale	2·22	79	*Antrim*	Aldergrove Airfield ...	2·88	105
,,	Keswick, High Hill ...	3·44	68	,,	Ballymena, Harryville...	3·54	95
,,	Ravenglass, The Grove	3·42	102	*L'derry*	Garvagh, Moneydig ...	...	...
Mon.	A'gavenny, Plâs Derwen	6·37	172	,,	Londonderry, Creggan	5·21	145
Glam.	Ystalyfera, Wern House	8·24	130	*Tyrone*	Omagh, Edenfel ...	2·92	82

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Frontispiece

MR. J. DURWARD, C.M.G., M.A.

M.O. 613 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 85, No. 1,006, APRIL 1956

JAMES DURWARD, C.M.G., M.A.

Mr. Durward retired on January 31, 1956 after nearly 37 years' service in the Meteorological Office.

At the outbreak of the First World War he was at the University of Aberdeen. He enlisted in the Gordon Highlanders and was on active service in France. In June 1915 he was transferred to the newly formed Meteorological Section of the Royal Engineers in France, was commissioned in February 1917 and was promoted to the rank of Captain in March 1918.

On his return from France after the cessation of hostilities he was posted in charge of the meteorological office at West Lavington which catered for the needs of the artillery and sound-ranging units on Salisbury Plain. In April 1919 he was appointed Senior Professional Assistant, and a year later the meteorological office at West Lavington was transferred to the School of Artillery at Larkhill where he remained until July 1922, when he was promoted to the rank of Assistant Superintendent and transferred to the R.A.F. Flying Boat Station, Calshot, where lecturing in meteorology to the long Navigation Courses was an important commitment.

In December 1926 he was promoted to the rank of Superintendent and posted to Headquarters R.A.F. Middle East (Cairo), where he was responsible for the provision of meteorological services to the Royal Air Force and to civil aviation, particularly Imperial Airways (subsequently renamed British Overseas Airways Corporation). This was the beginning of a close association with civil aviation which continued throughout the greater part of his subsequent service in the Meteorological Office.

The main forecasting centre was at Heliopolis, a suburb of Cairo, and subsidiary offices were established at Ismailia, Abu Qir (near Alexandria), Ramle, (Palestine) and Amman (Transjordan). Forecasts for the Middle East area were broadcast twice daily and a collective broadcast of 0700 G.M.T. reports for the Mediterranean-Middle East area was inaugurated. Subsequently, towards the end of 1931, the Meteorological Office took over, from the Royal Air Force, responsibility for the provision of meteorological services in Iraq, and a main meteorological office was established at Hinaidi (near Baghdad) and subsidiary offices at Mosul and Shu'aiba under the overall control of Mr. Durward.

In November 1936, he was seconded to the Iraq Government for three years as Director of the recently formed Iraq Meteorological Service. His efforts in developing and organizing an efficient meteorological service and in training

Iraqi staff in meteorological duties were prodigious, and well merited the award of the Order of Rafidain bestowed on him by the Iraqi Government in March 1940.

On his return to the United Kingdom he was posted as Principal Technical Officer to be Head of one of the Branches of the Royal Air Force Division of the Meteorological Office in March 1940, and later as Head of the Overseas Branch, in November 1941. In the winter of 1943–44 he went by air to the South-East Asia Air Command making a detailed inspection of all important R.A.F. Staging Posts *en route*.

In April 1946 he was promoted to the post of Assistant Director (Civil Aviation) and in January 1948 he was promoted to the grade of Deputy Chief Scientific Officer to undertake the duties of Deputy Director in charge of the provision of meteorological services for the Army, the Royal Air Force, the Ministry of Civil Aviation and the Ministry of Supply.

Since the conclusion of the Second World War Mr. Durward has become increasingly well known in international meteorological circles, has frequently undertaken the chairmanship of some of the meteorological committees, and has taken a leading part in the formulation of meteorological procedures and practices, particularly those for aviation in the early days of the International Civil Aviation Organization. His world-wide interests in meteorology may be appreciated from the list of international meetings at which he has been a delegate. He was an adviser at meetings of the Synoptic Weather Information Commission of the International Meteorological Organization, and was the principal United Kingdom delegate at meetings of the Aeronautical Commission of the same organization both before and after it became the World Meteorological Organization. He was also a principle delegate at meetings of the International Civil Aviation Organization of the North Atlantic, South Pacific, Caribbean and South Atlantic Regions; of special Meteorological Division meetings; and of Joint Support meetings in respect of meteorological services in Greenland and Iceland and of the operation of ocean weather ships in the North Atlantic.

Mr. Durward was also concerned with meteorological services in liaison with the Colonial Office. Mention may be made of his visits to the West Indies in 1945 and to British West Africa in 1947 for the purposes of advising on the meteorological organization necessary to replace the war-time organization which had been developed as a Meteorological Office responsibility.

In recognition of his invaluable services, in June 1953, Mr. Durward was made a Companion of the Order of St. Michael and St. George, an honour which gave great gratification particularly to those members of the staff who have had the good fortune to serve under him.

Since his retirement from the post of Deputy Director (Services) on December 31, 1954, Mr. Durward has been Scientific Officer to the Director of the Meteorological Office, in which capacity his aid was invaluable before and during the Second Congress of the World Meteorological Organization held at Geneva from April 14 to May 13, 1955, and the Conference of Commonwealth Meteorologists held in the Air Ministry, Whitehall Gardens, during May 23–26, 1955.

A host of colleagues with happy recollections of his geniality, able guidance and willing assistance at all times wish Mr. Durward a long and very happy retirement.

VARIATION WITH TIME OF WINDS AT 40,000 FT. AND 50,000 FT. OVER SINGAPORE

By L. S. CLARKSON, M.Sc.

Introduction.—The general significance of specified statistical parameters in relation to atmospheric circulation at high altitudes in the tropics and subtropics has been discussed by N. E. Davis[1], while Durst[2] has investigated the variation of upper wind with time (and distance) in an analysis which deals mainly with the results of observations made over the British Isles, although some data for equatorial regions are included.

In view of Durst's conclusion, "Unless winds are available from accurate contour charts, the route wind for high-altitude flights is best obtained from actual winds by the use of regression equations, and in the tropics this is always so, since geostrophic winds have no real significance", it was considered worth while to make a comparative statistical investigation of the variation of high-altitude winds with time over Singapore.

Analysis.—The vector mean wind $\mathbf{V}_R$ and the standard vector deviation σ at 40,000 ft. and 50,000 ft. over Singapore have been evaluated separately for each month from Army radar wind determinations considered by Hay[3], and from the daily ascents at 0300 G.M.T. subsequently undertaken by the Malayan Meteorological Service.

Vector differences between the winds observed at 0300 and 1500 G.M.T. have been obtained from the daily observations covering November 1953 to December 1955, inclusive, and the standard vector variation in 12 hr. σ_{12}, calculated for each month. Similarly from consecutive daily observations at 0300 G.M.T. the standard vector variation in 24 hr., σ_{24}, has also deen computed.

Values have been calculated of the stretch vector correlation coefficient r_t between winds separated by a time interval of t hr. from the relation given by Durst[2]

$$r_t = 1 - \tfrac{1}{2}\left(\frac{\sigma_t}{\sigma}\right)^2.$$

$\mathbf{V}_t$, the statistically most probable wind to be expected t hr. after an observed wind $\mathbf{V}$, is given by the equation

$$\mathbf{V}_t = \mathbf{V}_R - r_t\,(\mathbf{V}_R - \mathbf{V}),$$

and this is readily solved graphically by a diagram given by R. F. Zobel in an unpublished memorandum, and reproduced here for convenience. In Fig. 1, OA is drawn to represent the appropriate value of $\mathbf{V}_R$, and OB the observed wind $\mathbf{V}$. Then OD represents the most probable wind $\mathbf{V}_t$ when AD is made equal to $r_t \times$ AB.

The standard vector error, ε_t, of wind estimates using the above regression equation is given by

$$\varepsilon_t = \sigma\sqrt{(1 - r_t^2)}.$$

The standard vector error involved in adopting the vector mean wind $\mathbf{V}_R$ for the month as an estimate is given by σ, whilst that of using an observed wind as a forecast of the wind 12 or 24 hr. later is given by σ_{12} and σ_{24}, respectively.

Values of $\mathbf{V}_R$, σ, σ_{12}, σ_{24}, ε_{12}, and ε_{24}, with (in brackets) the numbers of observations or pairs of observations on which they are based, have been entered in Table I. Corresponding values for winds over Larkhill at 200 mb.

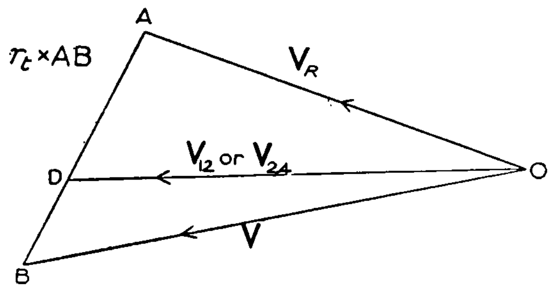

FIG. 1

taken or calculated from the data in Durst's[2] Table VII have been included for comparison.

Discussion.—The vector correlation coefficients of wind at 40,000 ft. with time for Larkhill and Singapore are comparable, although the 50,000-ft. winds separated by 12 hr. and 24 hr. are more highly correlated over Singapore. However, because of the lower variability, the standard vector variation in 12 hr. and 24 hr. is much smaller for Singapore than at corresponding heights for Larkhill. In consequence, the standard vector error involved in quoting the latest observed wind at 40,000 ft. or 50,000 ft. as an estimate of the wind to be expected 12 hr. or 24 hr. later over Singapore is roughly half the 33 kt. quoted by Durst[2] as the standard vector error of forecasts made at Dunstable of the wind 24 hr. ahead at 300 mb. over Larkhill in July 1951.

TABLE I—UPPER WIND STATISTICS OVER SINGAPORE AND LARKHILL

	Vector mean wind V_R		Standard vector deviations σ	σ_{12}	σ_{24}	Standard vector errors ε_{12}	ε_{24}	Stretch correlation coefficients r_{12}	r_{24}
	°	kt.		*knots*					
			Winds at 50,000 ft. over Singapore						
January ...	100	37	22 (64)	17 (45)	19 (44)	16	17	0·70	0·64
February ...	100	30	34 (75)	16 (53)	20 (50)	16	19	0·89	0·83
March ...	070	10	26 (85)	15 (59)	20 (54)	15	18	0·83	0·71
April ...	080	20	20 (78)	13 (59)	17 (58)	12	15	0·78	0·65
May ...	070	27·5	19 (78)	16 (59)	17 (54)	15	15	0·64	0·62
June ...	075	36	24 (75)	17 (53)	24 (54)	16	21	0·77	0·51
July ...	080	41	23 (76)	17 (59)	21 (56)	16	19	0·74	0·60
August ...	075	51	22 (64)	23 (49)	23 (43)	20	20	0·46	0·44
September	080	42	28 (65)	20 (45)	24 (39)	19	22	0·74	0·63
October ...	080	37	19 (77)	15 (52)	19 (52)	14	16	0·68	0·53
November	090	40	22 (97)	16 (75)	21 (74)	15	18	0·73	0·54
December	100	30	24 (70)	16 (53)	19 (46)	15	18	0·78	0·68
			Winds at 40,000 ft. over Singapore						
January ...	110	21	13 (65)	12 (47)	16 (45)	11	13	0·59	0·28
February ...	115	26	17 (78)	14 (55)	15 (54)	12	13	0·68	0·62
March ...	110	16·5	16 (85)	12 (59)	18 (54)	11	15	0·74	0·37
April ...	100	16	14 (79)	11 (60)	12 (58)	10	11	0·72	0·61
May ...	080	20·5	16 (81)	12 (60)	17 (56)	11	14	0·71	0·46
June ...	070	34	16 (81)	14 (55)	17 (56)	12	14	0·60	0·39
July ...	075	38	16 (84)	15 (62)	17 (60)	13	14	0·59	0·48
August ...	075	41	17 (77)	15 (56)	19 (51)	13	16	0·62	0·38
September	070	38	18 (71)	16 (52)	18 (49)	14	16	0·60	0·49
October ...	080	24	15 (81)	13 (57)	15 (57)	12	13	0·61	0·47
November	095	25	14 (96)	13 (75)	15 (72)	11	13	0·61	0·49
December	110	21	14 (78)	14 (55)	15 (50)	12	13	0·56	0·48
			Winds at 200 mb. over Larkhill						
March–May	290	21	35	29	34	26	30	0·66	0·53

From Durst's Fig. 4 the ratio σ_t/σ for $t = 3$ hr. can be found to be approximately 0·36, so that with an annual standard vector deviation at 200 mb. equal to 42 kt., 15 kt. is obtained as the estimated standard vector variation of winds at 40,000 ft. in 3 hr. over Larkhill. Thus for Singapore, quoting the vector mean 40,000-ft. wind for the month as a forecast will achieve about the same accuracy as will taking an observation of the 200-mb. wind 3 hr. old as representative of current conditions over Larkhill. Furthermore, for Singapore we can do appreciably better than using the vector mean as a forecast by adopting instead the appropriate regression equation, in which case the standard vector errors of 12-hr. and 24-hr. wind forecasts are reduced to approximately 10–15 kt. at 40,000 ft. and 15–20 kt. at 50,000 ft.

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WEATHER OF 1955

By R. E. BOOTH

The year on the whole was dry and sunny, cold during the first half and warm and mild during the second. It was notable for the cold winter when particularly heavy snowfalls and low temperatures were experienced in Scotland, the brilliant warm summer when many stations in the north-west exceeded long-standing sunshine records for July, the lateness of the seasons, and the long periods of drought which reached serious proportions in some parts of the country.

Temperature was below the average in each of the first six months of the year apart from April, and particularly low during February in Scotland and Northern Ireland. From July to December each month except October was warmer than average, especially August in the Midlands and the west of England. During the first six months rainfall was above the average in England and Wales except during March and April, but in Scotland, however, below the average every month except May. During the latter half of the year rainfall was below the average except during September, October and December in Scotland. Throughout the year the dry weather was particularly outstanding in Scotland and north-east England. Sunshine was above the average except during January, June, November and December in England and Wales.

Development of the synoptic situation.—From January 1 to March 22, anticyclones either over the Continent or in the region of Greenland maintained cold wintry weather over the British Isles, with an inflow of a cold easterly air stream from the Continent alternating with an arctic or polar air stream from the north, except for a period of milder south-westerly winds from January 19 to February 8. A mild south-westerly air stream with rain at times predominated during the first and last weeks of April and at the beginning of May, but during April 10–24 an anticyclone was almost stationary over the British Isles, and weather was dry and sunny with a drought over the major part of the country. An influx of arctic air from near Greenland brought unusually cold weather during May 10–21; snow extended as far south as

Bournemouth on the 17th. Active depressions off the south-west seaboard gave generally unsettled but rather cold weather during June and the first few days of July. On July 6 a ridge from the Azores anticyclone developed north-eastwards over the British Isles, and, except for an unsettled period August 14–19, the whole of the remainder of July and most of August was brilliantly fine and warm with pressure high from the region of the Azores across the British Isles to Scandinavia. A persistent low-pressure system near Iceland maintained mild and unsettled weather during the first half of September, but there were finer periods during the latter part of the month. The first major depression of the autumn crossed southern Scotland on October 5 accompanied by widespread and sometimes heavy rain and gales. The second week of October was unusually mild, but an arctic air stream on the 15th brought snow showers to Scotland and isolated sleet showers as far south as the Midlands. A large low-pressure system near western Ireland gave mainly unsettled weather during the period November 2–11, but during the remainder of the month the weather was anticyclonic and mostly dry and cooler. A generally mild westerly air stream which persisted during the greater part of December was interrupted by the break through of arctic air which spread over the country on the 11th and 17th; on the 20th snow fell continuously for more than 16 hr. in east Yorkshire and lay up to 14 in. deep.

Figs. 1–6 are maps of mean monthly barometric pressure prepared by the Overseas Climatological Branch for three winter and three summer months of 1955. It will be seen that the mean isopleths for January show the predominance of south-easterly winds over the British Isles during that month; in February mainly north-easterly winds were experienced, whereas in March winds were probably more northerly. During the summer months the July and August maps show a ridge from the Azores anticyclone firmly established across the British Isles, but in September the ridges had receded southward to the Bay of Biscay and in general there was a south-westerly air stream across the country.

Apart from transitory ridges only one well established anticyclone remained over the British Isles during the first half of the year, that which persisted from April 10 to 24, but during the second half of the year there was a period of anticyclonic weather every month.

Eleven major periods with arctic or polar air may be identified throughout the year; dates of commencement of the cold influx were: January 11, February 9, March 28, May 10, June 7, September 13, October 15 and 26, November 20, December 11 and 17; the most severe was that during May. Arctic or polar air spread over the country every month except the predominantly anticyclonic months of April, July and August.

Absolute droughts occurred during the months of April, July, August, and November.

Lateness of the seasons.—Wintry weather did not begin in the British Isles until January 1, and continued with some intervening milder periods until the end of March. The backwardness of the season was maintained during April, for although there were many sunny days there were no spells of warm weather. Spring was unusually cool, and summer weather really began on July 6 when a brilliantly sunny day marked the beginning of a period of unusually warm, dry and sunny weather which lasted until about the end of

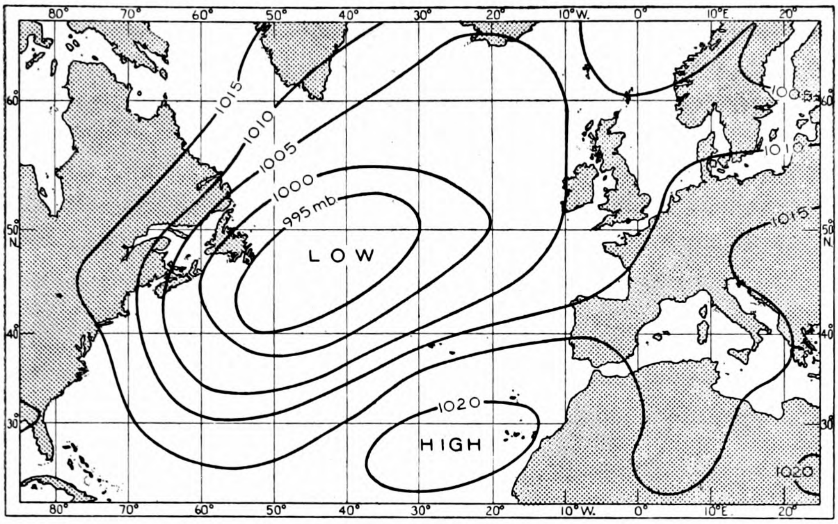

FIG. 1—MEAN BAROMETRIC PRESSURE AT SEA LEVEL, JANUARY 1955

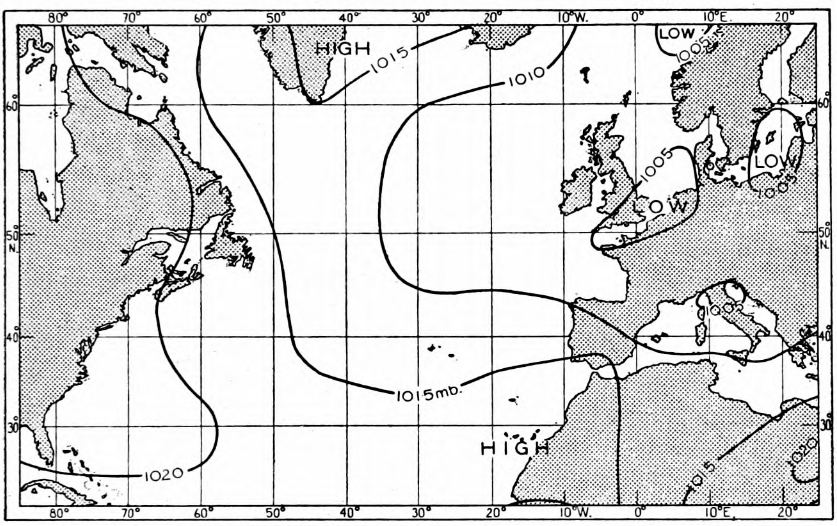

FIG. 2—MEAN BAROMETRIC PRESSURE AT SEA LEVEL, FEBRUARY 1955

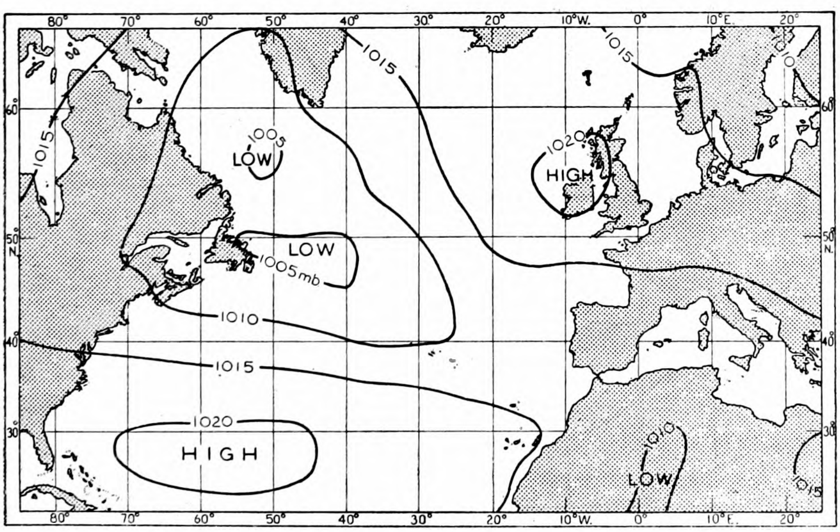

FIG. 3—MEAN BAROMETRIC PRESSURE AT SEA LEVEL, MARCH 1955

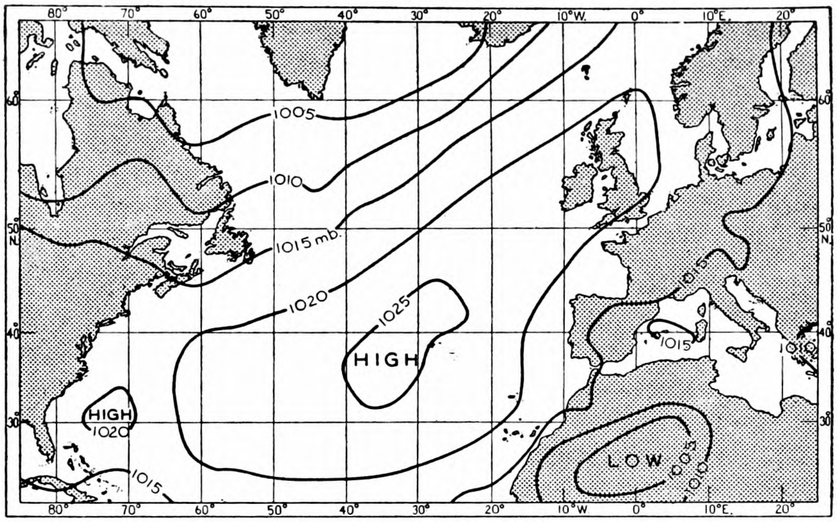

FIG. 4—MEAN BAROMETRIC PRESSURE AT SEA LEVEL, JULY 1955

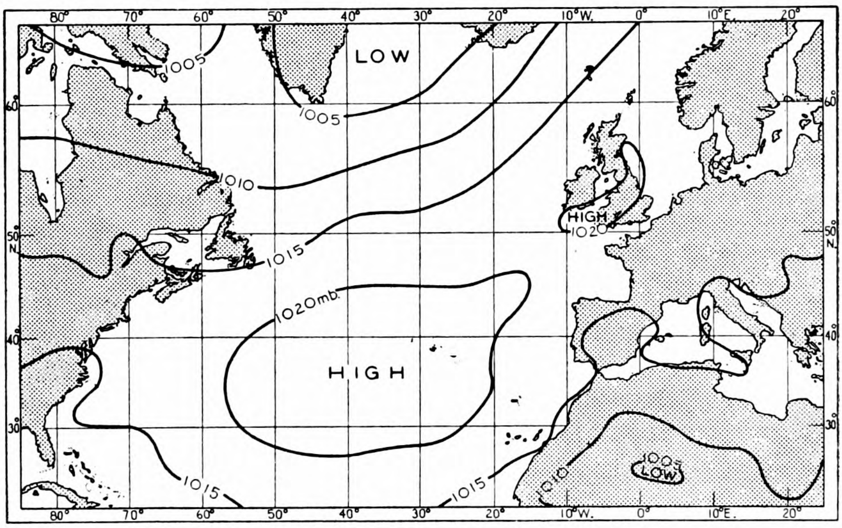

FIG. 5—MEAN BAROMETRIC PRESSURE AT SEA LEVEL, AUGUST 1955

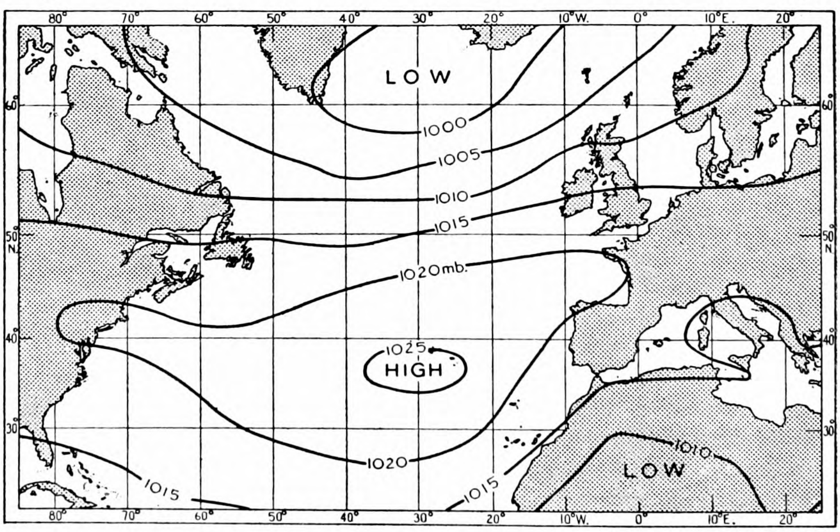

FIG. 6—MEAN BAROMETRIC PRESSURE AT SEA LEVEL, SEPTEMBER 1955

September. Late summer merged into autumn during October, the first month with temperature below the average since June, and apart from some wintry showers, mainly on high ground in the north but which extended as far south as the Chilterns and Exmoor on December 11, there was no real wintry weather until about December 20 in the north and none in the south-east.

Highlights of the year.—*Winter.*—During January and February snow lay to a depth of 18–24 in. over large areas of north and east Scotland, with drifts caused by high winds up to as much as 30 ft. deep. Many farms and villages were completely isolated for weeks and had to be supplied by air. This operation caused considerable interest in the press and elsewhere as it was the first time that organized relief had been carried out on such a large scale in the British Isles. Exceptionally low temperature was recorded in Scotland. During February temperature ranged from −13°F. at Braemar on the 23rd to 55°F. at Lephinmore on the 1st; the minimum temperature was the lowest screen temperature recorded in the British Isles since 1895, and the range of 68°F. for the month has only been exceeded twice—in February 1897 and January 1871—during 100 yr. of Scottish records. There were some remarkably cold periods; at many places temperature was continuously below freezing during January 11–18 and fell below 0°F. during February 22–24; on these last three days temperature at Dyce fell to −7°F., −5°F. and −5°F. respectively. Mean temperature was particularly low over a large part of north Scotland; for example, it was 14°F. lower than normal during the week beginning February 20. Among the places which had unusually cold days was Dalwhinnie where temperature did not rise above 15°F. on January 14 or above 18°F. on either February 20 or 22. Temperature in England and Wales was not so low, but there was an extremely cold period during January 15–20 when temperature frequently fell to 15°F., and during the last week of February the mean temperature in the Midlands was 11°F. lower than the average. Very cold weather continued into March; Birmingham had its coldest March since 1916, and only in 1917 has March been colder at Kew since 1892.

The first week of January was exceptionally dull in eastern England, where most districts had 5 per cent. or less of their normal amount of sunshine. In contrast north and west Scotland had more than double the seasonal average of sunshine during February; Stornoway's total of 96 hr. was the best in February since 1881, whilst at several other stations it was the sunniest February for 40 yr.

A severe gale south-west of England on March 23 drove the Norwegian ship *Venus* (6,272 tons) on the rocks in Plymouth Sound and other shipping suffered considerable damage. At some places mean hourly wind exceeded 33 kt. for more than 12 consecutive hours; a gust of 73 kt. was recorded at Lizard and 82 kt. at Scilly.

Spring.—The most remarkable feature of the spring was the snow which spread from Scotland to the south coast of England on May 17; parts of Wiltshire and Dorset had the worst mid-May snowstorm in living memory with snow lying to a depth of 3 in. over a wide area. Unusually low maximum temperatures of 40°F. or below were recorded at several stations including Ross-on-Wye where 40°F. was the lowest maximum temperature recorded during May at that station since 1875, whilst at Aberystwyth the temperature only reached 36°F.

Rainfall during May was also exceptional; many places had twice their monthly average and Hastings its wettest May since records began there in 1875.

Sunshine was above the average during April and May—Edinburgh had its sunniest May since 1901—but June, generally accounted one of the summer months, was remarkably dull and cold. Unusually low temperatures were experienced on the 9th when 24°F. and 22°F. were recorded in the screen at Glenlivet and Dalwhinnie respectively, the latter being the lowest temperature recorded anywhere in the British Isles in June for 100 yr.

Summer.—The summer, although it began late, was notably sunny, warm and dry. Temperature in England and Wales rose to 90°F. during both July and August; this was the first time for 22 yr., apart from 1947, that temperature had risen so high in both these months. In the south of England temperature rose daily to between 85° and 90°F. from August 20 to 25. In Scotland the mean August temperature, except for 1947, was the highest for any August since 1857; Elgin recorded 89°F. on the 25th and no higher temperature has been recorded in Scotland during August since 1876.

For Great Britain as a whole the two months taken together rank as the driest July and August since 1869, and also as the warmest and sunniest since 1911. There was a drought in many places from July 4 to August 8. Several places were completely rainless during the drought period including Camborne in Cornwall where there was no rain whatever from July 1 to August 2 and a total of only 0·36 in. for the two months. A second drought developed at many places from Sussex to Cornwall during the last three weeks of August; July to September was the driest of any similar period of three months for 85 yr. in England and Wales and also the driest, except for 1913, in Scotland over the same period.

There were several noteworthy thunderstorms, the one over Dorset on July 18 being the most outstanding; 11 in. of rain fell at Martinstown near Dorchester in 24 hr. This was by far the greatest fall ever recorded in the British Isles during the rainfall day; the second greatest occurred at Bruton, Somerset, during a storm in June 1917, when about 9·6 in. of rain were collected. A "very rare" fall was recorded, also on July 18, at Neath, Glamorganshire, when 3·32 in. of rain fell in 120 min. During heavy thunderstorms on August 13, 3·44 in. fell in 80 min. at Annaghanoon, County Down, and 3·50 in. in 120 min. at Sittingbourne, Kent.

Sunshine during the summer was outstanding, especially in the north-west, July being the sunniest month when many long-standing records were broken. During the second and last week of July sunshine was more than twice the average over Wales, north-west England, western Scotland and northern Ireland; it was 377 per cent. of the average in south-east England for the week commencing July 17. At Southport, July 1955 was the sunniest of any month since observations began in 1896, and many other stations had never recorded so much sunshine in July though in some cases observations covered a period of over 70 yr.

Autumn.—The relatively dry weather continued throughout the autumn in England and Wales, an unusual feature being the number of stations, chiefly in the southern half of England and in Wales, recording an absolute drought in November, a month which usually has few droughts[1]. It lasted in many places from the 11th or 12th to the 29th or 30th, and following such a dry summer forced some authorities in north-east England to introduce water rationing. The autumn drought contrasts sharply with the heavy rainfall experienced in south-east England during the third week of October, which was over four times the weekly average. A four-day period of fog occurred in the Midlands during November; fog persisted day and night at Manchester from the 17th to the 20th inclusive.

1955 will undoubtedly be remembered in north Scotland for the severe winter and unusually heavy snow; in north-east England as well as in Scotland for its unusual dryness; in the north-west of the country for the exceptionally sunny July; and in Dorset for the phenomenally heavy thunderstorms on July 18.

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AIR TEMPERATURES DURING SNOWFALL AT OCEAN WEATHER STATION I

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

The tragic loss of the two British trawlers *Lorella* and *Roderigo* during a storm off Iceland on January 26, 1955, is still a comparatively recent memory. At that time the two ships were on a fishing voyage a short distance north of North Cape, Iceland, when they encountered severe north-easterly gales, accompanied by low air temperatures, which lasted for several days. Spray from the heavy seas breaking over the vessels caused an accumulation of ice on their superstructures in such large quantities that both ships eventually capsized with the loss of all hands. A Public Inquiry into the losses of these trawlers was held recently, and, as a part of the meteorological evidence which was prepared, data were extracted in more detail than previously available regarding air temperatures at which snow and other forms of wintry precipitation fall over the open ocean. Data for ocean station I, the position of which for the purposes of this note can be regarded with sufficient accuracy as 59°00'N. 19°00'W. throughout the period considered, were used, and since the results have a general interest they are included in this note. When the work was undertaken, data for this ocean weather station were available on punch cards for the period between January 28, 1948 and May 26, 1954. The elements tabulated were the times of observation (in all cases synoptic hours), together with air and sea temperature, wind direction and force, and present weather.

On the punched cards three columns are allocated for describing present weather, in accordance with the code

1 = Snow	6 = Thunder
2 = Squalls	7 = Hail
3 = Rain	8 = Lightning
4 = Passing showers	9 = None of the above reported
5 = Drizzle	No observations = 000

The code thus makes it possible to distinguish between cases of snow, sleet, snow squalls and also of snow (or sleet) associated with hail.

In order to compare the results with those of a land station, comparable data were extracted for Shawbury (52°48'N., 2°41'W., height 249 ft. above M.S.L.) which, besides being a station for which such data were available, was also considered to have a suitable land exposure. All occasions of snowfall at synoptic hours (0000, 0300, 0600, 0900, 1200, 1500, 1800 and 2100, G.M.T.) during the period November 1946–May 1955, i.e. nine seasons, were examined and the corresponding air temperatures tabulated. The results are given in Table I which gives the number of observations, the mean air temperature, and the upper and lower 10-percentile values of temperature in which snow, sleet and hail occurred at Shawbury. The same data are included for station I with the addition of mean values of sea temperature observed during the same periods. Some idea is given in Table II of the diurnal variation of the frequency of snowfall at Shawbury and station I.

TABLE I—COMPARISON OF TEMPERATURES AT WHICH SNOW, SLEET AND HAIL FELL AT SHAWBURY AND STATION I

	Shawbury				Station I				
	Air temperature				Air temperature			Sea temperature	
	Mean	Upper 10 per-centile	Lower 10 per-centile	No. of obser-vations	Mean	Upper 10 per-centile	Lower 10 per-centile	Sea temper-ature Mean	No. of obser-vations
	degrees Fahrenheit				*degrees Fahrenheit*				
Snow ...	31·1	33·8	27·1	272	36·0	40·0	32·5	47·2	124
Sleet ...	35·1	37·1	33·3	94	39·3	44·5	36·0	47·7	31
Snow squalls...	...	...	...	...	37·2	44·5	32·0	47·5	34
Snow (or sleet) and hail ...	31·0	34·3	27·9	27	37·1	41·5	32·5	47·3	21

TABLE II—DIURNAL VARIATION OF SNOW, SLEET, AND SNOW OR SLEET AND HAIL

	0000	0300	0600	0900	1200	1500	1800	2100
	number of observations							
	Shawbury							
Snow	29	33	33	46	39	36	31	25
Sleet	18	11	16	7	10	4	10	18
Snow (or sleet) and hail	1	3	1	5	6	3	4	4
All types of snowfall	48	47	50	58	55	43	45	47
	Station I							
All types of snowfall	33	21	14	23	31	32	26	30

The mean values of the air temperatures at which snow and sleet occur at the ocean weather station I (36·0° and 39·3°F.) are thus substantially higher than the corresponding values for Shawbury (31·1° and 35·1°F.). The main reason is undoubtedly the relative warmth of the sea on the occasions of snowfall at station I, which results in a steep lapse rate being formed in the lowest layers. Over the land in winter on the other hand it is not uncommon for snow to fall from an approaching front through an isothermal layer or even an inversion. A fairer comparison can be made between snowfalls at station I and at Shawbury in spring when cold air is often travelling over a heated land surface, although the physical circumstances are not entirely similar since a supply of cold air quickly cools a land surface although it makes little difference to the sea-surface temperature. The fact that the differences of air temperature (station I minus Shawbury) between the various months, given at the end of Table III, do indicate some decrease from winter to spring, suggests that this explanation is correct.

The Shawbury data referred to a period which is just over two years longer than the period used for station I and included the cold winters of 1946–47 and 1954–55. As a check the corresponding mean air-temperature data were extracted for Shawbury for the period November 1947 to May 1954. For this period the mean temperatures at which snow and sleet fell were 32·2° and 35·3°F. respectively, 1·1° and 0·2°F. higher than those found for the longer period used in the tables. The values in individual months for the shorter period showed very close agreement, except for snow in January when the value was 1·2° higher and in February when the value was 1·1°F. lower than the longer-period values. The conclusion that the temperatures at which snow (and also sleet) fall are substantially lower at Shawbury than at station I thus appears to be justified.

TABLE III—SURFACE TEMPERATURE ON OCCASIONS OF SNOW OR SLEET

Shawbury

	Snow				Sleet			
	Temperature				Temperature			
	Mean	Upper 10 per-centile	Lower 10 per-centile	No. of occasions	Mean	Upper 10 per-centile	Lower 10 per-centile	No. of occasions
	degrees Fahrenheit				*degrees Fahrenheit*			
November ...	33·0	(33·7)	(32·2)	14	34·9	...	...	9
December ...	32·2	33·9	30·2	32	35·1	(38·8)	(33·2)	19
January ...	30·3	33·7	27·1	58	35·6	(38·4)	(33·4)	18
February ...	32·2	33·8	26·1	111	35·1	37·1	33·6	20
March ...	32·4	34·8	29·4	51	34·6	36·9	32·5	26
April ...	34·9	...	...	6	...	...	...	0
May... ...	...	...	...	0	40·5	...	...	2

Station I

	Snow		Sleet		Mean temperature differences Station I minus Shawbury	
	Mean temperature	No. of occasions	Mean temperature	No. of occasions	Snow	Sleet
	°F.		°F.		°F.	
October ...	42·0	2	(39·0)	1	...	...
November ...	(35·0)	1	...	0	(2·0)	...
December ...	35·6	15	37·8	6	3·4	2·7
January ...	34·8	24	42·4	5	4·5	6·8
February ...	35·4	35	37·7	6	3·2	2·6
March ...	36·8	19	38·1	8	4·4	3·5
April	36·7	23	(37·0)	1	1·8	...
May	37·8	5	42·4	4	...	1·9

The figures in brackets are estimates where there are insufficient observations to give a true percentile or a mean.

The higher humidity of the air in the lowest layers over the sea, as compared with the lowest layers of air over the land, can hardly be a reason for the occurrence of snowfall with higher temperatures over the sea than over the land; since the condensation which would occur on snowflakes falling through a very moist atmosphere would melt them more quickly than would otherwise be the case.

The figures for diurnal variation of frequency of snowfall show mainly the kind of variation which would be expected. Over land where the diurnal range of temperature is appreciable even in winter, snow or sleet is most frequent around 0900 G.M.T. At station I there is a maximum around

1500 G.M.T., presumably associated with the diurnal increase in the amount of cold-front rain in the afternoon first described by Goldie[1]. There is another equally pronounced maximum around midnight, which is possibly due to the passage of warm occlusions on occasions when the surface air temperature is lower than about 42°F. This would accord with the observation, also due to Goldie[1], that the maximum frequency of rainfall of warm-front type occurs during the night hours at stations along the north-west seaboard of Great Britain. It is also a result to be expected from the development of instability in the layers below medium cloud level at night, due to cooling by radiation[2].

The fact that snow and sleet occur at station I which is several hundreds of miles from the nearest land, at temperatures some 4–5°F. above those at which snow occurs most frequently at a typical land station in the British Isles is of some significance for the forecasting of visibility over the open sea at low temperatures. At temperatures below 40°F. (see Table I) precipitation at sea must occur more frequently in the form of snow than it does over land (other things being equal), and snow or sleet is more effective in reducing visibility than drizzle or rain. The frequent spells of poor visibility in sub-arctic and sub-antarctic waters associated with old occlusions on the poleward sides of stagnating depressions, must be prolonged to some extent from this cause in comparison with similar spells over land.

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OPACITY OF THE ATMOSPHERE AFTER JULY 1953

By S. FRITZ
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On the basis of measurements during total eclipses of the moon and visual evidence by other investigators, de Vaucouleurs[1] suggested that extensive pollution existed in widespread regions of the earth's atmosphere on July 26, 1953. He suggested that this might have been introduced into the atmosphere by the eruption of an Alaskan volcano on July 9, 1953. In order to investigate further the spread of the volcanic dust, de Vaucouleurs also suggested that a check be made of the pyrheliometric data in widely separated areas.

Such a check of the pyrheliometric data for stations in the United States has been made with the results shown in Fig. 1. The basic data are measurements of the direct solar beam. These measurements are made with Eppley normal-incidence pyrheliometers at Lincoln, Nebraska, and Blue Hill in Milton, Massachusetts. The more precise Smithsonian silver-disk and modified Ångström normal-incidence pyrheliometers are used at Table Mountain, California, and a silver-disk pyrheliometer is used frequently to check the Eppley instrument at Blue Hill. The data shown in Fig. 1 are the percentage departures D of the average monthly radiation from the monthly normal; the "normal" was based on the 19-yr. period 1934–52, since the Blue Hill record began in 1934. The small numerals on each curve show the number of observations made during each month. The data for Blue Hill and Lincoln were taken from *Climatological Data*[2], published by the Weather Bureau; for Table Mountain, the data were kindly supplied by Mr. L. B. Aldrich, Director of the Astrophysical Observatory of the Smithsonian Institution.

The instructions to the observers at the Weather Bureau stations, Lincoln and Blue Hill, are that observations should be taken at specified solar zenith distances Z only when there are no clouds obscuring the sun. This is sometimes a somewhat subjective matter and undoubtedly introduces some fluctuation into the data. At Blue Hill, a new observer reported for duty near the end of 1951, and has taken observations there since the beginning of 1952. He has chosen only the "clearest" skies, so that for $Z = 70\cdot 7^\circ$ the "normal" appropriate to his observations is apparently about 11 per cent. higher than the normal for the period 1934–52.

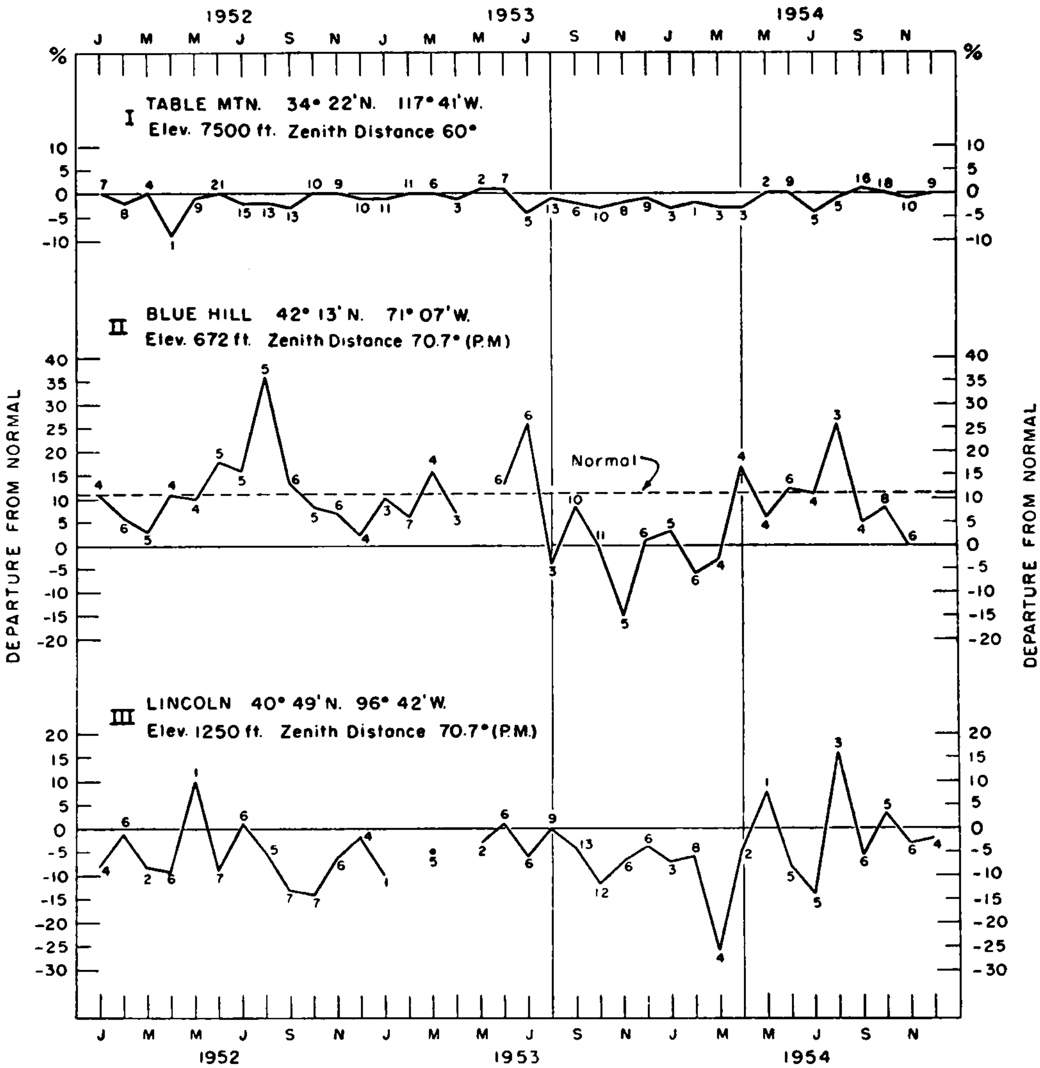

FIG. 1.—SOLAR RADIATION INTENSITY

In September 1953, all three stations showed D below normal and this situation prevailed until March 1954. My colleague, Mr. Enger, has found the measurements from each station for the period 1934–52 to be uncorrelated with those from either of the other two stations; moreover, he has found that during the six-month period, October 1953–March 1954, the average value of D was lower than the average D for any consecutive six-month period before August

1953 at each of the stations*. For this to have occurred simultaneously at all three stations is a rare event indeed.

The cause of the decreased radiation is speculative, although the eruption of the volcano on July 9 in Alaska is suggestive. Moreover, the lunar-eclipse measurements suggested some effect in July over large parts of the earth; but from the data of Fig. 1, because of the large fluctuations, we cannot conclude that the atmosphere was unusually opaque in the United States during July 1953. It apparently was unusually opaque during the following October to March.

Study of pyrheliometric data is continuing here, and a more detailed report may be published later.

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METEOROLOGICAL OFFICE DISCUSSION

Meteorological aspects of solar radiation

The discussion, which was held at the Royal Society of Arts on Monday, January 16, 1956, was opened by Mr. G. J. Day.

Mr. Day suggested that the importance of the study of the interaction of solar radiation with the earth's atmosphere was evident from two widely divergent aspects–dependence of the atmospheric circulation on radiation and the influence of the local radiation climate on the pattern of everyday life. He mentioned that radiation data were important in civil, aeronautical and agricultural engineering.

The sun emits electro-magnetic waves of wave-lengths between about $10^{-1}\mu$ and $10^{10}\mu$ (10 Km.) of which meteorology has been concerned with the band between 0·2 μ and 50 μ.

The intensity of the solar beam at normal incidence on the outer limit of the atmosphere is about 2·0 cal./cm.^{2}/min. Of this about 40 per cent. is returned to space without change of wave-length, and the remainder is absorbed by the earth and atmosphere and eventually re-radiated to space with a changed spectral distribution.

The spectral distribution of solar radiation corresponds roughly to that from a black body at 6,000–7,000°K. for wave-lengths between 0·45 and 25 μ and at 4,000–5,000°K. for wave-lengths between 0·2 and 0·45 μ. For wave-lengths less than 0·2 μ radiation from the solar corona is important, and lines corresponding to coronal temperatures of about 10^6°K. occur in the spectrum. The fairly sharp change in spectral character at about 0·2 μ has recently been confirmed during a rocket ascent to 112 Km.

The flux of radiation in free space (the solar constant) has been estimated to be about 1·94 cal./cm.^{2}/min. by the Smithsonian Institution workers. As a result of rocket ascents over America and accurate ground-level spectro-bolometer studies of atmospheric attenuation, Johnson[1] has recently disputed this value and has suggested an amended one of $2 \cdot 00 \pm 0 \cdot 04$ cal./cm.^{2}/min.

The return of the unmodified radiation to space is achieved by scattering processes in the atmosphere and at the earth's surface. Atmospheric gas molecules give rise to Rayleigh scattering, but even in the cleanest atmosphere there is additional scattering which Fowle[2] correlated with water-vapour content. It has been shown, however, that the additional attenuation is probably particulate in origin, and Ångström suggested that it is due to scattering and absorption by natural and artificial nuclei; scattering by larger particles and by undetected cloud also contribute. Data gathered at Kew[3] suggest a total attenuation of about 10 per cent. of the incident radiation from these causes. It is not thought that scattering by volcanic dust and the smoke from forest fires can have any noticeable effect on surface temperatures over considerable areas, since although the direct radiation may be attenuated the diffuse radiation is enhanced and the total not greatly reduced.

Theoretical work by Hewson[4] shows the considerable effect of cloud on the local flux of radiation. This work is considered to be based on faulty assumptions, but yields a reasonably good result for the solar altitudes experienced in temperate and high latitudes. Hewson's predictions of the amount of reflection by clouds is partly confirmed by Aldrich[5] who obtained albedos of about 0·8 for stratocumulus clouds; these appeared to be independent of cloud thickness. Observations from Meteorological Research Flight aircraft, however, show considerable variation between 0·28 and 0·84 with no consistent variation with cloud thickness. Similar measure-

*The average for the period April 1952–September 1952 was lower at Table Mountain, but this was influenced significantly by April 1952 which had only one observation. Also, in 1929, a six-month period with a lower average value occured at Table Mountain.

ments in America by both Fritz[6] and Neiburger[7] support the Meteorological Research Flight result.

Reflection of solar radiation by the earth's surface is very variable. Land surfaces have albedos between 0·1 and 0·3 rising to 0·8 for new snow and about 0·5 for old. The albedos of sea surfaces are a function of the state of the surface and the solar altitude, and range from 0·03 for zenith sun over smooth sea to about 0·4 for low-altitude sun. The roughness of the surface produces a significant change only for low-altitude sun. Measurements from Meteorological Research Flight aircraft over the English Channel have given albedos between 0·06 and 0·07.

The total albedo of the earth is the sum of the separate contributions, and has been determined to be 0·39 for the visible spectrum by measurements of the intensity of the earthlight and sunlight reflected from the moon. By combining this figure with estimates of the other components, Fritz arrived at an average value of 0·05 for cloud. This value may be compared with that of 0·43 for the mean atmosphere in summer and 0·49 in winter obtained by Blackwell, Eldridge and Robinson[3] from the Kew radiation data. A completely overcast atmosphere at Kew had an average albedo of 0·56.

Mr. Day then considered the 60 per cent. of the incident radiation which is modified in spectral distribution by the earth and its atmosphere. Of this about 2 per cent. is absorbed in the stratosphere above 20 Km., 15 per cent. in the troposphere and the remainder by the earth's surface.

The low density of the high atmosphere results in large temperature changes consequent on small changes in radiative flux. This fact has led to recent suggestions that there is a connexion between radiation effects on the high atmosphere and surface synoptic features; Palmer[8] has suggested that there is a close association between tropical high-level cyclones and sudden ionospheric disturbances. Similar suggestions by Farthing[9] linked enhanced short-wave activity during sun-spot activity with increased precipitation and the passage of cold fronts, though his investigation was confined to the central Mid-West of the United States. It was suggested by Mr. Day that, although the physical mechanisms were obscure and the simplicity of the associations remarkable, it was nevertheless desirable that such suggestions be investigated thoroughly in view of the paucity of medium-range and long-range forecasting techniques.

Mr. Day now turned to the question of the absorption by atmospheric gases. It was noted that solar radiation was of negligible energy for wave-lengths greater than 4 μ and that terrestrial radiation was of negligible energy for those less than 4 μ.; it was thus possible to treat the streams of solar and terrestrial radiation quite separately with respect to absorption.

In the stratosphere absorption of the solar beam is controlled by the Hartley band of ozone whilst in the troposphere the main infra-red bands of water vapour are of the greatest importance. For terrestrial radiation water vapour is of the greatest importance in the troposphere, though the carbon-dioxide band at 15 μ has some effect, but in the stratosphere water vapour, carbon dioxide and ozone are likely to be of comparable importance.

A knowledge of the interaction of the streams of solar and terrestrial radiation with the atmosphere and the earth, may be applied to the qualitative explanation of the temperature structure of the troposphere and stratosphere. The main regions of absorption of solar radiation are those due to oxygen above about 90 Km., to ozone in the layer 30–50 Km. and to the surface of the earth. At these points the atmosphere is heated leading to three main regions of relatively high temperature with minima between. Above the heated regions an approach to convective equilibrium may be expected and consequently the appropriate adiabatic lapse rate. The temperatures at the minima are probably controlled mainly by radiation processes.

About half the solar radiation reaching the earth is absorbed by the surface layers and produces local temperature changes. An equilibrium is established in which solar energy input is balanced by terrestrial radiation and various other losses. The equilibrium is much affected by the presence of cloud. Over the oceans the energy input is distributed by mixing processes through a considerable depth so that surface temperatures change little. About 30 per cent. of the incident radiation is used in evaporating water thereby producing the moisture for weather phenomena.

The amount of radiation falling on unit area of a horizontal surface at the outer limit of the earth's atmosphere varies with latitude and season. Additionally the amount of radiation reaching the earth's surface is affected by cloud amount and the distribution of atmospheric gases, particularly water vapour. It is found that incoming solar energy exceeds the outgoing terrestrial radiant energy only between the equator and a latitude of about 30°, there being an overall loss of energy from the earth-atmosphere system north of this latitude. Thus there is a transport of heat from the equator to the poles to maintain the long-term mean temperature distribution. This transport is achieved by the atmospheric circulation. Several workers have computed the mean poleward energy transport, the various estimates being given in Table I.

TABLE I—POLEWARD MEAN ENERGY TRANSPORT ACROSS LATITUDE 40°.

	10^{27} erg/day		10^{27} erg/day
Simpson, 1928	3·4	Raethjen, 1950 ...	4·9
Simpson, 1929	4·8	London, 1952 ...	2·4
Baur and Phillips, 1934	3·8	Houghton, 1954 ...	4·7

Robinson[10] has recently determined the energy budget of the atmosphere at Kew for one year and for summer and winter periods. He used the observations reported by Blackwell, Eldridge and Robinson[3] and measurements of conduction through the ground and estimates of evaporation for Kew by Roach. Only during the period May–July was there a net input of radiant energy into the earth-atmosphere system at Kew.

The presence of clouds has a profound effect on the energy balance, and Hewson has computed that absorption of solar radiation by clouds varies from 1 per cent. for very thin clouds to 7 per cent. for dense ones. Fritz[6] has reported aircraft measurements of up to 20 per cent. however, and measurements from Meteorological Research Flight aircraft of the radiation flux within strato-cumulus sheets suggest absorptions of about 12 per cent.

For terrestrial radiation all water clouds thicker than about 50 m. behave as black bodies. Little is known of the behaviour of ice-crystal clouds, but recent work by Houghton[11] suggests that tenuous cirrus cloud absorbs little more than would be expected from its constituent water vapour; measurements made from an aircraft of the Meteorological Research Flight showed that the emissivity of the earth for long-wave radiation was about 90–95 per cent. and that of dense water clouds always about 100 per cent.

Turning to a consideration of the instruments used for the measurement of solar radiation, Mr. Day described the two commonly used sub-standard instruments–the Ångström and the Smithsonian silver-disk pyrheliometers–and stated that the Meteorological Office relates its measurements to the Ångström scale, which differs from the Smithsonian scale by about 3 per cent. Continuous recording of solar radiation at Kew is achieved with Moll-Gorczynski thermopiles; one is mounted to receive sun-plus-sky radiation on a horizontal surface; another receives sky radiation alone; and three further thermopiles record the intensity of the direct solar beam–these latter are maintained normal to the solar beam by clockwork mechanisms.

The intensity of illumination is measured at Kew by a recorder in which a photo-cell corrected by filters to standard eye response receives the radiation from an opalescent diffusing screen.

Finally the ventilated flux plate radiometer was described. This instrument is used to measure the net flux of radiation in any direction by measuring with thermocouples the temperature gradient produced through a thin blackened plate exposed normal to the flux of radiation. The variable effects of natural convection are overcome by maintaining a constant blast of air over the plate.

Mr. Day concluded by mentioning some typical applications of radiation data to everyday life. These fall conveniently into the categories of agriculture and engineering, and include such diverse matters as the part played by solar radiation in plant growth and the heat balance of aircraft structures at great altitudes. In illustration of the application of radiation data the question of weathering of materials, particularly in the tropics, was discussed in some detail.

Dr. Stagg opened the general discussion by welcoming the visitors from outside organizations and inviting their participation.

Mr. Petheridge (Building Research Establishment) illustrated the application of radiation data to architectural problems by referring to the design of a school at Caithness. Estimates were made at Kew of the "luminous efficiency of daylight" for Caithness from total solar radiation data at Eskdalemuir and Lerwick. From this estimate daylight illumination at Caithness under typical conditions was computed, and window sizes chosen which gave an acceptable compromise between the need for natural illumination and that for adequate thermal insulation. He stressed the need for illumination data for places other than Kew.

Mr. Hoare (National Institute for Agricultural Engineering) cited the heating and ventilation of glass-houses as a problem in which radiation data were important. He discussed in particular the varying need for moisture of a plant under varying radiation conditions, and remarked that the plant was an integrator of radiant energy. Mr. Hoare concluded by emphasising the importance of radiation data in the discussion of biological experiments.

Mr. Ward mentioned his interest in the dispersal of radiation fog, and asked whether there was a simple and cheap instrument available for the measurement of radiation at outstations. He asked whether measurements of solar radiation had been made at ground level in fog, and whether there was any difference in the albedo of snow between total and diffuse radiation. Mr. Day replied that the cheapest instrument now available was the ventilated flux plate radiometer. There was some hope that a modified Bellani distillometer with a horizontal sensitive surface might prove acceptable for some purposes, and he referred Mr. Ward to Mr. Hoare's group for further information. Measurements of radiation in fog had been made at Kew incidentally in the course of routine continuous recording but the data had not been extracted. Data were available only for the albedo of snow for total radiation.

Mr. Hoare sought to place the importance of solar radiant energy in perspective by remarking that far more energy is used by plants in fixing carbon than is used in producing electrical energy. About 2 per cent. of the incident energy is used by the plant.

Mr. Spurr (Central Electricity Authority) remarked on the considerable difference in the demand for electricity between clear and cloudy days, and requested that attention be paid to the forecasting of daylight illumination.

Mr. Ward asked whether there was a direct relation between daylight intensity and diffuse radiation. Mr. Day, in reply, said that a factor termed the "luminous efficiency of daylight" was used to relate the intensity of daylight to total solar radiation, and that this was well known for Kew for representative conditions; the factor varied from place to place. There was presumably a relation between diffuse daylight and diffuse solar radiation. Recording of diffuse daylight was not at present undertaken within the Meteorological Office, and therefore no definite answer could be given.

Mr. Page (Building Research Establishment) mentioned the need for tropical radiation data, and called attention to the differences between the luminous efficiencies measured in the United Kingdom, South Africa and the West Indies, and concluded with a plea for the organization of a working group on radiation for the United Kingdom.

Mr. Veryard queried the opener's statement that smoke and dust at great altitude did not greatly affect total radiation and thus temperature at the surface.

Dr. Robinson, in reply to Mr. Veryard, stated that volcanic dust would only cause a significant change in total solar radiation at the surface if it lay so thickly that multiple scattering processes became important. He added that the effect of smoke and dust in the London winter atmosphere was to increase depletion by scattering and absorption by 10 per cent. on average. In this connexion he asked for an explanation of the increase in crop yield of tomatoes following the change of location of a field station from the Lea Valley to the south coast. It would hardly be due to the increase of total radiation.

Mr. Gloyne observed that the increase in the tomato crop was probably a threshold effect due to the small extra amount of radiation in the early spring.

Mr. Hoare supported this statement and emphasized the importance of exceeding a threshold amount of radiation in plant growth.

Mr. Gloyne asked what changes in spectral distribution of solar energy were caused by dust. Mr. Day replied that sufficiently detailed filter measurements were not made in the Meteorological Office to answer the question, but agreed that it was one of some importance.

Mr. Sawyer sought information on the more explicitly meteorological aspects and asked what variations in solar radiation might be expected over periods of five to ten days. Dr. Robinson replied that it might be possible to integrate the solar radiation received over large areas for various periods, and referred in illustration to Danjon's lunar measurements which gave appreciable daily variations in the albedo of a whole hemisphere of the earth.

Dr. Stagg pointed out that Danjon's work gave no indication of changes in the spectral distribution, and remarked that it was believed that the ultra-violet component might be important.

Cmdr. Frankcom remarked that it was hoped to obtain solar radiation measurements at sea during the International Geophysical Year, and asked whether any such work had been done previously. Mr. Day said that he had no knowledge of earlier work; whilst agreeing that such measurements were very desirable, he stressed the attendant instrumental difficulties.

Mr. Petheridge observed that some measurements had been made over the sea by the Marine Biological Research Station.

Dr. Stagg asked whether instruments embodying distillation principles had been produced. Mr. Day, in reply, described the Bellani type of instrument, and said that the new type with a flat receiving surface showed considerable promise as a radiation integrator for use in field work.

Mr. Sawyer returned to the meteorological applications and said that he doubted the value of correlations between solar flares and similar phenomena and weather.

Mr. Hayward (Imperial College) mentioned his interest in the application of solar energy to house heating and similar matters, and stressed the need for a simple instrument of the calorimeter type for field measurements of the heat energy produced by solar radiation.

Mr. Gold drew attention to the tendency to over-emphasize the need for local measurements of solar radiation, and suggested that when data for a given solar elevation were known for clear-sky conditions it was merely necessary to know the local cloud amounts in order to give a reasonable estimate of average radiation conditions.

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7. NEIBURGER, M.; Reflection, absorption and transmission of insolation by stratus cloud. *J. Met., Lancaster Pa,* **6**, 1949, p. 98.
8. PALMER, C. E.; The impulsive generation of certain changes in the tropospheric circulation. *J. Met., Lancaster Pa,* **10**, 1953, p. 1.
9. FARTHING, E. D.; A possible relationship between the solar corona and weather conditions in the central midwest. *Bull. Amer. met. Soc., Lancaster Pa,* **36**, 1955, p. 427.
10. ROBINSON, G. D.; The energy balance of surface and atmosphere at Kew, May 1953 to April 1954. *Met. Res. Pap., London,* No. 929, 1955.
11. HOUGHTON, J. T.; and BREWER, A. W. Measurements of the flux of long-wave radiation in the upper air 1953–1954. *Met. Res. Pap., London,* No. 914, 1955.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

GEOPHYSICAL MEMOIRS

No. 97—Some features of jet streams as shown by aircraft observations. By R. Murray, M.A.

The results of an analysis of aircraft observations of temperature, frost point, cloud and turbulence near jet streams are presented; brief mention is also made of reports of condensation trails. It is shown from frost-point observations that between about 500 mb. and 200 mb. there is on the average a horizontal gradient of humidity across the jet stream, with the moister air on the high-pressure side. At about the level of the jet stream the average relative humidity with respect to ice is about 50 per cent. at 250–300 nautical miles on the right of the axis, looking down wind, and decreases to about 10 per cent. at the same distance on the left, but individual jet streams show considerable variability. The average humidity distribution indicates the existence of a relatively dry patch of air below the jet-stream axis in the vicinity of the frontal zone at about 500 mb.

Layer cloud, both medium and high, is a feature of the high-pressure side of the jet stream, although amounts vary from case to case; such cloud is rare at distances greater than about 100 nautical miles from the jet-stream axis on the low-pressure side. Layer cloud does not appear to occur above the level of the jet-stream axis. The average distribution of layer cloud and humidity is discussed in relation to the surface fronts and a dynamical model is suggested. The broad features of the accepted thermal structure of the upper troposphere and lower stratosphere near jet streams are confirmed. The occurrence of clear-air turbulence near jet streams agrees with the results put forward by Bannon.

PROFESSIONAL NOTES

No. 117—Barometric changes and the efflux of gas in mines. By C. S. Durst, B.A.

A relation is obtained connecting the variation of atmospheric pressure and the efflux of methane in a coal mine. In one particular mine experiments were undertaken with the aid of which the constants in the relation have been determined. Light is shed on the type of mine which is liable to suffer from efflux of methane owing to sharp pressure falls.

Experiments were undertaken in forecasting high emission of methane, and it was found that the forecasts from the Central Forecasting Office, Dunstable, are effective for this purpose on 65 per cent. of occasions.

No. 118—Rainfall of depressions which pass eastward over or near the British Isles. By J. S. Sawyer, M.A.

Depressions are classified according to the latitude in which they move eastward over or near the British Isles. Maps of the average rainfall and frequency of rain from depressions in each class have been constructed and are discussed. The rainfall amounts of individual depressions are examined in relation to the characteristics of the depression concerned, but no relations have been found which are close enough to be of much value in forecasting.

METEOROLOGICAL RESEARCH COMMITTEE

The 20th meeting of the Instruments Sub-Committee was held on October 20, 1955, under the chairmanship of Dr. A. W. Brewer who has succeeded Prof. P. A. Sheppard. The development in the United Kingdom of a searchlight technique for the measurement of atmospheric density up to heights of 60 Km. has been under study for several years. Memoranda on this subject by Dr. J. S. Hey and Mr. P. G. Smith of the Radar Research Establishment and by Dr. R. Frith and Mr. J. R. Bibby of the Meteorological Office were before the meeting. After discussion of these papers and other information the Sub-Committee noted the difficulties associated with the practical development of the pulsed-light technique to the routine operational stage, and recommended that effort should be concentrated on the modulated-beam method in order to institute an observational programme as soon as possible. Consideration of Mr. Almond's report[1] on the work done on an experimental pulsed-light cloud-base meter since 1950 led to the conclusion that further development would be justified if this type of equipment were required, but that prior attention should be given to work on the model of a modulated-beam searchlight in order that accurate and immediate information on cloud-base height can be provided for landings of aircraft. The Sub-Committee noted that the refrigerated-disc icing meter described by Mr. Day[2] would facilitate measurement of the higher ranges of liquid water content of cloud, and that it should be possible to use the instrument on routine meteorological reconnaisance flights. During the discussion of the two papers[3,4] relating to the measurement of upper wind by radar, comment was made that radar No. 3 Mk 7 is more mobile than radar GL III but the errors of the particular Mk 7 equipment used in the trials were greater than the errors of GL III radar; and that the state of the sea appears to have little effect on the mean vector difference between the radar measurements of wind made at the same time on two ocean weather ships near together. Information on a comparison of heights derived by means of a radar altimeter and a pressure altimeter installed in an aircraft was presented by Mr. Durbin. It was considered that this subject called for further investigation by the departments concerned.

The 36th meeting of the Synoptic and Dynamical Sub-Committee was held on October 25, 1955. Mr. Hay's paper[5] prompted suggestions on further investigation of factors which may influence the times of occurrence of daily maximum and minimum air temperature at sea. Some surprise was voiced at the high frequency of precipitation days (about 320 annually) at the ocean weather stations I and J. In presenting a paper[6] on the mean wind at 60 mb., Mr. Bannon referred to evidence of the occurrence of a narrow belt of westerly wind at 60 mb. at places near the equator. There was discussion on the jet-stream appearance of the 60-mb. contours over North America and South Greenland in winter. The hope was expressed that regular wind measurements at this level would be obtained in the Antarctic during the International Geophysical Year. The paper[7] by Mr. Hoyle gave rise to discussion on the mechanism of origin of the sub-tropical jet stream and to a tentative suggestion that the type of circulation model outlined in the paper may have interest in relation to atmospheres other than that of the earth. In the discussion on Mr. Harding's paper[8] it was suggested that it would be desirable to supplement the work described by making special aircraft flights extending southward from Wadi Halfa and also in the Aden region, and at a greater altitude.

The 34th meeting of the Physical Sub-Committee was held on November 2, 1955. The account[9] by Dr. Houghton and Dr. Brewer of the first results obtained with a new radiometer mounted in an aircraft was welcomed. Suggestions were made for further studies of the flux of long-wave radiation in the upper air, including the radiational effects of cloud. Most of the remaining time of the meeting was devoted to a discussion of cloud-seeding and experiments on a ti-ficial production of rain. Arising from comments on aspects of this question received from Dr. Bowen of Australia, it was agreed to examine the practicability of undertaking silver-iodide seeding experiments in a mountainous part of the United Kingdom. The lack of direct evidence that silver iodide released at ground level does reach the sub-freezing parts of cloud and that the nucleating properties of this agent are not adversely affected by the heat of the generating process or other factors was recognized. Mr. Jenkinson's paper[10] and the subsequent discussion confirmed the complexities in the design and assessment of results of rain-making experiments. In the discussion of a report by Dr. F. Pasquill support was given to the suggestions that the proposed further experiments on the diffusion of airborne particles should cover a variety of meteorological conditions and that a method of sampling in cloud should be sought.

ABSTRACTS

1. ALMOND, R.; An experimental pulsed-light cloud-base meter. *Met. Res. Pap., London*, No. 941, S.C. I/106, 1955.

Ultra-rapid light pulses produced by discharging a condenser across an air gap are beamed vertically by a paraboloid mirror, and the return from cloud droplets is focussed on to a rapid-response photocell, the resulting voltage pulse being amplified and displayed by a cathode-ray tube. The delay between emitted and received pulses gives the height. The details of the apparatus after trials are set out. The instrument is satisfactory over a range from about 600 to 15,000 ft. Specimen records are shown. Some suggestions for improvement are made. Appendices discuss some aspects of the theory and summarize the trial reports.

2. DAY, G. J.; A refrigerated disk icing meter. *Met. Res. Pap., London*, No. 916, S.C. 1/99, 1955.

An instrument for measuring liquid-water content of clouds, supercooled or not, is described. It consists of a hollow copper disk, cooled inside by liquid nitrogen, rotating twice a minute edge on to the local air stream. The thickness of ice on the edge is measured by a transducer. Theory, tests in the laboratory and in the air, and calibration are described.

3. ELSE, C. V.; Wind-finding trials of radar A.A. No. 3 Mk VII (Second series). *Met .Res. Pap., London*, No. 922, S.C. I/100, 1955.

Nine flights giving 500 sets of simultaneous readings of the A.A. No. 3 Mk 7 (GL VII) and the GL III at slant ranges up to 66,000 yd. are described and the results summarized. The GL VII can provide results comparable in accuracy with GL III up to at least 40,000 yd., and although complicated it is easier to operate (one observer instead of three) and service.

4. HARRISON, D. N.; Radar wind comparisons on the ocean weather ships (second series). *Met. Res. Pap., London*, No. 928, S.C. I/102, 1955.

Trials were made in 1953-54 to assess the improvement in radar wind accuracy since 1949 by comparing observations of pairs of ships. A small improvement was found.

5. HAY, R. F. M.; Five-year means of meteorological observations made at the ocean weather stations ITEM and INDIA, JIG and JULIETT, 1948–52. *Met. Res. Pap., London*, No. 923, S.C. II/192, 1955.

Monthly five-year averages at stations I (mean position 59°29'N. 19°29'W.) and J (53°06'N. 19°25'W.) are tabulated and discussed. Tables include mean wind velocity (with other windy stations for comparison showing that averages of 17·7 and 18·3 kt. were exceeded only by Adélie Land), wind frequencies by direction and force, pressure, air and sea temperature, days of phenomena, frequencies of visibility and low cloud height. Some values of diurnal variation are included.

6. BANNON, J. K.. and JONES, R. A.; The mean wind at 60 mb. *Met. Res. Pap., London*, No. 925, S.C. II/194, 1955.

Vector resultant winds at 60 mb. (20 Km.) were constructed from the few wind observations available and from contour charts of 100-mb. level extrapolated to 60 mb., for January, April, July and October. Values of direction and speed are tabulated for 83 stations ranging from 61°N. to 52°S., plotted on Mercator charts and discussed.

7. HOYLE, H. D.; The subtropical jet stream of the eastern North Pacific in January and April 1952. *Met. Res. Pap., London*, No. 924, S.C. II/193, 1955.

A thorough analysis is made of the two jet streams in the North Pacific. Daily schematic charts, 60–15°N., 180–120°W., show the positions of jets (> 100kt.) at 300–400 mb. near the polar front and at 200 mb. 1,000 miles south. Vertical cross-sections in 160–150°W. show by isokinetics, isotherms and fronts 3 types of probable structure (strong W.–E. jet stream near Hawaii, weaker jet stream with N. component, and subtropical jet stream displaced northward). The 250-mb. or 300-mb. and 60-mb. isotherms, contours of various surfaces, and mean surface isobars are also plotted as monthly means and means for different types. The jets show pronounced shear and are associated with 3 tropopause levels, tropical (90 mb.), subtropical (200 mb.) and polar (300 mb.).

8. HARDING, J.; The profile of jet streams in the Middle East. *Met. Res. Pap., London*, No. 932, S.C. II/195, 1955.

Ground photographs from aircraft between Habbaniya and Bahrain, Port Said and Wadi Halfa and airspeed gave wind direction and speed. Eleven "windy runs" are discussed. "The strong westerly winds over the Middle East in winter, at heights approximating to those of maximum wind speeds, contain a belt of very strong winds which may be as wide as 200 nautical miles or more, and in which horizontal gradients of wind speed are small or negligible". Surface and 200–mb. or 300–mb. charts and wind profiles showing winds of 100–200kt. are given for January 28 and February 6, 1953, January 16 and February 25, 1954 and March 5, 1955.

9. HOUGHTON, J. T. and BREWER, A. W.; Measurement of the flux of long-wave radiation in the upper air 1953–1954. *Met. Res. Pap., London*, No. 914, S.C. III/185, 1955.

Upward and downward flux of long-wave radiation at night were measured by radiometer in an aircraft at 3,000-ft. intervals up to 40,000 ft. Temperature and humidity were also measured. The downward flux below 30,000 ft. agreed with Elsasser's chart with a pressure correction and Yamamoto's chart for radiation from carbon dioxide multiplied by 1·2. The upward radiation was affected by cloud. Dense clouds had 100 per cent. emissivity, thin clouds down to 10 per cent. and ground 90–95 per cent. A clear atmosphere cooled by 1–2°C./day. Observations in the stratosphere were disappointing.

10. JENKINSON, A. F.; Some statistical aspects of a rain-making experiment. *Met. Res. Pap., London*, No. 931, S.C. III/190, 1955.

The problem is to test results of seeding with silver iodide on Salisbury Plain. The location of the plume and vertical and horizontal extent of effective seeding in cloudy frontal conditions are discussed. From rainfall statistics on 92 selected occasions in 1945–54 it is concluded that if the trials are made with five generators on a line of 20–25 miles on suitable occasions, a difference of 13 per cent. between rainfall of known seeded and control areas would be significant at the 1 per cent. level. If the seeded area is not known, a difference of 25–30 per cent. would be required.

ROYAL METEOROLOGICAL SOCIETY

Snow accumulation and ablation

A joint meeting of the Royal Meteorological Society with the British Glaciological Society was held on January 18, 1956. Dr. Sutcliffe, President of the Royal Meteorological Society, took the Chair, supported by Mr. Seligman, President of the British Glaciological Society. There was a discussion on snow accumulation and ablation.

Mr. R. A. Hamilton, who was Chief Scientist on the British North Greenland Expedition at Brittania Lake, opened the discussion with a brief geographical and meteorological description of Greenland. Brittania Lake, in the north-east corner separated from the coast by 20-mile wide glaciers, is rarely visited by disturbed weather and has one of the driest climates in the northern hemisphere. Net radiational loss of heat is usual and katabatic winds are easily formed over the fringes of the ice cap and flow down glaciers and fiords reaching gale force at times. It is, however, possible for a stagnant cold pool of air to form in a fiord with the katabatic wind flowing overhead.

Mr. H. Lister described, with the aid of a film and slides, some of the work done at Brittania Lake to help in the study of ablation—with particular reference to radiation, eddy convection and evaporation. Two stations, three miles apart with a difference of 150 m. in altitude, were established on Brittania Glacier, and a third station 230 miles to the west near the centre of the ice-sheet. During the ablation season temperature and humidity were recorded in screens at heights of 30 cm. and 300 cm., and checked by a whirling psychrometer; radiation was measured by a M.O. bimetallic radiation recorder; wind by cup counter anemometers and a 3-min. M.O. electrical impulse recorder connected to a cup contact anemometer; and ablation by means of stakes driven into holes drilled deep into the solid ice of the glacier. During special 48-hr. periods more detailed temperature and humidity measurements were made at heights of 2, 6, 10, 30, 100, 200, 300 and 400 cm. using an aspirated electrical apparatus developed by Pasquill, whilst wind was measured by sensitive cup anemometers at heights of 30, 100, 200 and 400 cm., and radiation, both total from above the horizontal and reflected from below, by a Moll thermopile (face downwards for the reflected radiation). Difficulty was experienced with the surface markers of an ablatograph which would persist in sinking into the snow; plaster-of-paris hemispherical bowls of 16·5 cm. diameter, made on the site, solved the difficulty. Many of the instrumental clocks developed troubles; the Meteorological Office clocks were best. The electrical impulse recorder Mk II was very successful.

Mr. Lister compared his results with those obtained by Deacon over short grass* and found great difficulty in correlating the variations of the three elements: wind, temperature and vapour pressure. For coarse sastrugi snow his roughness parameter z_0 was 1·1 cm. (very high for snow); as the snow melted and the glacier developed hummocks the value of z_0 decreased to 0·5 cm.

* DEACON, E. L.; Vertical profiles of mean wind in the surface layers of the atmosphere. *Geophys. Mem., London*, **11**, No. 91, 1953.

The ratio of wind speeds (u_{200}/u_{30}) seemed constant and independent of the vertical temperature gradient which was almost always an inversion, even in summer, because of the permanent snow or ice surface. The temperature gradient in the very lowest layers was very marked—with sudden changes from inversion to lapse and back again; much more change occurred between the surface and 30 cm. height than between 30 cm. and 300 cm. and it was therefore useful to remember that with melting at the surface the conditions there would be 0°C. and 100 per cent. humidity. Further investigation of the lowest 100 cm. gave a value of z_0 of 0·1 cm. over ice on Brittania Lake. Only by superimposing profiles of wind, temperature and vapour-pressure variation could he find as high a correlation coefficient between the mean gradients of wind speed and temperature as 0·52 (individual correlation coefficients between temperature and wind at different heights; 30 cm., 0·658; 100 cm., 0·589; 300 cm., 0·472). There was little correlation with vapour pressure. Mr. Lister attributed this loss of correlation to lack of turbulence at lower velocities and stronger inversions over ice surfaces.

Radiation measurements showed that a small increase of cloud (above the usual small amounts of north-east Greenland) would initially increase the radiation received—probably because of multiple reflection from clouds and snow or ice surface. Diurnal change of the elevation of the sun was more important than changes in the ice surface in albedo measurements during ablation. The incoming heat responsible for melting was: radiation 69 per cent., convection 28 per cent. and condensation 3 per cent.

Mr. Ward described some of the difficulties in the measurement of ablation directly on a glacier. The glacier is moving; the character of the snow (crystals or firn) changes with time and depth even without any net ablation; melt water can flow through the sub-surface or over the top of the glacier from higher levels; the loosely packed snow near the surface can provide a reservoir for water; and ice at different depths may melt and freeze several times in a season. To multiply the change in stake depth by a suitable density factor would not suffice when the change may have, and possibly has, been caused by settling due to melt water. Day-to-day ablation measurements were therefore difficult particularly in north-east Greenland where the snowfall is very small and ablation occurs in short intervals.

Among the questions that were asked at the meeting, Mr. Gloyne asked about the higher albedo at night and why the roughness parameter should decrease as hummocks developed on the surface. Mr. Lister said that the sun's elevation merely decreased at "night" and the greater proportion of red rays would be coincident with reflection. Mr. Ward said that when the sun was low the albedo was almost 1. The hummockiness observed after melting did not have as much resistance to the wind as surface roughness. Dr. Frith thought the increase in albedo with cloudiness might be due to a change in surface conditions. Mr. Lister said that surface melting continued through the "night" and surface changes of texture occurred principally during the first week of summer. Mr. Sawyer asked what was the effect on the wind of a rock surface (the film showed rocky country in parts). Mr. Lister said the lower station was ½ mile from the valley wall and the upper station ¾ mile, but the wind was down glacier giving a fetch of 3 miles of a homogeneous snow or ice surface for flow at the anemometers.

Mr. Hamilton stressed the difficulties of instrumental work on expeditions, and mentioned that by observation of the refractive index of the air he had measured the vertical temperature gradient to an accuracy of 1×10^{-2}°C./m.

LETTER TO THE EDITOR

Variation between measurements of rainfall made with a grid of gauges.

In my paper on the measurement of rainfall with a grid of gauges, published in the November 1955 issue of the *Meteorological Magazine*, it was stated that the areas of the funnels of nine standard Meteorological Office rain-gauges were all in excess of the nominal value by between 0·8 and 1·3 per cent. It has been pointed out by the Meteorological Office that if this were so the diameters of these funnels would all have been outside the normal limits of error laid down by the Meteorological Office, which are that the maximum error in a mean diameter is 0·01 in., and that the maximum error in any individual diameter is 0·02 in.

The diameters of the funnels were subsequently measured, and it was found that with the exception of one, which had a maximum error in an individual diameter of 0·025 in., they were all within the specification. The reason for the discrepancy was that the original measurements were made with a specifically adapted planimeter to measure the areas directly, and a re-examination of the method showed that it gave rise to a small but consistent over-estimation of the areas. Since the paper was concerned entirely with the differences between the amounts of rainfall collected by the gauges the conclusions given in the paper are not affected.

L. H. WATKINS

Road Research Laboratory, Harmondsworth, February 16, 1956

NOTES AND NEWS

Changes in B.B.C. weather forecasts

Changes in the times and contents of B.B.C. weather broadcasts will be introduced on Sunday, April 22, 1956. Essentially these consist of the transfer of all shipping information to the Light Programme and a consequent increase in the broadcasting time available for land-area forecasts on the Home Service. The primary reason for having the shipping bulletins in the Light Programme is that reception at sea has been found to be better on 1,500 m. than on the medium wave-band, so the longer wave-band only will be used.

The major obstacle to including in the Light Programme four shipping broadcasts a day at intervals of about 6 hr. arose from the nature of their contents. A weather bulletin intended primarily for a particular section of the community is not easily fitted into a programme for the general listener. However, 5-min. periods have been provided in the early morning and afternoon and at midnight, but only 2-min. periods in the early evening. Moreover, the times of two of the broadcasts will be different on Sundays because of the different pattern of the programmes. The schedule of broadcasts is as follows, in clock times, except for the broadcast at 0645 G.M.T.:

Week-days	Sundays
0645 – 0650 G.M.T.	0645 – 0650 G.M.T.
1340 – 1345 CLOCK TIME	1200 – 1205 CLOCK TIME
1758 – 1800 CLOCK TIME	1928 – 1930 CLOCK TIME
2400 – 0005 CLOCK TIME	2400 – 0005 CLOCK TIME

The 5-min. broadcasts will comprise a gale-warning summary, a general synopsis, forecasts for coastal sea areas for the next 24 hr. and a selection of the latest observations from a few coastal stations. The increase in broadcasting time will enable the wishes of the seaman to be met to the extent of providing a more detailed picture of the synoptic developments than is possible at present and no doubt this will appeal also to many amateur meteorologists on shore, while the broadcasting of actual reports will revive memories of AIRMET, although the number of stations included will not be comparable. Another innovation is to give the forecast areas in a fixed order, although a name may be followed only by a reference to another sea area with which it is bracketed later in the bulletin. This arrangement will help the listener at sea who often has to assimilate the forecast in difficult circumstances. The 2-min. broadcast in the evening will necessarily be confined to one item, namely the forecasts for the coastal sea areas, and these may at times have to deviate from the standard order.

In February of last year an informal meeting was held in De Bilt by representatives of the meteorological services which are directly concerned with the weather of the North Sea. One of their recommendations was that there should be uniformity in the coastal sea areas used in different shipping forecasts. In consequence four new names appear in the B.B.C. broadcasts. The eastern parts of the present "Forties" and "Dogger" become "Viking" and "Fisher" respectively, and "Heligoland" is renamed "German Bight", while "Iceland" becomes "south-east Iceland" to avoid confusion with "North Iceland", an area introduced into the North Atlantic Weather Bulletin last November.

Times of weather broadcasts on the Home Service are unaltered but the broadcasts at 0655, 0755, 0855 (Sundays), 1255 and 1755 will be of 4-min. duration. This means that forecasters will be less handicapped by the need to compress their land-area forecasts within a number of words which has often proved inadequate during complex weather situations. No major changes are proposed in the general plan of these forecasts but it will be possible to adopt a somewhat freer style of presentation.

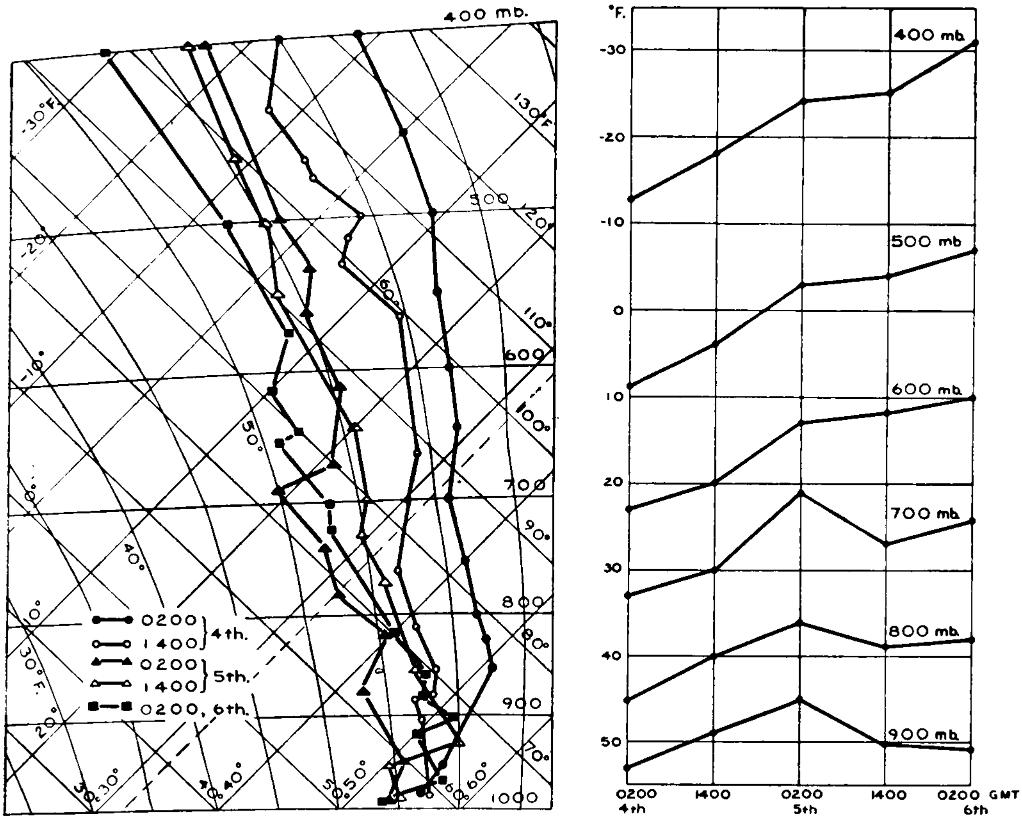
Exceptionally severe thunderstorm

A very violent thunderstorm of almost tropical severity occurred in the Cambridge area on the night of November 5–6, 1955. The intensity of the storm was so great that people living in the locality were awakened and alarmed by the noise of the hail falling on the roofs of the houses and the exceptionally brilliant lightning and heavy thunder claps. In the village of Whittlesford (population 900) over a thousand panes of glass were broken, and at the R.A.F. Station, Duxford, over 500 panes were broken by the large hailstones.

One extraordinary feature of the storm was the small amount of rain that fell compared with the amount of hailstones. These were generally of a round pellet formation of clear ice with a very small opaque core and averaged between 1 and 1½ in. diameter. A large number of the hailstones remained in the ice stage for quite a long time after the storm, one particular mass of them continued as ice for over 36 hr. despite the fact that they were lying at the foot of a south wall and the average screen temperature for the period was about 50°F.

During the 36 hr. preceding the storm a complex depression was almost stationary to the west of Ireland with a very moist south-westerly air stream crossing the country. A cold front, which cleared east and south-east England by midnight on the 4th, was followed by an unstable air mass with sferic activity reported as far south as Spain. By 1200 on the 5th the sferic activity had increased northwards and become intense between Scilly and Finisterre. A belt of rain and heavy showers extending from Liverpool to the Channel Islands, with a thunderstorm at Portland Bill reported at 2100 on the 5th, seemed to indicate that an upper cold front or trough was moving east over southern England, and this was supported by the fall of temperature at Crawley between 0200 on the 4th and 0200 on the 6th, as shown on the graphs in Fig. 1. This fall of temperature was more pronounced above 700 mb., and was probably the cause of the surprisingly heavy fall of hailstones of larger than usual diameter.

The small amount of evidence on the surface charts to indicate the upper front appears to be an interesting point, but no doubt the surface air and the air in the lower layers had been warmed in its travel over the sea whereas the air in the higher layers, above 700 mb. for instance, had been brought around the periphery of the depression from the northern side, and was more likely to retain its polar characteristics than the air in the lower layers.



Tephigrams Time chart

FIG. I—DECREASE OF UPPER AIR TEMPERATURE AT CRAWLEY, NOVEMBER 4–6, 1955

The size and speed of the falling hailstones left their mark on a number of caravans in the locality, the outer metal skin of the caravans being pock-marked very noticeably and sufficiently deep to show up on the photograph facing p. 128.

J. A. HICKS

[Thunderstorms were not confined to the Cambridge area; the whole of south-east England, east of a line from the Isle of Wight to Lincolnshire, experienced widespread thunderstorms during the 5th and 6th. In the Midlands they were scattered. They were particularly severe at Chorley Wood, Hertfordshire, where eight women in a home for elderly people had to leave their beds when the building caught fire after being struck by lightning. Considerable lightning damage was also reported from Fareham, Hampshire and from Iwade and Sittingbourne in north Kent.—Ed., *M.M.*]

Beiträge zur Physik der freien Atmosphäre

All meteorologists will be pleased to learn that, thanks to the initiative of Prof. H. Koschmieder and Prof. W. Georgii, the *Beiträge zur Physik der freien Atmosphäre*, which was a leading meteorological periodical until it had to cease publication during the Second World War, is to appear again in the near future.

The journal will be published by the Akademische Verlagsgesellschaft M.B.H. at Frankfurt-am-Main, Germany, and the committee of editors consists of Prof. H. Flohn, Prof. W. Georgii, Prof. B. Haurwitz, Prof. H. Koschmieder and Prof. Dr. J. van Mieghem.

Papers will be welcomed on synoptic and dynamical meteorology, the meteorology of the high atmosphere, radiation and heat balance, turbulence and convection, the meteorology of gliding and soaring, the physics of condensation, clouds and precipitation, atmospheric electricity, radio meteorology, and the instruments and methods used for the exploration of the free atmosphere.

We extend our best wishes for the success of the *Beiträge* which will, we are sure, maintain the high standards established by the founders, R. Assmann and H. Hergesell.

REVIEW

On the mathematical expression of the annual variation of temperature. By L. Mavridis. *Meteorologica* No. 3, $9\frac{1}{2}$ in. × $6\frac{1}{2}$ in., pp. 44, *Illus.*, University of Salonica, 1955.

The annual variation of temperature has often been expressed by a harmonic form in which the temperature for the nth month is given by

$$T_n = a_0 + \sum_{j=1}^{k} (a_j \cos j\theta_n + b_j \sin j\theta_n)$$

where a_0, a_j, b_j are parameters characteristic of the station, and θ_n is the mean value during the nth month of an angle θ which increases from 0° to 360° during the year. The present author discusses another representation in which

$$\tfrac{1}{2}(T_n + T_{13-n}) = A + C \sin (L_n - V)$$

and

$$\frac{T_{13-n}}{T_n} = \frac{p}{1 - e \cos (L_n - w)}.$$

Here L_n, the geocentric longitude of the sun, corresponds closely to θ_n in the harmonic representation, while A, C, V, p, e, w are six parameters to be determined for each station. Slight variations in L_n allow for the presence of leap years, and it is claimed that the parameters are more amenable to physical interpretation than those used in the harmonic representation.

Mr. Mavridis shows how to find the parameters by a method of least squares, and does so for monthly mean temperatures for Copenhagen, Vienna, Prague and Berlin. He finds the parameters for every decade of each record, or about 60 sets of values in all. He examines the residuals not accounted for by his mathematical form, and finds that these exceed the residuals left after fitting a three-term harmonic form (with seven parameters), but are less than those left after fitting a two-term harmonic form (with five parameters).

The demonstration though reasonable is not wholly convincing, because the four stations used are too closely grouped to furnish independent evidence, while the harmonic analyses are not carried out in quite the most accurate way. Nevertheless, the author has shown that the Xanthakis procedure gives reasonable results. The argument that the parameters are capable of easy physical interpretation is an attractive one, and the method deserves examination by any worker concerned with this branch of climatology.

J. M. CRADDOCK

BOOK RECEIVED

The I.B.G.: Retrospect and prospect. By R. O. Buchanan. *Trans. Pap. Inst. Brit. Geogr., London,* No. 20, 1954. $9\frac{3}{4}$ in. × $7\frac{1}{4}$ in., pp. 14, *Illus.*

OBITUARIES

Dr. A. W. Lee.—We regret to report the death of Dr. Lee on February 10, 1956, in his 57th year.

His studies were interrupted by service with the R.E. Signals (Wireless Section) 1917–19, and he took the degrees of B.Sc. (Physics) in 1920 and of M.Sc. in 1922 at the Imperial College of Science. He was one of the first post-graduate students in the Meteorology Department of the College, working under Sir Napier Shaw. A paper on "The relation of the circulation in the upper air to a circumpolar vortex", published in 1924, was one of the results of this work. He joined the staff of the Meteorological Office in 1923, and after a period at Calshot was transferred in 1924 to take charge of Lerwick Observatory, a post he occupied for five years. This was followed by a spell of 10 years at Kew Observatory. In the spring of 1939 he went to Eskdalemuir Observatory as Superintendent. The outbreak of war saw the end of his long connexion with observatories, and he served first as a forecaster at the Headquarters of Bomber Command, and then for five years as Senior Meteorological Officer at No. 12 Fighter Group R.A.F. Early in 1945 he was transferred to a Headquarters branch, but three years later he suffered a serious breakdown in health. He made a remarkable, though incomplete, recovery, and was not able again to face the strain of travel to central London. The last six years of his service were spent at Kew Observatory, but the journey to work became increasingly difficult for him and he retired in January 1954 at the age of 55.

Dr. Lee's duties at Kew Observatory were concerned mainly with seismology, and his stay was marked by the publication of a remarkable series of papers on this subject. He was acknowledged to be one of the world's leading authorities on microseisms. His work on the effects of geological structure, and his paper "On the direction of approach of microseismic waves" are still relevant to the problem of detection of meteorological disturbances by means of microseisms. He also made studies of individual earthquakes, and is the author of five *Geophysical Memoirs.* He was awarded the degree of D.Sc. of the University of London in 1935 for work on microseismic waves, and was a member of the British Association Committee on Seismological Investigations from 1933 to 1954.

He married whilst stationed at Lerwick and his wife, who survives him, shared in the life of the Observatory there and at Eskdalemuir. To her, and to his son and daughter—the former now in Australia— we extend our sympathy.

G. D. ROBINSON

Sidney Andrew Hodson.—It is with deep regret that we announce the death of Senior Aircraftman S. A. Hodson who was a passenger in the York aircraft which crashed at Malta on February 18, 1956. He joined the Office in September 1952 as a temporary Scientific Assistant and after a course at the Training School he was posted to an aviation station. He was called up for National Service in February 1954 and, shortly afterwards, he was posted to the Middle East. S.A.C. Hodson was returning to the United Kingdom for his release from National Service when the accident occurred.

METEOROLOGICAL OFFICE NEWS

Retirement.—Mr. B. G. Brame, Senior Experimental Officer, relinquished his appointment as Senior Experimental Officer on December 1, 1955. He joined the Office in February 1911 as a Laboratory Boy in the Instruments Division and at the time of his retirement he had completed 45 years' service. In 1915 he was transferred to Kew Observatory for about four months for training prior to his posting to Eskdalemuir Observatory. In 1921 he was transferred to the Climatology Division at Headquarters where he served in various sections dealing with different aspects of the work of the Division. In 1934 he returned to the Instruments Division to be in charge of the test room. In 1936, after a short spell at Kew Observatory, he was posted to the General Services Branch where he worked with Mr. E. Gold until 1939. From 1939 to 1946 he served in the Overseas and Royal Air Force Branches on adminstrative duties. For the past ten years he has held the post of Senior Experimental Officer in the Royal Air Force (Home Commands) Branch. He was also concerned with the compilation of Meteorological Office Standing Orders. For the last ten years Mr. Brame has been Honorary Treasurer of the Meteorological Office Social and Sports Committee. He was appointed a Member of the Order of the British Empire in the Birthday Honours List of 1944.

At a ceremony in the Conference Room in Victory House on March 2, 1956, Mr. T. W. V. Jones presented Mr. Brame with a cheque subscribed by his colleagues. In expressing his thanks Mr. Brame recounted some interesting and amusing recollections of the Office as it was over 40 years ago.

Mr. Brame has accepted a temporary appointment in the Meteorological Office.

Sports activities.—*Athletics.*—Messrs. Garrod, Bird, Stratton and Messem were members of the Air Ministry team which won the Civil Service Cross-Country Championship at Epsom on December 10, 1955.

Yachting.—Mr. L. S. Clarkson, Chief Meteorological Officer, Headquarters F.E.A.F. and Honorary Sailing Secretary of the Royal Air Force Changi Yacht Club won the International Snipe Class Race at the Royal Singapore Yacht Club Open Regatta on Saturday, January 8, 1956.

Netball.—Miss B. M. Edwards and Miss N. Edwards were selected to play for a Civil Service representative side against the Australian Ladies Netball team on February 29, 1956, at the Chiswick Sports Ground.

Swimming.—Mr. J. V. Evling was a member of the successful Ariel Club swimming team which won the Burton Cup for Civil Service medley relay teams at the Ironmonger Row Swimming Baths on February 29, 1956.

WEATHER OF FEBRUARY 1956

The month will rank as a notably cold February in most parts of Europe, the mean temperature for the month being 12°C. below normal in Saxony, eastern Bavaria and Bohemia, with negative anomalies in all parts of the Continent mostly in excess of 5°C. The freezing-point isotherm ran through northern Spain and central Italy. Western Siberia, Mongolia and the Vladivostok province were also colder than usual. By contrast, mean temperature was above normal over the eastern half of North America (maximum anomaly +6°C. or more in the region of north Quebec –south Baffin Land) and over much of the Arctic (anomalies over Iceland and Greenland +3–4°C., Spitsbergen +7°C.). The mean temperature was generally 1–3°C., and locally 5°C. below normal in the Rocky Mountains region.

The pressure distribution was marked by vigorous depressions over the western Atlantic sending offshoots north and north-west towards Greenland and Labrador and south-east towards the Mediterranean (mean pressures 5–6 mb. below normal in 50°N. 50°W. and north Quebec, 8 mb. below normal in the Azores and 8–10 mb. below normal in Italy and the central Mediterranean). A great warm, southerly air stream was directed from mid Atlantic towards Spitsbergen and east of this anticyclones built up to attain at times exceptional extent and intensities over north Europe and Asia; 1074 mb. was observed at Salekhard, north-west Siberia on the 15th, a value only twice known to have been exceeded since 1872. The mean pressure for the month reached 1040 mb. near the Gulf of Ob and the maximum pressure anomaly was +22 mb. at the mouth of the Yenesei and +21 mb. at Thorshavn and in Lapland. Nevertheless there were frequent changes and movements within the region dominated by high pressure with several cold fronts and occlusions crossing Scandinavia from the north-west during the month. There was also some appearance of a 7-day rhythm in a series of short-lived tongues of Atlantic mild air passing south-eastwards and southwards near or over the British Isles on the 5th, 12th, 19th and 26th.

Precipitation totals were below normal everywhere in western Europe, above normal (generally over 200 per cent.) all through the Mediterranean, and more slightly above normal in most places between 15° and 25°E.—i.e. east and north of the mountains—from Bear Island and northern Scandinavia to the Hungarian Plain. Precipitation was also well above normal in Iceland and east Greenland.

In the British Isles a very cold easterly air stream from the Continent dominated the weather for most of the month. The lowest temperature occurred during the first three days, but remained very low from the 9th to the 27th with considerable snow especially in the east of the country. A mild westerly air stream brought a rise of temperature of 15–20°F. and a rapid thaw on the 28th.

On the 1st, with pressure high over Scandinavia and low over southern Europe, very cold continental air which had arrived with easterly winds the previous day spread to the whole country. Temperature at Kew rose only to 24°F.—the lowest day maximum temperature recorded there since 1895—and maximum temperatures in the west were just as low: 24°F. at Ross-on-Wye and 22°F. at Bristol. Snow showers were frequent and snow lay to a depth of 2 in. at Sprowston and 7 in. at Hull. That night temperature fell to 9°F. at many places in East Anglia and to about 0°F. on the ground, and there were power cuts in the London area owing to the excessive demand for electrical heating. Renewed falls the next day brought reports of level snow lying a foot deep in parts of Kent and of 5-ft. snow drifts in the Midlands. Day temperatures remained below freezing until the 3rd, but the direct continental air supply by then was being gradually cut off as high pressure was slowly transferred from Scandinavia to southern England. With an anticyclone in the western English Channel on the 4th, a milder westerly air stream and rain spread to all areas. From the 5th to the 8th this anticyclone moved eastward and northward to cover much of the British Isles, but weather was generally dull with some slight occasional drizzle and patches of fog in many places. Very cold easterly winds returned again on the 9th as the British anticyclone became a ridge to a larger anticyclone which had formed over Scandinavia; temperatures fell generally below freezing point except in north-west Scotland and snow spread west and north to reach north Devon and south Scotland, but the chief falls were in eastern England. Along the Kent coast between Dungeness and Greatstones, Romney Marsh, cakes of ice formed as the sea came in on the rising tide and were piled up to a foot high on the beach. Pressure became highest to the south of Iceland on the 11th, and there was a temporary incursion of warmer maritime air over much of the country on the 12th and 16th; on the latter date 10 in. of snow fell in 24hr. at Scarborough and drifts 10–15 ft. deep were reported from parts of Yorkshire. Cornwall had its heaviest snowfall of the winter with 9–10 in. in the Newquay-Lizard area on the 19th and 20th as minor disturbances moved southward over western districts. East Kent was so badly affected by this time that the Kent County Council had to enlist military assistance to keep the roads clear. By the 21st the Icelandic anticyclone had joined with another over Russia restoring the very cold easterlies to the whole of Great Britain. During the next few days the high-pressure belt moved southward over the country, weather remaining very cold though dry in the south but becoming milder in the north with westerly winds spreading into Scotland. The milder air stream spread over the whole country on the 28th with widespread drizzle and rapidly rising temperature.

Precipitation was about half the average in most areas, but near the east coast there was an excess, particularly in Yorkshire. Sunshine was above the average over much of the country but well below in east-coast districts. Temperature was 7–10°F. below normal over most of England and Wales, and at some places in the Midlands and east mean temperature was below freezing point. Most farm work was at a standstill throughout the month. The severe frost, with only slight snow cover, apart from drifts, had a disastrous effect on most autumn-sown crops, but cereals and beans will probably recover. Fuel consumption for glasshouses was excessive. In the south-west the anemone crop was completely ruined, but daffodils were only retarded. As a result of plentiful fodder and mainly quiet conditions sheep and lambs are in reasonable condition.

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 ...	57	1	−8·0	44	−1	107
Scotland	55	−2	−3·2	70	−1	93
Northern Ireland ...	54	11	−4·6	52	−6	114

RAINFALL OF FEBRUARY 1956

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	0·30	18	*Glam.*	Cardiff, Penylan ...	0·32	11
Kent	Dover	2·51	131	*Pemb.*	Tenby	1·17	40
,,	Edenbridge, Falconhurst	0·68	31	*Radnor*	Tyrmynydd	0·95	18
Sussex	Compton, Compton Ho.	0·26	10	*Mont.*	Lake Vyrnwy	0·90	20
,,	Worthing, Beach Ho. Pk.	0·24	12	*Mer.*	Blaenau Festiniog ...	1·52	19
Hants.	St. Catherine's L'thouse	0·16	8	,,	Aberdovey	0·70	23
,,	Southampton (East Pk.)	0·10	4	*Carn.*	Llandudno	0·29	15
,,	South Farnborough ...	0·23	12	*Angl.*	Llanerchymedd ...	0·86	34
Herts.	Harpenden, Rothamsted	0·60	31	*I. Man*	Douglas, Borough Cem.	0·91	29
Bucks.	Slough, Upton	0·18	11	*Wigtown*	Newton Stewart ...	1·03	27
Oxford	Oxford, Radcliffe ...	0·43	26	*Dumf.*	Dumfries, Crichton R.I.	0·66	20
N'hants.	Wellingboro' Swanspool	0·47	29	,,	Eskdalemuir Obsy. ...	2·11	43
Essex	Southend, W. W. ...	0·41	30	*Roxb.*	Crailing...	2·03	110
Suffolk	Felixstowe	1·26	100	*Peebles*	Stobo Castle	2·09	76
,,	Lowestoft Sec. School ...	2·15	154	*Berwick*	Marchmont House ...	3·30	159
,,	Bury St. Ed., Westley H.	0·87	58	*E. Loth.*	North Berwick Gas Wks.	1·86	119
Norfolk	Sandringham Ho. Gdns.	1·90	115	*Midl'n.*	Edinburgh, Blackf'd. H.	1·86	112
Wilts.	Aldbourne	0·43	19	*Lanark*	Hamilton W. W., T'nhill	1·35	47
Dorset	Creech Grange... ...	0·21	7	*Ayr*	Prestwick	0·90	38
,,	Beaminster, East St. ...	0·12	4	,,	Glen Afton, Ayr San. ...	1·43	33
Devon	Teignmouth, Den Gdns.	0·17	6	*Renfrew*	Greenock, Prospect Hill	1·87	35
,,	Ilfracombe	0·31	11	*Bute*	Rothesay, Ardencraig ...	1·38	35
,,	Princetown	0·23	3	*Argyll*	Morven, Drimnin ...	3·32	63
Cornwall	Bude, School House ...	0·52	21	,,	Poltalloch	2·68	62
,,	Penzance	1·03	31	,,	Inveraray Castle ...	3·22	47
,,	St. Austell	0·96	25	,,	Islay, Eallabus	1·72	41
,,	Scilly, Tresco Abbey ...	1·22	44	,,	Tiree	2·16	63
Somerset	Taunton	0·19	9	*Kinross*	Loch Leven Sluice ...	1·85	65
Glos.	Cirencester	0·28	12	*Fife*	Leuchars Airfield ...	1·13	65
Salop	Church Stretton ...	0·63	27	*Perth*	Loch Dhu	2·53	34
,,	Shrewsbury, Monkmore	0·44	28	,,	Crieff, Strathearn Hyd.	1·54	44
Worcs.	Malvern, Free Library...	0·29	16	,,	Pitlochry, Fincastle ...	1·87	64
Warwick	Birmingham, Edgbaston	0·52	28	*Angus*	Montrose, Sunnyside ...	1·64	89
Leics.	Thornton Reservoir ...	0·51	31	*Aberd.*	Braemar	2·27	80
Lincs.	Boston, Skirbeck ...	0·90	62	,,	Dyce, Craibstone ...	1·78	78
,,	Skegness, Marine Gdns.	1·56	102	,,	New Deer School House	2·30	108
Notts.	Mansfield, Carr Bank ...	0·72	37	*Moray*	Gordon Castle	2·28	119
Derby	Buxton, Terrace Slopes	1·48	39	*Nairn*	Nairn, Achareidh ...	1·40	86
Ches.	Bidston Observatory ...	0·19	11	*Inverness*	Loch Ness, Garthbeg ...	3·19	92
,,	Manchester, Ringway...	0·59	41	,,	L. Hourn, Kinlochourn	7·38	74
Lancs.	Stonyhurst College ...	0·98	29	,,	Fort William, Teviot ...	4·28	57
,,	Squires Gate	0·41	19	,,	Skye, Broadford ...	4·43	69
Yorks.	Wakefield, Clarence Pk.	1·03	60	,,	Skye, Duntuilm ...	2·94	64
,,	Hull, Pearson Park ...	1·95	117	*R. & C.*	Tain, Mayfield... ...	1·79	78
,,	Felixkirk, Mt. St. John...	2·21	131	,,	Inverbroom, Glackour...	4·98	98
,,	York Museum	1·50	99	,,	Achnashellach	6·76	98
,,	Scarborough	3·07	183	*Suth.*	Lochinver, Bank Ho. ...	3·22	80
,,	Middlesbrough... ...	1·80	138	*Caith.*	Wick Airfield	1·84	81
,,	Baldersdale, Hury Res.	2·23	76	*Shetland*	Lerwick Observatory ...	1·32	42
Norl'd.	Newcastle, Leazes Pk....	2·50	163	*Ferm.*	Crom Castle	1·52	52
,,	Bellingham, High Green	2·16	85	*Armagh*	Armagh Observatory ...	1·07	48
,,	Lilburn Tower Gdns. ...	2·64	133	*Down*	Seaforde	1·10	36
Cumb.	Geltsdale	1·64	63	*Antrim*	Aldergrove Airfield ...	1·19	49
,,	Keswick, High Hill ...	0·78	16	,,	Ballymena, Harryville...	1·37	42
,,	Ravenglass, The Grove	0·55	18	*L'derry*	Garvagh, Moneydig ...	1·48	47
Mon.	A'gavenny, Plâs Derwen	0·35	10	,,	Londonderry, Creggan	2·25	71
Glam.	Ystalyfera, Wern House	0·54	11	*Tyrone*	Omagh, Edenfel ...	2·20	74

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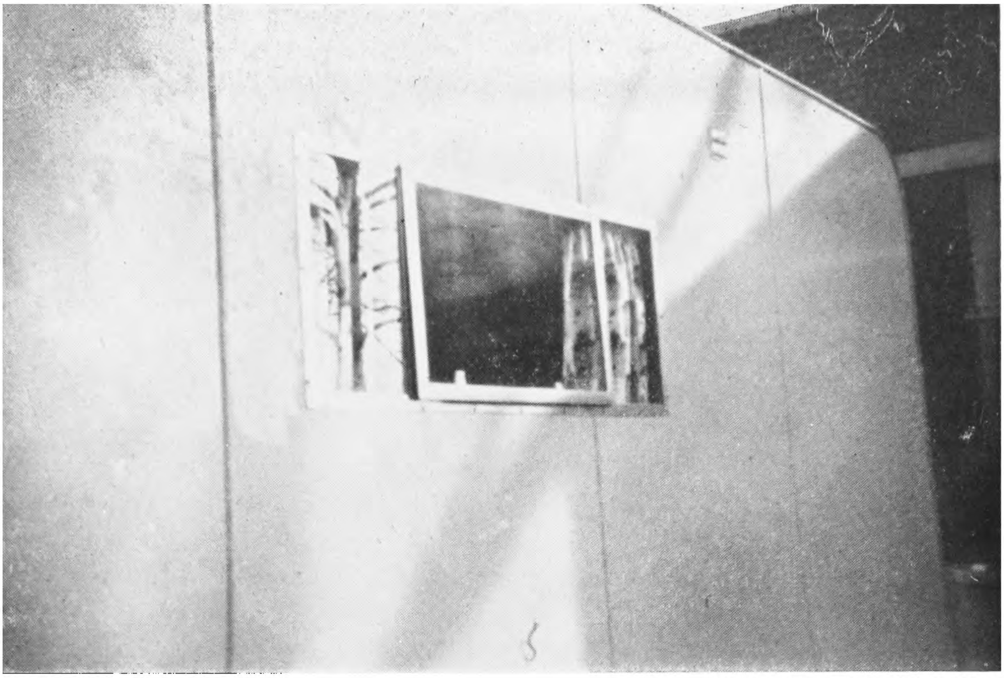

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DAMAGE TO A CARAVAN PRODUCED BY LARGE HAILSTONES
(see page 122)

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M.O. 613 AIR MINISTRY

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WIND SUMMARIES AND AIRFIELD USABILITY

By J. WADSWORTH, M.A.

The usability of the runways of an airfield is limited to some extent by the wind, for if the cross-wind component (component of the wind at right-angles to the runway) exceeds a certain strength it may be hazardous to attempt to land an aircraft. An estimate of the amount of time during which an airfield runway may be out of action owing to the strength of the cross-wind component may be derived from a summary of the winds experienced there over a number of years, which must be compiled in such a way that the frequency distribution of the wind forces or wind speeds is shown for each sector of the compass into which the summary is divided. If the frequency distribution of wind force and wind direction is then exhibited on a polar diagram the proportion of time during which the cross-wind component on any particular runway exceeds some specified limit may readily be estimated by a graphical method[1].

The preparation of a complete wind summary of this nature demands however a considerable amount of work, and at many stations the summaries of wind are not available in such an elaborate form. In the past it has rather been the custom to summarize the wind forces separately irrespective of wind direction, and likewise the wind direction separately irrespective of the speed of the wind. An approximate estimate of the usability of a runway can nevertheless still be obtained from these simpler forms of wind summary by applying a method due to L. Jacobs[2]. This method depends on an empirical result which is expressed in the equation

$$\log_e n_v = a - bv^2 \quad , \qquad \ldots\ldots (1)$$

where v is the speed of wind, n_v is the frequency of wind observations exceeding a specified speed v, and a and b are constants.

The tables and graphs presented by Jacobs in his memorandum are designed to enable the computer to assess directly the amount of time during which the cross-wind component on any particular runway, the orientation of which must be known, exceeds any specified limit. The limits commonly adopted for cross-wind components are of the order of 15, 20 or 25 m.p.h., varying according to the size and type of the aircraft. The method proposed by Jacobs implies tacitly that a wind rose can be constructed from the wind data available; but it is not necessary to set out the wind rose explicitly in order to calculate, by this method, the runway usability as limited by cross-winds.

The operation of aircraft is also affected, to some extent by components of wind directed along the runway, which if arising as headwinds may improve

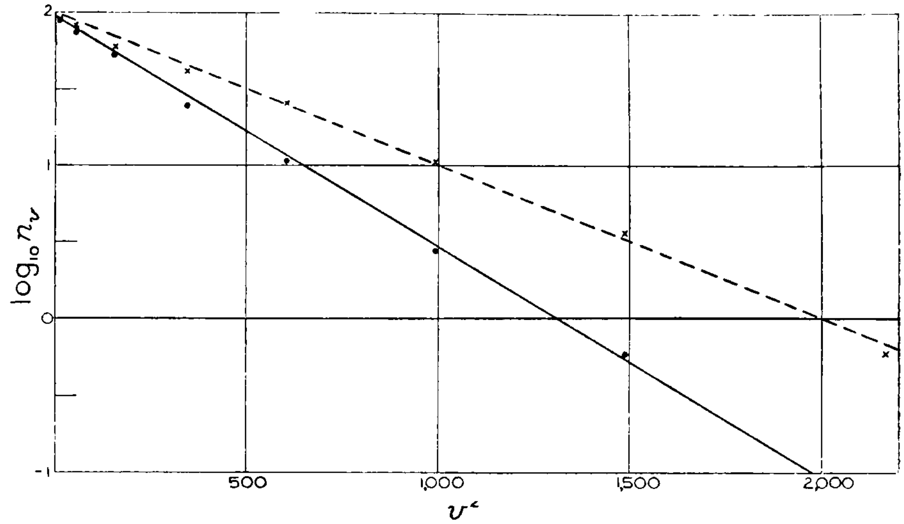

FIG. 1—GRAPHS OF $\log n_v = a - bv^2$

the usability of a short runway or alternatively as tailwinds may diminish it, and it is now suggested that in computations involving wind frequency the summary of speeds and directions should be set out in full in a table or a polar diagram, using the relation (1) to determine the frequency distribution of the various forces of wind within each sector of the wind rose. For this purpose Table I has been calculated giving values of $\exp(bv^2)$ to assist in the computation.

The relation (1) between n_a and v^2 is equivalent to

$$n_v = \frac{\exp(a)}{\exp(bv^2)}$$

The quantity e^a is the number of observations of wind within a certain sector of the compass exclusive of calms[2]. The quantity b appears to depend on the exposure of the meteorological station, and it is also related to the mean speed of the wind, again exclusive of calms[3]. In the British Isles the numerical values of b for wind speeds expressed in miles per hour vary according to Jacobs from about 2×10^{-3} in well exposed places to 7×10^{-3} at sheltered inland sites*. If we take v to be equal successively to the upper limits of the Beaufort wind forces we obtain a series of values of n_v from which by subtraction we may obtain the frequencies of the separate Beaufort forces. The resulting wind summary may then be set out on a polar diagram and from it we may obtain graphically the runway usability as limited by cross-wind components in the manner already described by Durst[1]. Besides this we shall also be in a position to estimate the effects of wind components along the runway or for new aerodromes to decide on the best orientation of the main runway. This method of computation naturally produces the same results as far as time loss due to cross-wind components is concerned as that due to Jacobs but it has the merit of greater simplicity.

Examples.—The wind-frequency distributions at Guernsey and Skeabrae are given in Table II, condensed to 8 points of the compass and in Beaufort wind force.

Guernsey.—From the summary of wind forces at Guernsey the numerical value of the coefficient b in the equation $\log_e n_v = a - bv^2$ is found, by the

* The validity of the larger values of b is somewhat doubtful, because in sheltered sites the range of wind speeds is restricted.

TABLE I.—NUMERICAL VALUES OF $\exp(bv^2)$

v	$b \times 10^3$ 2·0	2·5	3·0	3·5	4·0	4·5	5·0	5·5	6·0	6·5
m.p.h.										
0·5	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00
3·5	1·02	1·03	1·04	1·04	1·05	1·06	1·06	1·07	1·08	1·09
7·5	1·12	1·15	1·18	1·22	1·25	1·29	1·33	1·36	1·40	1·44
12·5	1·37	1·48	1·60	1·73	1·87	2·02	2·18	2·36	2·55	2·76
18·5	1·98	2·35	2·79	3·31	3·93	4·67	5·54	6·57	7·79	9·25
24·5	3·32	4·48	6·05	8·17	11·0	14·9	20·1	27·2	36·7	49·5
31·5	7·28	11·9	19·6	32·2	52·9	86·9	143	234	385	632
38·5	19·4	40·7	85·3	179	376	788	1650	3470	7280	15300
46·5	75·5	223	656	1930	5690	16800	49600	146000	431000	1270000

TABLE II.—WIND FREQUENCY DISTRIBUTION AT GUERNSEY AND SKEABRAE

Direction NE.	E.	SE.	S.	SW.	W.	NW.	N.	Calm	Beaufort force 1	2	3	4	5	6	7	8	9
								per mille									
Guernsey, States Airport 49° N. 2°35′ W., 1950–54																	
114	61	65	135	144	159	142	122	58	45	142	220	287	139	81	22	6	<1
Skeabrea 59°04′ N. 3°16′ W., 1943–45																	
55	48	170	128	178	143	122	103	53	30	90	217	201	154	148	70	31	6

TABLE III—OBSERVED AND COMPUTED WIND FREQUENCIES AT GUERNSEY AND SKEABRAE

Beaufort force		NE.	E.	SE.	S.	SW.	W.	NW.	N.
					per mille				
Guernsey (States Airport) 1950–54							Calms: 58 per mille		
1	Computed	5	3	3	6	6	7	6	5
	Observed	6	4	5	6	4	5	5	10
2	Computed	15	8	9	18	20	22	19	17
	Observed	20	12	15	21	15	16	18	25
3	Computed	28	15	15	33	35	38	35	29
	Observed	26	17	23	34	31	31	30	30
4	Computed	32	17	18	37	39	44	39	33
	Observed	31	17	16	43	51	54	42	31
5	Computed	20	11	12	24	26	29	24	23
	Observed	19	6	4	19	26	29	22	14
6	Computed	10	5	6	12	13	15	15	11
	Observed	10	4	1	9	14	15	18	10
7	Computed	3	2	2	3	4	4	4	3
	Observed	2	1	<1	3	3	5	5	3
8	Computed	1	<1	<1	1	1	1	1	1
	Observed	<1	<1	<1	1	1	2	2	1
9	Computed	...	...	...	...	...	...	...	...
	Observed	...	...	...	...	<1	<1	<1	<1
Skeabrae 1943–45							Calms: 53 per mille		
1	Computed	2	1	5	4	5	4	3	3
	Observed	3	1	8	4	4	4	3	3
2	Computed	5	5	16	12	17	14	12	10
	Observed	9	7	19	12	11	10	9	11
3	Computed	10	8	30	22	32	25	22	18
	Observed	13	13	39	32	41	28	27	24
4	Computed	13	12	42	32	43	35	30	25
	Observed	13	11	35	31	38	29	25	20
5	Computed	11	10	34	26	36	29	24	21
	Observed	9	7	28	21	26	25	20	18
6	Computed	8	7	26	19	27	21	19	15
	Observed	7	7	27	18	29	29	19	13
7	Computed	4	3	11	9	12	10	8	8
	Observed	1	2	8	7	17	14	13	8
8	Computed	1	1	4	3	5	4	3	2
	Observed	<1	1	5	1	9	5	5	5
9	Computed	<1	<1	1	1	1	1	1	1
	Observed	<1	<1	<1	<1	1	2	1	1

method of least squares, to be $3 \cdot 43 \times 10^{-3}$ (common logarithms being used in Fig. 1 the values of the coefficients are $a = 1 \cdot 95$ and $b = 1 \cdot 49 \times 10^{-3}$). The numerical value of b can still be calculated even if the wind forces are grouped, which is commonly the case. The mean value of the wind speed, excluding calms, is found to be 14·7 m.p.h. and the corresponding standard deviation is 7·9 m.p.h.

The value of b calculated from the standard deviation by means of the formula $\sigma^2 = (1-\pi/4)/b$ is $3{\cdot}44 \times 10^{-3}$ (Napierian logarithms) and the mean wind speed (excluding calms) given by the formula $\bar{v} = \frac{1}{2}\sqrt{(\pi/b)}$ is 15·1 m.p.h. in satisfactory agreement with the observed values. Taking the value of b as $3{\cdot}5 \times 10^{-3}$ and using the values of exp (bv^2) given in Table I the derived frequency distribution of wind directions and wind speeds at Guernsey is as shown in Table III.

Skeabrae.—The value of b deduced from the summary of wind forces in Table II by the method of least squares is $2{\cdot}28 \times 10^{-3}$. In Fig. 1 where common logarithms are used, the coefficients of the equation $\log_{10} n_v = a - bv^2$ become $a = 1{\cdot}98$ and $b = 0{\cdot}99$. We also find that, excluding calms the mean wind speed is 18·3 m.p.h. and the standard deviation 10·2 m.p.h.

The corresponding average wind speed, calculated by means of the formula $\bar{v} = \frac{1}{2}\sqrt{(\pi/b)}$, is 18·6 m.p.h., and the standard deviation, calculated from the formula $\sigma^2 = (1-\pi/4)/b$, is $\sigma = 9{\cdot}7$ m.p.h., again in good agreement with the observed values.

The frequency distribution of wind speeds and wind directions at Skeabrae, computed on the assumption that b is equal to $2{\cdot}3 \times 10^{-3}$, is shown in Table III.

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SERIES OF COMPUTED FORECAST CHARTS AND THE MOVEMENT OF A DEPRESSION, AUGUST 19–21, 1954

By I. J. W. POTHECARY, B.Sc. and F. H. BUSHBY, B.Sc.

Introduction.—On August 19, 1954, a depression became stationary over the North Sea, contrary to expectation at the Central Forecasting Office at Dunstable until shortly before it occurred. The use of conventional methods of forecasting suggested that the depression would continue eastward to western Germany.

Computed forecasts of the 1000-mb. and 500-mb. contour charts and the associated thicknesses were made at 12-hr. intervals to cover the period from 1500 G.M.T., August 19, to 0300 G.M.T., August 21, which included the cessation of the eastward movement of the depression and its subsequent drift south-westward. Although a number of individual numerical forecasts had previously been computed with results which were, on the whole, comparable in accuracy with those obtained by conventional methods, this was the first time that a sequence of such numerical forecasts, dealing with the evolution of the synoptic situation over 60 hr. had been computed in the Forecasting Research Division at Dunstable. The series of computed charts (Charts (*c*) and (*d*) of Figs. 3–6) achieved considerable success in respect of the movement of the depression.

Synoptic history.—The depression had developed from a wave on a trailing cold front and acquired its first closed isobar (1008 mb.) south-east of ocean weather station J (50°N. 18°W.) at 0000, August 17. During the following 48 hr. the depression moved north-east to the North Sea where the centre remained stationary for nearly 30 hr. By 0600, August 20, the centre had begun to move south-west and 24 hr. later it had crossed the Midlands and southern England and was filling up over the western English Channel. This movement is illustrated in the 1000-mb. charts covering the period (Charts (*a*) of Figs. 1–6).

The movement of the depression was related to events on a larger scale over the North Atlantic. Low pressure extended from eastern Canada to the Denmark Strait and a warm south-westerly air stream extended northward over Iceland. This stream persisted until, by 0300, August 20, the 18,000-ft. thickness line was approaching its northernmost extreme.

A cold trough in the 1000–500-mb. thickness pattern was being maintained over the west of the British Isles by the depression as it moved across the country, and this, with the warm ridge extending north of Iceland, led to the formation of an anticyclogenetic region from the Azores to northern Scandinavia. High pressure eventually extended from the Azores to north-west Russia and a cold pool was cut off west of the British Isles.

At 0300, August 19, the depression became slow moving over the North Sea, and by 1500 it was stationary and the circulation over it was closed up to 100 mb. The cutting-off process was complete.

Discussion of the electronic computations.—In order to facilitate comparison of the charts shown in Figs. 1–6 the following order of presentation is used:

Charts (*a*): Actual 1000–500-mb. thickness and 1000-mb. contours.
Charts (*b*): Actual 500-mb. contours.
Charts (*c*): Computed 1000–500-mb. thickness and 1000-mb. contours.
Charts (*d*): Computed 500-mb. contours.

The first 24-hr. forecast charts were computed from the data for 1500, August 18, at which time the depression was moving east into the North Sea after crossing northern England. The last forecasts of the series were computed from the data for 0300, August 20, when the depression was still stationary over the southern North Sea.

The computations were based on the Sawyer-Bushby two-parameter model which has been described elsewhere[1,2]. For this series the observed changes around the edge of the area were used as boundary conditions during the calculations, but it is thought that the computed values near the British Isles are not materially affected by the boundary assumptions. A non-adiabatic heating term was introduced to allow for the modifying effect of heating over the sea. Some of the computations were based on data for an upper level of 600 mb., but the results were extrapolated to 500 mb. for comparison with the 500-mb. charts. The computed forecasts and the actual charts are briefly compared in the following paragraphs.

1500, August 19 (Fig. 3).—The pattern of the computed 1000-mb. contours shows substantial agreement with the actual chart and the movement of the centre was correctly forecast, although the central pressure was computed to be about 5 mb. too low. The maintenance of cyclonic curvature over the

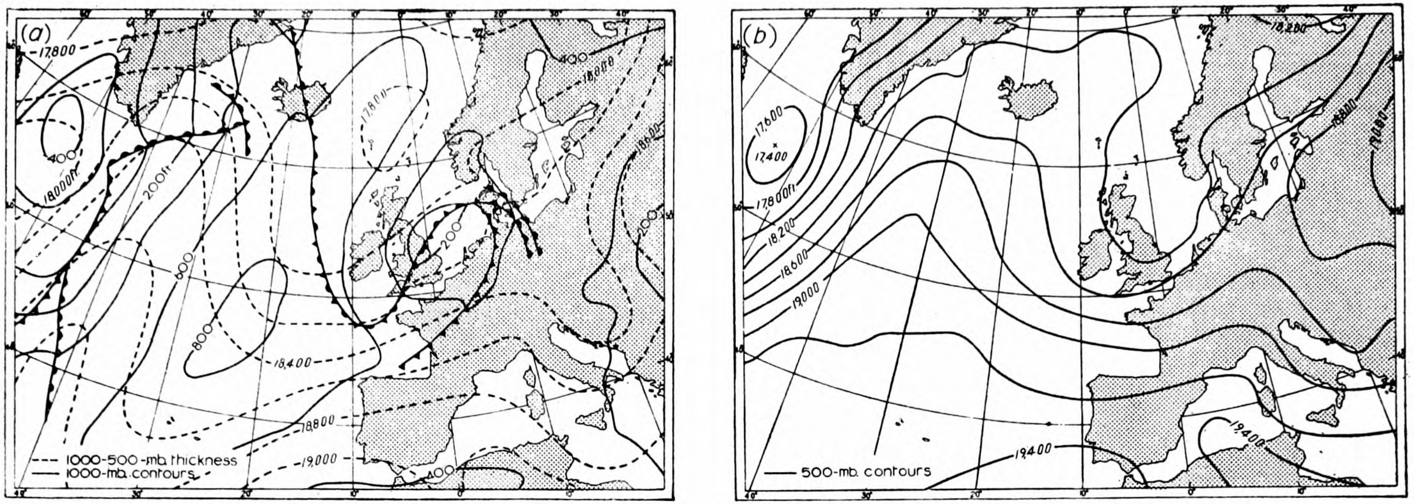

FIG. 1—ACTUAL CONTOUR AND THICKNESS CHARTS, 1500 G.M.T., AUGUST 18, 1954

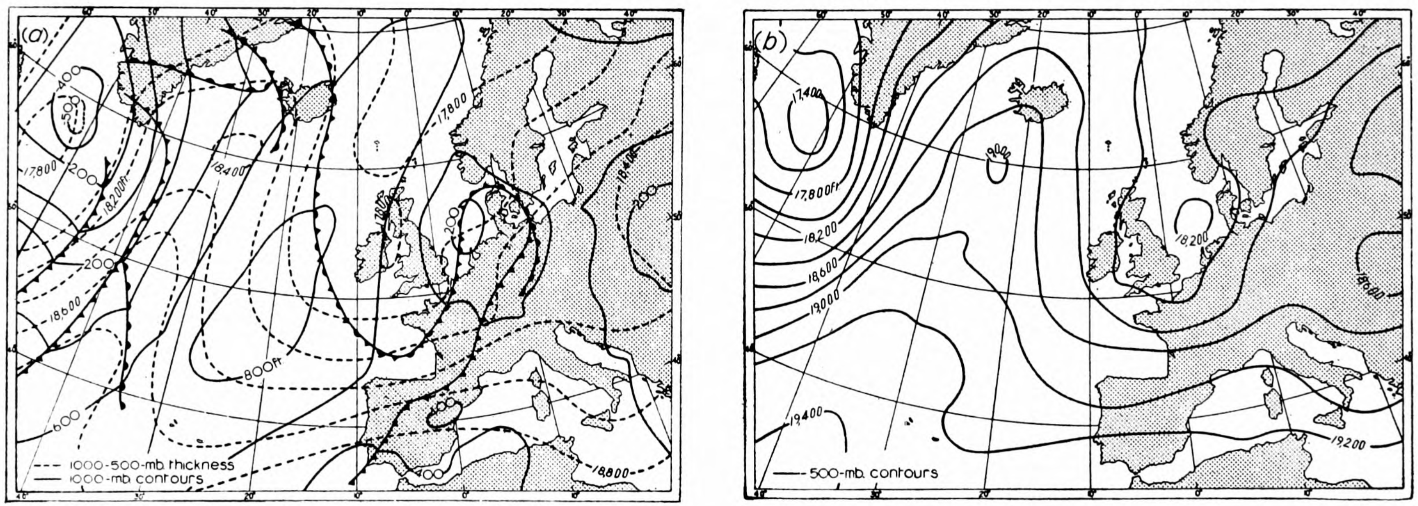

FIG. 2—ACTUAL CONTOUR AND THICKNESS CHARTS, 0300 G.M.T., AUGUST 19, 1954

Actual charts

Computed charts

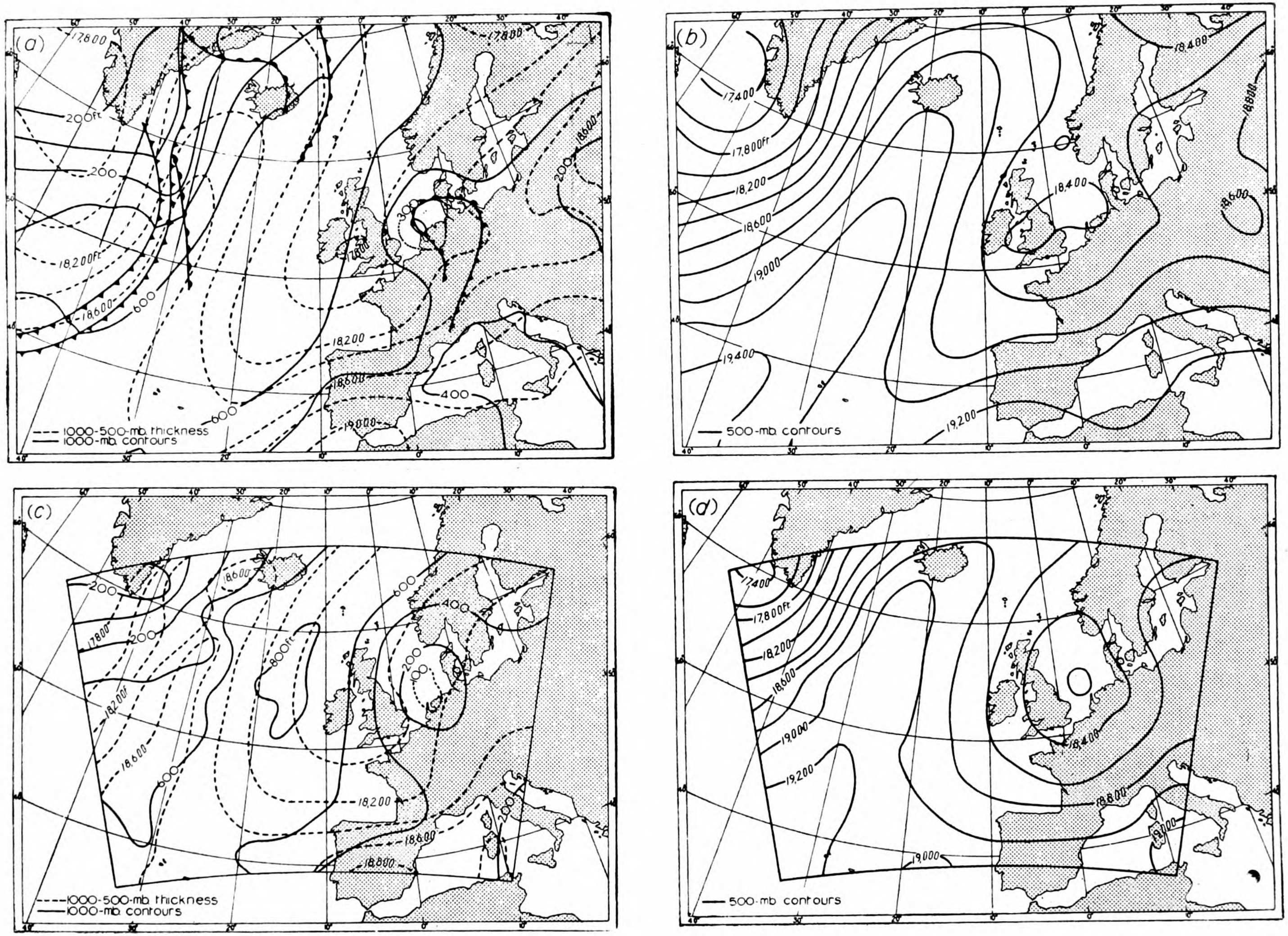

FIG. 3—CONTOUR AND THICKNESS CHARTS, 1500 G.M.T., AUGUST 19, 1954

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MOCK SUNS SEEN FROM KEW, 0740 G.M.T., MARCH 1, 1956

Reproduced by courtesy of A. W. E. Barber

SUN PILLAR, EAST HILL, 1655 G.M.T., FEBRUARY 23, 1956

Photographic details: Film FP3, exposure 1/100 sec., aperture F5·6, Ilford Tricolour red filter.

(see p. 155)

Actual charts

Computed charts

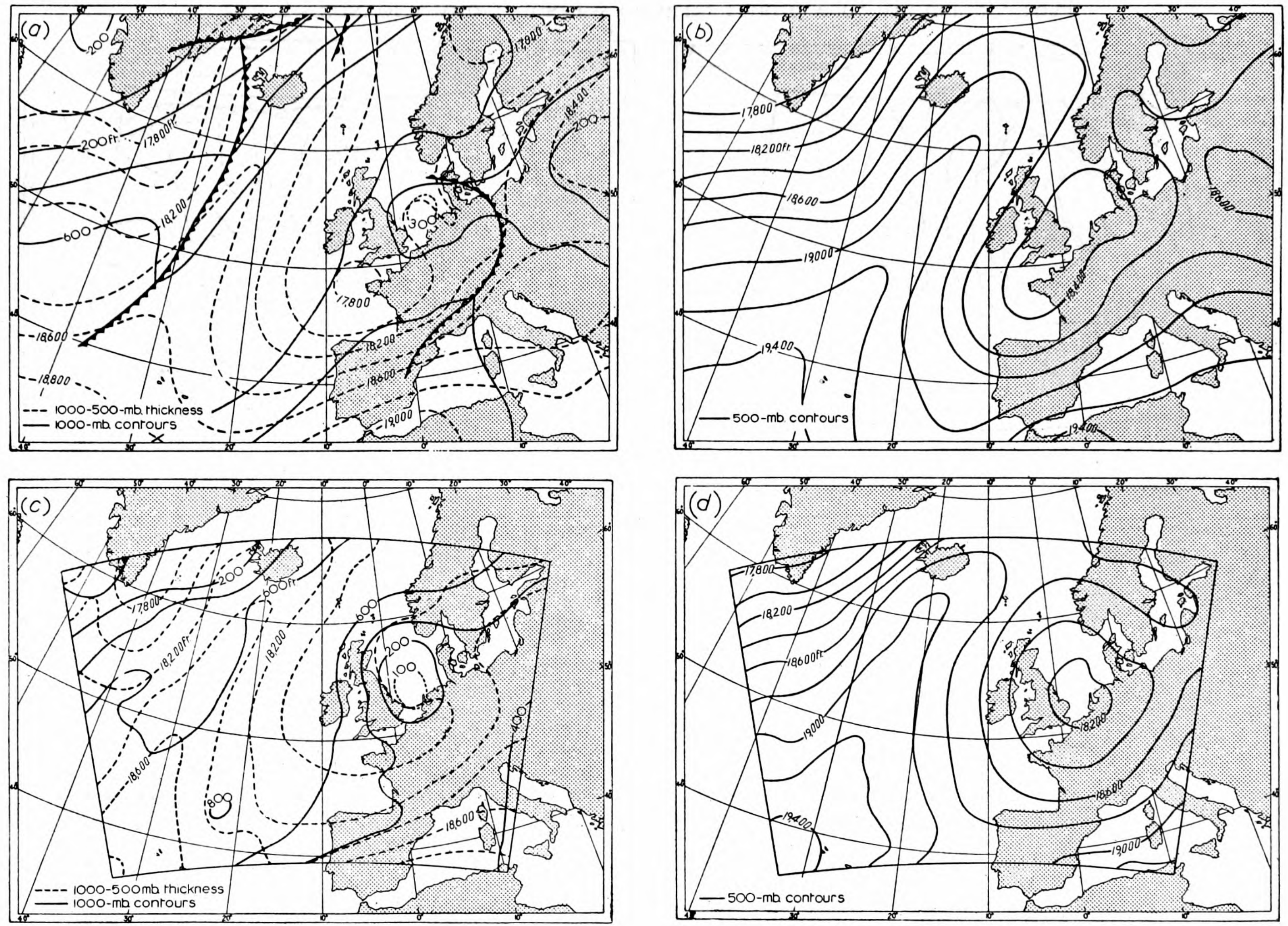

FIG. 4—CONTOUR AND THICKNESS CHARTS, 0300 G.M.T., AUGUST 20, 1954

Actual charts

Computed charts

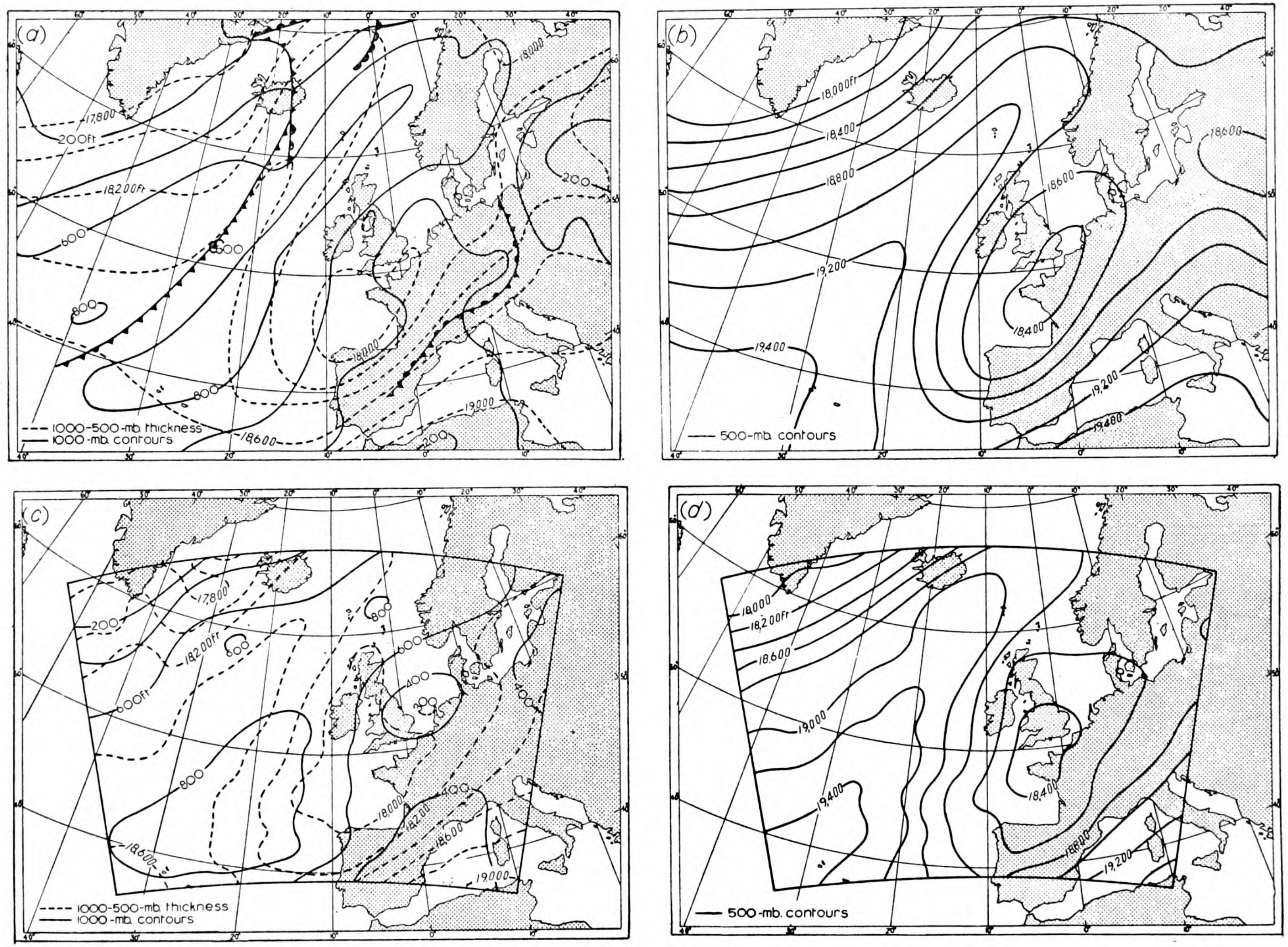

FIG. 5—CONTOUR AND THICKNESS CHARTS, 1500 G.M.T., AUGUST 20, 1954

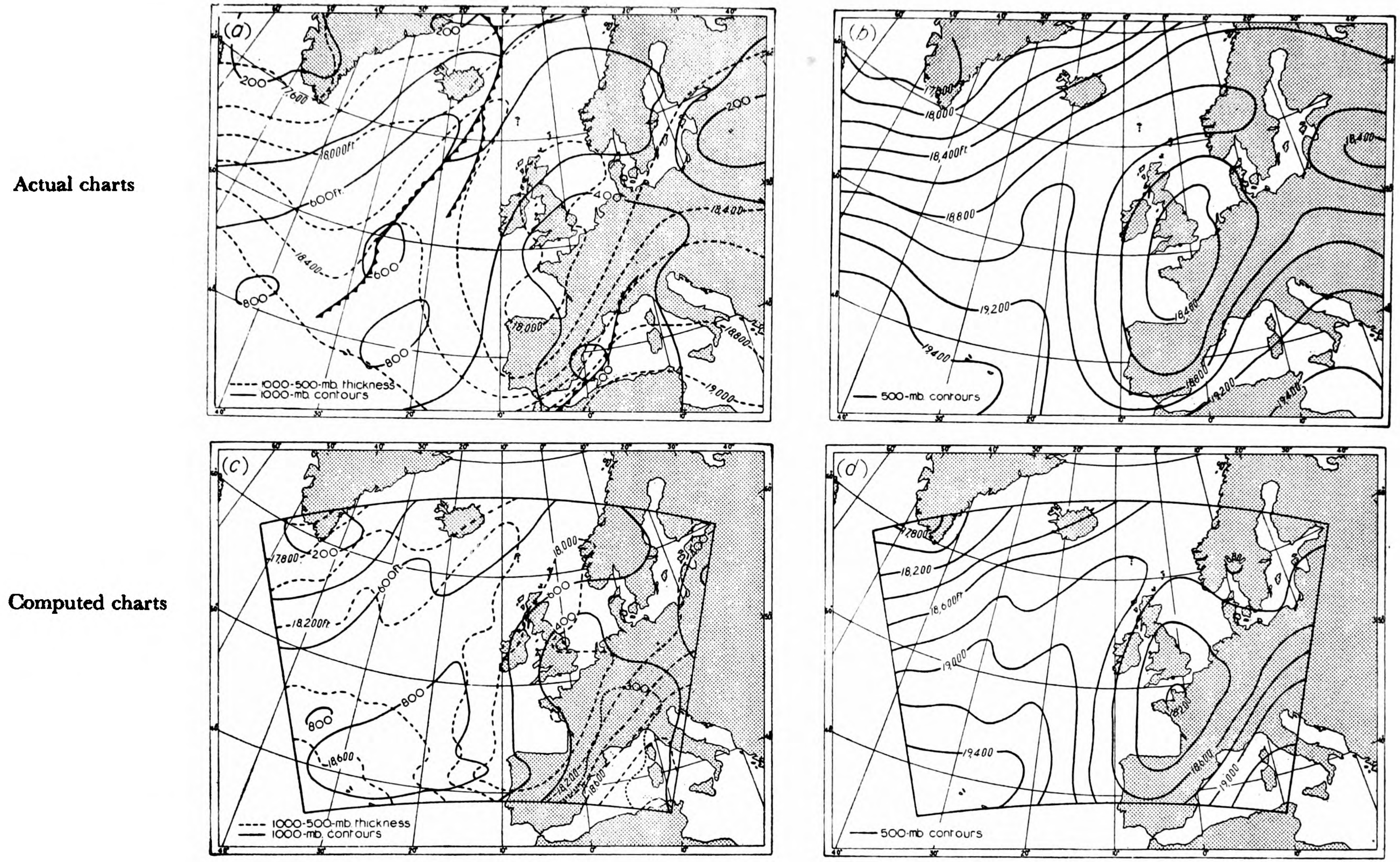

FIG. 6—CONTOUR AND THICKNESS CHARTS, 0300 G.M.T., AUGUST 21, 1954

British Isles and the position and intensity of the 1000-mb. ridge over the eastern Atlantic correspond with the actual chart. The amplitude of the thickness ridge over the Atlantic was reasonably well forecast, but the small cut-off cold pool over the Irish Sea was not indicated although the broad outline of the cold trough was maintained. The computed 500-mb. contours are in close agreement with the actual chart.

0300, August 20 (Fig. 4).—The centre of the depression was held stationary over the southern North Sea in close agreement with actual events. The extension of high pressure from the Azores to northern Scandinavia was correctly indicated and cyclonic curvature of the 1000-mb. contours was maintained over England and Wales. The position and intensity of the cold trough over the British Isles was correctly indicated but the formation of a cut-off pool over the western English Channel was not shown.

1500, August 20 (Fig. 5).—The centre of the depression was actually moving south-west over East Anglia and filling up at this time. The relatively low pressure over south-east England is indicated by the computations but the centre was held back over the southern North Sea. The cut-off cold pool over the Bay of Biscay and the western approaches and the maintenance of the warm ridge over the eastern Atlantic are shown in the computed charts. The computed and actual 500-mb. contours are almost exactly similar.

0300, August 21 (Fig. 6).—By this time the remnant of the actual centre was over the western English Channel. The computations placed a weak centre over Lincolnshire but the larger-scale distribution of the actual and computed 1000-mb. level is similar. The cut-off cold pool was computed to be more extensive and deeper than shown on the actual chart. The 500-mb. computed and actual contours show a similar distribution.

Examination of some other forecasting methods.—The initial information available on the charts for 1500 and 1800, August 18 and 0000, August 19, shortly before the depression became stationary, was examined in detail, apart from electronic computation, to find how much evidence for the future movement it contained, since, as mentioned earlier, conventional forecasting methods proved inadequate at that stage. Some of the techniques of analysis, such as the calculation of isopleths of the Sutcliffe development term, are rather too complicated for routine use in a forecast office.

The Rossby stationary wave-length was greater than the actual trough-to-trough wave-length of the 500-mb. pattern over the Atlantic and Europe which indicated eastward progression of the pattern. But by 1500 August 18 the amplitude of the oscillation in the 500-mb. flow over the Atlantic was becoming very large with a strong flow north-eastward forward of the up-stream trough over Newfoundland. Only part of this flow was involved in the down-stream trough over western Europe, and, in the event, the wave-length measurements were misleading. The formation of a cut-off circulation over or near the British Isles occurred.

Calculation of the Sutcliffe development terms alone at 1500, August 18 showed a cyclonic development area over the Skagerrak, and suggested the formation of a new centre there and the swinging south-east of the original centre to a cyclonic development area over the Low Countries. These developments would have led to the continued eastward motion of the depression.

The isallobaric evidence at 1800, August 18, indicated that these developments were in progress, but at 0000, August 19, the greatest pressure falls were concentrated over the Low Countries and the falls elsewhere, particularly between Denmark and Sweden, were very much reduced, which was more consistent with the subsequent actual movement of the centre.

The 1000-mb. flow around the depression at the times the forecast charts were prepared was asymmetric with the strongest flow, and considerable advection of cyclonic vorticity, on the north-western side.

If the upper level in the Sutcliffe development equation[3] is considered non-divergent then

$$- l \operatorname{div}_p \mathbf{V}_0 = \frac{D\zeta_0}{Dt} = \frac{\partial \zeta_0}{\partial t} + \mathbf{V}_0 . \operatorname{grad} \zeta_0 = - \mathbf{V}' . \operatorname{grad} (l + \zeta' + 2\zeta_0)$$

and the local rate of change of 1000-mb. vorticity, $\partial\zeta_0/\partial t$, can be obtained from

$$\frac{\partial \zeta_0}{\partial t} = - \mathbf{V}' . \operatorname{grad} (l + \zeta' + 2\zeta_0) - \mathbf{V}_0 . \operatorname{grad} \zeta_0$$

where l is the Coriolis parameter, $\mathbf{V}_0$ is the 1000-mb. wind, ζ_0 is the vorticity at 1000 mb., $\mathbf{V}'$ is the thermal wind in the 1000–500-mb. layer and ζ' is the thermal vorticity.

The final term, which represents the advection of vorticity with the surface flow, may be important with asymmetric depressions. Isopleths of the surface vorticity advection can be constructed by use of the Sawyer-Matthewman scale and the field of $\partial\zeta_0/\partial t$ is then obtained by gridding with the isopleths of relative divergence.

By 1500, August 18, the circulation of the depression was asymmetric with a much stronger flow on its north-western side; surface vorticity advection was computed for this time and the local rate of change of 1000-mb. vorticity was obtained.

The Sutcliffe development terms indicate the type and intensity of development following the motion, whereas the local rate of change of surface vorticity indicates the change of circulation at a fixed point. The local development was becoming more cyclonic over the Skagerrak, and over the Low Countries and eastern England, and less cyclonic over the eastern half of the North Sea and the rest of the British Isles.

The Sutcliffe development equation neglects the effect of vertical stability on development. This factor was taken into account in an evaluation of vertical velocity and thickness tendency from Sutcliffe's theory[4], and an empirical factor of 0·27 emerged by which the vertical velocity, closely related to the development, should be modified to take account of vertical stability. Isopleths of the development reduced in this way were gridded with isopleths of the advection of vorticity at 1000 mb. to produce a modified field of the local rate of change of surface vorticity.

The distribution of the local rate of change of surface vorticity when stability was taken into account did not indicate the transference or the movement of the centre eastward, but there was some indication that the centre should either have become stationary over the North Sea or have moved south-east. In the event the centre continued to move slowly north-east until the early hours of August 19, and then became stationary with a tendency to drift slowly south.

Conclusion.—The case history of this depression illustrates a type of situation in which an upper depression over the British Isles was being cut off from the main westerlies, and this had an important effect on the motion of the surface depression and associated weather over the British Isles.

The inclusion of the stability in the derivation of the local rate of change of surface vorticity, assuming zero divergence at 500 mb., provided a little more information about the future motion, but it would have been difficult to have foreseen the actual motion of the centre even had this information been available to the forecaster. Such information cannot, in any case, be produced by hand in the limited time at his disposal.

This situation was adequately dealt with by electronic computation, presumably because the model takes into account processes which could not properly be assessed by visual inspection of the charts. The success of the computed forecasts must also be attributed partly to the method of computation which involves steps of one hour and hence the calculation of development from continually changing data; this must be a considerable advantage where the motion of a depression undergoes a radical change.

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METEOROLOGICAL OFFICE DISCUSSION

International Geophysical Year

The Discussion on Monday, February 20, 1956, held at the Royal Society of Arts was opened by Mr. R. F. M. Hay who dealt with the programme and objectives of the International Geophysical Year (I.G.Y.). Some of the more detailed aspects of the I.G.Y. described by Mr. Hay have been omitted from this report; they are given in Mr. Absalom's article in the February 1956 number of this Magazine. After pointing out that the programme of scientific work on the scale to be attempted between July 1957 and December 1958 was being supported by 40 nations, Mr. Hay briefly recalled that International Polar Years were held in 1882–83 and 1932–33. The United Kingdom took part in both these efforts and maintained a station at Fort Rae on both occasions. Under the leadership of Dr. Stagg the Fort Rae party had carried out an extensive programme of auroral, magnetic, ionospheric and meteorological observations in the Second Polar Year.

When in 1950 Dr. Berkner proposed a repetition of the International Polar Year, the International Council of Scientific Unions suggested the more ambitious scheme now known as the International Geophysical Year, and appointed the Special Committee for the International Geophysical Year, with Professor S. Chapman as President, to be responsible for its organization.

Each participating country has appointed a National Committee and programmes of work would be carried out by sections with responsibilities as follows:— World Days, Meteorology, Geomagnetism, Aurora and Air glow, Ionosphere, Solar Activity, Cosmic Rays, Latitudes and Longitudes, Glaciology, Oceanography, Rockets, Publications and Publicity. The cost of the project would probably amount to about £35,000,000 and the central organization is being strongly supported by the United Nations Educational, Scientific and Cultural Organization. The United Kingdom I.G.Y. Expedition to Coats Land would cost about £250,000, a sum which is being provided by the Royal Society, while the additional Meteorological Office expenditure would amount to about £76,000.

Describing the organization proposed for I.G.Y. Mr. Hay began with the activities of the "World Days" Section. The intention behind the choice of "World Days" is to ensure that the largest possible number of observations are made on days coinciding with eclipses and meteor showers and, if possible, with periods of marked solar activity, all of which events are linked with phenomena in the high atmosphere. Hence this section had devised the classification of World Days which has been described in Mr. Absalom's article.

The Special Committee for the I.G.Y. aims to set up many additional stations, and is concentrating in particular upon the arctic, antarctic and equatorial regions. They attach importance to providing several close networks from pole to pole along certain meridians of longitude in particular those of 80°W., 10°E. and 140°E., besides some shorter lines of stations for the purpose of obtaining meteorological vertical cross-sections. These include a northern-hemisphere meridian section at 20°W. to which the ocean weather stations will make an important contribution. Mr. Hay next drew attention to the 21 expeditions that will be setting up bases on the Antarctic mainland during the I.G.Y.

Dealing with the main problems to be studied, the opener first reviewed briefly some features of solar activity. Attention was drawn to the 11-yr. sun-spot cycle and to the physical characteristics and magnetic fields of sun-spots. One of the main reasons for holding the I.G.Y. in 1957–58 was that the next fairly intense sun-spot maximum is expected to occur then. Solar flares, short-lived great increases of energy in the ultra-violet, responsible for at least a small part of the variation in the solar constant were then described. These flares are associated with "faculae"—bright patches near or surrounding sun-spots which suddenly and unpredictably become very bright for periods lasting up to 3 hr.—and are believed to originate as a result of streams of electrons upwelling from the sun's centre.

During the I.G.Y. a "solar-flare patrol" would be maintained to keep an uninterrupted world-wide watch on the sun. This would be done by solar observatories equipped with spectroheliographs, the intention being to take photographs of the entire solar disc in hydrogen light automatically at half-minute intervals.

The forecasts of solar activity would be made by the United States Central Radio Propagation Laboratory. When the forecasters at the Laboratory judged the activity of a newly appeared spot region to be high, their judgement being based on reports of flares, sun-spot size, radio noise and magnetic fields, they would issue a "Special World Alert". Whenever such activity is maintained for the next few days—the time between a spot appearing first at the sun's limb and crossing its central meridian being about 7 days—they would call for a "Special World Interval" at 12 hr. notice. In this way they hope to have full-scale observations "laid on" just before the terrestrial effects of a solar flare begin to be felt.

The United Kingdom intends to contribute to this programme with observations at the Royal Greenwich Observatory, Jodrell Bank Radio-Astronomy Observatory and in British East Africa, among other places.

After briefly recalling a few facts about the ionosphere, including Appleton and Naismith's discovery in 1939 that the electron concentration in the ionospheric layers increased between sun-spot minimum and sun-spot maximum, which afforded proof that the solar intensity varied in the ultra-violet, Mr. Hay drew attention to the practical importance of the layers for reflecting radio signals used by long-distance navigational aids for ships and aircraft. Since the concentration of electrons needed to reflect the waves increases with frequency, there is, for a given layer, always a "maximum usable frequency" for satisfactory transmissions. This maximum usable frequency conforms in periodicity with the variations of electron concentration through the sun-spot cycle, a fact used by radio engineers to predict maximum usable frequencies some months ahead. However, these predicted values are not yet considered to be accurate enough. A 50-per-cent. increase in the existing number of ionospheric observing stations is aimed for during the I.G.Y., special interest attaching to the geomagnetic equator and the Antarctic. The "vertical-incidence" method of sounding will be the chief method to be used at most of the stations. In addition there will be studies of the world-wide pattern of ionospheric drifts, and part of the programme will be devoted to an intensive study of radio fade-outs associated with the onset of solar flares.

Ionospheric investigations by the United Kingdom would comprise programmes by the Radio Research Organization of the Department of Scientific and Industrial Research in this country and in the Falkland Islands as well as by Jodrell Bank.

After drawing attention to the main features of aurorae and to the practical and theoretical work of Birkeland and Størmer respectively in explaining some of the more important features connected with them, and mentioning some problems which are still unexplained, such as the discrepancy between the actual radii of the zones of maximum auroral frequency and those predicted by Størmer's theory, the opener dealt with the I.G.Y. auroral programme. For the purpose of the I.G.Y. the world has been divided into three regions, the most important to be called the "auroral region" lying between 60° geomagnetic latitude north and south, and the north and south magnetic poles respectively. Observations would be undertaken by means of a visual watch to be kept by meteorologists, astronomers and amateurs, and by programmes of photographic, photometric and spectral observations. It is hoped that many more measurements of auroral height using the Størmer method will be made together with numerous determinations of wave-lengths and intensities in conjunction with observations of auroral height and type. The Gartlein all-sky camera, which takes a picture every 5 min. on 16 mm. film and can be managed by untrained personnel, should greatly assist the photographic programme. Lastly, investigations will be made at Jodrell Bank of the scintillation of radio stars observed while aurora is in progress. Also in the United Kingdom the auroral survey operated from Edinburgh over many years will provide a contribution to the I.G.Y. which will be reinforced by spectrographic studies at St. Andrew's University.

The opener recalled the special importance of terrestrial magnetism for air and sea navigation, in the interests of which it is advisable for a world-wide survey of the earth's magnetic field to be made about every 25 yr. The small-scale fluctuations lasting a few minutes to several days were also described, and the theory outlined which relates the occurrence of great magnetic storms with the arrival of solar corpuscular radiation reaching the earth about 26 hr. after the onset of a solar flare lying within about 45° of the central solar meridian. The main feature of these storms—the weakening of the earth's field—during their main phase is ascribed by the Chapman-Ferraro-Martyn theory to the formation of a ring current in space around the earth in the equatorial plane whenever the earth traverses a neutral corpuscular stream. Mention was made of the difficulty that smaller magnetic storms which show no obvious relation to sun-spots often recur at 27-day intervals for months on end. The existence of so-called M-regions actively emitting corpuscles for long periods is put forward to account for storms of this type, although such regions have not yet been identified with any visible feature on the sun. The opener recalled that the experimental proof of the existence of streams of solar corpuscles and of their velocity of approach to the earth, which must be of the order of 1,600 Km./sec., is so far very unconvincing.

The Special Committee for the I.G.Y. have already commented that few complete records of any great magnetic storms were obtained during the two Polar Years, and that a denser network of magnetic observatories than before is needed during the I.G.Y. to infer even the broader features of the ionospheric-current systems. They also recommend that auxiliary recording instruments should be operated up to 40 Km. from certain parent stations. Their aim here is to provide additional information on the height and intensity of the narrow localized currents—electro-jets—in these regions. The Meteorological Office intends setting up two such auxiliary stations around the Observatory at Lerwick.

Mr. Hay next described the Special Committee's programme for meteorology, to which the World Meteorological Organization has substantially contributed. Most of the problems relate to the general circulation. They are

(i) re-distribution of momentum, absolute vorticity and all forms of energy.

(ii) influence of surface features—the largest mountain ranges—on momentum and heat exchange between the atmosphere and the earth's surface.

(iii) thermal economy of the atmosphere. This includes radiation studies, albedo and determinations of ozone distribution.

Besides the arrangements already described for setting up additional stations, the opener mentioned that Whaling Companies are being asked to allow meteorologists to accompany their factory ships to secure upper air soundings in the Southern Ocean. Thus sufficient stations may well be available from which to derive mean values of the three-dimensional temperature, water-vapour and wind distributions prevailing for the particular period of the I.G.Y. However, it remains to be seen whether the observational network in space and time will really be detailed enough to allow a viable theory of the general circulation to be constructed.

Mr. Hay then showed some slides of temperature and wind cross-sections including two showing mean zonal components of wind for the northern hemisphere for January and July. These slides give the most detailed vertical cross-sections at present available.

Further examples of investigations which should be helped by data from the I.G.Y. are the splitting of a jet stream to westward of a continent, for which the data from the cross-section at 20°W. would be valuable; and atmospheric circulation over the polar regions, including the behaviour of the tropopause over the Antarctic in winter. High-level wind information to be provided during the I.G.Y. should also enable the seasonal reversal of winds at great heights to be studied in greater detail, besides being of great value operationally and economically to present-day and future aviation. The opener could not explain the restriction of "World Meteorological Intervals" to the solstices and equinoxes which have no great significance from the meteorological standpoint.

Instruments for use in radiation studies included the Moll-Gorczynski thermopile solarimeter and the vertical-flux plate radiometer, the latter instrument having been developed in the Meteorological Office.

Attention was drawn to the need for making observations of the earth's total albedo during the I.G.Y. by the method of Danjon which had long been neglected. Danjon's individual measurements gave values varying between 30 per cent. and 50 per cent. and all his measurements were made in France. Hence the observations should be repeated from other parts of the world to ensure measurements of the total albedo being made while the Pacific Ocean faced the sun. The Special Committee of the I.G.Y. have asked the International Astronomical Union to do this during 1957–58. At the same time it is intended to make measurements of cloudiness as accurately as possible aboard merchant ships and at ocean weather stations.

After briefly reviewing the contribution of Dobson and others to our knowledge of the world distribution of ozone, the opener showed two slides giving the seasonal distribution and the vertical distribution of ozone respectively. He drew attention to two principal difficulties in explaining the distribution of ozone theoretically. First, the fact that day-to-day changes in total ozone amount at a single locality such as Oxford are larger than the normal difference in total ozone amount between equatorial and polar regions at most seasons, implies that the short-period changes cannot be explained by north–south advection. In the second place ozone vertical-distribution determinations have also been made from balloons as well as from rockets, but there is still disagreement between the vertical distribution derived from all these observing methods and by means of calculations such as those of Craig. Craig computed the equilibrium concentrations which must exist at various levels between molecular and atomic oxygen and ozone, dependent as the photo-chemical equilibrium between these constituents is upon the intensity of the sun's ultra-violet radiation and upon the absorption coefficients of these gases. The theoretical and computed distributions agree well above 35 Km., but below 20 Km. there is considerably more ozone in reality than the calculations suggest. Craig's calculations also failed to explain the latitudinal and seasonal variations of ozone amount and the association of ozone with surface weather systems and upper air flow patterns.

In addition, Fleagle has shown that stratospheric air, in moving from a ridge to a trough in the upper flow, undergoes marked lateral convergence and vertical subsidence. However, this subsidence is most marked close to the tropopause and hardly shows at 17 Km. To make matters worse, the layer where the rate of increase of ozone concentration with height is steepest has been believed to lie still higher than 17 Km. Some very recent work by Brewer, however, who made ozone determinations from an aircraft in northern Norway, suggests that there is a rather rapid increase of ozone upwards through the tropopause which may serve partly to overcome this difficulty.

Wulf and others have shown that the rates of opposing photo-chemical processes, those which destroy and create ozone respectively, vary greatly with altitude. Above about 35 Km. equilibrium must be reached very quickly in daylight, i.e. within a few hours; below this level photo-chemical equilibrium is seldom, if ever, reached. Hence below this level the ozone mixing ratio is generally a conservative property and descending air will carry its high ozone content down with it.

Evidently the observed distribution of ozone is brought about largely by vertical mixing, although it appears that downward velocities of about 1 m./sec. are necessary to explain the difference between Craig's computations and the observed values.

In its programme the Special Committee of the I.G.Y. recommends that ozone-measuring instruments (Dobson's spectrophotometers) be installed at stations near the meridians of 10°E. and 140°E., and on both sides of the subtropical jet stream. They consider many more detailed measurements of horizontal and vertical distribution of ozone are required.

Mr. Hay next described the United Kingdom's contribution to the meteorological programme, pointing out that the ocean weather stations I, J and K would contribute data to the 20°W., Malta to the 10°E. and Aden to the 15°N. (zonal) vertical cross-sections. He explained that on ordinary days throughout the I.G.Y. the normal number of soundings would be made to at least 50 mb., but in one of the combined daily temperature-wind ascents a large (1,250 gm.) balloon would be used to get up to 100,000 ft. (10 mb.) when possible. All these arrangements conformed closely with the Special Committee's recommendations. On "World Meteorological Interval" days, four combined temperature wind ascents with large balloons would be made at the ocean weather ship stations, at three stations in the United Kingdom and in the Mediterranean and Middle East.

Dealing with the radiation programme, he explained that observations would be made by Hemsby, Aberporth, Cambridge, the Meteorological Office Observatories, the Meteorological Research Flight, Malta, Aden and Port Stanley (Falklands).

In the United Kingdom measurements of total ozone amounts using the Dobson instrument would be continued at Oxford and made in addition at Lerwick, Aldergrove and Camborne. It was hoped a chemical method for measuring ozone concentration would be used by the Meteorological Research Flight for investigating relations between ozone amount, the subtropical jet stream and double tropopause structure. It was also intended to make ozone measurements at Aden, Bahrain and Habbaniya. The British sferics network in the United Kingdom linked to the Central Forecasting Office, Dunstable, would, of course, be available for thunderstorm location as required by the Special Committee.

Dealing with physical oceanography Mr. Hay said that a main requirement at present was for temperature and current measurements and water samplings to be made at all depths along selected ocean traverses. In this way a better understanding could be obtained of the ocean to atmosphere energy exchange and of the fluctuating fortunes of the fishing industry, among other important problems.

Oceanographers also wanted a programme included in the I.G.Y. for improving our understanding of short-period and long-period changes in sea level. For long-period changes of sea levels the recorders to be used would not respond to ordinary waves and swell, but would take account of those changes of level due to storms and seismic surges, to tides and seasonal fluctuations. A better understanding of unexpected changes in sea level which affect harbours and result in coastal flooding should follow from such work. The Royal Research Ship *Discovery II* and the Fishery Research vessels *Scotia* and *Ernest Holt* would take part, and the National Institute of Oceanography would be installing tide gauges in the United Kingdom and overseas.

Another recommendation of the Special Committee of the I.G.Y. was that sea-temperature measurements should be made regularly down to at least 200 m. using bathythermographs. Only discontinuous series of such observations have so far been made at any one point in the open ocean, mainly upon British and United States ocean weather ships. Meteorologists should thus be provided with data for investigating the relation between seasonal and longer-term fluctuations of anomalies of sea temperature in the topmost 200 m. The large-scale distribution of sea-temperature anomalies in this 200-m. layer and the overlying air-temperature anomalies, together with snow and ice cover over the polar regions and winter continental areas, must be very significant factors for determining seasonal climatic anomalies. The interdependence between them still needed working out in detail.

Glaciological problems under consideration by the Special Committee are mainly comprised under three headings. There are, first the characteristics of glaciers, their shape, size, thickness, rate of flow and advance and retreat, and then changes in these factors as an indication of present climatic trends. Internal glacier structure, seasonal bandings and so forth, will be used to derive recent climatic fluctuations. Lastly, all these studies together with thickness determinations of the ice caps in Greenland and Antarctica should yield more accurate estimates of rates of change of sea level. For instance, the rise of sea level due to melting ice is now estimated as 4 in. a century. In a region where land is subsiding for isostatic reasons, as in south-east England, at a rate of about 6 in. a century, the problem may become quite serious in due course.

Such measurements of ablation, accumulation and movements of glaciers are included in the Special Committee's programme, while the importance of establishing fixed survey points is emphasized to allow changes in glacier characteristics to be accurately measured in future Geophysical Years. Antarctica is given priority, although programmes are also recommended for little-known areas like the east African mountain glaciers (Kilimanjaro) and the far north of Canada.

Prof. Manley, in a letter regretting his inability to attend the Discussion, has drawn attention to the main features of the United Kingdom glaciological programme. In addition to the points mentioned in the Special Committee's programme the measurements already described will be made on one or two glaciers in South Georgia and related to meteorological factors. This island lies so near the Antarctic convergence that this programme may serve to elucidate the oceanic circulation as well as the atmospheric circulation in that area. Similar work at King George Island (62°S.) which has less precipitation and lower temperatures should show whether glacier movement and behaviour there are in phase or not with South Georgia, and better results should be obtained from annual bandings. Similar work which the I.G.Y. party based on Coats Land intend to carry out should yield valuable information on the climate of at least that part of the Antarctic.

Describing the rocket programme for the I.G.Y., Mr. Hay said the United States intends launching about 36 Aerobees, each capable of carrying up to 160 lb. of research instrumentation into the thermosphere, besides a large number of smaller rockets to be launched from balloons or aircraft. France also intended sending up a few rockets. Details of any rocket-launching programme under consideration by the United Kingdom are not yet available*.

It was intended to launch these rockets on selected "World Days". They could help to solve many problems. For instance, they could tell us more about the extension of the solar spectrum in the ultra-violet, they could be used to investigate the current systems responsible for the short-period fluctuations in the earth's magnetic field, for cosmic-ray investigations and to determine the constitution of the ionosphere. It was hoped a rocket could be launched to coincide with a solar flare, although such coincidence would be hard to achieve since preparations for an Aerobee launch take up to 24 hr. even when the geophysical equipment is ready at the outset. Launching of small satellite vehicles during the I.G.Y. is seriously recommended, since the time-scale of the information they could provide under all these headings would be so greatly extended.

Mr. Hay finally alluded to the work of the section responsible for publications and publicity, which is already preparing a history of the two earlier Polar Years, handbooks covering programmes, lists of instruments, observation manuals and so forth. The main task of this section would be to ensure speedy publication after the I.G.Y. of results from all the different fields of activity and to get this done on a uniform plan.

Cmdr Frankcom, opening the general discussion, referred to the opener's statement that it was hoped to make observations of total radiation aboard British ocean weather ships during the I.G.Y. He understood from Dr. Robinson that observations could be made satisfactorily with

* See JONES, F. E. and MASSEY, H. S. W.; Rocket exploration of the upper atmosphere. *Nature, London,* **177,** 1956, p. 643.

fixed instruments providing the ship's roll did not exceed 5°. This was true as regards the thermopile solarimeter. He went on to say that ocean weather ships have been observing aurorae on behalf of Mr. Paton's auroral survey for several years. He added that the Marine Division had always encouraged "selected" ships to make observation of meteor trails, and asked Mr. Hay whether such observations could be of any use for determinations of ionospheric drifts. Mr. Hay replied that this point had been mentioned by Mr. Graystone at a recent Meteorological Office Discussion. He understood that such visual measurements were useful providing the position of the trail was accurately determined against its background of stars. Visual observations could not compete in value with photographic records of meteor trails, particularly when made with a ciné camera. In both cases measurements from a single base only gave velocity components perpendicular to the line of sight.

Mr. Gold remarked that as one half of the atmosphere is contained between the parallels of 30°N. and 30°S., and in addition the tropics receive more than half the solar energy, he would like to know how many additional synoptic observations would be obtained from the tropics. He felt that the tropical regions ought to be allotted a substantial part of the £35,000,000 to be spent during the I.G.Y. He would like to know what plans are being made to set up an organization to deal with all the results. Admittedly the working up of the results of the last Polar Year was interfered with by the Second World War, but from the start there was a lack of a satisfactory organization to record and publish the observations. The synoptic data for the Antarctic should be a magnificent improvement on anything we have had before; Antarctica was the nearest approach to a symmetrical portion of the earth's land surface we could get. There was a need for an organization to tackle the meteorological results, not only to publish them but to see what can be got out of them. Mr. Hay said that the Special Committee had also provided for the running of a large number of additional stations along the whole length of the equator and for some shorter zonal strips in low latitudes. These stations were all in addition to those included in the pole-to-pole meridional sections already shown in a slide. He understood the coverage of stations proposed for the tropics would be reasonably adequate. As regards publishing the data, the Publications Section had already arranged for the Solar Activity Section to begin publishing its results directly the I.G.Y. ended, and to take necessary steps to ensure other sections published their data without delay.

Dr. Stagg said that he also felt some concern about the adequacy of the equatorial network. The original idea for 1957–58 had been another Polar Year, but meteorologists had insisted upon it being given a wider scope to cover the equatorial regions. Some people felt that a larger part of the British contribution might have been allotted to the equatorial regions; for instance it would have been a very good thing if stations could have been set up for the I.G.Y. on Christmas Island (south of Sumatra), in the Maldive and Laccadive Groups and at Addu Atoll. There certainly was a great need to provide adequate arrangements including provision of staff for publishing the data and for working up the results.

Dr. Eady considered that a concentration of stations on meridians was unsatisfactory, and that it would be better to have the stations spread out more uniformly.

Mr. Absalom explained that other meridians were going to be operated during the I.G.Y. besides those shown in Mr. Hay's slide; for instance, there was one at 30°E. between latitudes 30°N. and 30°S. which would be well covered with stations. The requirements for aerological work in the tropics were being increased in certain quarters, for instance, by Australia and New Zealand in the Pacific Islands. The World Meteorological Organization had already drawn up forms of presentation for the data. A great deal of work was being put in on these problems at the present time.

Mr. McNaughton explained that he had been in charge of upper air stations in the Falkland Islands for 10 years, building up a synoptic and aerological network in the Falkland Islands Dependencies. He would like to know if synoptic meteorologists believed that the setting up of the network already described for two years would solve the problems of Antarctic circulation or merely give them an appetite for more.

Mr. Lamb said that the one and a half years' co-ordinated observations would certainly be of value, and he hoped that they would confirm previous ideas. He doubted whether the idea of pressure surges emanating from the interior of the Antarctic continent put forward by Sir George Simpson still had a real validity today in scientific circles, although it was certainly true that the United States I.G.Y. programme provided for further investigation on this problem. He felt that until recently the Antarctic had been considered, meteorologically speaking, rather in isolation.

Mr. Leeson inquired whether there was any publication which gave an overall picture of the I.G.Y. activities as contemplated. Mr. Hay replied that a great deal of information about the I.G.Y. programme was contained in the *News Letters* Nos. 7, 8 and 9 of the International Union of Geodesy and Geophysics. Also, one of the tasks of the Publications Section of the Special Committee was the production of a handbook covering the full activity and programme of the I.G.Y. In reply to a query from Dr. Stagg, the United Kingdom National Correspondent for the Publications Section, Dr. Moore, who was present at the Meeting, said he did not wish to add anything to Mr. Hay's remarks.

Mr. Veryard asked whether details were available of the programmes for making surface observations such as soil temperatures. Mr. Absalom replied that these matters were under consideration.

Mr. Houghton asked for details regarding standardization of instruments, instancing variations between the aerological observations of different nations. He said that he had also found differences in sea temperatures as observed by French and British ships at the same place. He asked whether any plans had been devised for making measurements of surface observations over the sea, or over the land in an individual depression. Mr. Hay pointed out the obvious difficulty of selecting a suitable depression beforehand. To fulfil Mr. Houghton's suggestion some form of radio-communications linkage between national forecast offices would need to be arranged before the I.G.Y. on the same pattern as that already devised by the Solar Activity Section for notifying Special World Alerts. As regards standardization he hoped that the Radio-Sonde and Aircraft Instruments Branch of the Meteorological Office would be able to provide some information about the position.

Dr. Scrase said that a second series of instrument comparisons are due to be made in May. This would cover 12 different types of radio-sonde.

Mr. Ali Abandar (Jordanian Meteorological Service) asked for more explanation of the difference between the theoretical and actual curves shown in the slide giving the vertical distribution of ozone. Mr. Hay explained that the discrepancy between the calculated and the actual amounts of ozone below 20 Km. shown on the slide earlier was one of the outstanding difficulties of the subject. He referred to the seasonal distribution of total ozone amounts described earlier, and pointed out that if photochemical processes alone predominated the maximum ozone amounts should be found over the equator. Some very recent work had shown that, with winds of polar origin in spring a second ozone maximum was found at about 15–20 Km., this maximum did not show with winds of equatorial origin. It was very difficult to explain the observed distribution of ozone other than as a dynamic balance between photochemical processes creating ozone at high levels perhaps in low latitudes, with advection of ozone at high levels from low to high latitudes, after which descending currents carry ozone-rich air to lower levels, whence it is removed by dissociation. The process was complicated by the fact that the temperature of the stratosphere depended upon the amount of ozone present at various levels, while the absorption coefficients of ozone showed a dependence upon stratospheric temperature.

Cmdr Frankcom said that the question of the standardization of sea-surface-temperature observations was receiving consideration. He referred to the two methods: measurement by a canvas bucket and measurement of condenser intake temperatures, and said that this problem would be the subject of further study at the forthcoming Conference of the Commission for Maritime Meteorology to be held next September.

Mr. Reed said that he understood the United States was going to open a station at the South Pole itself during the I.G.Y. Was it the intention that scientific staff were going to live at the South Pole throughout the period? He also wanted to know whether it was seriously intended to launch earth satellites during the I.G.Y. Finally he referred to the difficulty of launching very large balloons from ocean weather ships during gales, and wished to know whether this had received consideration? The meteorological programme which had been described for the United Kingdom would require a large number of additional scientific staff and he would like to know whether these were to be found?

Mr. Absalom said that the £76,000 mentioned for the United Kingdom expenditure was purely intended for equipment, The additional number of staff needed was very small, and most of the additional commitments in the programme could probably be covered by present staff complements.

Mr. Lamb referred to the working up of meteorological data and to the desirability of a fairly uniform distribution of observations. He pointed out that two of the chosen pole-to-pole meridians lay along semi-permanent upper air troughs. He would also like to know whether consideration had been given to making radio-sonde observations from passenger liners.

Cmdr Frankcom said that it was hoped to obtain radio-sonde observations from whaling ships. The Japanese had agreed to do this and the United Kingdom were about to signify their agreement. United States Army Transports would also make radio-sonde observations, while the United States Weather Bureau also intended to put special observers on United States merchant ships traversing the Caribbean.

Dr. Scrase asked whether the World Meteorological Intervals were intended to cover consecutive days. He pointed out that they would not cover the whole period during which the east–west high-level wind transitions were known to occur, and considered the choice of equinoctial periods was unsatisfactory for this purpose. Mr. Hay replied that the World Meteorological Intervals were intended to be periods of 10 consecutive days. Although the date of their commencement was fixed, provision was made for their extension as necessary.

Dr. Stagg remarked that some authorities had not agreed with the intervals being fixed at the equinoxes, and had wanted them to be included to cover other portions of the calendar.

Dr. Sutcliffe said that the idea of World Meteorological Intervals had only developed from that of World Days. It was very easy to criticize the arrangements at this stage now that the main ideas for the meteorological programme had been put forward. In fact, meteorology is an advanced science compared with the other geophysical sciences. It was important that agreement had been secured that only problems needing world-wide observations should be included in the programme. The number of special stations needed was relatively small compared to the total of stations normally operating.

Dr. Eady considered that problems of more limited interest should nevertheless not be lost sight of. He would like to see a greater effort made in ocean regions.

Dr. Stagg, in conclusion, said that so far not very much thought had been given to minor items such as measurement of soil temperature. The Special Committee had spent most of their time on major items such as provision of up-to-date radar equipment. He again wished to emphasize the need for a proper evaluation of the data after the close of the I.G.Y. and the need to provide the necessary staff for the purpose. A great deal of effort had been devoted to the fitting out of the Royal Society's Expedition to Coats Land, and Meteorological Office staff were at present being selected to carry out the programme at Coats Land during the actual period of the I.G.Y. Referring to his own experiences in organizing the United Kingdom party to Fort Rae in 1932–33, he reminded his audience that in 1932 radio-sondes were just coming into existence. They had tried hard to get some of Multanovsky's radio-sondes for 1932–33 without success. He thought it not without significance that in 1932 radio-sondes were just coming over the horizon while at the outset of the coming International Geophysical Year the potentialities of satellites and rockets lay just ahead in the same sort of way.

METEOROLOGICAL RESEARCH COMMITTEE

The 37th meeting of the Synoptic and Dynamical Sub-Committee was held on November 15, 1955. An interesting item in the paper by Dr. D. G. James[1] is that cirrus occurred in the lower stratosphere on about 10 per cent. of the occasions considered, and the suggestion that there is some evidence of upward vertical motion in the lower stratosphere on these occasions. Mr. F. H. Bushby gave an account of his recent experience of the experiments in progress in Sweden on the electronic computation of 24, 48 and 72-hr. forecasts of the 500-mb. chart using a barotropic model of the atmosphere. Mr. E. Knighting then outlined parallel experiments which he had witnessed during a nine-months visit to the Joint Numerical Weather Prediction Unit, in the United States, where 12, 24 and 36-hr. forecasts of pressure contour heights for 900, 700 and 400 mb. are obtained using a three-level atmospheric model. The Sub-Committee welcomed Mr. J. S. Sawyer's proposal[2] for the use of an incompressible fluid model to facilitate the laboratory investigation of natural air flow over a ridge, and recommended that the practicability of the model suggested should be examined. The paper by Mr. G. A. Corby and Mr. C. E. Wallington[3], and the discussion of it, brought out the complex and sensitive relationships between lee waves and the characteristics of the air stream and the generating obstacle, and suggested that some earlier assumptions and ideas require reconsideration.

The Meteorological Research Committee held its 70th meeting on November 23, 1955, under the chairmanship of Sir Charles Normand who has succeeded Sir David Brunt. Dr. A. W. Brewer and Mr. J. Paton are new members of the Committee. The Committee accepted the Instruments Sub-Committee's recommendation that the modulated-beam searchlight method should be developed for the determination of atmospheric density at high altitudes, and noted that the Meteorological Research Flight had been equipped for the better investigation of clear-air turbulence to heights of about 50,000 ft. Progress during the past half-year in main items of the research programme was reviewed. Gratification was expressed that the Meteorological Office is to acquire an electronic computer for use in work on the application of numerical methods in forecasting problems. After the formal business Mr. E. Knighting, lately returned from a visit to the Joint Numerical Weather Prediction Unit, near Washington, United States, described the numerical techniques used by that unit, and the degree of success achieved in forecasting contour charts for 900, 700 and 400 mb. for periods up to 36 hr.

The 35th meeting of the Physical Sub-Committee was held on December 8, 1955. It was agreed, on a suggestion received from Dr. E. G. Bowen of Australia, that the Meteorological Research Flight would endeavour to carry out a programme for sampling the freezing-nucleus concentration in the free atmosphere during January 1956, in co-operation with similar attempts in Australia and South Africa to examine a possible connexion between the nucleus concentration and the occurrence of meteoritic showers. There was general agreement that the paper by Mr. W. T. Roach[4] is a mine of information, and that Dr. G. D. Robinson's discussion[5] on the energy balance of the earth's surface and atmosphere is a pertinent contribution. The increase in atmospheric ozone content at the tropopause in northern Norway, reported by Dr. A. W. Brewer[6], differs from the results obtained a few years ago in southern England. Further similar determinations by aircraft sampling in Norway, England and other latitudes were considered to be desirable. In the discussion of Mr. P. J. Meade's paper[7], which was prepared with a view to application to the problem of the plume emitted by a factory chimney, it was mentioned that an account of a theoretical and experimental investigation (at Cambridge University) of a plume in a stable atmosphere would be published soon.

ABSTRACTS

1. JAMES, D. G.; Investigations relating to cirrus cloud. *Met. Res. Pap., London,* No. 933, S.C. II/196, 1955.

Observations of cirrus from aircraft over the British Isles were analysed for frequency distribution of tops and bases relative to tropopause, heights of base and thickness. Ten cases (in 220) had tops above 40,000 ft. The surface charts, upper air soundings, 1000–500-mb. thicknesses, advection vorticity at 300 mb. and 300-mb. contours were also examined. Cirrus was associated with the area ahead of surface fronts, the high-pressure side of the jet stream, thermal ridges, high humidities at 500–300 mb., winds between S. and W. at 500–300 mb. (advection of warm air) and positive cyclonic vorticity at 300 mb.

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

To overcome the difficulty that air is compressible and to simulate a flow of air over a range of hills a model is examined in which an incompressible fluid flows through a narrow channel tapering upwards.

3. CORBY, G. A. and WALLINGTON, C. E.; Air flow over mountains—the lee-wave amplitude. *Met. Res. Pap., London,* No. 939, S.C. II/199. 1955.

Theoretical considerations (sufficient decrease of l^2 with height) suggest that lee waves should be common over the British Isles, but they are rarely reported by aircraft. This is because, to produce waves of large amplitude, large mountains need strong winds with an increase of speed and/or decrease of stability with height, and the air-stream characteristics must be favourable. The maximum amplitude and vertical velocity of lee waves in given conditions, and the variations of lee-wave amplitude and length, are calculated; they are very susceptible to small changes of conditions.

4. ROACH, W. T.; Measurements of atmospheric radiation and the heat balance at the ground at Kew, May 1953–May 1954. *Met. Res. Pap., London,* No. 936, S.C. III/192, 1955.

The theory of heat balance on a grass surface is discussed and the instrument set up described. Photographic records of surface temperature, radiation flux and flux of heat at 6 cm. in soil were obtained over a complete year; specimen records are shown. Values of net vertical flux of total, short-wave and long-wave radiation, downward flux of long-wave radiation, surface temperature, heat flux into ground, flux of water vapour and rainfall are tabulated for each month. Appendices describe calibration of instruments and a standard black-body cavity radiator.

5. ROBINSON, G. D.; The energy balance of surface and atmosphere at Kew, May 1953 to April 1954. *Met. Res. Pap., London,* No. 929, S.C. III/189, 1955.

Trial measurements from the ground of the radiation flux over the whole atmosphere were made in preparation for the International Geophysical Year. Determination of the albedo (photometric, visual and ultra-violet, and infra-red) under various assumptions as to absorption etc., gave estimates of: year 0·475, summer 0·46, winter 0·525. Terrestrial radiation at the limit of the atmosphere is set at 20 ± 3 mW./cm.^{2}. Terms in the energy budget are computed for year, summer and winter. It is concluded that measurements during the International Geophysical Year can be made with useful accuracy, which can be improved by measurements in the air, but in view of the year-to-year variations some stations should operate for at least 5 yr.

6. BREWER, A. W.; Ozone concentration measurements from an aircraft in north Norway. *Met. Res. Pap., London,* No. 946, S.C. III/195, 1955.

Ascents with a thermometer, dew-point hygrometer and ozone sampler were made to 40,000 ft. from Trondheim on June 27 and 28 and July 3 and 11, 1955. The results, shown graphically, indicate a three-fold increase in ozone concentration above the tropopause.

7. MEADE, P. J.; Convection from a small, continuous source of heat in a calm, neutral atmosphere (with an appendix on the bent-over plume). *Met. Res. Pap., London,* No. 952, S.C. III/196, 1955.

The theory of velocity and temperature field and the vertical variations of radius in the ascending plume from a point source of heat are discussed. Approximate solutions of the basic equations are set out and compared with observations. Computed values of excess potential temperature and vertical velocity against height are compared with laboratory observations by Railston and Schmidt, with good agreement. An appendix compares computed data with those of Priestley and Ball for two chimneys in the Oak Ridge area.

ROYAL METEOROLOGICAL SOCIETY

Measurement of humidity at high altitudes

At the meeting of the Society held on February 15, 1956, after the transaction of formal business, the President, Dr. R. C. Sutcliffe handed over the Chair to Dr. A. W. Brewer to take charge of the ensuing discussion on the measurement of humidity at high altitude.

Dr. Brewer opened the discussion with a historical review of the development of, and observations obtained by, the Dobson-Brewer frost-point hygrometer first brought into use in 1943. He described the instrument and exhibited the first and current models. He emphasized the surprise with which he had found that the humidity of the lower stratosphere was so low, and of how on one early flight a condensation trail being made in the troposphere was cut off as though by a knife on crossing the tropopause. Curves of the variation of frost point with height, measured by the hygrometer and by radio-sonde, were shown, and the importance of the rapid changes revealed by the hygrometer but not by the radio-sonde pointed out.

He was followed by Mr. Goldsmith, formerly of the Meteorological Research Flight, who described the pressure-increase method of increasing the frost point. The artificial increase in frost point is necessary because at temperatures below −85°C. (−120°F.) the ice deposit on the cold plate of the hygrometer is glassy and invisible. If the frost point can be artificially raised above this temperature the deposit becomes crystalline and clearly visible. Compression of the air from the 115-mb. pressure (appropriate to 50,000 ft. in height) to 1013 mb. raises the frost point by over 20°C. The result follows at once from conservation of humidity mixing ratio. Mr. Goldsmith explained that the method had been conceived many years ago by Prof. Dobson, but could not be put into force until jet aircraft were employed for meteorological purposes. The system of obtaining air compressed about sixfold from the jet-engine compressor was explained in detail, as were the satisfactory results of checks against the ordinary method.

Mr. Murgatroyd then described the observations of the humidity of the lower stratosphere up to 50,000 ft. made by the Meteorological Research Flight on 35 flights over southern England during 1954. The frost point decreased with height in the lowest part of the stratosphere. The lapse of frost point also decreased with height until about 10,000–15,000 ft. above the tropopause to a constant value, independent of season, of about −82°C. (−115°F.) with relative humidity with respect to ice about 1 per cent. He thought sufficient was now known about the humidity structure in the stratosphere up to 50,000 ft. over England to make it unnecessary to make further flights especially to measure humidity, though observations of it would continue to be made on flights made primarily for other purposes. The need was for higher flights which called for special pressure suits, and especially for observations in other parts of the world to obtain the world pattern.

Prof. Dobson discussed the reasons for the low humidities of the lower stratosphere. Such low humidities could only be obtained by supposing the air had been cooled at some time to the observed frost point. Such low temperatures occurred at the same height only at the top of the equatorial tropopause and in the winter polar stratosphere. He believed the low frost points over England were in air which had risen in the equatorial regions, had nearly all its water vapour condensed out there, and then moved northward.

Dr. Houghton next described measurements of the precipitable water content of the stratosphere by radiation methods using the atmosphere and the sun as sources of radiation based on absorption of infra-red radiation by water vapour. These showed a precipitable water content of the order of 1 or 2 μ.

Dr. Gates of the United States Office of Naval Research described observations made with a balloon-borne spectrograph having a sun-seeking device to measure the absorption of solar radiation in the infra-red by water vapour. This gave values of precipitable water agreeing with those found by Houghton.

In the discussion which followed, Dr. Robinson inquired how many times the frost point had been measured in cirrus cloud and how many times it had been at the saturation value. He also asked if it was possible that at very low temperatures when the crystalline deposit disappeared the water was exchanging molecules with the surface. Mr. B. J. Mason described the different forms of ice obtained in the laboratory at low temperatures. Below -150°C. the ice was amorphous, and it was difficult to obtain a deposit at all, and asked to what extent this was a surface effect. Dr. Brewer said the ice formed at low temperatures gave no electronic diffraction pattern. At the temperatures where visible ice crystals were formed they were separated by crystal-free spaces on the plate. At very low temperatures the molecules had insufficient energy to move over the plate and aggregate into crystals. As regards observations in cirrus, it was difficult to tell from an aircraft that it was flying in cirrus. The hoar-frost apparatus gave a frost point when known to be in cirrus about 1°C. below saturation value. The latter points were confirmed by Mr. Murgatroyd who gave 2°C. as the frost-point depression in cirrus.

The question of the real existence of cirrus in the stratosphere as had been occasionally described was raised. Mr. Murgatroyd said he was not sure if it was not really dust, though he recalled one occasion when a vigorous cumulonimbus cloud lifted the tropopause. There was no occasion of seeing cirrus with a high humidity in the stratosphere.

REFERENCES

1. MURGATROYD, R. J., GOLDSMITH, P. and HOLLINGS, W. E. H.; Some recent measurements of humidity from aircraft up to heights of about 50,000 ft. over southern England. *Quart. J. R. met. Soc., London*, **81**, 1955, p. 533.
2. GOLDSMITH, P.; A method of increasing the range of the Dobson-Brewer frost-point hygrometer in jet aircraft. *Quart. J. R. met. Soc., London*, **81**, 1955, p. 607.

INSTITUTE OF NAVIGATION

Meteorological aspects of high-level navigation

On Friday January 20, 1956, three papers were read. Capt. Frost, a senior pilot of British Overseas Airways Corporation, described the jet streams of the North Atlantic from the point of view of the pilot trying to make the best use of these narrow "rivers" of fast-moving air. He was concerned with the layers between 18,000 and 25,000 ft., i.e. below the level of strongest winds, and he described in general terms where the strongest winds are to be found in relation to a typical North Atlantic depression and its associated fronts. Capt. Frost discussed the clues which help the pilot to locate and stay in the strongest winds. Temperature in the free air is the most reliable indication, the pilot endeavouring to find the warm edge of the strong horizontal temperature gradient which is always associated with jet streams. The position and orientation of bands of cirrus clouds are also of great assistance on some occasions, marking the approximate position and direction of the strongest winds. Unfortunately, only about 10 per cent. of North Atlantic jet streams have this distinctive cirrus band. Capt. Frost showed a number of remarkable photographs, taken from the pilot's seat, of clouds associated with jet streams, including one taken near the Bahamas which showed cloud which was probably along the subtropical jet stream. In one photograph the cirrus cloud could be seen to bend round on the horizon 600 or 700 miles away in association with a surface cold front.

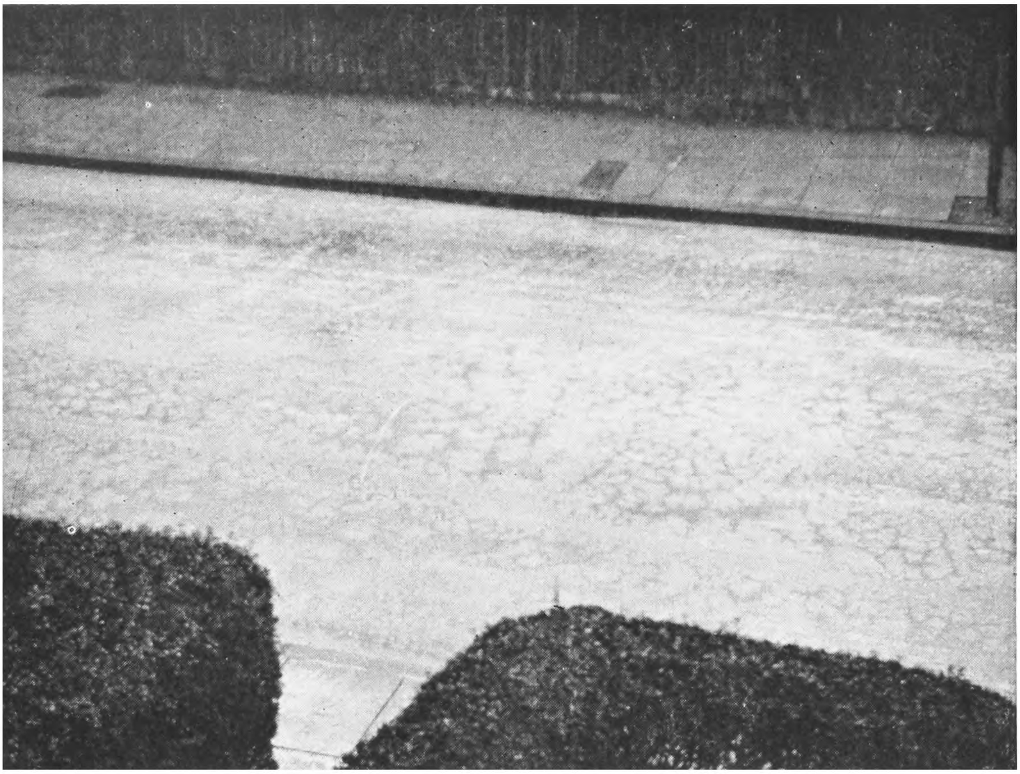
Mr. Bannon, of the Meteorological Office, next described the principal regions of strong upper winds over the world. The subtropical jet stream between latitudes 20° and 35° in winter is broader and more stable and therefore perhaps a more useful stream to the aerial navigator than the better known jet streams of temperate and high latitudes; its axis, the level of strongest winds, is about 40,000 ft., approximately 10,000 ft. higher than that of the jet streams in temperate latitudes. A comparatively low-level jet stream occurs infrequently in the Arctic in winter which has a structure similar to that of the temperate jet stream, but its axis is at about 20,000 ft. Westerly winds are also strong in the stratosphere on the edge of the Arctic and Antarctic in their respective midwinters, speeds exceeding 100 kt. at 50,000ft. and above on some occasions and probably increasing with height. A strong steady easterly flow occurs from June to August from Malaya across Ceylon and Africa to Nigeria which may also be important to navigation

[*To face p. 152*

Reproduced by courtesy of D. T. Tribble

ANVIL OF CUMULONIMBUS CLOUD
The photograph was taken looking vertically upwards.

To face p. 153]



Reproduced by courtesy of K. E. Woodley

ICE PATTERNS ON A ROAD, KEW, 0715 G.M.T., FEBRUARY 13, 1956 in the future. The axis of this stream is at about 47,000 ft., and though maximum speeds exceed 100 kt. on occasions they are usually about 60 kt. The strong winds are restricted to the upper troposphere and lower stratosphere.

Mr. Kirk (Meteorological Office) discussed some of the problems experienced by forecasters at London Airport in forecasting for high-altitude flight. The number of observations of temperature and wind in the upper air by sounding balloons are fewer at greater heights, and inaccuracies in the observations and in the forecasting techniques increase with height. The time taken to analyse the higher observations is also an adverse factor; observations for 30,000 ft. and above are received later than those for lower levels, and their analysis depends to some extent on the analysis of the data for lower levels. For example, the chart for 200 mb. (approximately 40,000ft.) for the North Atlantic is not completed at London Airport until nine hours after the relevant observations have been made. Forecasters at London Airport have gained experience on routine forecasting for Viscount aircraft operating at 20,000–25,000 ft. over European and Mediterranean routes, for Comet I aircraft operating at 35,000–40,000 ft. on the route London to Rome, and for "paper" operation of Comet III aircraft over the North Atlantic at similar levels. Mr. Kirk showed a diagram comparing the forecast equivalent headwinds on the London-to-Gander route with those which occurred; the forecasts were for 12–24 hr. at the level of 200 mb. and, although the agreement was on the whole quite good, on one occasion the error was as much as 40 kt. He stressed that when the track of the aircraft can be varied at will in accordance with meteorological advice at briefing, the effect of uncertainty in the meteorological situation can be reduced. Mr. Kirk pointed out that though, as explained by Capt. Frost, the temperature method of finding and staying in strong winds worked well below the level of strongest winds, the temperature field above the axis of the jet stream becomes more complicated, and the interpretation of aircraft observations more difficult. He explained that carefree riding of meandering jet streams may often take the aircraft so far off track that time may be lost; there is no substitute for careful flight planning. He also described other high-altitude weather features of interest to the navigator, namely "cut off" lows and highs and "shear lines".

In the discussion following these papers a number of interesting points were made. The routes for probably 90 per cent. of transatlantic flights westwards, direct crossing, are planned to take into account forecast weather and wind. So many aircraft are now flying over the Atlantic, however, that it may be necessary to restrict flights to certain lanes. Pilots would like to have more specific forecasts of the position of jet streams. One speaker praised the forecasts of jet streams given by the Canadian Meteorological Service at Montreal. Upper cloud is absent from the subtropical jet stream near Japan in winter and spring.

ROYAL ASTRONOMICAL SOCIETY

Large-scale water circulation over the earth

A geophysical discussion on the above subject was held at the Royal Astronomical Society on December 16, 1955, with Dr. G. E. R. Deacon, F.R.S. in the Chair.

The first speaker, Mrs. Mary Morgan, dealt with the hydrological equation, precipitation equals evaporation plus run-off plus storage, for land areas. Evaporation and run-off depend critically on local conditions; deforestation increases run-off by 60 per cent., most of which is compensated by a decrease in evaporation. As regards storage of the water of the earth, 97 per cent. was in the sea, 1 per cent. in snow and glaciers and 2 per cent. in the soil; the contribution of water in the atmosphere was very small in comparison.

Dr. Munk spoke on the annual water budget of the oceans and the annual water interchange between sea and land. Tide-gauge records, which gave coherent results over thousands of kilometres, revealed annual changes in sea level mostly of 1 or 2 dm., but reaching 1 m. in the Bay of Bengal. The latitudinal variation of level is large poleward of the belts of westerly winds, small in the westerlies, increases again in the subtropical anticyclone belt, and falls to a few centimetres along the equator. Changes in sea level can be due to changes in total mass of water or to changes in temperature of the upper layers of the sea; the former predominates in the polar regions and the second in the equatorial belt. The variations in the southern hemisphere are less than in the northern one.

The total mass of water in the seas varied during the year by 3 gm./cm.^{2} of the surface. The mass of snow in the northern winter accounted at the right time of year for about one third of this fluctuation. Dr. Privett spoke about the transfer of water from sea to air, applying the simple equation, evaporation equals the product of a constant wind speed and saturation deficit, to climatological data. His data were compared with those of Jacobs and differed appreciably from them. Privett found on calculating the evaporation by zones that over the zone 0–40°N. it was 120 cm./yr. whereas over the zone 0–50°S. it was 140 cm./yr. The evaporation was highest over the warm currents reaching 0·7 cm./day over the Gulf Stream. The latent heat carried by the evaporated water vapour, derived from solar radiation, is the main source of energy in the atmosphere.

Dr. Sutcliffe described recent work in the Meteorological Office on the water content of the atmosphere as found from radio-sonde data, and gave mean humidity-mixing-ratio values at various heights on a diagram with a cosine scale of latitude. The amount of precipitable water averaged over the areas stated was found to be in January, 1·9 cm. over the northern hemisphere, 2·5 cm. over the southern and 2·2 cm. over the world; the corresponding values for July were 3·4 cm., 2·0 cm. and 2·7 cm. As the average annual rainfall over the world was 90 cm., the period of turn-over was about 10 days. The fluctuations in atmospheric water content were not known exactly, but could account for a substantial part of the variations in sea level. He believed the aerological water-balance equation, precipitation equals advection plus evaporation minus atmospheric storage, could be more readily solved than the hydrological equation, precipitation equals evaporation plus run-off plus land storage.

In the course of the discussion the importance in the balance of the release of "fossil" water by burning oil and coal was mentioned.

LETTER TO THE EDITOR

The occurrence of spells in London rainfall and temperature

Mr. D. H. McIntosh in his article on the above subject states, on p. 366 and p. 369 of the *Meteorological Magazine* for December 1955, that he does not confirm some of my earlier work. This earlier work has been published under the title of "The reliability of rainfall", and the conclusions have stood the test of time, since the first paper was published by the Institution of Water Engineers in 1930. Mr. McIntosh states "the effect reported by Glasspoole is absent from these London data". This effect was interpreted by the reviewer in *Weather* as follows: "if a run of four very dry months have provided only about a third of the average rainfall, then the next four months are likely to redress the deficit to some extent, though the whole period may be below average". While this statement is not so precise as that given originally[1] in the *Quarterly Journal of the Royal Meteorological Society*, there is no justification for the interpretation given by Mr. McIntosh that this shows that compensating wet spells must necessarily follow four very dry months. Indeed, Mr. McIntosh finds on p.369 that "In the 61 dry spells. . . the succession of three dry months had an aggregate rainfall about 40 per cent. of normal; the four following months were all dry on the average, and aggregated 90 per cent. of normal". Thus the 40 per cent. did not continue, but was followed by a period with 90 per cent., thus confirmnig my original statement. The diagrams also bring out the decrease in the deficiency with periods longer than three months.

Mr. McIntosh does not appear to have seen earlier statistical work on rainfall sequences. Thus Mr. Bilham has shown[2] that "the chances of a given month being wet or dry are roughly even, independently of past history".

While much has been written about rainfall fluctuations and frequencies, there is room for further statistical work; but the first essential is to examine existing literature on the subject. Some references are given in the paper on "Rainfall in relation to water supply".

J. GLASSPOOLE

REFERENCES

1. GLASSPOOLE, J.; Rainfall in relation to water supply. *Quart. J. R. met. Soc., London*, **81**, 1955, p. 268.

2. BILHAM, E. G.; Notes on sequences of dry and wet months in England and Wales. *Quart. J. R. met. Soc., London*, **60**, 1934, p. 514.

[I owe Dr. Glasspoole an apology for accepting without confirmation a reviewer's version of his contribution to a discussion of water supply, held in November 1954. I agree that the presence of a "compensation" effect cannot be inferred from the written contribution that subsequently appeared in the

Quarterly Journal of the Royal Meteorological Society. A precise interpretation of Dr. Glasspoole's figures in terms of a possible compensation effect is however not straightforward because the effect of the annual variation of rainfall is not eliminated.

Dr. Glasspoole appears to imply that my paper would not have been written had I been more conversant with existing literature. The conclusion of Bilham is, of course, sufficiently true for practical purposes. But the various investigations of rainfall (and temperature) monthly sequences have in fact shown a small excess of longer, and deficit of shorter, sequences as compared with chance expectations. It was for this reason that it was stated in the Introduction to the paper that various investigations had shown that the probable result of an investigation concentrating on systematic effects associated with spells would be to reveal some degree of persistence in the monthly values before a return to normal. The results obtained give a measure of the magnitude and duration of these effects which, so far as I know, is not available elsewhere and cannot readily be deduced from other work. The probable duration of the effects—four months in rainfall and even longer in temperature—seems to me to be a matter of some interest and even surprise.—D. H. MCINTOSH]

NOTES AND NEWS

Sun pillar

On Thursday, February 23, 1956 at 1655 G.M.T. a sun pillar was observed from East Hill, Houghton Regis.

It was amber in colour and tapered to the top. The phenomenon lasted 15 min. during which time short-term fluctuations of height accompanied by corresponding changes of brightness could be seen. Such fluctuations covered periods of between 3 and 10 sec.

The photograph facing p. 137 was taken at 1708 G.M.T. and shows the sun pillar at its greatest intensity.

Low cloud was 2 oktas stratocumulus at 4,500 ft. Cirrostratus was not obvious at this time, but half an hour later it appeared to cover half the celestial dome. Above the western horizon there were numerous decaying condensation trails. Visibility was 8–10 miles. Radar showed no weather echo within 120 miles of the station.

At 1800 G.M.T. a weak cold front moving slowly southwards extended from north Jutland to the Moray Firth and an occluded frontal system was approaching from mid Atlantic.

A. W. E. BARBER

REVIEW

Weather and the Land. Prepared by the Agricultural Branch of the Meteorological Office (Air Ministry) *Bull. Minist. Agric., London,* No. 165. $9\frac{1}{2}$ in × 6 in., pp. iv + 36, *Illus.* H.M. Stationery Office, London, 1955. Price: 3*s.*

Economic success in farming is subject to so many variables that until yesterday few farmers kept books. It was widely held that no conclusions could safely be drawn from them, and the case of old John furnished food for much merriment. (That prosperous worthy was persuaded by a reforming landlord to start account keeping; but he found the accounts always showed a loss so he burnt his books and lived happily ever afterwards.)

The position is different today. Thanks to patient accumulation through several decades of detailed financial records of many farms—and in part to those seemingly endless forms farmers had to fill in during the war—it is now possible to deduce the main principles of farm finance, though admittedly the "laws" have to be hedged about with a good many provisos and qualifications.

In the light of this experience farmers and their scientific advisers will be predisposed to welcome this bulletin which embodies the results of study of even greater masses of data on interacting variables. They are prepared for it also by the striking improvement in the reliability of forecasts in post-war years. The bulletin divides broadly into three sections dealing, respectively, with analysis of climatic factors, the impact of climate on farm practice and weather forecasting.

The analytical section sets forth with admirable clarity the succession of events in the development of "fronts", depressions and anticyclones, and details the types of weather associated with typical synoptic situations. It is much too brief to convey to a lay reader a clear conception of cause and effect, and plan drawings, though useful, are of but limited value in illustrating three-dimensional changes. Nevertheless, the section forms a useful introduction to the description of climatic differences within the country and the effects of climate on farming. Naturally the influence of rainfall and temperature is stressed. More might perhaps have been said on the influence of length of day on growth curves of crop plants.

In treating of weather and farmers, priority is given to the problems of the fruit grower and market gardener. Fruit growing in this country is everywhere subject to a certain amount of frost risk; so is vegetable growing since the livelihood of the market gardener depends largely on the earliness of his crops. But enough evidence has now been accumulated to enable the meteorologist to calculate these risks with some accuracy and to define the geographical and topographical conditions in which they are small or large. This marks a real advance. Many other risks of course remain—in particular those of markets—but it is a great gain to be able to estimate chances of failures from frost, for of the various devices for guarding against it none offers much real hope of success.

A good beginning has also been made in the study of irrigation-need. Measurements of crop transpiration and comparisons with rainfall figures have made it possible to define the frequency with which crop growth is likely, without irrigation, to fall below the maximum. The "law" can again only be stated in terms of degrees of probability, but within these limits a map of England's irrigation needs can now be constructed.

Scientifically great interest attaches to a recent development in forecasting as an aid to control of plant disease. The spread of potato blight is determined by the occurrence of favourable climatic conditions. It can be controlled by timely spraying—early warning of "blight weather" is therefore valuable.

But relatively blight spraying is of little consequence compared with preserving our grass crops. As agricultural techniques advance the timing of hay harvest becomes ever more important. In the days of horses and lumbering wagons and abundant labour hay harvest was in any event long drawn out. Though everyone hoped for fine weather it could not reasonably be expected to last throughout the whole harvest. Modern tools and modern speeds enable us to reduce the period to a few days, given favourable weather; but if the power available is to be used to advantage it is essential to choose the precise moment to start. In lesser degree the same is true of silage making, for, though silage can be made in any weather, rain is a sore handicap and a source of much spoiled material.

The bulletin does well therefore, while explaining the manner in which forecasts are interpreted and the bearing of local conditions thereon, to call attention to the special services now available. They cannot banish the farmer's primeval hazards, but at least they set bounds to his anxieties.

W. B. MERCER

OBITUARY

John Patterson, O.B.E., M.A., LL.D., F.R.S.C.—We regret to learn of the death of Dr. Patterson, formerly Controller of the Meteorological Division, Ministry of Transport, Canada, on February 22, 1956, in his 85th year.

Dr. Patterson was a schoolmaster for some years before he entered the University of Toronto where he studied physics and mathematics. He graduated in 1900 and won an 1851 Exhibition Science Research Scholarship in the same year. After two years at the Cavendish Laboratory, Cambridge, he became Professor of Physics in the University of Allahabad. In 1905 he was appointed Meteorologist to the Government of India, but he returned to Canada in 1910 to join the Canadian Meteorological Service. He was appointed Assistant Controller of this Service in 1925 and Controller in 1929.

He was a pioneer investigator of the upper air by balloon meteorographs and made important advances in anemometer and barometer design.

Dr. Patterson will be remembered too for his many contributions to international meteorology, and his deep interest in the International Meteorological Organization and later in the World Meteorological Organization. Soon after the Commission for Instruments and Methods of Observation was instituted in 1946 Dr. Patterson became its President, and at the first meeting at Toronto in 1947, where most of the members were less than half his age, he surprised them by the energy with which he set about the task of organizing the work of the new Commission. He was re-elected President at the end of the meeting, and continued to lead the activities of the Commission for the next seven years. He again presided at the second meeting also at Toronto in 1954, and it was only after then, at the age of 83, that his active service for international meteorology ceased, but his interest in the work of the Commission for Instruments and Methods of Observation continued.

He was President of the Conference of British Empire Meteorologists held in 1935, and attended the similar Conferences held in 1929 and 1946.

Perhaps his greatest achievement was the guidance of the Canadian Meteorological Service through a period of unparalleled expansion in the early days of the Second World War to meet the meteorological requirements of the British Commonwealth Air Training Plan. He was unsparing in his efforts to make members of the Meteorological Office staff, sent to stations in Canada for duty at R.A.F. Training Schools, feel at home, and dealt sympathetically with the problems and difficulties affecting the work and welfare of his British colleagues. His wisdom, judgement and absolute integrity played a large part in settling many difficult questions of meteorological organization in which the British

Commonwealth and the United States of America were involved, before and after Pearl Harbour.

Among the honours he received from scientific societies were his election as President of the American Meteorological Society in 1931, and to Honorary Membership of the Royal Meteorological Society in 1941, and of the American Meteorological Society in 1953. The citation for his honorary membership of the American Meteorological Society referred to him as the "grand old man" of Canadian meteorology, Director of Canadian Meteorological Services through periods when those Services seemed to be subject to neglect by higher authority and through periods of great growth and achievement. The citation continued to state that he performed his duty as Director with great dignity and the highest of professional and scientific ideals, and to recognize his great contribution to meteorological instrumentation and his services as Councillor and President of the Society.

He retired as Controller in September 1946, but continued to take an active interest in meteorology until a few months before his death. His long and outstanding services to meteorology were recognized by the inauguration of the Patterson Medal to be awarded annually by the Canadian Government to a Canadian resident for achievement in meteorology. Dr. Patterson was the first recipient of this medal in March 1955.

O. G. SUTTON

METEOROLOGICAL OFFICE NEWS

Ocean weather ships.—The following is an extract from the Radio Overseer's report of Voyage 66 of the *Weather Watcher*.

As usual on Station A certain difficulties were encountered in maintaining communication on the channels available; this was particularly so during the major ionospheric disturbance which started on the morning of Thursday, February 23 and which affected the station's communications for varying periods from that date until Sunday, February 26. It was noted that particularly during the first 24 hr. of this disturbance frequencies down to about 600 Kc./sec. were affected, whereas from previous experience such disturbances had only affected frequencies down to approximately 2,500 Kc./sec. During these periods of poor propagation traffic was cleared on M/F through Reykjavik or else through an American weather ship to Washington. Also during this period a number of signals were cleared for overflying aircraft when this ship was very often the only radio contact the aircraft had had since getting out of VHF range of their departure point.

It was during this period that a British submarine was reported missing for several hours, the reason being that she could not communicate with the Admiralty.

Sports activities.—Mr. M. Garrod was a member of the Air Ministry team which won the Civil Service 14-mile road relay race around the City of London on Saturday, March 17.

WEATHER OF MARCH 1956

Information was very incomplete for much of the northern hemisphere, particularly over the oceans and in the Asiatic sector, at the date of writing. Most features of the general circulation appear, however, to have followed very much the normal pattern for March. Chief interest might well be attached to the notable frequency of intense circulations, particularly of depressions over the western North Atlantic where the lowest mean pressure for the month was close to normal (1003 mb.) near 60°N. 35°W. This was accompanied by deeper than normal depressions (990 mb.) passing into the Arctic by way of east Greenland and the Barents Sea where there was pronounced advection of warm air. At the same time the Eurasian anticyclones established a dominance over Europe throughout the month, mean pressure at Helsinki reaching 1023 mb. (anomaly + 10 mb.) with persistent cold easterly and south-easterly winds over southern and central Europe occasionally reaching England. Low pressures over the Canadian archipelago were largely the result of depressions passing through Davis Strait from the Atlantic, but at least one intense depression came across northern Canada from the Pacific. About the middle of the month cyclonic activity from both sides of Greenland spread to the region of the North Pole. Mean pressure for the month was 6–8 mb. below normal over all Greenland, and there was a notable absence of northerly outbreaks in the east Greenland Sea.

There were no outstanding temperature anomalies, though most of Europe and North America were rather cold, the anomaly reaching −6°C. in the Canadian archipelago, whereas Bear Island and much of the Barents Sea were 5–6°C. less cold than normal.

Precipitation was excessive in a broad region of the Canadian Rockies and Prairies, along a strip from the Appalachians and New England to north-east Greenland, where three times the normal amount was collected at one station, and also in the Iberian peninsula, the central and eastern Mediterranean, Turkey and a small area in central Europe including the eastern Alps.

In the British Isles, apart from the first week which was changeable with generally westerly winds, the weather was mainly dry and sunny and dominated by winds from between S. and SE. which were maintained by a persistent anticyclone over European Russia and an equally persistent low-pressure area to the south-west of Ireland.

During the first three days strong westerly winds brought dull, mild weather with periods of rain. Most of the rain fell in Scotland where it was heavy on the 1st, more than 1 in. falling at Renfrew in 24 hr., but apart from this, daily totals of rainfall were small throughout the whole month. Winds veered towards the NW. on the 4th and the cooler, less stable air stream gave sunny but showery weather; the showers were well scattered in the south, but in Scotland they were rather frequent and occasionally fell as snow or sleet. The following day was also sunny, the showers in the south died out and winds backed again to W. as an anticyclone developed over the western English Channel. Another anticyclone moving south-east from Greenland reached the northern North Sea on the 7th where it joined with a ridge from the anticyclone off our south-west coasts. The resulting high-pressure system moved eastwards and was centred over northern Germany on the 9th, and the next day was absorbed into an anticyclone which had developed over European Russia. Except for a dull wet day over Scotland and Northern Ireland on the 9th, the second week of the month was generally dry, sunny and rather cold over most of the country with mainly light south-easterly winds. Day temperatures were about normal except in the south, but there was widespread frost at night, temperature falling as low as 21°F. at Birmingham on the 12th. On the 14th and 15th colder air from the Continent brought slight snow to the eastern districts of England and Scotland, but on the 16th winds veered somewhat and temperature returned to normal in most places, though the weather was rather dull with occasional rain as a small secondary depression moved over south-west Ireland. By the 20th a deep depression had formed off western Ireland, and winds reaching southern England were mainly of Atlantic origin. The following week was mild with rain at times in all parts of the country but some sunshine on most days. Temperature exceeded 60°F. at many places on the 23rd and 26th; on the latter date 65°F. was reached at Mildenhall and Cardington and there were fairly widespread thunderstorms. Winds became easterly again on the 27th as the depression off south-west Ireland filled up, but on the 29th a low-pressure area developed over the North Sea and winds backed further towards the north. Weather was mainly dry with variable cloud during the last five days of the month, but on Good Friday, the 30th, and the following day, the north-easterly winds gave dull and cold conditions over parts of north-east Scotland and eastern England, but further west it was sunny and rather warm, outstandingly so in the Hebrides where sunshine for the last week of the month averaged 10 hr. / day.

The dry sunny weather was nearly ideal for all land cultivations and sowings. Work is therefore well forward, even on heavy soils. Sheep, lambs and cattle are in good condition, but the growth of grass for which warm rain is needed has been retarded. In the south-west the main crop of daffodils, though late, is good, but last month's frost has caused widespread devastation of most other flowers and early vegetables.

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 ...	66	16	+0·3	46	−6	119
Scotland	65	17	+0·5	58	−7	114
Northern Ireland ...	60	27	+1·4	64	−4	107

RAINFALL OF MARCH 1956

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	0·99	54	*Glam.*	Cardiff, Penylan ...	1·37	43
Kent	Dover	0·44	21	*Pemb.*	Tenby	0·95	31
,,	Edenbridge, Falconhurst	1·07	43	*Radnor*	Tyrmynydd	4·05	75
Sussex	Compton, Compton Ho.	0·59	21	*Mont.*	Lake Vyrnwy	3·24	72
,,	Worthing, Beach Ho. Pk.	0·27	14	*Mer.*	Blaenau Festiniog ...	5·06	59
Hants.	St. Catherine's L'thouse	0·31	16	,,	Aberdovey	2·04	61
,,	Southampton (East Pk.)	0·68	30	*Carn.*	Llandudno	1·31	65
,,	South Farnborough ...	0·53	27	*Angl.*	Llanerchymedd ...	1·20	40
Herts.	Harpenden, Rothamsted	0·97	47	*I. Man*	Douglas, Borough Cem.	1·37	46
Bucks.	Slough, Upton	0·63	36	*Wigtown*	Newton Stewart ...	2·03	59
Oxford	Oxford, Radcliffe ...	0·68	41	*Dumf.*	Dumfries, Crichton R.I.	1·56	52
N'hants.	Wellingboro' Swanspool	0·85	47	,,	Eskdalemuir Obsy. ...	2·58	53
Essex	Southend, W. W. ...	0·60	39	*Roxb.*	Crailing...	0·75	35
Suffolk	Felixstowe	0·85	57	*Peebles*	Stobo Castle	1·84	63
,,	Lowestoft Sec. School ...	0·71	44	*Berwick*	Marchmont House ...	0·79	30
,,	Bury St. Ed., Westley H.	0·65	34	*E. Loth.*	North Berwick Gas Wks.	0·80	43
Norfolk	Sandringham Ho. Gdns.	0·76	40	*Midl'n.*	Edinburgh, Blackf'd. H.	1·07	54
Wilts.	Aldbourne	0·43	18	*Lanark*	Hamilton W. W., T'nhill	2·05	73
Dorset	Creech Grange... ...	0·94	33	*Ayr*	Prestwick	1·23	53
,,	Beaminster, East St. ...	1·01	34	,,	Glen Afton, Ayr San. ...	3·68	88
Devon	Teignmouth, Den Gdns.	0·98	38	*Renfrew*	Greenock, Prospect Hill	3·14	68
,,	Ilfracombe	1·13	39	*Bute*	Rothesay, Ardencraig ...	3·10	86
,,	Princetown	3·96	58	*Argyll*	Morven, Drimnin ...	2·20	45
Cornwall	Bude, School House ...	2·52	103	,,	Poltalloch	2·87	75
,,	Penzance	1·61	50	,,	Inveraray Castle ...	5·03	79
,,	St. Austell	2·26	66	,,	Islay, Eallabus	2·66	70
,,	Scilly, Tresco Abbey ...	1·69	65	,,	Tiree	1·42	42
Somerset	Taunton	0·85	41	*Kinross*	Loch Leven Sluice ...	1·75	59
Glos.	Cirencester	0·53	22	*Fife*	Leuchars Airfield ...	1·04	53
Salop	Church Stretton ...	1·52	63	*Perth*	Loch Dhu	4·62	70
,,	Shrewsbury, Monkmore	1·00	60	,,	Crieff, Strathearn Hyd.	2·29	72
Worcs.	Malvern, Free Library...	0·86	44	,,	Pitlochry, Fincastle ...	2·93	106
Warwick	Birmingham, Edgbaston	1·04	49	*Angus*	Montrose, Sunnyside ...	1·17	56
Leics.	Thornton Reservoir ...	1·05	57	*Aberd.*	Braemar	2·34	79
Lincs.	Boston, Skirbeck ...	0·93	60	,,	Dyce, Craibstone ...	1·59	60
,,	Skegness, Marine Gdns.	0·84	51	,,	New Deer School House	1·36	53
Notts.	Mansfield, Carr Bank ...	0·67	32	*Moray*	Gordon Castle	0·67	29
Derby	Buxton, Terrace Slopes	2·31	56	*Nairn*	Nairn, Achareidh ...	0·74	40
Ches.	Bidston Observatory ...	1·25	66	*Inverness*	Loch Ness, Garthbeg ...	1·82	55
,,	Manchester, Ringway...	1·07	49	,,	Loch Hourn, Kinl'hourn	3·64	39
Lancs.	Stonyhurst College ...	1·47	40	,,	Fort William, Teviot ...	3·94	59
,,	Squires Gate	0·89	39	,,	Skye, Broadford ...	3·58	59
Yorks.	Wakefield, Clarence Pk.	0·64	36	,,	Skye, Duntuilm ...	1·63	37
,,	Hull, Pearson Park ...	1·06	58	*R. & C.*	Tain, Mayfield... ...	1·19	53
,,	Felixkirk, Mt. St.John...	0·60	30	,,	Inverbroom, Glackour...	2·83	57
,,	York Museum	1·11	66	,,	Achnashellach	1·57	23
,,	Scarborough	0·88	49	*Suth.*	Lochinver, Bank Ho. ...	0·90	24
,,	Middlesbrough... ...	0·48	31	*Caith.*	Wick Airfield	1·63	72
,,	Baldersdale, Hury Res.	2·36	82	*Shetland*	Lerwick Observatory ...	2·30	73
Norl'd.	Newcastle, Leazes Pk....	1·03	50	*Ferm.*	Crom Castle	2·36	76
,,	Bellingham, High Green	0·92	31	*Armagh*	Armagh Observatory ...	2·74	117
,,	Lilburn Tower Gdns. ...	0·93	35	*Down*	Seaforde	1·80	62
Cumb.	Geltsdale	1·75	63	*Antrim*	Aldergrove Airfield ...	1·45	58
,,	Keswick, High Hill ...	2·13	47	,,	Ballymena, Harryville...	1·50	48
,,	Ravenglass, The Grove	1·37	44	*L'derry*	Garvagh, Moneydig ...	1·27	41
Mon.	A'gavenny, Plâs Derwen	1·40	42	,,	Londonderry, Creggan	1·34	42
Glam.	Ystalyfera, Wern House	2·50	47	*Tyrone*	Omagh, Edenfel ...	2·11	67

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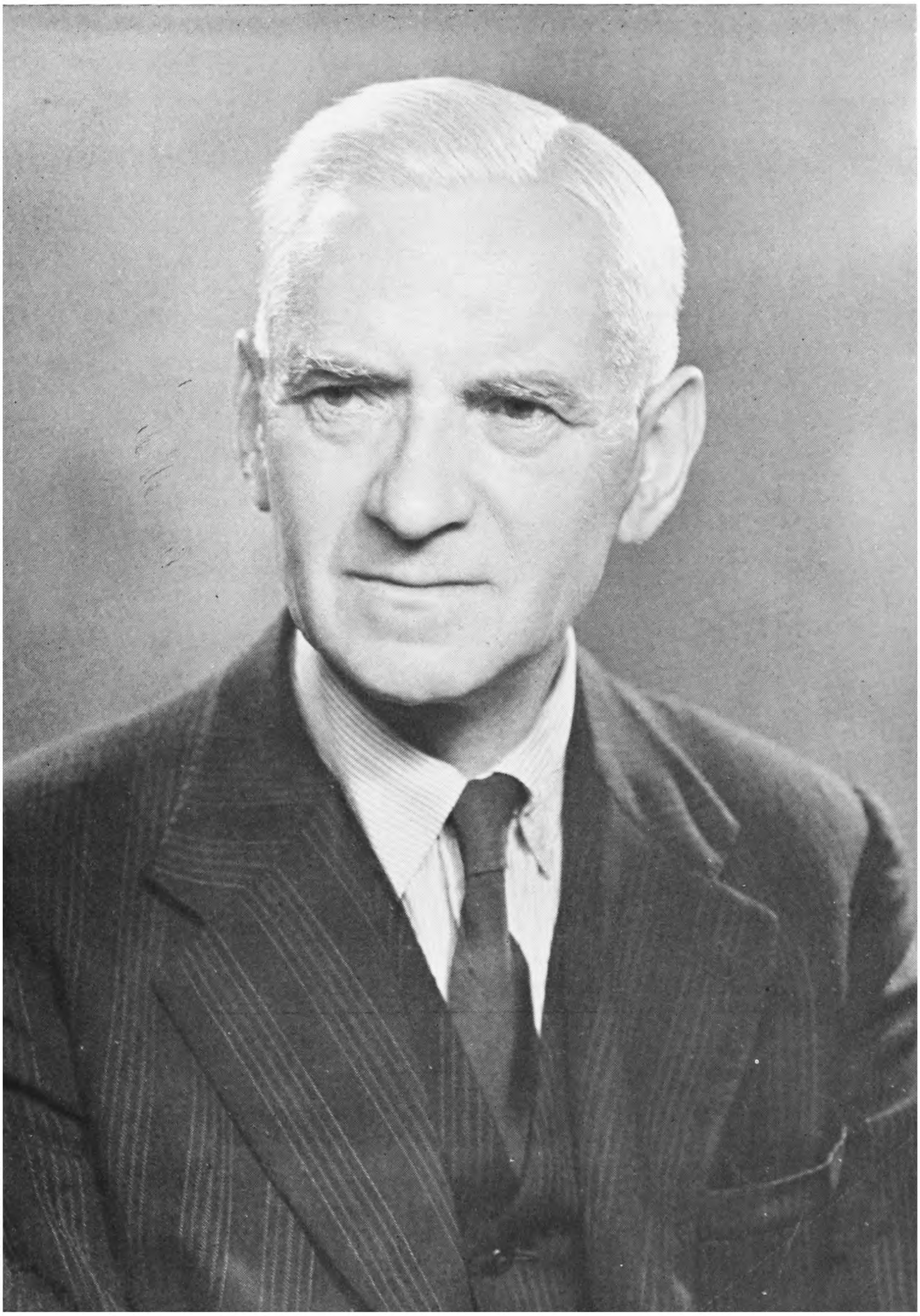
Frontispiece]



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SIR DAVID BRUNT

M.O. 613 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

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SIR DAVID BRUNT

Born June 17, 1886

I take this opportunity of wishing the Meteorological Office and its staff, and the *Meteorological Magazine* and its readers, long life and prosperity. I have a great faith in the prospects of rapid advances in Meteorology in the near future. The science of Meteorology is rapidly taking on a new guise, and I envy only those who are young enough to be able to see what Meteorology will be like in A.D. 2000.

To readers of this journal I express the hope that they may always be too busy to have time to think of themselves.

DAVID BRUNT

SCHOLAR, TEACHER, ADMINISTRATOR

By SIR GRAHAM SUTTON, D.Sc., F.R.S.

When one considers Sir David Brunt's long and varied career, both as a mathematician and as a practical meteorologist, it is evident that nothing short of a lengthy memoir could hope to do justice to the influence he has exercised on the development of meteorology, not only in this country but throughout the world. On this, the occasion of his seventieth birthday, I propose to comment only briefly and generally on three aspects of his work, in the fields of research, pedagogy and administration, respectively, as a tribute to a man who has done so much for the science of the atmosphere.

Brunt's early training, at Aberystwyth (where he acquired an almost legendary reputation for mathematical skill) and at Cambridge (where he was the Newton Scholar), was that of an applied mathematician, and his approach to meteorology has always been that of the classical mathematical physicist. His work, like that of Rayleigh, Prandtl, and Sir Geoffrey Taylor, is characterized by the ability to solve apparently complex problems easily, without the need to indulge in highly complicated mathematics. Success in applied mathematics depends largely on making approximations by appeals to the underlying physics, and Brunt has always excelled in selecting aspects of a problem of physical significance, and thus getting to the heart of the matter by the shortest route. The "frontal assault" has never appealed to him! There are many examples to be found of this enviable gift, including the well known paper in the *Proceedings of the Royal Society* which amounts to little more than the solution of a quadratic equation, but by way of illustration I can hardly do better than to cite his classic treatment of the fall of surface temperature on a clear night, a pioneer study that opened the way for many later investigations. At first glance the problem appears to offer little opportunity for a straightforward mathematical investigation, for the nocturnal loss of heat from the ground involves at least four cross-linked factors that are difficult to estimate, namely, long-wave radiation to and from the atmosphere, conduction in the soil, conduction from the air and the release or absorption of latent heat by condensation and evaporation. Brunt's analysis is characteristic in its boldness and effectiveness. The evaluation of radiation flux is rendered amenable by a simple modification of Stefan's fourth-power law to allow for back-radiation from the water vapour in the lower layers of the air, after which the atmosphere itself is eliminated from the problem by the assumption that the surface temperature is mainly determined by the condition that the movement of heat in the soil adjusts itself to maintain a sensibly constant outward flux of heat at the surface. The problem then becomes one familiar in the classical theory of conduction of heat in a solid body, the solution being the well known "parabolic" expression for the fall of surface temperature during the night. Later investigations have followed this lead by making allowance for factors neglected by Brunt, but the improvements in accuracy are not very significant. In a word, Brunt's analysis produced the dominant term and, equally important, revealed at a glance the considerable effect of changes in the physical constants of the soil. The whole work, including the discussion of the water-vapour spectrum, is an admirable illustration of Brunt's use of physical insight with mathematical technique playing, as it should, a subsidiary role, and is characteristic of all his work in dynamical meteorology.

Brunt left the Meteorological Office in 1934 to succeed Sir Gilbert Walker as Professor of Meteorology at Imperial College, London. In the same year there appeared "Physical and dynamical meteorology". It is perhaps a little difficult for the younger generation of meteorologists, with the wealth of texts available today, to realize fully the significance of this book at the time it was published. Those who wished to study meteorology as a branch of mathematical physics in the 20's and early 30's had to rely mainly on Exner's "Dynamische Meteorologie", Humphreys' "Physics of the air" and Shaw's "Manual of meteorology", none of which is ideal for the purpose. Exner's work is extremely academic in its approach and Humphreys' text is too preoccupied with meteorological optics and his dubious theory of "vulcanism" to give the newcomer a balanced view of dynamical meteorology. As for Shaw's Manual, what can one say of this immense work? It is the *magnum opus* of a fine scholar who did more than any other man of his time to make meteorology a branch of physics and ranks today as a classic of our science, but as a technical treatise, or a work of reference for the busy professional meteorologist, it has many shortcomings. Too often it is meteorology in the after-dinner atmosphere of a Cambridge Senior Combination Room—urbane, pleasant and full of facts but, somehow, never quite what one wants in a hurry!

Brunt's work is very different. From the opening chapter ("The facts that call for explanation") it is strongly realistic and carries over into a teaching text the emphasis on a sound physical background that is so characteristic of the author. For the most part the earlier books on dynamical meteorology began with problems in hydrodynamics and sought out examples from the observations as illustrations; Brunt reversed the procedure by starting with 'the facts that call for explanation', and thereafter selecting from hydrodynamics and thermodynamics only those parts that are significant in the real problems of the atmosphere. The book itself is a delight to read. The style might well serve as a model for writings in science, and although at times the lucidity and ease of presentation tend to conceal the depth of the physical insight, one is conscious always of following the thought of a master craftsman. It is an intensely personal book that reminds one of Brunt's conversation, for the text abounds in phrases that blow away the mists of academic pretentiousness, like the oft-quoted sentence that it is a waste of time to measure air temperature to a hundredth of a degree Centigrade: "the air does not know its own temperature to that degree of accuracy". "Physical and dynamical meteorology" set a new fashion in the exposition of the science of the real atmosphere, and its influence can be traced in most of the textbooks that have appeared since.

In addition to writing this standard text, Brunt built up a strong school of meteorology at South Kensington, and the high reputation enjoyed by the Department of Meteorology of Imperial College today reflects in no small degree the excellence of his work as an administrator in academic circles. The combination of first-class scientific and administrative ability is, unfortunately, somewhat rare, not always because the scientist is lacking in the qualities that make the good administrator but more often because he is inclined to regard the running of the machine as a minor task to be done during intervals of scientific work. Brunt has never made that mistake, and has always given his administrative duties the concentrated attention that ensures success, whether it be in his work as a civil servant, as a professor or as Secretary of the Royal Society. This is well illustrated by the way in which he ensured the creation of a school of micrometeorology in this country from 1921 onwards. After the 1914–18 war the Meteorological Office, newly placed under the Air Ministry, was faced with the double task of assisting in the development of aviation, and of resuming its traditional work of producing daily forecasts and collecting climatological data. Organized research within the Office did not come into being until nearly twenty years later. It was left to Brunt to fill the gap elsewhere, which he did in the somewhat unexpected field of chemical warfare. Gas had played a large part in the war, but it had been used empirically by both sides. In 1920 little or nothing was known of the mechanism of atmospheric diffusion, and the meteorology of the lowest regions of the atmosphere was almost as obscure as that of the stratosphere. The opening of the Chemical Warfare Experimental Station at Porton in 1921 gave Brunt an opportunity which he seized with characteristic vigour. He placed at Porton a small but select team of workers, with the late Sir Nelson Johnson in charge and, as Chairman of the Meteorological Sub-Committee of the Chemical Warfare Committee (a post he held without a break for the next 21 years) he ensured that their programme was broad, fundamental, and never too closely defined—conditions essential for success in any branch of research.

The meteorological work at Porton was often heavily veiled by the Official Secrets Act, and, except for a few highly significant *Geophysical Memoirs* and some papers in scientific journals, remained largely undisclosed until after the Second World War. Even now it is difficult for an outsider to realize, from the published material, how much Brunt contributed to the evolution of micrometeorology as a quantitative science. It must suffice here to say that during his long period of chairmanship, he was the trusted guide, counsellor and friend of all who took part in the work, and it was in no small part owing to his efforts that when the Second World War came, this country was far ahead of all others in its knowledge of the characteristics of the lower atmosphere and their significance in chemical warfare. But apart from maintaining a wide and flexible programme of investigations, his shrewd management kept the team intact during many difficult periods and laid on those who served at Porton a debt that can never be fully repaid.

When one meets Sir David today, the word "retirement" seems utterly inappropriate for this alert and kindly Welshman is as much at the heart of affairs in the scientific world as ever. He is now, as always, the "happy warrior", a man with friends everywhere and enemies nowhere. But no account of his success, however brief, would be complete without a tribute to Lady Brunt who, educated in the liberal arts, has brought to the social side of the world of science a grace and charm that is entirely her own. To Sir David and Lady Brunt we, their friends in the Meteorological Office, send our sincere wishes for their continued happiness.

POLIOMYELITIS AND WEATHER

By E. N. LAWRENCE, B.Sc.

The affliction known to us today as "polio" or infantile paralysis has recently come into the headlines. It was reported in the press that the Salk experiments in vaccinating half a million children in the United States had shown encouraging results, but that differences, mainly climatic, preclude a definite hope of equal success in this country. Many in these Islands may already hold ideas concerning the relation between weather and poliomyelitis, for the year 1947, when the disease hit Britain badly, was also an outstandingly dry year with an exceptionally cold winter and hot summer—in fact, a year of continental climate. People in Britain had perhaps for the first time become familiar with this dangerous and devastating disease, and for most of us a year of such climatic conditions had not occurred within living memory. The year 1947, though not very dry as a whole, had exceptionally dry individual months—August with 17 per cent. of average rainfall (1881–1915) was estimated to be the driest for 200 yr. The epidemic during the fine dry July and August of 1955, following a fairly cold winter, again drew attention to this subject. When it is remembered also that for many years poliomyelitis has been a dangerous and serious disease in the United States and that in the years just before the war it hit very hard at Switzerland (though without seriously affecting the surrounding countries) the association of the disease with certain aspects of continental climate appears possible. Although the problem has been the subject of extensive research both in Britain and abroad, no definite relation with climate has yet been proved. The reason for this may be that the more important factors are not meteorological. They may include low resistance, due to social or economic causes, or some special immunity as seemed to be experienced by Plymouth in 1947 when it was the only place in Britain to escape the epidemic, notwithstanding that in 1946 it was the only place to experience one. Finally we have to accept the possibility of mere chance infection. Nevertheless the relation between the disease and climate is worthy of investigation.

In 1935 Petersen and Benell[1] associated poliomyelitis with "polar infalls" (indicated by rising barometric pressure) and concomitant changes in the humidity (lowering), temperature (lowering), storms, wind, etc. They claimed significant comparisons with other diseases—based on the work of de Rudder[2]. Again, in 1951, Wada[3] asserts that there is a close relation between infantile paralysis and atmospheric phenomena. He maintains that the maximum number of notifications is related to preceding high humidity and low rainfall. It is noteworthy that this combination often distinguishes Britain fron continental countries during a hot dry summer.

After the 1947 epidemic, investigations multiplied in this country, and Mr. R. G. Veryard, Assistant Director for Climatological Services, has drawn attention to some unpublished works on this subject. These include data of the broad aspects of weather for a number of years. A study of the salient climatic features for the outstanding years of poliomyelitis incidence in Britain showed that during the three years of very high incidence—1926, 1938 and 1947—the weather was "warm and dry", and that for the year of very low incidence—1918—the weather was "warm and wet", a rather significant result.

Another promising formula (developed in the Meteorological Office and based on data for the period 1933–35 given in the League of Nations Epidemiological Report, October–December 1935) relates the number of days after April 1 on which the average temperature (defined as the mean of daily maximum and minimum temperatures) reaches 55°F. (t) and the number of days from April 1 to the date when poliomyelitis cases reach a maximum (z). This formula, $z = 0{\cdot}63t + 138$, gave a standard error of the estimate of z as 15 days, i.e. (assuming a Gaussian error distribution) there is, approximately, an even chance that for a particular country the maximum will occur within ten days on either side of the date given by this formula. This formula cannot be accepted as truly representative but it certainly shows that climate is a factor to be considered.

In 1949 Dr. C. E. P. Brooks, in a survey of Britain based on the period 1922–47, reached the following conclusions: (1) there is clear evidence of maximum incidence in late summer and early autumn. There is some slight, but not decisive evidence that both minimum and maximum incidence begin earlier in the west and north then in the east and south; (2) there is also some evidence that epidemics which begin in winter are short while those which begin in spring last longest; and (3) although no outstanding effect can be attributed to weather, the following suggestions appear:—

(i) Unsettled months tend to be free of epidemics, especially if there is a good proportion of sunshine (the effect of sunshine disappears in summer).

(ii) Cold autumns tend to favour freedom from epidemics.

(iii) There is little relation to wind direction but there is a slight tendency for epidemics not to end during months of light variable winds.

(iv) A distinct tendency for epidemics to begin shortly after a spell of hot weather.

(v) There is some slight indication that cold spells precede epidemics, possibly because they are quiet and dry, and rooms tend to be overheated.

These were only tentative conclusions.

Throughout the investigations both of the Meteorological Office and others, it has been shown that there is a tendency for poliomyelitis to be associated with warmth and/or low rainfall. With these ideas in mind, Bradley and Richmond[4], with the help of the Meteorological Office, investigated the meteorological conditions in relation to poliomyelitis in England and Wales for the period 1947–52 inclusive. They studied chiefly dry-bulb temperature and vapour pressure, averaging the daily readings at 3 a.m., 9 a.m., 3 p.m., 9 p.m., to obtain weekly mean values. Their conclusions were as follows:—

(i) Meteorological readings such as these are unlikely to be of material value in predicting the incidence of poliomyelitis.

(ii) The seasonal rise each year did not take place without the attainment of certain minimum values of temperature and humidity. On the other hand, reaching these values did not necessarily mean that the rise began.

(iii) The seasonal fall is not initiated by alterations in temperature or humidity.

(iv) The incidence of poliomyelitis during the season is not influenced to any great degree by variations in temperature and humidity.

(v) In the short period of six years studied there was a tendency for those seasons with the lower average dry-bulb temperature or vapour-pressure readings to show the lowest incidence of poliomyelitis. This could have occurred by chance.

Perhaps these results are a little disappointing but it must be remembered that only six years were considered. Further, only the "pure elements" or

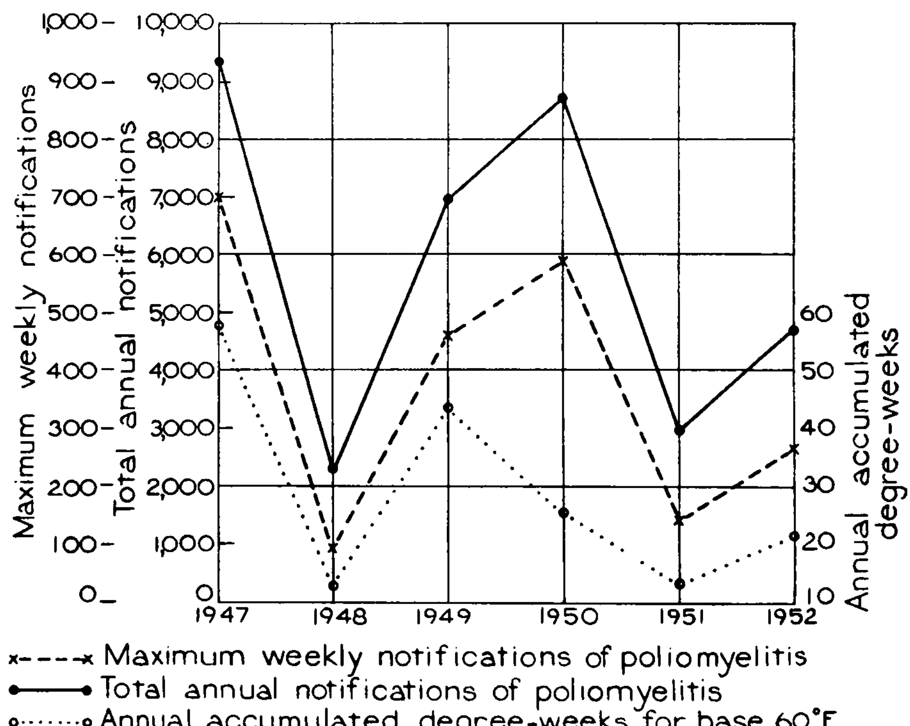

FIG. I—RELATION BETWEEN POLIOMYELITIS AND ACCUMULATED TEMPERATURE IN ENGLAND AND WALES

Based on data given by W. H. Bradley and A. E. Richmond[4].

their simple combination were studied; whereas the more important meteorological parameter may be a complicated function of temperature, vapour pressure or humidity, wind, sunshine, rainfall, etc., —as for example, a measure of evaporation. The writer has computed the correlations of maximum weekly notifications and total annual notifications with annual "accumulated degree-weeks" (computed from the weekly mean temperature in England and Wales) from a base of 60°F.; these correlations of approximately 0·85 and 0·83 respectively (see Fig. 1) are indeed rather striking, for the odds against their occurring by chance are between 20 and 50 to one. In view of these findings, it is suggested that success in other aspects also may be achieved by considering degree-days (temperature), millibar-days (vapour-pressure), or percentage-days (humidity) with reference to a particular threshold value and to a particular period or combination of periods, thus taking into account the sequence of weather characteristics. Increased medical and biological knowledge of the development of the virus might help to select, for the different stages of its growth, the relevant meteorological variables.

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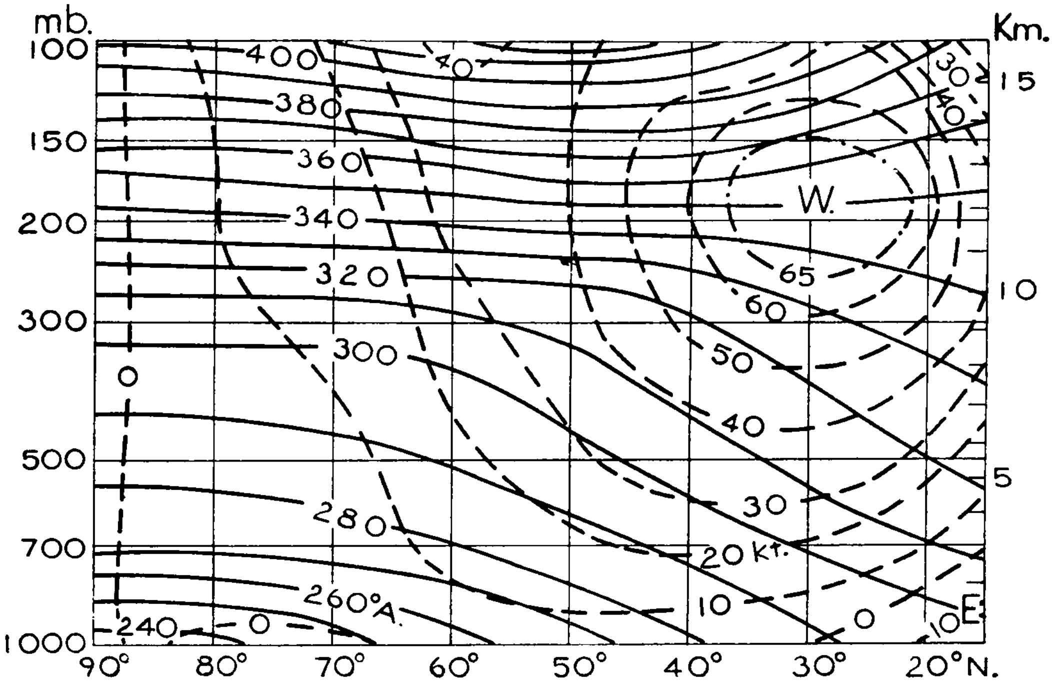
CROSS-SECTIONS OF THE MEAN ZONAL COMPONENT OF GEOSTROPHIC WIND

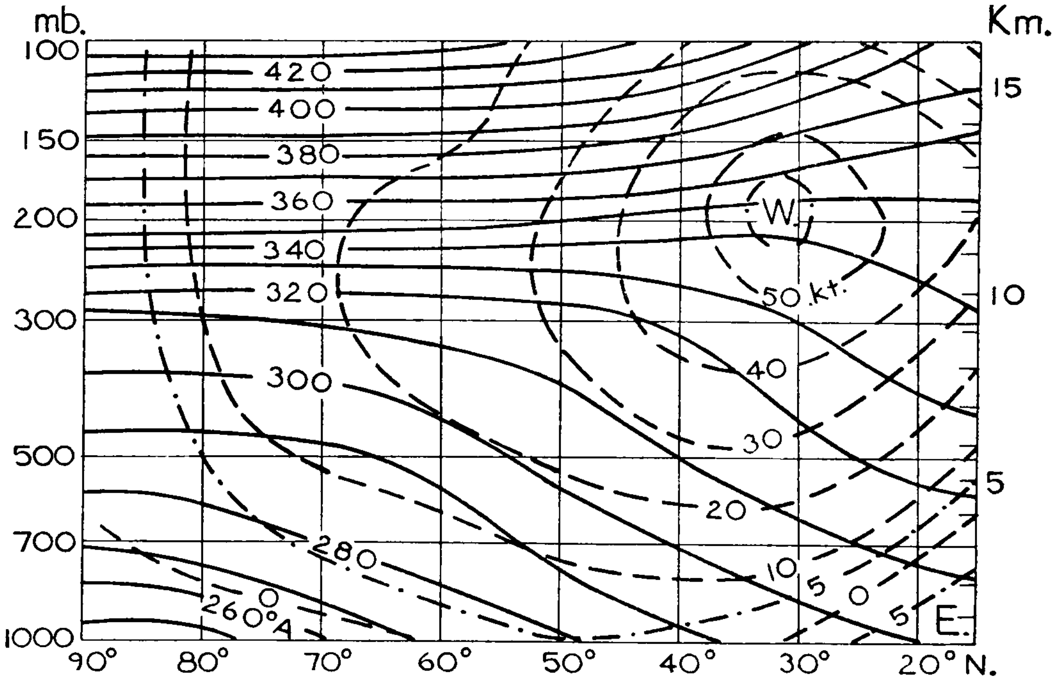
By J. G. MOORE, B.Sc.

Introduction.—In an investigation into the average distribution of upper air temperature over the world, the results of which have been prepared for publication as a *Geophysical Memoir*[1], world charts of average temperature for the mid-season months at the standard pressure levels were drawn. These have been used to prepare for January, April, July and October mean meridional cross-sections averaged over all longitudes (Fig. 1) showing values of the mean zonal component of geostrophic wind and of mean virtual potential temperature (standard pressure 1000 mb.). The cross-sections extend from the North Pole to 15°N. and from the surface to the 100-mb. level. Comparisons are made between these and earlier published cross-sections.

Data used.—The data on which the charts were based were chiefly observations made by radio-sonde ascents between the years 1941 and 1952. These were supplemented by pre-war data from balloon-sonde ascents at some stations in Europe and India and by radio-sonde ascents over the U.S.S.R. In regions where data were few, observations from aircraft were also used up to 300 mb. The number of years for which data were used varied considerably, and no attempt was made to adopt a uniform period, although some adjustment for differences of period was made when drawing the charts.



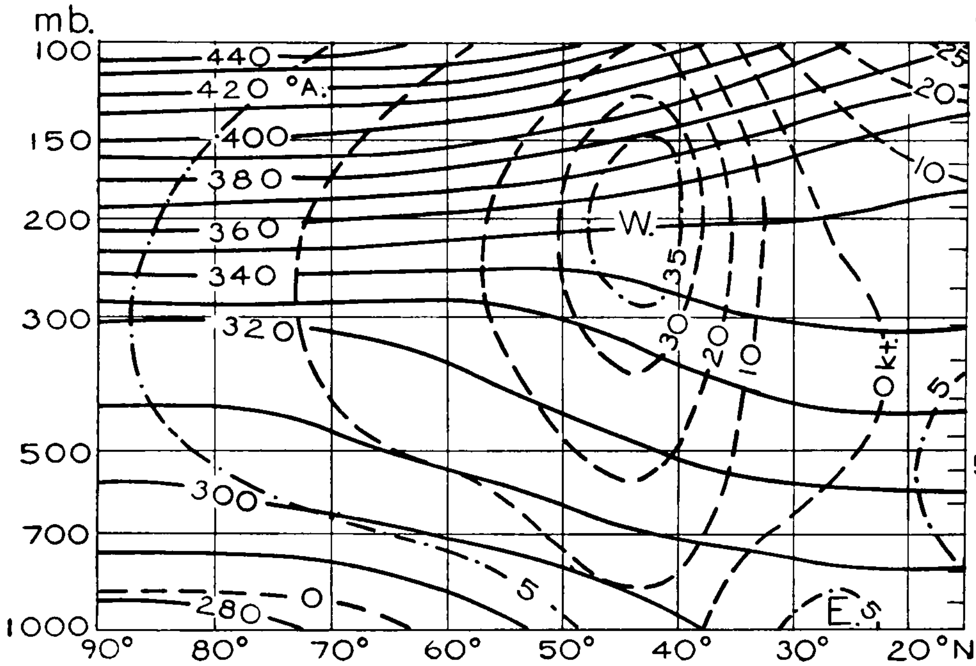
January



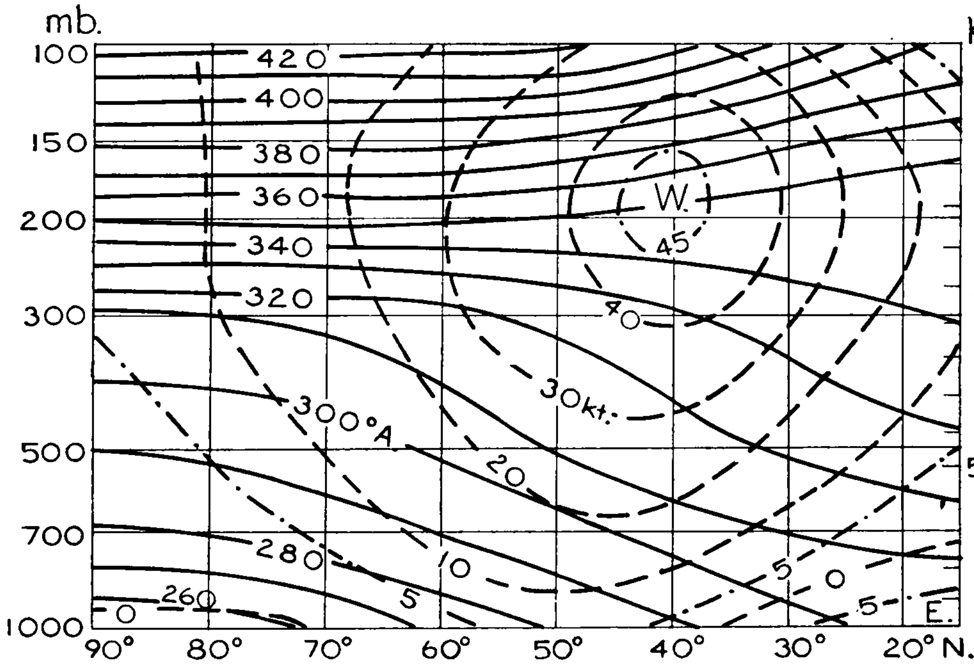
April

FIG. 1—MEAN MERIDIONAL CROSS-SECTIONS

The potential temperature is given by full lines and the mean zonal component of the geostrophic wind by broken lines.



July



October

FIG. 1—*continued*

Other data used were:

(i) Average values of surface and upper air relative humidity for different latitudes in the northern hemisphere in winter and summer given by Telegadas and London[2].

(ii) Average values of mean-sea-level pressure for different latitudes and months given by the Institut für Meteorologie und Geophysik der freien Universität Berlin[3].

(iii) Average values of mean-sea-level temperature for different latitudes in the mid-season months from data in the Meteorological Office[4].

Treatment of the data.—Values of average temperature were read from each temperature chart at every 5° of latitude and 20° of longitude from the North Pole to 15°N. Mean-temperature values for each latitude and month, level by level, were then derived, and these, with appropriate values of relative humidity, converted to the corresponding virtual temperatures and virtual potential temperatures. For April and October the values of relative humidity were assumed to be the mean of the winter and summer values. Possible errors in virtual temperature or virtual potential temperature resulting from this assumption will be small since virtual temperature is insensitive to changes in relative humidity.

Having computed the height of the 1000-mb. level from the average pressure and temperature at mean sea level, the heights of the isobaric surfaces for every 5° of latitude were derived by adding to these the thicknesses of successive layers found from their mean virtual temperatures by means of standard tables, i.e. "Smithsonian meteorological tables"[5].

The average geostrophic-wind components in knots were then computed from the isobaric height differences between successive steps of 5° of latitude using the appropriate value of the Coriolis parameter.

Isopleths of mean wind speed and virtual temperature were drawn; the slopes of the latter were used to check levels of maximum wind and hence to make minor corrections to the former.

Cross-sections.—On the cross-section for January the maximum component of W. wind of over 65 kt. occurs at about 190 mb. near 30°N. This is some 5° further north and 10–15 kt. slower than suggested by the cross-sections of Petterssen[6] and Mintz[7]. Another point worthy of note is the increase of W. wind with height that occurs at 60°N. near the 100-mb. level.

By April the centre is situated slightly further north at approximately the same pressure level but of speed less than in January.

In July the centre occupies a position near the 200-mb. level at 45°N. The speed at the centre is considerably weaker than in January and April; this is at approximately the same latitude and at a speed slightly greater than given on the Petterssen and Mintz cross-sections.

The centre of strong W. wind in October occurs at about the same level as in January and April at 40°N., both position and speed being intermediate to those for April and July.

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CORRELATION BETWEEN THE 500-MB. TEMPERATURE AND THE 500–300-MB. AND 500–400-MB. THICKNESSES

By R. BERGGREN, Fil. Lic.
(Swedish Meteorological and Hydrological Institute)

The high linear correlation between some meteorological variables in the middle and upper troposphere is a well known fact, and has been discussed by many authors[1–4]. Petterssen[1] gives a coefficient of about 0·97 for the correlation between the 500-mb. temperature and the 500–400-mb. thickness. The coefficients are computed from British radio-sonde data. Murray[2] gives coefficients for the correlation between the 500-mb. temperature and the 500–300-mb. thickness. The data used were the material from the British radio-sonde stations Larkhill and Lerwick during January, April, July and October 1947 and the correlation coefficient is as high as 0·97.

These high values indicate that it might prove valuable to compute regression equations and use these in the daily aerological work. As the same coefficients and equations referred to above are computed from the data from the Swedish radio-sonde station Torslanda near Gothenburg (57°42′N. 11°47′E.) it might be of some interest to compare them with the earlier ones.

500–300-mb. correlation.—The correlation coefficients for the 500-mb. temperature and the 500–300-mb. thickness are given month by month in Table I. All values for Torslanda in this paragraph are computed from a 10-yr. series (July 1940–June 1950). The highest coefficient is 0·95 (May) and the lowest is 0·89 (January); the standard error is 0·01 or less. The values in Table I are somewhat lower than those given by Murray[2].

TABLE I—CORRELATION COEFFICIENTS FOR THE 500-MB. TEMPERATURE AND THE 500–300-MB. THICKNESS

	Correlation coefficient	No. of observations		Correlation coefficient	No. of observations
January ...	0·888	291	July ...	0·941	260
February ...	0·913	279	August ...	0·937	257
March ...	0·941	308	September ...	0·940	255
April ...	0·900	294	October ...	0·934	257
May... ...	0·953	291	November ...	0·925	245
June... ...	0·931	283	December ...	0·916	261

The equation for the regression of the thickness on the temperature can be written as

$$a = b_1 T + b_2$$
$$\text{or } a' = b_1' T' + b_2'$$

where a (in geopotential metres) and a' (in feet) are the values of the thickness, T (in degrees Celsius) and T' (in degrees Fahrenheit) are the values of the temperature, and b_1, b_1', b_2, b_2' are constants, whose values are given in Table II.

TABLE II—CONSTANTS FOR THE REGRESSION EQUATIONS OF 500–300-MB. THICKNESS ON THE 500-MB. TEMPERATURE

	b_1	b_2	b_1'	b_2'
	gpm./°C.	m.	ft./°F.	ft.
January	10·63	3781·6	19·37	11787
February...	11·37	3796·3	20·72	11792
March	10·49	3783·5	19·12	11801
April	11·12	3803·7	20·27	11831
May	11·77	3817·3	21·45	11837
June	13·26	3858·3	24·17	11885
July	13·79	3865·5	25·13	11878
August	12·57	3849·1	22·91	11895
September	12·94	3853·2	23·58	11887
October	12·31	3839·0	22·44	11877
November	12·11	3831·2	22·07	11863
December	11·48	3804·7	20·92	11813

The standard errors of the estimate are given in Table III. The corresponding value given by Murray[2] is 20 gpm. (66 ft.) and this is slightly lower than the average value for Torslanda.

TABLE III—STANDARD ERROR OF ESTIMATE OF THE 500–300-MB. THICKNESS

	Standard error	
	gpm.	ft.
January	32	105
February	28	92
March	22	72
April	24	79
May	15	49
June	21	69
July	17	56
August	18	59
September	22	72
October	24	79
November	27	89
December	26	85
Murray's estimate ...	20	66

During the computations it turned out that the monthly regression equations given by the constants in Table II could for all practical purposes be brought together in two groups:

June–November

$$\left.\begin{aligned} a &= 12{\cdot}83\, T + 3849{\cdot}4 \\ a' &= 23{\cdot}38\, T' + 11881 \end{aligned}\right\} \qquad \ldots\ldots (1)$$

December–May

$$\left.\begin{aligned} a &= 11{\cdot}14\ T + 3797{\cdot}9 \\ a' &= 20{\cdot}30\ T' + 11811 \end{aligned}\right\} \qquad \ldots\ldots (2)$$

An overall mean gives

$$\left.\begin{aligned} a &= 11{\cdot}99\ T + 3823{\cdot}6 \\ a' &= 21{\cdot}85\ T' + 11845 \end{aligned}\right\} \qquad \ldots\ldots (3)$$

Murray's formula is

$$\left.\begin{aligned} a &= 12{\cdot}88\ T + 3851{\cdot}1 \\ a' &= 23{\cdot}47\ T' + 11884 \end{aligned}\right\} \qquad \ldots\ldots (4)$$

In order to see if there are any great differences in the values computed from these four sets of equations Table IV was constructed.

TABLE IV—COMPARISON BETWEEN THE ESTIMATED VALUES OF THE 500–300-MB. THICKNESS COMPUTED FROM THE FOUR FORMULAE

Formula	Temperature: Degrees Celsius −10	−20	−30	−40	Degrees Fahrenheit 20	0	−20	−40
	geopotential metres				*feet*			
(1)	3721	3593	3465	3336	12349	11881	11413	10946
(2)	3687	3575	3464	3352	12217	11811	11405	10999
(3)	3704	3584	3464	3344	12282	11845	11408	10971
(4)	3722	3593	3465	3336	12353	11884	11415	10945
Maximum difference	35	18	1	16	136	73	10	54

From Table IV is is quite clear that the differences are small but not quite negligible. It is interesting to note that the formula given by Murray (4) is almost identical with the formula for the summer and autumn months (1) given in this paper. Furthermore, it is interesting to compare equations (2) with (1) which show a great change from one half of the year to the other.

One effect, which reduces the values of the correlation coefficients discussed here, is that of the variable tropopause. If the tropopause is found at relatively high pressures it is self-evident that the connexion between the 500-mb. temperature and the 500–300-mb. thickness is a poor one.

TABLE V—PERCENTAGE NUMBER OF CASES WITH THE TROPOPAUSE PRESSURE GREATER THAN OR EQUAL TO 300, 350 AND 400 MB. RESPECTIVELY

	Pressure at the tropopause ⩾300 mb.	⩾350 mb.	⩾400 mb.
	percentage frequency		
January ...	23	6	1
February ...	16	3	1
March	12	4	3
April	25	8	2
May	12	2	0
June	13	2	0
July	4	0	0
August	5	0	0
September ...	9	½	0
October... ...	8	1	2
November ...	13	1	0
December ...	21	5	1
Murray ...	8	...	...

Table V gives the percentage of cases with tropopause pressure above certain limits. For comparison Murray's value, which is markedly lower is given. To some extent this can be explained by the fact that the year used by Murray (1947) was by no means a normal year. For the Torslanda material the 10-yr. mean of tropopause pressure was 246 mb. but for the months January, April, July and October 1947 it was 237 mb. The difference in the geographical location of the stations used naturally accounts for most of the discrepancy. It is not likely that the difference can be explained by different definitions of tropopause, because the British definition is used in both cases and was probably applied in the same manner.

500–400-mb. correlation.—Table VI gives the coefficients for the correlation between the 500-mb. temperature and the 500–400-mb. thickness for the period 1950–53. For all months these are high, from 0·93 in April to 0·99 in December. These values agree well with that given by Petterssen[1].

TABLE VI—CORRELATION COEFFICIENTS FOR THE 500-MB. TEMPERATURE AND THE 500–400-MB. THICKNESS

	Correlation coefficient	No. of observations		Correlation coefficient	No. of observations
January ...	0·968	236	July ...	0·958	235
February ...	0·984	221	August ...	0·980	240
March ...	0·981	234	September ...	0·976	232
April ...	0·934	231	October ...	0·974	234
May... ...	0·970	231	November ...	0·982	237
June... ...	0·963	229	December ...	0·987	234

The mean regression equation is in this case

$$\left.\begin{aligned} a &= 6{\cdot}43\,T + 1742{\cdot}8 \\ a' &= 11{\cdot}72\,T' + 5343 \end{aligned}\right\} \qquad \ldots\ldots (5)$$

The equations given by Petterssen are

January, February

$$\left.\begin{aligned} a &= 6{\cdot}31\,T + 1740{\cdot}4 \\ a' &= 11{\cdot}5\,T' + 5342 \end{aligned}\right\} \qquad \ldots\ldots (6)$$

March, April

$$\left.\begin{aligned} a &= 6{\cdot}58\,T + 1746{\cdot}5 \\ a' &= 12{\cdot}0\,T' + 5346 \end{aligned}\right\} \qquad \ldots\ldots (7)$$

May, June

$$\left.\begin{aligned} a &= 6{\cdot}69\,T + 1749{\cdot}1 \\ a' &= 12{\cdot}2\,T' + 5348 \end{aligned}\right\} \qquad \ldots\ldots (8)$$

July, August

$$\left.\begin{aligned} a &= 6{\cdot}80\,T + 1751{\cdot}6 \\ a' &= 12{\cdot}4\,T' + 5350 \end{aligned}\right\} \qquad \ldots\ldots (9)$$

September, October

$$\left.\begin{aligned} a &= 6{\cdot}53\,T + 1745{\cdot}0 \\ a' &= 11{\cdot}9\,T' + 5344 \end{aligned}\right\} \qquad \ldots\ldots (10)$$

November, December

$$\left.\begin{aligned} a &= 6{\cdot}47\,T + 1743{\cdot}0 \\ a' &= 11{\cdot}8\,T' + 5341 \end{aligned}\right\} \qquad \ldots\ldots (11)$$

The standard errors of the estimate by means of equations (5) are given in Table VII and they are low.

TABLE VII—STANDARD ERROR OF ESTIMATE OF THE 500–400-MB. THICKNESS

	Standard error			Standard error	
	gpm.	ft.		gpm.	ft.
January ...	8	26	July ...	7	23
February ...	6	20	August ...	5	16
March ...	6	20	September ...	7	23
April ...	11	36	October ...	8	26
May... ...	6	20	November ...	6	20
June... ...	8	26	December ...	4	13

If equations (5)–(11) are compared it is obvious that the mean equation given for Torslanda is nearly identical with Petterssen's equation for November and December.

Table VIII gives some values computed from equations (5)–(11). The correspondence between the different values is striking. The greatest deviations are again found at higher temperatures.

TABLE VIII—COMPARISON BETWEEN THE ESTIMATED VALUES OF THE 500–400-MB. PARTIAL THICKNESS COMPUTED FROM THE FORMULA GIVEN IN THIS PAPER AND FROM PETTERSSEN'S FORMULAE

	Temperature						
	Degrees Celsius			Degrees Fahrenheit			
Formula	0	−20	−40	20	0	−20	−40
	geopotential metres			*feet*			
(5)	1743	1614	1486	5577	5343	5109	4874
(6)–(11)	1740–1752	1614–1616	1480–1488	5572–5598	5341–5350	5102–5112	4854–4882

The influence of the height of the tropopause is negligible in this case.

Construction of 300-mb. and 400-mb. charts.—The fact that the regression equations are similar over large areas, which was suggested by Murray, can be used in daily aerological work. If for some reason a rapid analysis is wanted, the following method may be used to get a zero approximation. The method supposes that a 500-mb. analysis is available under all circumstances. The 500-mb. contours are analysed as usual. Instead of drawing the isotherms for −10°, −15°C. . . . . or 10°, 0°, −10°F. . . . . , however, certain temperature values are computed from the regression equations in such a way that they correspond to the thickness contours wanted (the same contour intervals as are used for the 500-mb. chart). If the corresponding isotherms are drawn and added graphically to the contours of the 500-mb. chart, the result is a 300-mb. or 400-mb. chart, which is reasonably accurate.

For the 500–300-mb. partial thickness an isotherm interval of about 3°C. corresponds to 40 gpm., and about 9°F. to 200 ft. The corresponding values for 500–400 mb. are about 6°C. and about 17°F.

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METEOROLOGICAL OFFICE DISCUSSION

Progress in numerical weather prediction

The Meteorological Office Discussion held at the Royal Society of Arts on Monday, March 19 on progress in numerical weather prediction was opened by Mr. E. Knighting.

Mr. Knighting said that he was going to deal mainly with the experiment now being carried out in Washington by the Joint Numerical Weather Prediction Unit. Numerical prediction of the pressure distribution, using electronic computers, has been investigated at different centres since the late 1940's, and this method has shown enough promise to make it perhaps the major subject of research in forecasting. The United States Weather Bureau, Navy and Air Force set up the Joint Numerical Weather Prediction Unit, each body providing the necessary staff, equipment and money, believing the time to be ripe to translate some of the research into a forecasting tool. The Unit's objects are to put numerical weather prediction on an operational basis, to examine the results of the predictions and to find methods of improvement.

The numerical predictions that had been made hitherto had been made *post facto* and at leisure, little heed being paid to the time involved in making the forecast. It is doubtful if the computers which had been used in the earlier stages of development would have been able to deal with the calculation on an operational basis, that is to produce the forecast in a time comparable with that taken by an ordinary forecaster. The Weather Prediction Unit was fortunate in being supplied with a very fast and reliable computer (the I.B.M. 701) which has an electrostatic storage capacity of over 2,000 words, a drum memory of over 16,000 words and additionally uses magnetic tapes which hold virtually an infinite number of words. The opener showed two views of the computing room at the Prediction Unit, commenting upon the compactness achieved compared with the earlier computers.

In order to make a numerical forecast it is necessary to use some crude model which approximates in physical fact to the behaviour of the real atmosphere and which is mathematically simple enough, so that the numerical calculations can be carried out. When the Washington Unit came into existence there were several models available, not very different in their physical content,varying in the mathematical detail. The Princeton Group, using a three-parameter model, had had some success in forecasting strong cyclogenesis in a few cases which are famous in the United States because they occurred on public holidays and gave bad weather in contradistinction to the forecast. The physical basis of this model is simple and corresponds to what is observed in the atmosphere in a gross way; the dynamical assumptions are that the wind is almost geostrophic and almost horizontal so that the hydrostatic equation is obeyed; the thermodynamical assumption is simply that the motion is adiabatic for the period over which the forecast is made, about three days at the most, although this assumption cannot be true over a much longer period. Mr. Knighting sketched briefly on the blackboard the equations which are used, showing that the vertical advection of vorticity had been neglected along with a term which dealt with the distortion of the pressure surface. The most questionable of all the assumptions was that the absolute vorticity, when it appears as a multiplying factor, can be replaced by the vorticity due to the earth's rotation (the Coriolis parameter), for in anticyclonic regions the absolute vorticity is often much less than the Coriolis parameter, becoming nearly zero, while in strong cyclonic motion the absolute vorticity can be several times as great as the Coriolis parameter. It is noted that the approximation is at its worst in the regions where rapid changes are likely to take place.

The integration procedure is carried out on a rectangular mesh placed over a stereographic projection of the northern hemisphere which, as used by the Prediction Unit covered the United States, part of Canada and of the Atlantic and Pacific Oceans. The mesh length varied with latitude, being about 300 Km. in the middle latitudes. In the numerical solution some assumption must be made as to the behaviour near the boundaries of the mesh, and this causes errors to arise which tend to spread inwards. For this reason the forecasts which were finally issued did not refer to the whole area covered by the mesh but to a rather smaller area. The integration is carried out in half-hour time steps, so that if the initial chart corresponds to time t hr. the first forecast refers to time $t + \frac{1}{2}$ hr. Using this forecast as the new initial chart a forecast referring to time $t + 1$ hr. is made, and the process repeated. Most of these forecasts are simply held inside the computer, and eventually lost; those corresponding to 12, 24 and 36 hr. forecasts are printed out. The forecasts are made at the three levels 900, 700 and 400 mb., but interpolation and extrapolation are used to print out the forecasts at the more usual levels, 1000, 700 and 500 mb. Each time step takes about $\frac{1}{2}$ min. so that the whole process takes about $1\frac{1}{2}$ hr. including the printing-out time. Before the calculation can be made the observational data must be transmitted to the Prediction Unit, the charts must be plotted and analysed and the contour heights read off at each of the grid points. At first the plotting and analysis were done by orthodox methods, as used in the British Central Forecasting Office, but later this was done by the computer, which saved some time. The forecasts are available about 8 hr. after the time of observation, about 1 hr. before the orthodox forecaster issues his bulletin, most of the delay lying in the transmission of the observations.

In addition to these "baroclinic" forecasts a "barotropic" forecast was made at the 500-mb. level for periods of 24, 48 and 72 hr. over a much larger area than that covered by the "baroclinic" forecasts, covering nearly the whole of the northern hemisphere. These forecasts were originally intended to help in specifying the boundary conditions for the "baroclinic" forecasts but proved to be of considerable interest in themselves.

Forecast verification has customarily been given in terms of the correlation between the forecast and actual height changes observed at the grid points of the mesh, with the root-mean-square forecast error or a regression equation connecting the forecast and actual height changes. There has never been agreement that this is the best way of presenting the results, and it suffers from the disadvantage that these numbers are not readily interpreted for everyday use. The Prediction Unit decided to present the comparisons in quite a different way. At each grid point one can form the geostrophic wind for both the forecast and verifying charts, and for any other chart with which comparison is desired. It is these geostrophic winds which are compared.

Mr. Knighting showed a series of slides giving some of the statistics which had been computed for the forecasts made during the latter half of 1955. These figures showed that on the whole the 24-hr. forecasts were more successful over the eastern United States than over the area which covered the whole of the United States and parts of the Atlantic and Pacific Oceans. The forecasts seemed to be better at 400 mb. than at 700 mb., and better at 700 mb. than at 900 mb. The forecast error was less than the error which would arise if the winds were forecast to remain unchanged, and substantially so at 400 mb. The mean wind over the whole chart was usually forecast to remain almost unchanged, whereas the mean wind did in fact change with time. The root-mean-square forecast wind error expressed as a fraction of the root-mean-square wind on the verifying chart showed that the forecasts were rather more successful in the autumn than in the summer, and re-emphasized the result previously obtained—that the 400-mb. forecasts are the best and the 900-mb. forecasts are the worst. The "barotropic" forecasts at 500 mb. which were started in late October proved almost as good as the "baroclinic" forecasts at 400 mb. in November and December. The forecasts deteriorate with time, but even after 36 hr. it is usually found that the forecast errors are less than those due to a persistence forecast.

The "barotropic" forecasts at 500 mb. showed almost as good verification figures as did the "baroclinic" forecasts at 400 mb., but the mesh length was twice that used for the "baroclinic" forecasts, and the increase in mesh length tends to smooth out the extreme winds and to decrease the forecast error. The "barotropic" forecasts were verified over five areas, Atlantic, Pacific, United States, Canada and North Pole regions, and showed that over all the areas the forecast error was less than that made by a persistence forecast except for the 72-hr. forecast over the United States. The results showed how the uncertainty of analysis over an area containing few observations, such as the Pacific Ocean, spreads with time so that after 72 hr. the best forecast was found over the Atlantic where initial observations are scarce, and the worst forecast found over the United States where observations are numerous.

The opener said that from a synoptic point of view the numerical forecasts appeared to be quite as good in general as those produced by the more orthodox forecaster, especially at 700 mb. and 500 mb., while at 1000 mb. the general positioning of cyclones and anticyclones was as good as that made in the usual way. The United States Weather Bureau forecaster showed great interest in the numerical forecasts which were available to him about 1 hr. before he issued his forecasts. Notable faults of the numerical forecasts were (*a*) spurious anticyclogenesis which seems to occur in most waxing high-pressure systems and which leads to a serious over-estimation of the pressure—numerical models used so far all seem to lead to spurious anticyclogenesis; (*b*) failure to forecast well in the lee of the Rockies—the model assumes that the ground is flat and makes no allowance for topography, although this can be included; (*c*) failure to forecast what are clearly non-adiabatic processes, e.g. the formation of heat lows over the desert regions in summer; (*d*) a tendency to move low-pressure systems to the left and to deepen them too much—this is not as obvious as the spurious anticyclogenesis.

Finally Mr. Knighting drew attention to the co-operation which had been given by the Prediction Unit. The results contained on the slides were unpublished, and yet the Prediction Unit had made them available for the first time for this discussion. The co-operation was manifest in other ways: sending to us forecast charts and the exchange of ideas. We must be grateful to Dr. Cressman and his associates for their close co-operation.

Mr. D. E. Jones showed two slides of numerical forecasts which had been made by the Prediction Unit for a period of four days commencing October 10, 1955. These slides showed the forecast and actual positions of a low-pressure system moving over the north-east of the forecast map. On successive days the numerical forecast placed the low too far north and underestimated its central pressure. A high-pressure system moving in from the Pacific was also traced, and showed clearly the spurious anticyclogenesis which had already been mentioned.

Mr. Bushby described the work that had been carried out by the Meteorological Office during the past twelve months. A series of numerical forecasts had been made when the official forecasts had proved to be substantially in error. In nearly all these cases the numerical forecast had been essentially correct although in detail there were differences when the level of non-divergence was changed from 500 mb. to 600 mb. Experiments had been carried out using a stream function in place of the assumption that the wind was related to the contour height by the geostrophic relation. Only in one case was there any marked improvement. Considerable work had been done on objective analysis of the observations, approximating the local shape of the pressure surface by using quadratic and cubic surfaces. Mr. Bushby sketched out the method on the blackboard showing how he proposed to deal with areas in which there were very few observations by using lightly weighted forecast values. He described the new Ferranti Mark II electronic computer which will be acquired by the Meteorological Office in 1957.

Dr. Wilkes asked why the simpler "barotropic" model should give results which are as good as those given by the more elaborate "baroclinic" models. Mr. Knighting said that it was true that "barotropic" forecasts made for the 500-mb. level were about as good as those made at the same level using a "baroclinic" model because the profile of vertical velocity with pressure showed a maximum somewhere in the middle of the troposphere; there $\partial\omega/\partial p$ became zero (where ω is the vertical velocity dp/dt, and p is the pressure). When $\partial\omega/\partial p$ was made zero the baroclinic equation at that level reduced to the barotropic equation.

Dr. Forsdyke asked what assumptions were made in the United Kingdom about the contour heights at the boundaries. Would it be possible to apply the same methods to a grid covering the hemisphere, so getting rid of the lateral boundary conditions? If so, would the systems run down since no energy was being put in? Mr. Knighting and Mr. Bushby replied that hemisphere forecasts had been made in the United States and had been quite good after 3 days. The Stockholm "barotropic" forecasts also covered a great part of the hemisphere. Friction was not included in the model and hence the forecast systems would not run down.

Dr. Forsdyke asked if the spurious anticyclogenesis was due to neglect of friction. Mr. Knighting said he did not know. There were so many things that could cause spurious effects—linearization, neglect of variation of the Coriolis parameter, the use of the geostrophic assumption among them. In an anticyclone the air did flow across the isobars whereas the models kept the air moving along the isobars and this frictional effect could lead to spurious anticyclogenesis, and a similar effect could lead to spurious cyclogenesis. The partial neglect of the variation with latitude of the Coriolis parameter must lead to spurious anticyclogenesis when air was moving northward.

Dr. Sutcliffe asked why the variation was ignored when the "barotropic" forecast depended essentially on it. Did the "barotropic" forecasts show the spurious effect? Mr. Knighting replied that in the model the variation was only ignored in one term and kept in the others. It was not totally neglected. The "barotropic" forecasts did show spurious anticyclogenesis.

Mr. Douglas (Cambridge University) asked why the equations should not be used over the whole of the earth's surface. Mr. Knighting said that there was a difficulty in the region of the equator where the relation between wind and contour height became indefinite. We would need to change our equations in this region. From a practical point of view we could not do this using computers now available and still make a forecast in a sufficiently short time.

Mr. Douglas said that in ten years' time machines would be one or two orders faster than now, and then surely, it would be possible to work from the primitive equations.

Dr. Sutcliffe asked if any problem as complicated as the meteorological problem had been tackled. At any time there were perhaps 50 depressions and anticyclones, and we are now trying to forecast the movement of one or two.

Mr. Douglas suggested using a coarse grid as had been done in other problems.

Mr. Bushby pointed out that if the full equations were to be used one would require the observed initial field of vertical velocity everywhere. It was not possible to measure it, and in general the number of observations over some areas made it impossible to be sure what the actual initial conditions were.

Dr. Eady said it was a matter of time economics. The easiest way of making a forecast was to use the primitive equations but their use demanded a very short time step. We operated on the equations to get rid of the short time step. Using a coarse grid came to much the same thing.

Professor Sheppard asked about numerical rainfall forecasts which were not very good. Is it possible that we can forecast the horizontal fields well but not the vertical fields? If this is so it is very disturbing since we are having to forecast weather which depends so much on the vertical velocity field. Mr. Knighting said that the rainfall forecasts were poor when viewed from the point of view of a single station. The vertical velocity was a mean for a square of side 200 miles in length, and if one took the actual rainfall inside the square and averaged it out the numerical forecast did not look so poor.

Mr. Sawyer remarked that as soon as condensation commenced the adiabatic assumption was falsified by the latent heat. Some calculations showed that the terms which had been left out of the equations of the present models, especially the twisting term, were very important, and it is unlikely that good estimates of rainfall could be made except by treating the smaller-scale motions which were only grossly represented on the grid size that was being used.

Dr. Sutcliffe added that it was optimistic to expect to get even the mean rainfall over a grid square correct when small systems such as thunderstorms occurred within an air stream that might appear stable when viewed in the large.

Mr. Chambers pointed out that the relative errors seemed to decrease with height, and hoped it would be possible to go higher—above the tropopause. The delay in getting the observations to the forecast centres was very important, and forecasts would be much improved by knowing what was going on at present. He instanced an error in the forecast movement of a depression which turned to the right of the expected track, saying that had the complete observations been available the forecast would have been much better.

Mr. H. H. Lamb asked if it was possible to say in what particular areas of the synoptic map the forecast errors are most likely to take place, for example in areas of heating or of strong winds. Mr. Knighting replied that the forecasts could be improved by inspection in certain places, such as including heat lows in summer. On the whole the summer of 1955 in the United States had been rather quiet with the quickly moving systems to the north and near to the grid boundary, so that it was not easy to say if regions of strong wind were particularly susceptible to error, although the non-geostrophic effect might be larger there.

Mr. Bushby mentioned that the "baroclinic" forecasts made in the United Kingdom allowed for the non-adiabatic heating which occurred in northerly outbreaks of cold air over the Atlantic. The non-adiabatic term was inserted using the results obtained by Mr. Craddock, and improved forecasts were obtained.

Mr. Turner asked if the spurious anticyclogenesis was more marked in particular geographical areas such as over Sweden or Greenland. Mr. Knighting replied that the effect seemed to occur anywhere.

Dr. Sutcliffe in summing up said that no one interested in meteorology could fail to be interested in the new methods which combined more data, better computers and people with ideas. Much more work was required to decide statistically where the numerical forecasts were best and where they were likely to go wrong. The old methods of forecasting did not give any idea as to why the forecast was in error, but in the numerical forecasts it was possible to start with simple models and trace the error to the neglect of certain terms. The simple model gave about as good an answer to the questions we were asking as did the more complex models, and this may be because over the period for which the forecast is made, a day or so, the atmosphere moves coherently.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:

PROFESSIONAL NOTES

No. 119—*High cloud over southern England.* By R. J. Murgatroyd, B.Sc. (Eng.) and P. Goldsmith.

Data are presented of the frequencies of occurrence of high cloud over southern England, diurnal and seasonal variations, types of high cloud, heights and temperatures of bases and tops, thickness, visibility, and humidity in its vicinity. These data are based on surface observations and six years' high-level ascents by aircraft of the Meteorological Research Flight. The relation between the persistence of condensation trails and the presence of high cloud is discussed. Finally some mechanisms are suggested for the formation of high cloud over the British Isles.

No. 120—*Distribution of wet-bulb temperature at Aberdeen and Eskdalemuir.* By A. B. Thomson, M.A.

This paper outlines the results of an analysis of hourly wet-bulb temperature at Aberdeen and Eskdalemuir. Monthly, seasonal and annual distributions are shown, on a percentage basis, in tables and diagrams. Consideration is given to the determination of the approximate distribution of wet-bulb temperature at other places in Great Britain.

WORLD METEOROLOGICAL ORGANIZATION

Second Session of Regional Association VI (Europe)

The Second Session of Regional Association VI (Europe) of the World Meteorological Organization took place at Dubrovnik, on the Adriatic coast of Yugoslavia, during March 12–24, 1956, under the chairmanship of the President of the Association, Professor Lugeon, Director of the Meteorological Service of Switzerland. It was attended by 71 delegates from 30 Member countries, and a number of observers. The United Kingdom delegation of four, consisting of three from the Meteorological Office and one from the Naval Weather Service, was led by Mr. S. P. Peters, Deputy Director (Forecasting) of the Meteorological Office. The Secretary-General of the World Meteorological Service, Mr. D. A. Davies, was present during the first few days of the Session. The opening plenary Session was attended by His Excellency the Minister Plenipotentiary Dr. Jaksić who delivered an address of welcome to the delegates on behalf of the Yugoslav Government.

For the conduct of the detailed work of the Session, two committees were established, one under the chairmanship of Mr. C. V. Ockenden, of the United Kingdom delegation, to deal with those items on the agenda involving the international exchange of data, and the other, under the chairmanship of M. Bessemoulin, of the French delegation, to handle other questions. Of the 48 or so Resolutions and Recommendations approved in plenary sessions some mention may be made of the more important ones.

At the Washington Session of the Commission for Synoptic Meteorology in 1953, the question of the times of upper air observations was considered, and it was noted that certain scientific advantages might be obtained by having these observations synchronous with the primary surface observations, but the practical aspects of the then existing situation required the realization of this objective to be postponed. That Commission considered, however, that Regional Associations should continue to study the problem, in order to provide recommendations for its guidance at the next session. Accordingly, this question was included in the Agenda for the Second Session of Regional Association VI, and the result of its examination was agreement to recommend that the standard hours be fixed at 0000, 0600, 1200 and 1800 G.M.T., the Executive Committee being invited to consider the question as a matter of urgency and to seek the approval of Member countries by correspondence. It was felt desirable that the change should be made in time to be effective during the forthcoming International Geophysical Year.

A requirement for a wider dissemination within the Region of upper air data for high levels resulted in the adoption of a Resolution that the levels of 150 and 100 mb. shall be standard isobaric surfaces in the Region. In order that the inclusion of data for these levels in aerological reports should not cause undue delays in dissemination of upper air data, it was agreed that messages containing these data should be divided and transmitted in two parts, the first part containing reports up to the 100-mb. level inclusive, and the second part information for all higher levels. It was also decided that the time of launching of balloons shall be 0200, 0800, 1400 and 2000 G.M.T. (as long as the present standard times for these observations remain unchanged), and that the filing time for the first message shall not be later than two hours after the launching of the balloon, every effort being made to reduce this interval to the minimum possible.

Although the subject of forecasting for high-level flights was included on the Agenda, no opportunity was afforded for the discussion of actual forecasting techniques, and it seemed that only a few countries represented had, as yet, sufficient experience in this field to be in a position to make any substantial contribution to such a discussion in respect of levels above 300 mb. It was, therefore, resolved to invite Members of the Region to inform the World Meteorological Organization Secretariat regarding these aspects of forecasting for high-level flights on which they considered it desirable to have an exchange of opinion. The information so obtained would be circulated to all Members of Regional Association VI for comments, and the President will then, at his discretion, convene a meeting of experts from Member countries interested to examine the problems raised.

The subject of the preparation of climatological atlases on a regional basis gave rise to considerable discussion. Many delegates thought it premature to consider preparing such atlases whilst a number of countries were still deeply engaged in constructing national atlases. Notwithstanding that a Working Group on Climatological Atlases has been established by the Executive Committee, it was decided to set up a Working Group within Regional Association VI consisting of representatives of Sweden, Austria, Italy and the Federal Republic of Germany to advise the Executive Committee's Working Group regarding particular problems arising from the preparation of national atlases within Region VI.

The importance of correcting radio-sonde observations for radiation errors as a means of improving the homogenity of these observations within the Region was recognized, and it was decided to recommend that the World Meteorological Organization Secretariat should request Members to notify the Secretariat of the nature of the radiation corrections currently applied in their respective Services, and to state, if no corrections are made, whether they plan to introduce such corrections before the beginning of the International Geophysical Year on July 1, 1957. The results of this inquiry would be distributed to Members of the Organization and also to the President of the Commission for Instruments and Methods of Observation, for further study.

The problem of the measurement of the radio-activity of precipitation and of the atmosphere was considered, and it was decided that, since this matter is one of practical and scientific interest to Members, notwithstanding that observations made may not be directly used in the activities of all meteorological services, Members should be invited to arrange as far as possible for their Meteorological Services to participate in the making of such observations, taking into account the interest of public health organizations in this matter, and encouraging close co-operation between meteorological services and other organizations interested in radio-activity.

For the past five years the Netherlands Meteorological Service has been required to meet an increasing demand for temperature forecasts for several places abroad. In particular, international transport companies operating in the Netherlands are interested in such forecasts in connexion with the transport by land, sea or air of perishable goods such as bananas, potatoes and flour, and temperature forecasts for Belgium, Czechoslovakia, Denmark, France, Germany, Italy, Norway, Sweden and the United Kingdom are now prepared daily on a routine basis. The Netherlands delegation accordingly invited a discussion on the question of whether a system for the exchange of temperature forecasts similar to that which operates in regard to landing forecasts for aviation might be introduced. Stations in the United Kingdom in respect of which forecast temperatures are being supplied by the Netherlands Meteorological Service are Glasgow, Liverpool and London. As a result of the discussions a Resolution was adopted specifying the code to be used for the exchange of these temperature forecasts, and Members requiring such forecasts from other Members will arrange for their exchange on the basis of bi-lateral or multi-lateral arrangements.

In the field of telecommunication, one of the interesting features is the recognition by a large majority of countries that the exchange of meteorological data by Morse radio is well on its way to becoming a thing of the past so far as Europe is concerned. The emphasis now is on the use of teleprinter circuits and broadcasts, both land-line and radio, not only because teleprinter technique is almost three times faster, but also because it lends itself so easily to automatic tape-relay operation. Since January 1, 1956 the broadcast from New York has been by radio-teleprinter, and Australia has also adopted this form of transmission, but it was hardly expected that so many European countries would show as much readiness to extend the use of the newer form of communication for meteorological purposes as they did at Dubrovnik.

One resolution adopted at the Session called for a study by the principal "sub-continental" broadcasting centres of the best means of implementing radio-teleprinter transmission broadcasts; these may eventually take the place of the existing Morse broadcasts which have been in operation for the past quarter of a century. Another re-emphasized the economy which would be effected both in transmitters and radio-frequencies if those countries which have a relatively small amount of data to disseminate were grouped together. One country would undertake to make a single combined broadcast to replace three or four separate "territorial" (previously known as "national") broadcasts. Another recommendation related to the need for a detailed investigation to be made of all communication channels now used in Europe both for the exchange of basic synoptic bulletins and data required specifically for aeronautical meteorological purposes. Such an investigation will require very considerable research in the available facilities and the collection of material which would need to be put before a special joint meeting of the World Meteorological and International Civil Aviation Organizations. It is highly probable that the use of land-line teleprinter circuits will be exploited to the full, and that Morse radio broadcasts will be limited to those cases where no other means of exchange can be utilized.

Perhaps the most striking Resolution, however, was that containing a decision that the teleprinter network which has functioned so well in western Europe, with focal points at Dunstable, Paris and Frankfurt, and familiarly known as "IMTNE" (International Meteorological Teleprinter Network in Europe) should be linked with a network which comprises circuits between Prague, Potsdam, Budapest, Warsaw and Moscow. Details of the connexion, the circuit to be adopted and schedules for the exchange of meteorological information have still to be worked out, but the final outcome should lessen very considerably the necessity for main meteorological centres having to depend on the interception of outmoded hand-speed Morse radio broadcasts. A suggestion was made at the Dubrovnik meeting that one link between the two teleprinter networks should be between Frankfurt and Prague. Countries which are served by the existing Western European Network are France, Belgium, Netherlands, United Kingdom, Italy, Switzerland, Denmark, Norway, Sweden, Western Germany, Austria, Finland and Ireland*.

The exchange of weather maps by facsimile was also discussed at some length at the Session. It was recognized that this technique particularly lends itself to the reception of actual and forecast analysis charts covering a wide area. Telegraphy involves the laborious coding and decoding of a vast number of selected points on curves for many levels of the atmosphere, and the resultant drawings, based as they must be on the limited amount of data (number of points) for which transmission time is available, are often far from satisfactory. Facsimile provides the recipient with a chart identical with that prepared at the analysis centre without the expenditure of any man-power or time in decoding and plotting. The following European countries are already making use of facsimile either operationally or experimentally: Austria, Belgium, Denmark, Greenland, Finland, France, Germany, Italy, Norway, Sweden, United Kingdom, U.S.S.R. The meeting agreed to a resolution asking that existing broadcasts be continued and that all main "sub-continental" centres should ultimately provide scheduled broadcasts. It is obviously of paramount importance at this stage in the development of facsimile that apparatus produced in various countries should be compatible. A working group produced specifications for standardization based principally upon meteorological requirements, and it was agreed that these should be presented to the appropriate Study Groups of the International Telegraph Consultative Committee as a contribution to their studies of the technical considerations involved.

* OCKENDEN C. V.; A new international meteorological communications centre at Frankfurt. *Met. Mag., London*, 83, 1954, p. 122.

It is, of course, difficult to forecast the rate of progress in the fields of radio-teleprinter and radio-facsimile transmissions, but it may be that, even in two years' time, main meteorological collecting centres will no longer require to receive messages in Morse except from isolated locations and weather ships, and that material for the whole of a hemisphere will be collected by the use of only a very few receiving aerials. The integration of the requirements of the different Regions of the World Meteorological Organization is, of course, a matter for the Commission of Synoptic Meteorology, and it is probable that its Working Group on Telecommunication will, as a result of Regional developments, be in a position to recommend very substantial modifications to the "continental", "sub-continental" and "territorial" Morse broadcasts which have served so well in the past but which are now having to be replaced by more mechanized techniques. The advent of numerical forecasting methods is one factor which has emphasized the requirement for exchanging raw data within a wide area with a much higher speed than has hitherto been necessary; another factor is, of course, the increasing use of high-speed jet aircraft both for civil and military purposes.

At the conclusion of the session Dr. A. Nyberg (Sweden) was elected President in succession to Professor Lugeon, and Mr. Perović (Yugoslavia) was elected Vice-President.

LETTER TO THE EDITOR

An unusually smooth wave pattern in a condensation trail

In his article in your February issue on the deformation of a condensation trail in a series of lee waves Mr. Harper states with regard to standing waves, that "increase of wind with height in the lower layers of the air stream, and the presence of a deep isothermal layer are very favourable for their development". Although I am sceptical about Mr. Harper's explanation of the form of the trail he saw, because I do not think that standing waves of the amplitude he requires would have been set up, I found his discussion of what would happen to a trail in waves most interesting.

However, the statement he makes about conditions for lee waves is not correctly applied in the instance in question. Theoretical justification for the statement is based on the assumption that in the layers of strong wind (or, more correctly, of small value of l) the amplitude of the waves decreases upwards so that at levels above the tropopause, for instance, where l increases again, the amplitude is quite negligible. Perturbation theory cannot at present be applied to the layers in which l increases upwards to great heights and is only applicable to the lower layers, as in the case reported upon by Mr. Chambers in the article following Mr. Harper's, and the observations confirming the theoretical ideas have all been made in the lower layers of air well below the wind maximum.

Imperial College, London, March 23, 1956. R. S. SCORER

[I gladly accept Dr. Scorer's warning that there is as yet no support from theory for the occurrence of standing waves in the higher layers of the atmosphere. I included the l^2 profile as evidence that conditions were favourable for standing waves in the lower layers. This was admittedly not evidence that they could occur at higher levels, but conditions in the lower layers unfavourable for standing waves would of course have been strong evidence against the possibility.—W. G. HARPER.]

NOTES AND NEWS

Storm at Tengah, December 21, 1955

At 1606 local time (0836 G.M.T.) on December 21, 1955 a squall lasting almost 1 min. moved across the airfield at Tengah from north-east to south-west.

During the period of the squall the following phenomena occurred.

Surface wind rose suddenly to 40 kt. having been north-easterly 2–4 kt., 1·4 mm. (0·05 in.) of rain was recorded, almost all of which fell in 30–40 sec., i.e. at a rate between 125 and 170 mm./hr. (or between 5 and 6·5 in./hr.).

Atmospheric pressure fell 1 mb. instantly followed by a period of steadiness, and then the normal diurnal fall continued.

Temperature fell instantly from 85°F. to 80°F. Relative humidity rose from 54 to 84 per cent. (approx.).

The state of the sky immediately before and after the storm was as follows:

Before.—Two oktas, fair-weather cumulus, base 2,500 ft. tops 5,000 ft., scattered generally over the whole sky but with a greater concentration between north and east.

After.—Three large clouds, cumulus or cumulonimbus, base 1,500 ft. tops above 20,000 ft. in the following positions relative to the airfield: one 5–10 miles to the west-north-west, one 5–10 miles to the south and one 3–5 miles to the south-east. Four oktas altocumulus scattered generally over the whole sky.

The upper winds at 1630 local time over south Malaya were 20–40° 15–20 kt. at 3,000 and 5,000 ft. and 340–360° 5–10 kt. at 10,000–20,000 ft.

The storm itself passed over the airfield at about 30 kt. The rain for a very short period, a matter of seconds only, was torrential, reducing the visibility to 500 yd. or less, but at no time did there appear to be any cloud above the storm or up wind of it apart from the fair-weather cumulus. The large cumulus and cumulonimbus previously mentioned were visible long after the storm had disappeared and were moving much more slowly.

These phenomena were observed by several witnesses including a meteorological observer who was off duty at the time, the Duty Air Traffic Control Officer, and a pilot who was landing at the airfield at the time of its occurrence. All agreed that there was no cloud above the storm itself which, after crossing the airfield, either dispersed or went out of sight to the south-west.

P. W. SHORNEY

February 1956—a very cold month in Western Germany

February 1956 was a notably cold month in most parts of Europe and this was particularly true in Western Germany where the severe cold was a complete contrast to the relative mildness of December and January.

The month opened with two days of very severe cold weather. Maximum temperatures on the 1st were exceptionally low and were the lowest recorded during the month at all meteorological stations in north-west Germany. At many stations in the eastern part of north-west Germany the maximum temperature was no more than 5°F. and did not exceed 8°F. at Wildenrath in the western part. After a relatively mild spell lasting from the 3rd to the 8th during which several stations reported maximum temperatures of above freezing point, very severe weather returned on the 9th. From the 9th to the 26th only three stations, Sylt, Wahn and Wildenrath recorded a temperature above freezing point. Milder weather developed on the 27th–29th with maximum temperatures on the latter date ranging from 37° to 45°F.

The lowest temperature of the month occurred during the second severe spell; on the night of the 15th–16th at most stations in the area. The exceptionally low temperatures reported on this night were much lower than any experienced in the ten previous winters. One of the coldest places was Fassberg with a minimum temperature of −15°F. while many stations reported minima within the range −5° to −12°F. These may have been record low temperatures in many parts of the area, although it is difficult to be certain for no pre-war records are available for many of the present stations and little climatological data are as yet readily available for the period 1930–45. However, comparison with some data available for the approximate period 1881–1930 would suggest that the February 1956 minimum temperatures recorded in the western part of north-west Germany are lower than any given in the records so far available. For the eastern and northern parts of the area, lower temperatures were probably recorded in 1929 and possibly in 1881.

The unusual severity of the weather is reflected in the high number of ice days reported during the month, i.e. days on which the maximum temperature did not exceed 32°F. With one exception, Laarbruck with a total of 16, all stations reported between 20 and 25 ice days in the month. These figures may be compared with a 50-yr. average February figure of 4–5 days/month for a representative selection of stations in western Germany.

Finally, although probably not making any contribution to temperature records created during the month, it is interesting to report the very large daily range of temperature recorded at Fassberg on the 25th and at Wahn on the 26th. It amounted to 40°F. in both cases.

REVIEWS

Surveys in mechanics: G. I. Taylor 70th anniversary volume. Edited by G. K. Batchelor and R. M. Davies. 8½ in. × 5½ in., pp. viii + 475. *Illus.*, Cambridge University Press, 1956. Price: 50*s.*

It was a happy thought of Dr. Batchelor and Prof. Davies to bring out this volume of essays, a specially bound copy of which was presented to "G. I. " at a dinner in Trinity College, Cambridge, on his seventieth birthday, March 7, 1956. Sir Geoffrey Taylor is our leading classical mathematical physicist, a scientist in the great tradition of Kelvin, Stokes, Maxwell and Rayleigh, and the "surveys of the present position of research in some branches of mechanics" which make up this volume reflect the wide range of subjects to which he has added significantly. In addition, he is an ingenious and skilled experimenter, and it is appropriate that the frontispiece of this book shows him, characteristically, making an adjustment to apparatus which, one suspects, is concerned with a problem in fluid motion, was probably made up of bits and pieces at very low cost, and works perfectly!

The book opens with a brief delightful biography by Sir Richard Southwell. There follow three essays on the physics of the solid state: on plastic deformation by Hill, on dislocations in crystalline solids by Mott and on stress waves in solids by Davies. But the real love of Taylor's life is fluid mechanics, and this is well covered by contributions from Squire on rotating fluids, Lighthill on sound waves of finite amplitude, Lane and Green (of the Experimental Station, Porton) on drops and bubbles, Ursell on wave generation by wind, Batchelor and Townsend on turbulent diffusion, Ellison on atmospheric turbulence and finally K. S. M. Davidson (of New York) on the mechanics of sailing ships and yachts. There is something here for everyone who is interested in classical physics, but for obvious reasons this review will be confined to topics of interest in meteorology.

Lane and Green give a comprehensive and most useful review of existing knowledge on drops and bubbles, beginning with an account of the shape and (laboratory) production of drops and proceeding to a discussion of terminal velocities of water drops in air. Very minute drops obey Stokes' Law, larger drops behave like rigid spheres up to about 1 mm. diameter, but drops bigger than these are subject to deformation (which increases the drag) and to internal circulation (which causes slip at the boundary and a reduction in drag), and exact calculation is not feasible. The accurate measurement of terminal velocities is a difficult problem, but values tabulated in this essay show that there is now substantial agreement between the various experimenters. The earlier determinations of Lenard, Schmidt and Flower, which have appeared so long in meteorological literature, may now be disregarded, and Best's simple empirical formula for terminal velocities can be looked upon as sufficiently accurate for most practical purposes. The remainder of this well written contribution deals with the break-up of drops by air streams, impact on solid bodies and the dynamics of bubbles.

Ursell's essay on wave generation by wind gives a useful critical review of the various theories that have been advanced in this difficult subject and, in addition, discusses the "roughness" (in the aerodynamical sense) of the sea. The need for more accurate determinations of velocity profiles over the ocean is emphasized, but this is an exceedingly difficult problem for meteorologists, and progress is doubtful.

"Turbulent diffusion", by Batchelor and Townsend, is in the main a digest of recent mathematical papers by Batchelor, with illustrations from the measurements of Townsend and others (chiefly in America) on diffusion in pipes and behind a grid in a wind-tunnel (decaying homogeneous turbulence). This is "basic research" in the true sense, not always easy to follow because of its abstract nature and the condensation into essay form, but obligatory reading for anyone who wishes to make headway in this difficult subject. The application to the atmospheric problem is not immediate, as the authors point out, but the insistence on postulates of a fundamental nature and the emphasis on mathematical rigour are salutary, and this admirable essay may well become a much quoted reference in the future.

The account of current research on atmospheric turbulence by T. H. Ellison is hardly likely to satisfy the professional meteorologist, for it repeats much of what is now commonplace in meteorological texts, and unfortunately, is often misleading regarding what has happened, and is happening, in meteorological research. The article is concerned mainly with the velocity field near the surface. The problem of the approach to the geostrophic wind with the eddy viscosity varying with height is dealt with as if it were new; actually, complete mathematical solutions were published over twenty years ago by Köhler (one-layer power-law formulation) and by Rossby and Montgomery (two-layer formulation), but neither memoir is mentioned. The discussions of the recent work of Sheppard and others on winds in the friction layer, and of the effects of stability on the profiles, are excellent, but the same cannot be said of the account of the turbulent velocity fluctuations. Here the author reverts to the early bi-vane investigations of Taylor and Scrase, and states that "no definite dependence on stability was found", but he omits to explain that this is because Scrase carefully restricted his observations to occasions when stabilizing forces were absent. For a detailed study of the effects of temperature gradient one must go to Best's well known *Geophysical Memoirs* No. 65, published in 1935, but this work is ignored, and there is no mention of recent American studies of the spectrum of turbulence. Further, the most reliable data show that equality of the lateral and vertical eddy velocities is reached at a height between 20 and 25 m., and not at 25 ft. as stated in this essay. The meteorologist will rub his eyes when he reads the categorical statement that "Findeisen (1936) and Gödecke (1935) were the first to use hot-wire anemometers in the atmosphere"; actually, Albrecht published a description of his instrument in 1930, Best used a hot-wire anemometer in 1931, and, if the point were of importance, a little diligent search of the literature would doubtless produce even earlier examples.

The account of heat transfer is inadequate as an expression of modern trends in this research (restriction on space may, of course, account in part for this) and it includes a speculation on the relation between air and surface temperatures which is very unlikely to be true. Current research in micrometeorology is moving away from artificial concepts such as *austausch* coefficients, and is much more concerned with direct measurements and interpretations of the fluxes and the fluctuations in its attempt to construct a reliable working model of atmospheric transfer processes. The essay fails to bring this out, and may well leave the impression that the meteorologist is still somewhere in the Stone Age of physics!

"G. I." is a renowned yachtsman, and it is appropriate that the book concludes with a delightful informative essay by Davidson on the aerodynamics of sailing and the factors that make for high efficiency in racing yachts. Even non-sailors will find this interesting and rewarding reading.

The book is produced in conformity with the high standards of the Cambridge University Press, but it is a pity that the editors did not see fit to include an index, for the ground covered is immense and the book is likely to prove a useful work of reference.

O. G. SUTTON

Realms of water. Some aspects of its cycle in nature. By P. H. Kuenen. $9\frac{1}{2}$ in. $\times 6\frac{1}{2}$ in., pp. 327, *Illus.*, Cleaver-Hume Press Ltd, London, 1955. Price: 35*s.*

Modern highly organized societies, though always tending to take for granted any well run communal service, are slowly becoming more hydrosophic or water-wise. This is understandable and not before time. Rapidly increasing demands for enormous supplies of water for domestic and industrial use, for hydro-electric power, and for irrigation, have begun to impose a severe strain even in lands where large-scale water-supply undertakings have a long history of successful achievement. The difficulties experienced during an unusually dry period are still not widely enough appreciated outside the domains of water-supply engineers and their professional associates, but we may yet reach a stage where most of us, having the necessary knowledge forced on our attention, will be actually afraid of a really fine summer. (It should be remembered that the magnificent summer weather of 1955 in Great Britain, which resulted in water shortages and reduced yields of important crops, including potatoes, did not begin until early July.) Moreover, in nearly all the under-developed regions of the earth a copious and controllable supply of water is the basic requirement before there can be any significant development of agriculture or industry, or any appreciable improvement in the standard of living.

Leaving out of account, at present, problems concerned with snow and ice or with water in the oceans, all with some bearing on human activities, the other side of the picture is that flood hazards are not abating. Whether or not there has been, of late, either a cyclic or non-cyclic increase in the frequency of the catastrophes with which man is troubled, it is beyond doubt that, by building on or otherwise developing or reclaiming land which in earlier times was relatively left alone, he is putting himself in ever larger numbers in the direct natural path of both tidal and river floods—without always being able to take adequate precautions to ensure that their destructive power can be kept within controlled bounds. Concurrently, through highly developed means of communication even the most distant neighbours can be kept informed of what is happening, and we have long been accustomed to learning, without much delay, about floods in China, India and the United States, as well as in Holland and on the east coast of England, or in Lynmouth and Weymouth. If this is not enough, the man-made problem of storm-water drainage in imperviously paved urban areas can, for some of us, bring a milder nuisance to (and over) our own doorsteps.

In recent decades there has therefore appeared a growing international literature, mainly technical and scientific, relating to hydrology and kindred studies. It is perhaps inevitable that this will be followed by a festive season for the popularizers and (probably even worse) the producers of semi-popular works. Both the fully popular and the semi-popular are dangerous fields in which to operate. The few successful products are likely to give long and valuable service, but any specimen from the remainder is equally likely, after a short time, to be displayed as a "book bargain" at a smallish fraction of its original price. For complete success an author must have an understanding which is broad as well as deep, for he must be capable of a sound appreciation of both the minds from which he learns and those he hopes to instruct, and he must also have a command of language enabling him to combine accuracy of information and precision of style with a compelling clarity or even simplicity—but without patronizing naïvety or whimsy. It is a further advantage if he has a main theme with an immediate appeal to the imagination, of which he wishes to give a lucid exposition, and in relation to which he can select the most important material and arrange it in a coherent pattern without digressing too much over additional information. The alternative is to face the risk of presenting a hotchpotch of miscellaneous knowledge which it is hoped will be interesting or amusing. (It need hardly be added that the job should preferably be tackled for the sheer love of it, as the financial reward is not likely to be commensurate with the qualifications suggested).

Reading this book with such thoughts in mind, it loses points on all counts, and even by far less rigorous standards it could not be called more than a limited success. A first impression is that the translation is not altogether happy, the very title preparing the mind for this; a second, without having to read very far, is that the original cannot have been the happiest of material to translate. There are interesting, informative, and moderately well written passages, some of them long, but the text is uneven and in other parts it abounds in statements which make one wonder what ought to be done about popularizers. One of the plums, for meteorologists, appears somewhat unexpectedly in the chapter on the oceans: ". . . the rainfall in Great Britain has been related to the temperature of the water in the vicinity of Newfoundland in the previous year. On this basis, long-term weather forecasts can sometimes be made for north-west Europe." Not the least interesting exercise to be derived from this quotation is to ponder on the exact meaning of "sometimes" in that context—whilst accepting, purely for the purpose of the exercise, everything else. The choice of word or phrase is frequently faulty, and though the translator may occasionally be to blame, it seems probable that the author is much more frequently guilty. The nadir is reached in a sentence rounding off the definition of cumulus: "Their contours are well defined and, fair-weather clouds as they are, it is upon them that the cherubs are reputed to frolic (Plate VII, 1)." The plate thus referred to reproduces a completely inoffensive photograph of large cumulus which is worthy of being brought to notice in a much more dignified way.

The plan of the book is ambitious. There is a brief introduction with a general discussion of the hydrological cycle and a summary of the special properties of water which make it "the most extraordinary of all compounds known to science"—an interesting conclusion which, even if not accepted, should not be underrated through a superficial familiarity with the substance. Then follow chapters with suitably "popular" headings running here and there through the fields of oceanography, hydrometeorology, cryology, geohydrology, and potamology and limnology, thus following the course of the major cycle. Examples in geomorphology are thrown in, for good measure, in the appropriate chapters, and indeed they provide some of the best material offered. The conclusion deals with the hydrological and salinity balance for terrestrial waters as a whole. It is obvious that to succeed in covering all this ground at all adequately in a book of this size, however popular the treatment, would be little short of miraculous. It is not surprising, therefore, that within the major framework, admirable as such, the subject matter of individual chapters is very "bitty" and sometimes takes disconcerting leaps. It is true that the author has given a warning about this in his foreword, and it might not be a serious fault in itself if the separate bits were always clear. Too often there are "explanations", sometimes of relatively simple ideas, which are laboured and confusing, and the frequent use of a certain type of phrase, usually "as we have seen", vaguely referring back to equally confused explanations, or merely to bald assertions, is not very helpful. It is a pompous didacticism which is used most and irritates most in bad teaching. The definition and discussion of capillarity, in dealing with soil moisture and ground water, extend over three pages, with diagrams, to constitute one of the least effective passages in the book. This is a great pity, the more so as there is a failure to provide any adequate treatment of water in the soil, and the reader without previous knowledge must inevitably be left with merely a hazy idea that it connects in some sort of way with ground water. After the barest mention of soil moisture, any water which is not in the ocean, in the atmosphere, or visible on the surface as snow, glacier, river or lake (with their smaller variations), tends to become confused with ground water proper, or at best with the capillary zone immediately above the ground water table. But the behaviour and function of soil moisture are of the utmost significance in nearly all problems of land hydrology, and a very important "realm"—the most important for the social and economic life of the human race, and in fact for all animal and vegetable life on land—is thus lightly passed over.

The main theme of the book, that water passes continuously through a cycle, with sub-cycles, is probably too slender for a work of this kind. The theme with the resultant framework, enlarged to include a separate chapter on soil-moisture relationships, could make an excellent foundation for a serious textbook, but it cannot sustain the lengthy digressions which are necessary to treat the subject at large and at the same time retain a popular appeal. Again and again the volume is on the verge of becoming the "Tristram Shandy" of hydrology. Praiseworthy though it undoubtedly is for its intention, it fails through its own internal stresses set up by trying to shape a poorly prepared alloy in an unsuitable mould.

A. BLEASDALE

Prilog teoriji higrografa (*Zur Theorie des Hygrographen*). By Branko Maksić. *Abh. Abt. math. phys. tech. Wiss., Zagreb*, **1**, 1955, 11¼ in. × 8 in., pp. 41, *Illus.*

This pamphlet gives an elaborate discussion of the geometry of the hair hygrograph. It opens by finding a series in powers of relative humidity for the Gay-Lussac number, ratio $(l_u - l_0)/(l_{100} - l_0)$, where l is the length of the hair at relative humidity u. A series terminating at u^3 gives u from the Gay-Lussac number with an accuracy better than 1 per cent. over the whole range 0–100 per cent. and better than ½ per cent. over most of it. This series is then applied to the geometry of a hair hygrograph with the hair gripped by a hook at any point and moving the pen by a lever, as in the Fuess hygrograph, in which a short arm is fixed to the hook and a second carries the pen. Formulae giving displacements of hair and pen and the scale value in terms of relative humidity are determined. In fact the hook is approximately at the centre, and the formulae are used to examine the effects of zero adjustment obtained, as in the Fuess hygrograph, by moving one end of the hair towards or away from the other and altering the length of the short arm. Tables and diagrams of the corrections necessary after adjustment are provided.

G. A. BULL

OBITUARY

J. G. Balk.—We regret to report the sudden death on April 9, 1956, of Mr. J. G. Balk, who was an observer at the Radcliffe climatological station Oxford for 51 years, until his retirement in June 1954. During this long period of observing, rarely equalled, Mr. Balk gave the closest co-operation to the Meteorological Office, and maintained the highest standards of reporting. His note on the frequency of solar and lunar halos at Oxford, 1882–1951, published in the *Meteorological Magazine* in September 1952, was an instance of Mr. Balk's absorbing interest in weather recording. He will be remembered for the notable way in which he upheld the best traditions of the voluntary observing on which so much of the work of the Meteorological Office Climatological Branch depends.

METEOROLOGICAL OFFICE NEWS

Retirements.—*Mr. W. G. Davies*, Senior Experimental Officer, retired on April 30, 1956. He first worked at the Royal Observatory, Greenwich from 1909 until August 1914 when he joined the Armed Forces. He later transferred to the Meteorological Section of the Royal Engineers and was commissioned in December, 1918. He joined the Office in August 1920 and served for 11 years in the Forecast Division at Headquarters. Since 1932 he has served at aviation outstations and has spent no less than 12 years at overseas stations. For the last four years he has served at the Air Traffic Control Centre at Watnall.

At a ceremony at Watnall on April 28, Mr. J. Briggs presented Mr. Davies with a cheque subscribed by his colleagues.

Mr. W. F. Peatfield, Experimental Officer, retired on May 2, 1956. He joined the Office in May 1921 after serving in the First World War. From then until 1940 he served at aviation outstations and from 1940 to 1947 at Porton. For the last eight years he has worked at Harrow.

At a ceremony at Harrow on April 27, Dr. A. G. Forsdyke presented Mr. Peatfield with a cheque subscribed by his colleagues.

Mr. Peatfield has accepted a temporary appointment in the Meteorological Office.

Staff.—Under the terms of the Anglo Iraqi Agreement of 1955 the Meteorological Office at Shaibah has been transferred to the Iraqi Authorities and in consequence, the Meteorological Office has lost the valuable service of Mr. Raymond Fernandez. The Iraqi Authorities have re-engaged him with other locally employed meteorological staff, and he is Senior Observer in charge of the Office.

Mr. Fernandez was engaged as meteorological observer on April 1, 1932. His long experience was of great value to the more transient United Kingdom-based staff at Shaibah and the many meteorologists who have served in Iraq will doubtless remember him and wish him well in the future.

Ocean weather ships.—The following are extracts from reports of ocean weather ships:

Weather Explorer—Voyage 65 at station K. March 9 to April 2, 1956.

The fine weather brought on a revival of cricket; inter-section matches were fought with great spirit to the cheers and jeers of a very partisan crowd.

Weather Observer—Voyage 69 at station J. March 4–27, 1956.

On March 25, the French Weather Ship *Mermoz* passed close to, bound from Alfa to Base. One of the Radio Operators exercised his French on the R/T with his opposite number on the *Mermoz*; he must have done quite well as a bottle of wine was ditched, which we recovered, as a token of friendship.

WEATHER OF APRIL 1956

April showed strongly anticyclonic conditions dominating the northern polar regions with mean pressures up to 10 mb. above normal, in marked contra-distinction to March 1956 when the mean circulation over the central Arctic was cyclonic. Pressure in April was also above normal over the eastern Atlantic and British Isles, where the dry weather, cold in the eastern half, was reminiscent of April last year; the associated patterns over the rest of the hemisphere were, however, radically different in 1955 and 1956. Cyclonic activity over the North Atlantic in April 1956 was rather scattered, affecting different parts of the ocean (chiefly latitudes below 50°N. and the region Newfoundland–south Greenland) in different parts of the month, and was seldom deep. The most vigorous and regular cyclonic activity over the northern hemisphere appears to have been over the North Pacific. There were also rather low pressure and excessive rainfall (up to 2½ times the normal) in a strip across Europe from the western Mediterranean to the eastern Baltic, though there cannot be said to have been movement of depressions from south to north along this track; the systems were generally moving east and south-east or coming to a halt in this part of the map.

Pressure was 5 mb. below normal over Mexico, where there were also great excesses of rainfall at many stations. This seems to have been related to a long extension of the polar anticyclone southwards in longitudes about 105°W. (pressures up to 6 mb. above normal) and an abnormal southward displacement of the polar-front activity during most of the month in this sector.

The month was generally rather cold in Europe, except over Ireland and the Balkans, and in the Norwegian Sea (greatest anomalies −7°C. in east Greenland, −4°C. in Lapland and −3°C. in central Germany). Temperature was also below normal across the whole of northern Asia north of 55°N. and over most of North America except the Arctic zone and north-eastern segment (main anomaly centres −4° to −7°C. over the Prairies, but +3°C. in the region Baffin Land–northern Quebec).

Over the British Isles which, for the major part of the month, either lay within an area of ill defined pressure distribution or came under the influence of nearby anticyclones, there was a marked absence of vigorous cyclonic activity.

The month began with sunny weather over most of the country, but owing to a north-easterly air stream off the North Sea, it was dull and cold in the south-east. An anticyclone over the central Atlantic intensified on the 3rd and freshening northerly winds brought showers to most parts of the British Isles, with local thunderstorms, but on the 5th more widespread outbreaks of rain accompanied the passage of a wave depression southward across eastern counties; the following evening a renewal of northerly winds behind the depression brought snow showers as far south as Spurn Head. A depression near Iceland deepened on the 7th, and the associated westerly winds over this country brought four days of milder cloudy weather; there were periods of rain in western and northern districts, but in the south this was the warmest part of the month with temperature rising to the mid-sixties in many places. An influx of arctic air, associated with a deepening depression over the Baltic, caused a sharp fall of temperature on the 11th; in parts of East Anglia afternoon temperatures were as much as 20°F. lower than on the previous day. The northern boundary of the Atlantic air moved slowly south over Wales and southern England between the 12th and 14th giving prolonged rain, the only very wet period in southern England during the month. There was a rise of pressure to the west of Ireland on the 15th and a northerly flow soon became established over the country bringing showers to the north, but in the south it was dry and sunny. By the 18th an anticyclone was centred over Scotland, and from that date until the 23rd the weather was dry and rather cold with widespread ground frost and some keen air frost locally. Pressure however over the British Isles was slowly falling during this period, and by the 24th the anticyclone had disappeared allowing a renewed influx of arctic air; there was slight rain in many parts of the country with isolated thunderstorms, and on the following day rain was prolonged over northern England with snow in places, especially in Yorkshire where in the Pennines it lay locally to a depth of 6 in. From the 26th, low pressure over western and central Europe gave rise to rather cold N.—NE. winds over the British Isles, with some scattered showers and long sunny periods, but on the last day of the month warmer air from the Atlantic brought temperatures back nearer to the normal.

It was a generally cold month. In the Midlands and eastern half of England both night and day temperatures were 2–4°F. below normal, and in some districts near the east coast even as much as 5°F., but in western and northern districts day temperatures were mostly near the average though the nights were unusually cold. Sunshine, except in parts of the Midlands and south-east England, was considerably above average. Parts of Devon, Cornwall and Lincolnshire had 50 hr. more than normal and Tynemouth had its sunniest April since 1939. Rainfall was below average almost everywhere, many places had less than half their usual amount. The growth of crops and grass has been retarded by the dry cold weather but most farming operations have progressed without hindrance. Fruit blossom has been vulnerable to frost for much of the month, especially in south-east England, and some damage was caused as a result of the frosts on the nights of the 6th–7th and 19th–20th.

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 ...	69	18	−2·8	75	−4	109
Scotland	65	18	−1·5	70	−2	124
Northern Ireland ...	63	25	−0·5	56	−4	112

RAINFALL OF APRIL 1956

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·16	75	*Glam.*	Cardiff, Penylan ...	1·85	74
Kent	Dover	0·74	46	*Pemb.*	Tenby	1·13	49
„	Edenbridge, Falconhurst	1·40	75	*Radnor*	Tyrmynydd	2·30	62
Sussex	Compton, Compton Ho.	2·54	127	*Mont.*	Lake Vyrnwy	1·76	56
„	Worthing, Beach Ho. Pk.	1·49	96	*Mer.*	Blaenau Festiniog ...	2·73	44
Hants.	St. Catherine's L'thouse	1·96	122	„	Aberdovey	1·53	59
„	Southampton (East Pk.)	2·03	110	*Carn.*	Llandudno	1·43	85
„	South Farnborough ...	·93	61	*Angl.*	Llanerchymedd ...	1·92	87
Herts.	Harpenden, Rothamsted	1·10	67	*I. Man*	Douglas, Borough Cem.	1·11	45
Bucks.	Slough, Upton	1·15	80	*Wigtown*	Newton Stewart ...	2·30	90
Oxford	Oxford, Radcliffe ...	1·89	118	*Dumf.*	Dumfries, Crichton R.I.	0·97	41
N'hants.	Wellingboro' Swanspool	1·04	70	„	Eskdalemuir Obsy. ...	1·05	31
Essex	Southend, W. W. ...	1·39	109	*Roxb.*	Crailing...	0·62	39
Suffolk	Felixstowe	0·66	55	*Peebles*	Stobo Castle	0·94	45
„	Lowestoft Sec. School ...	0·81	55	*Berwick*	Marchmont House ...	0·72	36
„	Bury St. Ed., Westley H.	0·97	63	*E. Loth.*	North Berwick Gas Wks.	0·44	32
Norfolk	Sandringham Ho. Gdns.	1·14	75	*Midl'n.*	Edinburgh, Blackf'd. H.	0·55	37
Wilts.	Aldbourne	1·77	90	*Lanark*	Hamilton W. W., T'nhill	0·76	41
Dorset	Creech Grange... ...	2·23	103	*Ayr*	Prestwick	0·90	52
„	Beaminster, East St. ...	1·07	45	„	Glen Afton, Ayr San. ...	1·64	55
Devon	Teignmouth, Den Gdns.	0·73	36	*Renfrew*	Greenock, Prospect Hill	1·97	57
„	Ilfracombe	1·50	72	*Bute*	Rothesay, Ardencraig ...	1·78	60
„	Princetown	2·14	42	*Argyll*	Morven, Drimnin ...	2·68	73
Cornwall	Bude, School House ...	0·76	40	„	Poltalloch	1·60	53
„	Penzance	0·68	28	„	Inveraray Castle ...	3·65	79
„	St. Austell	1·40	50	„	Islay, Eallabus	2·29	80
„	Scilly, Tresco Abbey ...	1·33	68	„	Tiree	2·36	96
Somerset	Taunton	1·81	103	*Kinross*	Loch Leven Sluice ...	0·84	44
Glos.	Cirencester	2·61	135	*Fife*	Leuchars Airfield ...	0·74	47
Salop	Church Stretton ...	1·39	64	*Perth*	Loch Dhu	...	...
„	Shrewsbury, Monkmore	1·53	103	„	Crieff, Strathearn Hyd.	0·94	43
Worcs.	Malvern, Free Library...	1·71	95	„	Pitlochry, Fincastle ...	0·81	36
Warwick	Birmingham, Edgbaston	1·53	80	*Angus*	Montrose, Sunnyside ...	1·24	68
Leics.	Thornton Reservoir ...	1·10	65	*Aberd.*	Braemar	1·58	67
Lincs.	Boston, Skirbeck ...	1·23	91	„	Dyce, Craibstone ...	1·55	75
„	Skegness, Marine Gdns.	1·15	86	„	New Deer School House	1·24	62
Notts.	Mansfield, Carr Bank ...	2·05	118	*Moray*	Gordon Castle	1·72	98
Derby	Buxton, Terrace Slopes	2·28	78	*Nairn*	Nairn, Achareidh ...	1·95	139
Ches.	Bidston Observatory ...	2·76	169	*Inverness*	Loch Ness, Garthbeg ...	2·86	125
„	Manchester, Ringway...	2·78	154	„	L. Hourn, Kinlochhourn	5·85	94
Lancs.	Stonyhurst College ...	1·65	61	„	Fort William, Teviot ...	3·89	86
„	Squires Gate	1·35	76	„	Skye, Broadford ...	2·99	66
Yorks.	Wakefield, Clarence Pk.	2·04	121	„	Skye, Duntuilm ...	2·93	90
„	Hull, Pearson Park ...	1·29	83	*R. & C.*	Tain, Mayfield... ...	2·27	124
„	Felixkirk, Mt. St.John...	1·40	84	„	Inverbroom, Glackour...	2·95	79
„	York Museum	1·66	104	„	Achnashellach	4·74	89
„	Scarborough	0·76	49	*Suth.*	Lochinver, Bank Ho. ...	2·51	88
„	Middlesbrough... ...	0·83	61	*Caith.*	Wick Airfield	1·69	85
„	Baldersdale, Hury Res.	1·03	47	*Shetland*	Lerwick Observatory ...	1·66	72
Norl'd.	Newcastle, Leazes Pk....	1·36	85	*Ferm.*	Crom Castle	0·87	34
„	Bellingham, High Green	0·85	39	*Armagh*	Armagh Observatory ...	1·07	51
„	Lilburn Tower Gdns. ...	0·93	47	*Down*	Seaforde	1·93	74
Cumb.	Geltsdale	1·41	66	*Antrim*	Aldergrove Airfield ...	1·00	47
„	Keswick, High Hill ...	1·20	39	„	Ballymena, Harryville...	1·40	53
„	Ravenglass, The Grove	0·91	37	*L'derry*	Garvagh, Moneydig ...	...	...
Mon.	A'gavenny, Plâs Derwen	2·16	78	„	Londonderry, Creggan	2·01	78
Glam.	Ystalyfera, Wern House	1·16	31	*Tyrone*	Omagh, Edenfel ...	1·43	54

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[*To face p. 192*

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ALTOCUMULUS FLOCCUS

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WORLD METEOROLOGICAL ORGANIZATION

Eighth Session of the Executive Committee, April 17–30, 1956

By SIR GRAHAM SUTTON, D.Sc., F.R.S.

When the Executive Committee met in Geneva on April 17, one of its first duties was to designate an acting elected member to replace Dr. A. Nyberg of Sweden, who was appointed as an elected member by Congress last year but who now sits as President of the European Regional Association. The Committee designated Dr. I. J. Lugeon, the Director of the Swiss Meteorological Service for the vacancy thus created. Dr. Lugeon was a member of the Executive Committee during the first financial period and has had much experience in international meteorology.

Although the session was short, a great deal of work was accomplished. As usual, the Committee split into two Working Committees; one to deal with technical questions under Dr. M. A. F. Barnett of New Zealand, the other to deal with administrative and financial problems under Prof. H. A. Ferreira, of Portugal. Both Working Committees performed their tasks expeditiously, but some difficult questions had to be postponed until the next session, and the general opinion was that two weeks is not long enough to complete the work which confronts the Executive Committee at its annual sessions.

The task of the Executive Committee is to supervise the work of the World Meteorological Organization between sessions of Congress. This means that at every session, the work of the Regional Associations and the Technical Commissions has to be reviewed, the annual budget approved and various matters connected with the central administration considered. This year the Committee had before it the report of the session of Regional Association VI (Europe) at Dubrovnik, as well as arrangements for the International Geophysical Year. For the latter, the scheme whereby the Secretariat of the World Meteorological Organization will act as the main collecting centre of meteorological information for the world was further considered, in both its technical and financial implications, and some important decisions were taken. The basis of the scheme is that the World Meteorological Organization Secretariat will reproduce the data on micro-opaque cards and afterwards sell sets of these cards to any country or institution which requires them.

The micro-opaque card system is likely to prove of considerable interest to meteorologists, who are becoming increasingly embarrassed by the problem of storing records and charts in an easily accessible form. A single card, measuring

3 in. × 5 in. can contain from 40 to 60 pages of material and can be read with comfort with the special viewing apparatus in a well lit room. Full details are given in the *WMO Bulletin**.

Among other matters, the Committee considered the problem of permanent accommodation for the World Meteorological Organization in Geneva. There are two possibilities: to make use of the proposed extension to the Palais des Nations or to accept the offer of the Canton of Geneva to rent a separate new building adjacent to the Palais. After much debate, the Executive Committee, by a large majority, decided to recommend to Members that the Canton offer be accepted in principle, and that the President and Secretary-General should be authorized to enter into detailed negotiations at an early date.

At the Second Congress last year, it was decided to utilize the greater part of the remaining funds of the old International Meteorological Organization to create a prize for outstanding work in the field of meteorology. The first recipient of the International Meteorological Organization Memorial Prize is Dr. T. Hesselberg who retired from the post of Director of the Norwegian Meteorological Service last year. The Executive Committee decided at this session that the Prize should consist of a substantial sum of money, a gold medal and a certificate with a citation. There was a lively and amusing debate on the language for the inscription on the medal, and finally it was decided to use Latin. The translation will be entrusted to an eminent classical scholar who, no doubt, will need to exercise his ingenuity to convey essentially modern concepts in the language of a long-dead civilization.

The weather during the session was anything but good, and this may well have influenced the Executive Committee when it decided that the next session will be in September 1957.

AVERAGE WIND AT 60 MB.

By J. K. BANNON, B.A. and R. A. JONES, M.Sc.

The average winds over the world at levels up to 100 mb. (approximately 16 Km.) have been described by Brooks and others[1] and more recently by Jenkinson[2]. This note presents charts of average winds at 60 mb. (approximately 20 Km.) prepared from the few data available for that level. A full description of methods of preparing these charts and tables of mean resultant vector winds and frequencies of wind directions at the 60-mb. level are contained in a report to the Meteorological Research Committee[3].

The charts were constructed from data obtained from many varied sources:

Radar wind and pilot-balloon observations[4–21].

Acoustical propagation studies for some American and Panama Canal Zone stations[22–25].

Contour-height data[2,26,27].

Temperature data[4,26,28–31].

The charts, Figs. 1–4, show the average stream-lines and isotachs for the months of January, April, July and October. In temperate and high latitudes the contour lines of the height of the 60-mb. pressure surface are taken as stream-lines and the isotachs are also derived from these contours, using the

* RIGBY, M.; Use of micro-opaque cards in meteorology. *WMO Bull., Geneva*, 5, 1956, p.53.

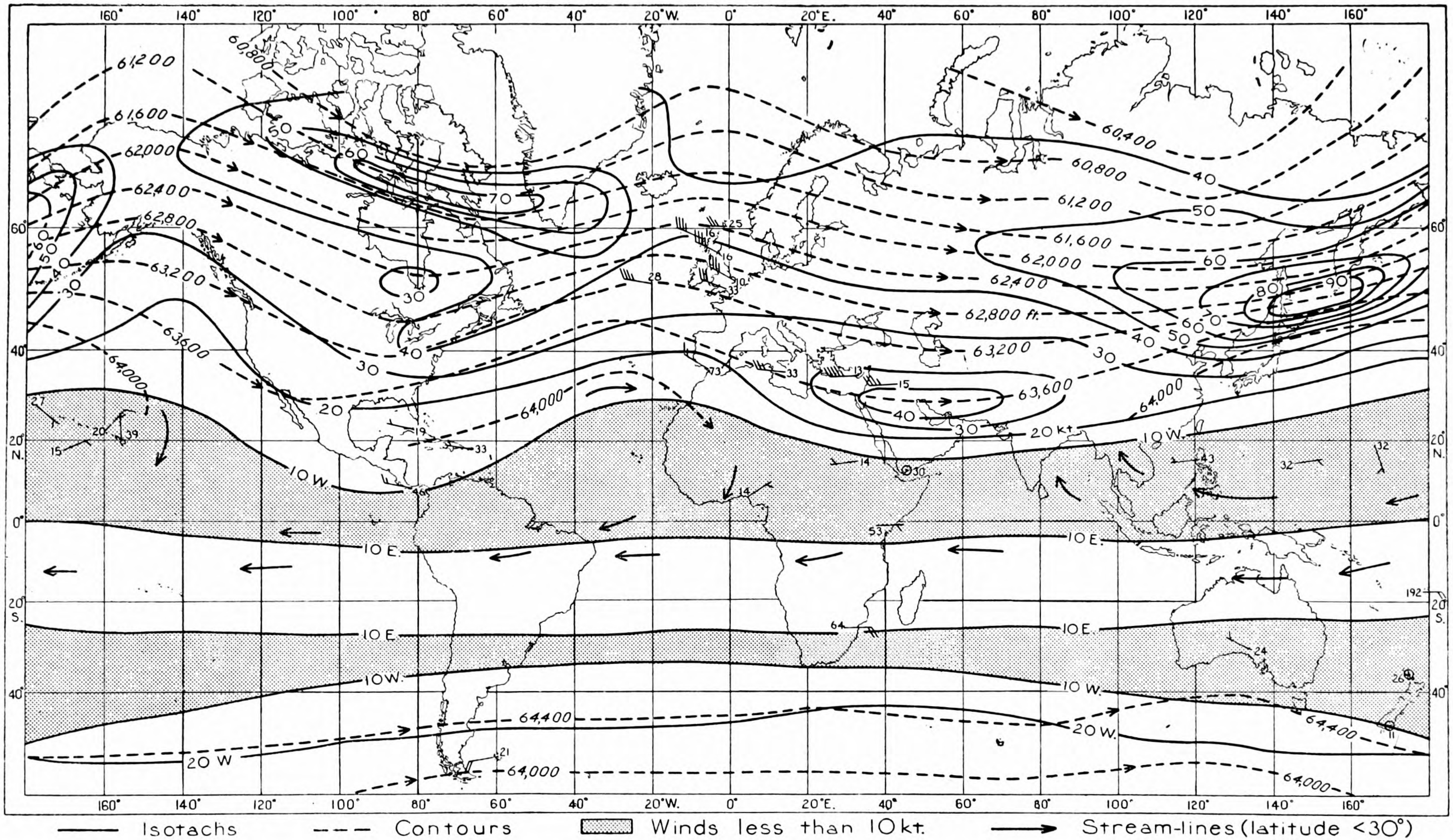


FIG. 1—MEAN WIND FLOW AT 60 MB., JANUARY
Number of observations is indicated near each wind arrow; wind speeds in knots are shown by conventional barbs

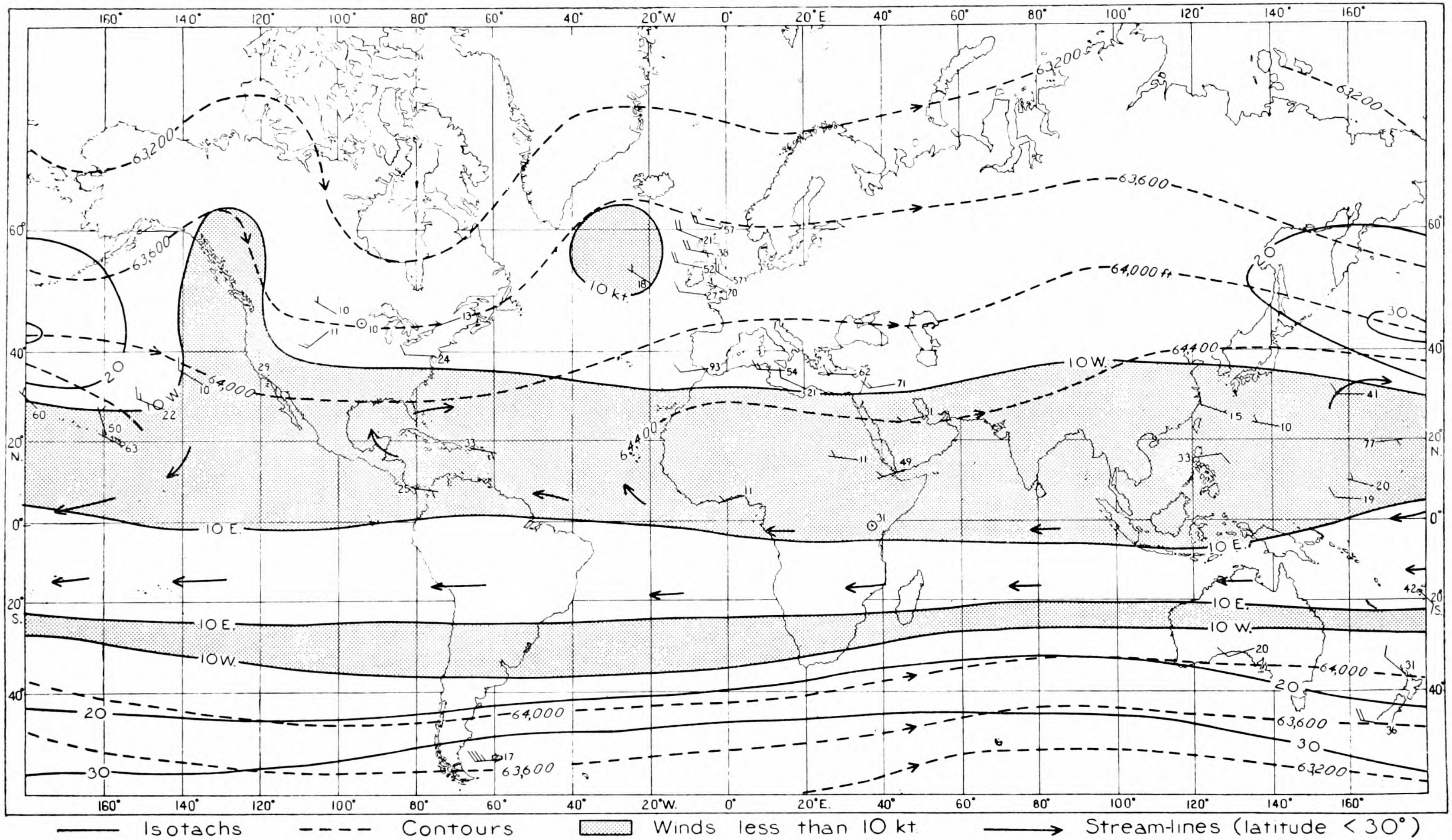


FIG. 2—MEAN WIND FLOW AT 60 MB., APRIL
Number of observations is indicated near each wind arrow; wind speeds in knots are shown by conventional barbs

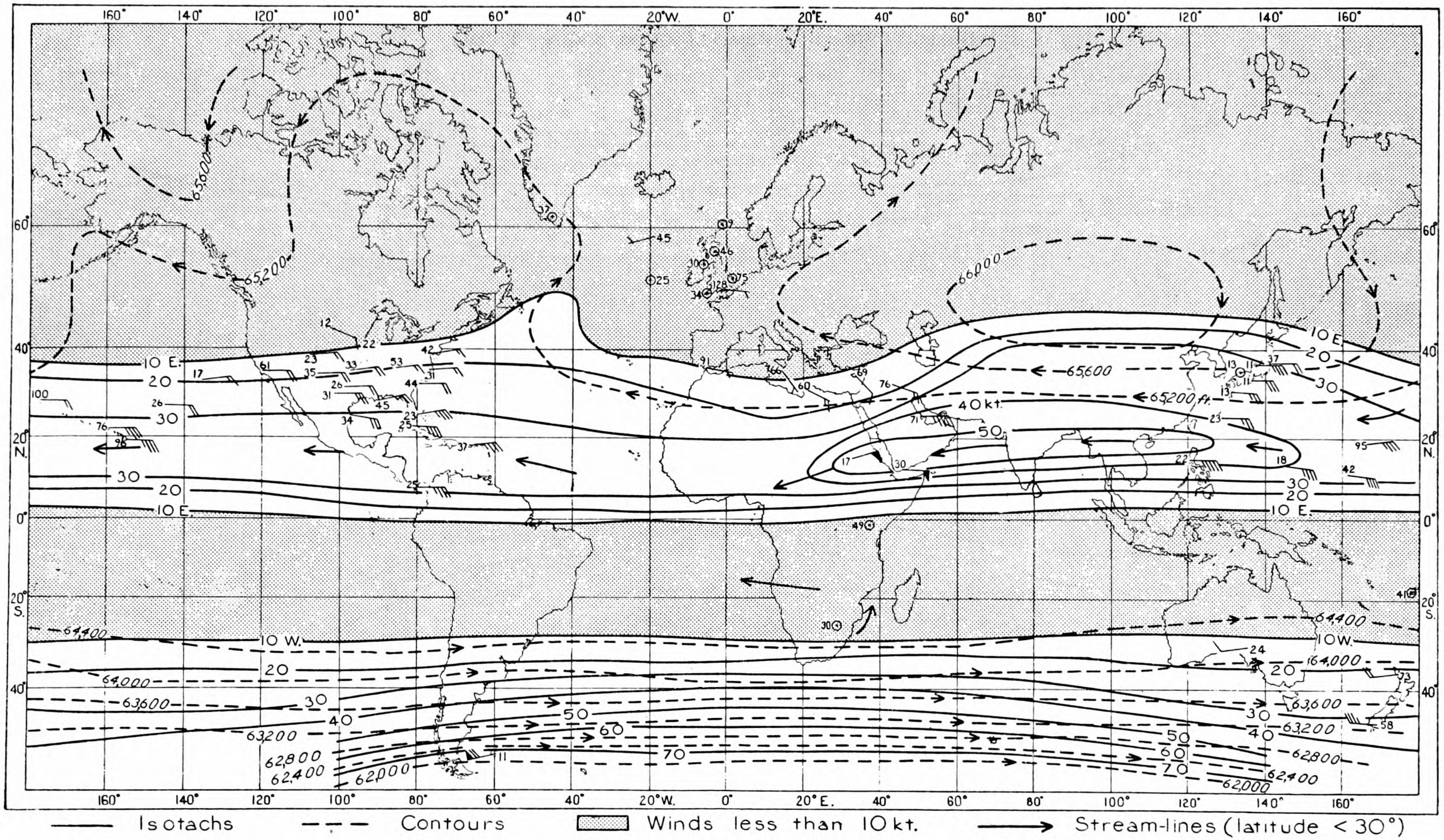
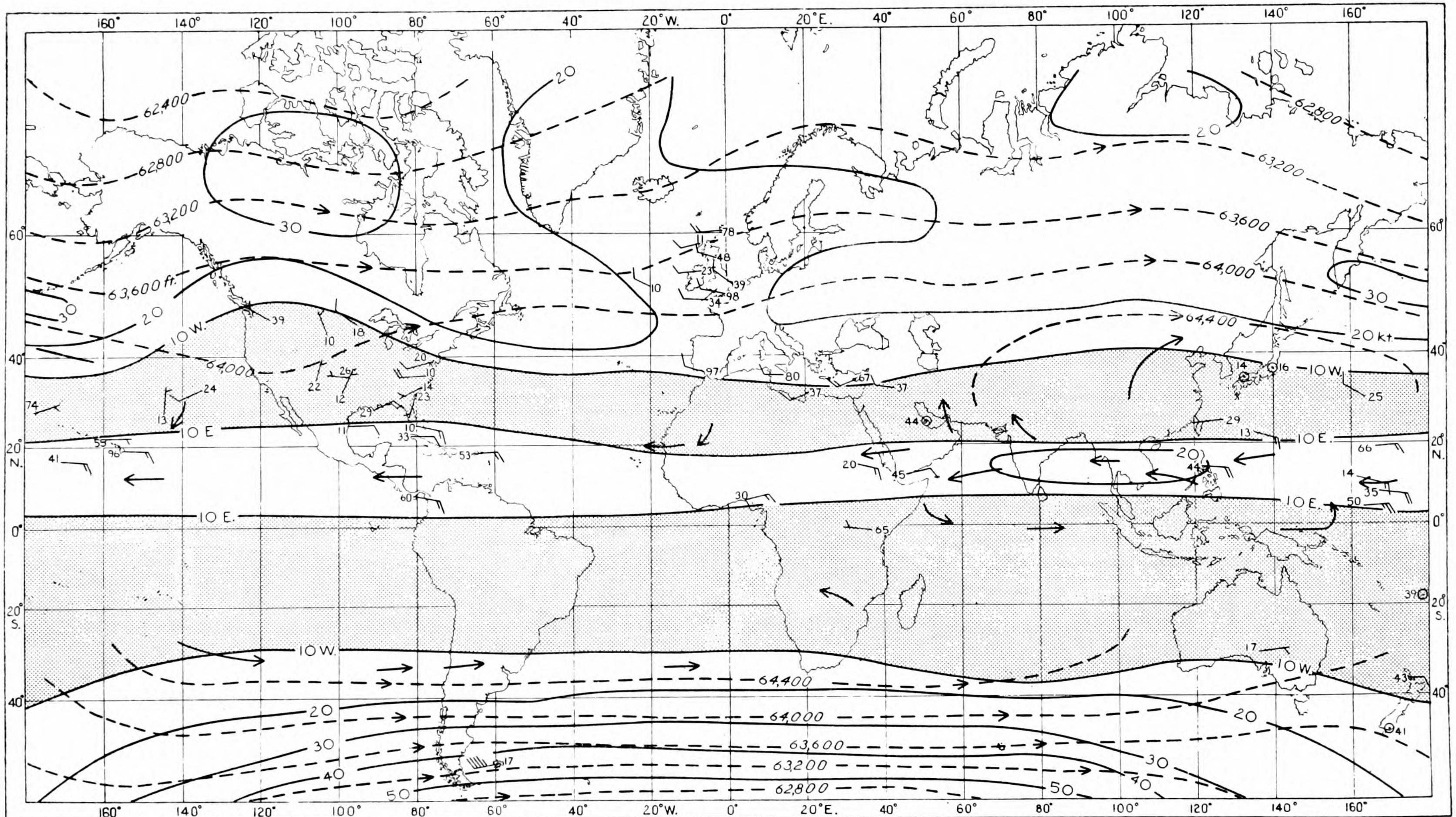


FIG. 3—MEAN WIND FLOW AT 60 MB., JULY
Number of observations is indicated near each wind arrow; wind speeds in knots are shown by conventional barbs



—— Isotachs - - - - Contours [shaded] Winds less than 10 kt. ⟶ Stream-lines (latitude < 30°)

FIG. 4—MEAN WIND FLOW AT 60 MB., OCTOBER

Number of observations is indicated near each wind arrow; wind speeds in knots are shown by conventional barbs

geostrophic relation[32]. For latitudes less than about 30°, the stream-lines and isotachs are based on direct observation of wind. Average vector resultant winds are plotted on the charts, the number of observations from which each resultant was computed being indicated at the head of the arrow.

The contours of the 60-mb. surface were constructed from charts of the height of the 100-mb. surface, the latter having been computed in the Upper Air Climatology Branch from charts of temperature[28] at standard levels up to 100 mb. The thickness of the layer 100–60 mb. was computed from the temperature at 100 mb. and the lapse rate in the layer, estimated from the scanty data available; this thickness was then added to the 100-mb. heights to obtain the 60-mb. chart. The resulting contours at 60 mb. may be in error in many places. Errors may be significant over Siberia and some regions in the southern hemisphere, where observations at all heights are few or non-existent; elsewhere errors are probably not large and the general pattern is satisfactorily defined. Contour charts of the 100-mb. and 50-mb. surfaces over North America[26] were consulted when drawing the 60-mb. contours in that region.

In the tropics, the data are so few that the charts drawn from them may not give an adequate description of even the main features.

Palmer[33] has suggested that a narrow band of steady westerlies (Berson westerlies) is to be found near the equator at heights between 18 and 23 Km. at all seasons. Palmer's evidence for this stream is mainly from observations made in the west and central Pacific in certain months[34,35]. A few observations at Singapore[36] (less than 10 in each month), even fewer from Batavia and a year's data from Canton Island (3°S., 172°W.)[37] (which became available after Figs. 1–4 had been drawn) comprise the only other evidence known to the authors in support of this suggestion. No attempt therefore was made to chart this westerly flow which is light when it can be found and seems to cover a small area.

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WEA—AN AUTOMATIC WEATHER-FORECAST SERVICE

By W. R. HANSON, B.Sc.

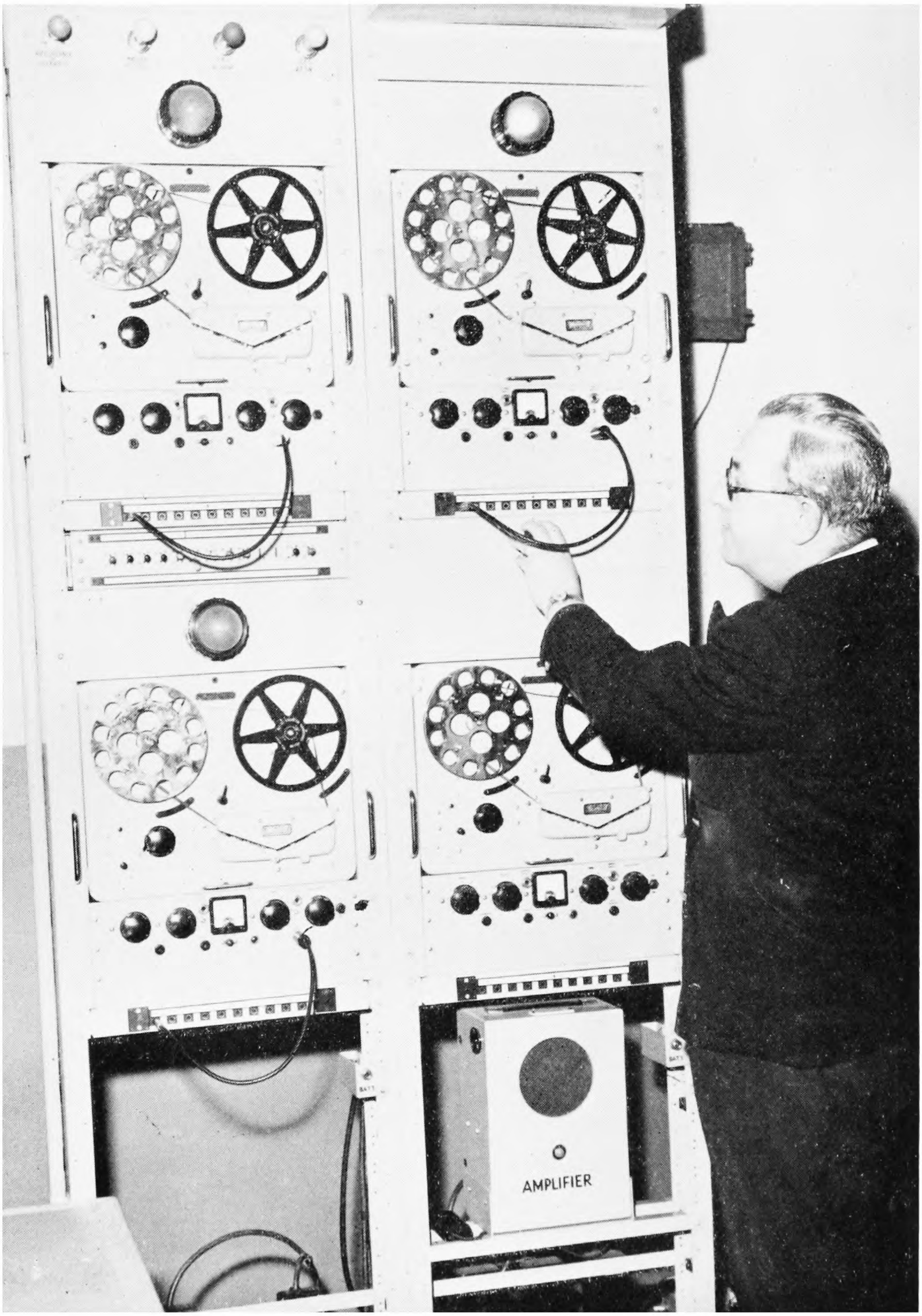
The first automatic weather-forecast service by telephone in the United Kingdom came into operation at midnight on March 4–5 this year. It provides a forecast for a period of 9 hr. for the London area within a 20-mile radius of Oxford Circus. This forecast is intended for the needs of those living or working within that area, but it is also available in any part of the country should people in the provinces have a particular interest in London's weather. In the latter part of 1955 and the first two months of 1956 the General Post Office and the Meteorological Office had been working on plans for the launching of this service and, after a trial period of three weeks, a figurative switch was thrown and the service made available on the public telephone network.

The fact that TIM and WEA are both automatic telephone services might lead one to suppose that they are operated in the same way. This is not so. TIM is automatic from start to finish. It is operated from discs which are "geared" into the controlling clock, changing the message in step with the time. WEA is operated by speech from a magnetized tape, and, although the 9-hr. period of validity is carried forward with the passage of time, there is nothing automatic about the changing of a forecast when this becomes necessary.

[*To face p. 200*

GENERAL POST OFFICE TELEPHONIST RECORDING WEATHER FORECAST

To face p. 201]



TAPE RECORDERS USED IN AUTOMATIC WEATHER-FORECAST SERVICE

The arrangements behind the scenes for the operation of this service are relatively straightforward. The Meteorological Office provides the forecasts and the General Post Office staff record these on tape for transmission from a London telephone exchange. The writing of the forecasts, however, is made rather more difficult by the need to keep within the rigid limits of the transmitting apparatus.

Each forecast must be written in such a way as to occupy a maximum of either 15 or 30 sec. of reading time including a pause at the end of the forecast. This pause must not be longer than 4 sec. or else the break-down mechanism will come into operation. It must also take into account the fact that the forecast will be read by any member of the General Post Office telephonist staff at the exchange and not by specially selected announcers, hence the normal pitfalls of everyday speech and of weather terminology in particular must be avoided in composing the message.

While the forecast specifically covers a period of 9 hr. from the time the subscriber makes his call, it avoids any artificial ending to the weather in the middle of normal daily activities by the inclusion of an outlook extending to some recognized division of the day. This arrangement demands that the forecast must be kept constantly under review since the period of validity of the 9-hr. forecast is carried forward with the passage of time. Fresh forecasts are therefore not issued at set times but whenever the 9-hr. period enters changing weather or when the time divisions used on the forecast become invalid. This has been found to give flexibility in the application of the forecast to the subscribers' needs.

Once the forecast is prepared the process of telephoning, checking back, recording and transmitting becomes a fixed routine in which the particular characteristics of the apparatus used by the General Post Office take a controlling part. The recording is done with the aid of a control or cut-out clock and microphone with head attachment as shown in the photograph facing p. 200. The recording telephonist first times with a stop watch her own reading of the message. When she feels that she can read the forecast satisfactorily and in the correct time, the telephonist informs the General Post Office engineer in the adjoining room. The red "proceed" lamp will glow as soon as the recording equipment is ready, and then one second after pressing the control-clock button the telephonist will read the forecast with one eye on the clock.

The telephonist must finish reading between the 26th and 29th seconds whether reading a short 14-sec. forecast twice or a long forecast once. The control clock is set to stop after 29 sec. and to disconnect automatically the microphone and glow lamp from the recording circuit. So after a check run the endless tape is ready to provide the forecast for the 620 lines that have been set aside to carry calls on WEA 2211 simultaneously. It is perhaps interesting to note in passing that even with all these lines the "number engaged" signal, showing saturation, has been reported.

A battery of four tape recorders, shown in the photograph facing this page, takes care of such matters as continuity during fresh recordings, or the risk of break-down in the primary circuit. It is the practice to make the recordings on two tape machines so that should a fault develop in the operating one, a gap of more than 5 sec. will automatically cut out that machine and bring in the machine that is at "stand-by". The third machine is employed for making the new recordings while the current forecast is still being transmitted. The fourth machine is for use in an emergency when the failure cannot be dealt with by the existing cut-out device.

In the first month of its use by the public, the total number of calls on WEA was 561,377. This figure was swollen in the first week by callers who were merely curious, but the calls far outnumber those that were made for similar information before the introduction of WEA. This may be because the previous service was not publicized sufficiently, though it is more likely to be due to the impersonality of the present service. The man in the street has a certain timidity when asking for information from any scientific source. Perhaps he fears that he may be questioned about the reasons for asking, or that he may be giving unnecessary trouble to someone. Whatever the reason may be, the fact remains that the great majority of those now using the weather service did not previously make telephone calls to ascertain the weather. For comparison, the total number of "weather" calls at the London Office for the previous month, February, was 17,128. Other countries who introduced this service some years ago found the same striking increase when it was brought in. In Western Germany, Frankfurt-on-Main, a city of about half-a-million population, introduced this kind of weather service on April 27, 1953, and the total number of calls made on it the following month, May, was 27,522. This figure was more than twice the number of inquiries for the whole of the previous year at the Frankfurt Weather Office.

It is too early yet to draw long-term conclusions concerning WEA. The seasons carry their own peculiar weather interests for the public and these usually bring weather inquiries to a peak in summer months. However, if the present public interest in WEA is a comment on its usefulness then its future is assured.

NOCTURNAL DISSIPATION OF STRATOCUMULUS CLOUD

By D. G. JAMES, Ph.D.

Summary.—Occasions were selected when extensive sheets of stratocumulus cloud were reported during the afternoon. These occasions are divided into two classes: those when the cloud sheet dispersed within 12 hr. of an afternoon radio-sonde ascent, and those when the cloud persisted through the night. The physical and dynamical processes operating on the cloud are examined statistically, and some of them are shown to be significantly different for the two classes. A combination of three parameters is obtained which may have some forecasting value.

Introduction.—The difficulty encountered in forecasting the dissipation or persistence of a sheet of stratocumulus cloud suggests that the cloud layer is in a delicate state of balance with its environment.

Subsidence or ascent within the air mass at cloud heights can dissipate or reinforce the cloud sheet, whilst advective changes may transfer the layer from one locality to another. Radiation from the cloud layer produces a net flux of heat outwards which cools the cloud sheet, and mixing by eddy diffusion occurs at cloud base and top with the air below and above the layer; in addition the radiative cooling of the cloud may be sufficient to produce mixing by convective turbulence at the cloud base. Generally, analysis of surface synoptic charts and radio-sonde observations gives little indication as to which processes dominate the behaviour of the cloud sheet, though instances of considerable vertical motion or advection at cloud levels would at once be evident. Thus it seemed desirable to select a number of cases and examine them statistically for significant differences between the means of the parameters (or combination of the parameters) involved, for the two classes of dissipating and non-dissipating cloud.

Selection of cases.—The choice of examples for statistical analysis was made from the years 1952–54, and was governed by the following simple criteria:

(i) The stratocumulus sheet was bounded at its top by a dry type inversion, i.e. a rapid decrease of humidity with height through the region of temperature increase (this was realized in almost all cases of non-frontal stratocumulus).

(ii) There was no surface front within 400 miles of the locality of the cloud sheet.

(iii) The cloud base was above the expected condensation level of thermal convection over land during the previous day, and of any convection from the sea. All cases considered were of cloud sheets over land.

(iv) The cloud sheet was extensive, covering perhaps several hundred square miles, and gave almost complete cover, i.e. greater than 6 oktas for at least two consecutive hours. The cloud was considered to have dissipated if the sheet had broken to 2 oktas or less for at least two consecutive hours.

(v) Only nocturnal dissipation or persistence was considered because there was then no continuous maintenance of the cloud by convection from the surface.

In general, cloud bases were determined from surface observations and cloud tops from the vertical temperature profiles obtained by radio-sonde ascents at the same time. In some cases, when the cloud bases reported from the ground were not fully consistent with the vertical temperature profiles indicated by the ascents, the values of the cloud bases used were obtained by the use of the temperatures and dew points given by the soundings. Several cases were rejected where the cloud bases so obtained were completely at variance with those reported from the ground.

Advection and vertical motion.—Advective changes were rarely responsible for the dissipation of sheets of stratocumulus cloud of the type considered. This was concluded from the examination of hourly surface charts in cases when the stratocumulus dispersed, i.e. extensive areas of cloud present at one hour had almost completely vanished by the next. The process of dispersal when it occurred was usually quite sudden, and no cases were observed in which the edge of the cloud sheet retreated steadily with the wind as would be expected with advective clearance. It did appear, however, that local fluctuations in cloud height were often caused by minor advective changes.

Consideration of the potential temperatures, humidity mixing ratios and wet-bulb potential temperatures of soundings through the air masses relevant to the cloud sheets showed little evidence that vertical motion in the atmosphere was the chief cause of the persistence or dissipation of the cloud.

Although, on occasions, subsidence of the order of 4–5 mb./hr. could be detected at 700 mb. and above, little direct evidence of the influence of subsidence could be observed at cloud heights. In order that a cloud sheet should disperse by subsidence alone, a descent at least equal to the thickness of the cloud would be required. No such change was evident on any of the occasions considered. Thus it was thought that, for the cases selected, advective changes and vertical motions in the air masses were not primarily responsible for the behaviour of the cloud sheet.

Radiation from the cloud.—The net radiative flux from a cloud sheet was calculated for several cases by use of the Elsasser radiation chart. The loss of heat flux was of the order of 20 cal./cm.^{2}/3 hr. and varied little from case to case, being almost independent of cloud thickness. Thus the variation of radiative flux did not seem to be a principal factor in determining persistence or dissipation of the cloud sheet. To calculate the cooling of the cloud layer the cloud was regarded as a black body, and the cooling depended greatly upon cloud thickness. Hewson[1] has demonstrated how such cooling could be responsible for the dissipation of scattered fragments of cloud. In this process the cloud fragments cool by radiation and sink relative to the environment, so ultimately dispersing. In considering such a mechanism Hewson neglects any compensating up-currents in the environmental air. This is quite legitimate if the cloud comprises only isolated fragments. If, however, the cloud amount is substantial, or indeed the cloud is continuous, the up-currents cannot be neglected in this way. They would almost certainly have the effect of continuously reforming the cloud. Thus Hewson's process cannot be invoked to explain the dissipation of a continuous sheet of stratocumulus cloud. The effect of the radiational cooling of the cloud is to establish an adiabatic lapse rate below the cloud, and thus convective mixing between the cloud and the air below. Such convective mixing could in theory result in the dispersal of the cloud provided the sub-cloud air was dry enough not to reach saturation at cloud height. It was found that the extreme dryness necessary did not occur; in fact, convective mixing with the air below the cloud would, in general, retard rather than assist dissipation of the cloud.

In the course of carrying out the radiation calculations it was noted that the calculated amount of cooling of the cloud was considerably greater than that suggested by successive radio-sonde ascents, even after allowing for the latent heat released by additional condensation. This fact supports the idea that continuous mixing with the air above and/or below cloud must be important processes in maintaining the temperature of the cloud and these were, therefore, considered further.

Turbulent mixing with air above the cloud top.—Turbulent mixing caused by eddy diffusion at the cloud-inversion interface would cause much warmer and drier air to enter the cloud. Consequently it was thought that there might be a significant difference between the warmth and dryness of the air above the cloud for the two classes of dissipation and persistence.

The depression of the dew point below dry-bulb temperature at a given pressure level was used as a simple parameter, and Table I was constructed relating the persistence or dissipation of the cloud (within 12 hr. of the radio-sonde ascent used) with the maximum depression within 50 mb. above the cloud top. It was thought that the error in estimating cloud top was such that the parameter used would be more representative than if a much smaller or much greater depth of air above cloud was taken. This was shown to be so when tables similar to Table I were prepared for the dew-point depression within 25 mb. and 100 mb. of the cloud top.

TABLE I—MAXIMUM VALUE OF DEPRESSION OF DEW POINT WITHIN 50 MB. ABOVE THE CLOUD TOP

	Mean	Standard deviation	Standard error of mean	No. of cases
		degrees Fahrenheit		
Breaks within 12hr.	24	13	2·6	26
No breaks within 12 hr.	28	14	2·7	27

"Student's" t evaluated for the difference between the means in Table I gave $t = 1 \cdot 60$ which showed that the means were significantly different at about the 10 per cent. level. The dryness of the air above the cloud must, therefore, be relevant to the problem of dissipation.

Turbulent mixing with air below the cloud base.—In all the cases examined the air below the cloud was not dry enough for any mixing at the cloud base to produce dissipation of the cloud. The radiative cooling of the cloud was usually great enough for the establishment of a dry adiabatic layer directly below the cloud, so that mixing by convective turbulence as well as eddy diffusion took place at these levels. These processes probably acted as a retarding factor on any dissipating mechanism produced by mixing through the inversion.

Table II presents the means and standard deviations of the hydrolapses averaged through 50 mb. below the cloud base for cases of "breaks" and "no breaks" in the stratocumulus sheets.

TABLE II—HYDROLAPSES OVER 50 MB. BELOW THE CLOUD

	Mean	Standard deviation	Standard error of mean	No. of cases
	10^{-2} × *grammes per kilogram per millibar*			
Breaks within 12 hr.	1·1	0·8	0·16	26
No breaks within 12 hr.	1·5	0·8	0·16	27

Evaluation of "Student's" t for the means above gave $t = 1 \cdot 77$ which indicated that the means were significantly different at about the 10 per cent. level.

Effect of cloud thickness.—Table III presents the means and standard deviations of the observations of cloud thickness for the two classes of "breaks" and "no breaks".

TABLE III—OBSERVATIONS OF CLOUD THICKNESS

	Mean	Standard deviation	Standard error of mean	No. of cases
		millibars		
Breaks within 12 hr.	33·5	20·0	3·9	26
No breaks within 12 hr.	43·5	19·0	3·9	27

For the above means, "Student's" $t = 1 \cdot 86$ which showed that the difference between the means was significantly different from zero at about the 10 per cent. level.

Combination of the parameters.—Tables I, II and III suggest that it would be worth devising a new parameter by a combination of the three variables used in the preparation of the tables. The new parameter was defined as

$$\xi = x + \alpha y + \beta z,$$

where x is the maximum depression in degrees Fahrenheit of dew point below the temperature at any pressure level up to 50 mb. above the cloud top, y is the average hydrolapse in grammes per kilogramme per millibar $\times 10^{-2}$ in the 50 mb. below the cloud base, z is the cloud thickness in millibars, and α and β are constants to be determined by the condition that the departure from zero of the difference between the means of ξ for cases of "breaks" and "no breaks" should have maximum significance. The conditions were determined by maximizing "Student's" t for the difference between the two means of ξ, and the final parameter was obtained as

$$\xi = x - 9 \cdot 15 y - 0 \cdot 77 z.$$

Table IV presents the means and standard deviations of ξ for the two classes of cloud behaviour.

TABLE IV—VALUES OF THE PARAMETER ξ

$\xi = x - 9 \cdot 15 y - 0 \cdot 77 z$

	Mean	Standard deviation	Standard error of mean	No. of cases
		degrees Fahrenheit		
Breaks within 12 hr.	−12·1	18·9	3·71	26
No breaks within 12 hr.	−28·4	16·4	3·35	27

"Student's" t now has the value of $3 \cdot 36$, which indicates that the means are significantly different at about the 0·2 per cent. level; the form of ξ is the best relationship that can be obtained by a linear combination of the three parameters used.

Fig. 1 shows the distribution of values of ξ for cases of "breaks" and "no breaks"; 74 per cent. of the cases of "no breaks" have values of ξ less than -20, whilst 76 per cent. of the cases of "breaks" have values of ξ greater than -20. These figures would be somewhat better were it not for two cases of each type which fall well to the wrong side of the dividing line at $\xi = -20$. These cases are perhaps worthy of some discussion if only to illustrate the difficulties encountered.

One case of dissipating cloud gives $\xi = -65 \cdot 8$ which is well to the wrong side of the dividing line at $\xi = -20$. This large value is given mainly by an assessed cloud thickness of 90 mb. which was consistent with the observations of cloud base (2,500–3,000 ft.). However, a thickness of 30 mb. is easily possible from the ascent, but this would require a cloud base of 4,500 ft.

A second case of dissipating cloud gives $\xi = -60 \cdot 2$ which is again to the wrong side of the dividing line. The cloud thickness used was 30 mb., although any value up to 70 mb. was possible, and hence uncertainties in the cloud thickness alone could not have been responsible for the excessively large value of ξ. The hydrolapse above the cloud had a shallow slope, but was verified by comparison with other soundings in the same air mass.

One case of persisting cloud gives $\xi = 14 \cdot 1$, well to the wrong side of $\xi = -20$. This discrepancy is again attributed to lack of definite information regarding cloud base and top. A thickness of 10 mb. was used in the statistical study implying a cloud base of 4,000 ft. This was a case when the surface reports of cloud base were rejected in favour of assessment from the ascent. Had the surface observations been accepted (2,000–3,000 ft.) a value for cloud thickness of from 120 to 70 mb. would have been indicated. It is possible, of course, that there were two layers in this case.

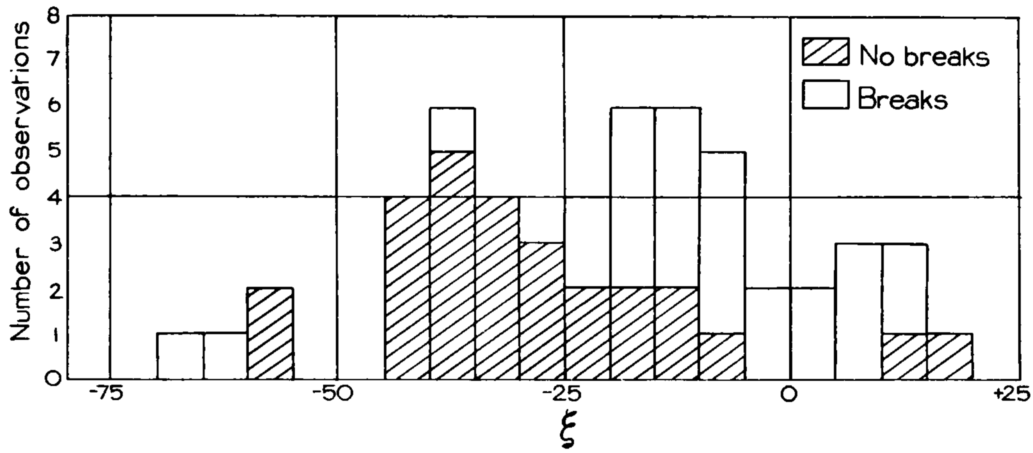


FIG. 1—FREQUENCY OF OCCASIONS OF STRATOCUMULUS CLOUD CLASSIFIED ACCORDING TO THE VALUES OF $\xi = x - 9 \cdot 15y - 0 \cdot 77z$

The final point well to the wrong side of $\xi = -20$ is given by $\xi = 19 \cdot 6$ for persisting cloud. The cloud was assumed to be 35 mb. thick with a base of 4,000 ft., although in surface observations the base was given as 2,000–3,000 ft. It is possible that there could have been two cloud layers, the first as already assumed, and the second with base 2,000 ft. and thickness 35 mb. The air above this lower layer was not very dry, and it is also possible that the layer was being reinforced by convection from the sea surface.

It is concluded that the most glaring discrepancies in the indication provided by the combined parameter ξ almost certainly arise from the difficulties and uncertainties of assessing cloud thicknesses in the absence of positive information.

Conclusions.—In the cases examined, there was little evidence to show that vertical motion in the atmosphere was responsible for the dispersal or persistence of stratocumulus cloud.

Hewson's processes for the dissipation of broken and scattered cloud by differential radiation could not explain the dispersal of a continuous sheet of cloud. Although mixing at the cloud base with air below was always present, exceedingly dry air below the cloud would have been required for dissipation.

Radiative cooling of the cloud sheet caused an intensification of the mixing process at cloud base, and could not produce dissipation of the cloud.

Turbulent mixing of the cloud with the dry air above seemed to be significant in the subsequent behaviour of the cloud.

A combination of three parameters expressing the warmth and dryness of the air above cloud, the hydrolapse below cloud, and cloud thickness gave means, the difference between which differed significantly from zero for cases of "breaks" and "no breaks". This result may be of some value for forecasting.

If mixing with the air above and below a stratocumulus layer is the main controlling process determining whether the cloud layer will persist or dissipate, it is doubtful whether any more specific criteria for the dispersal of the cloud can be developed on the basis of synoptic observations because of their limitations for determining the essential parameters—cloud thickness and humidity distribution above and below cloud.

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1. HEWSON, E. W.; The dissipation of scattered and broken cloud. *Quart. J. R. met. Soc., London*, **74**, 1948, p. 243.

PATTERN OF RAINFALL

By A. F. JENKINSON, M.A.

The curve fitted by Mr. Thomson[1] to the values N_r of the number of hours with rainfall greater than or equal to r mm. is a special case of the more general curve

$$N_r = a \exp\left(-\lambda r^{1/n}\right). \qquad \ldots\ldots (1)$$

The total rainfall R can be obtained since

$$\begin{aligned} R &= \int_0^\infty - r\, d(N_r) \\ &= \int_0^\infty N_r\, dr \\ &= \int_0^\infty a \exp\left(-\lambda r^{1/n}\right) dr. \end{aligned}$$

On substituting $t = \lambda r^{1/n}$ we evaluate the integral as

$$R = \frac{a\, n!}{\lambda^n}, \qquad \ldots\ldots (2)$$

and so

$$\frac{R}{N_r} = n!\, \lambda^{-n} \exp\left(\lambda r^{1/n}\right). \qquad \ldots\ldots (3)$$

The parameter n (which is greater than 1) shows the type of rainfall, of temperate-latitude type (low rates of rainfall) when n has lower values or of tropical type (high rates of rainfall) when n has higher values. The values of n can be mapped.

Nevertheless, Mr. Thomson's curve fitting reduces the number of parameters in the fit for N_r from three to two, and for R/N_r from two to one, and is thus most useful. By giving n the constant value 2, equation (3) becomes

$$\frac{R}{N_r} = \frac{2}{\lambda^2} \cdot 10^{0 \cdot 4343 \lambda \sqrt{r}},$$

or writing $k = 0{\cdot}4343\lambda$ to keep Mr. Thomson's k

$$\frac{R}{N_r} = \frac{1}{2{\cdot}65k^2} . 10^{k\sqrt{r}}. \qquad \ldots\ldots (4)$$

That is, the constant C in Mr. Thomson's and Mr. Waldo Lewis's work[2] is given by

$$\frac{1}{C} = 2{\cdot}65k^2. \qquad \ldots\ldots (5)$$

The numerical fitting used by Mr. Waldo Lewis[2]

$$\frac{1}{C} = 3{\cdot}30k^2 - 0{\cdot}24$$

overlooks the theoretical considerations expressed by equation (5).

Equation (4), which with Mr. Thomson's constant n (=2) has the single parameter k, can be used to fit corresponding values of R/N_r and r for stations all over the world; and then the values of the parameter k will show the rainfall type, as can be seen from the values of k quoted by Mr. Thomson and Mr. Waldo Lewis; k increases with latitude, and it has small values for tropical rainfall types. From equation (4), taking common logarithms,

$$\log_{10}(R/N_r) = k\sqrt{r} - 0{\cdot}423 - 2 \log_{10} k. \qquad \ldots\ldots (6)$$

The values of the expression on the right-hand side of equation (6) can be tabulated for different values of k and r. They are given in Table I for $k = 0{\cdot}3, 0{\cdot}4, \ldots. 1{\cdot}6$ and $r = 0{\cdot}1, 1, 2, \ldots. 7$ mm.

TABLE I—VALUES OF $\log_{10}(R/N_r) = k\sqrt{r} - 0{\cdot}423 - 2 \log_{10} k$

k	r or more millimetres of rain							
	0·1	1	2	3	4	5	6	7
0·3	0·71	0·92	1·04	1·14	1·22	1·29	1·35	1·41
0·4	0·50	0·77	0·94	1·06	1·17	1·26	1·35	1·43
0·5	0·34	0·68	0·89	1·15	1·18	1·30	1·41	1·50
0·6	0·21	0·62	0·87	1·16	1·22	1·36	1·49	1·61
0·7	0·11	0·59	0·88	1·10	1·29	1·45	1·60	1·74
0·8	−0·03	0·58	0·91	1·16	1·38	1·56	1·74	1·89
0·9	−0·05	0·57	0·94	1·23	1·47	1·68	1·87	2·05
1·0	−0·10	0·58	0·99	1·31	1·58	1·82	2·03	2·22
1·1	−0·16	0·59	1·04	1·39	1·69	1·95	2·19	2·40
1·2	−0·20	0·62	1·12	1·50	1·82	2·10	2·36	2·59
1·3	−0·24	0·65	1·19	1·60	1·95	2·26	2·53	2·79
1·4	−0·27	0·69	1·27	1·71	2·09	2·46	2·72	2·99
1·5	−0·30	0·73	1·35	1·83	2·23	2·62	2·90	3·20
1·6	−0·32	0·77	1·43	1·94	2·37	2·79	3·09	3·40

Interpolating from Mr. Thomson's data for Poona,

r (mm.)	1	2	3	4	5	6	7
$\log_{10}(R/N_r)$	0·64	0·91	1·10	1·25	1·37	1·46	1·54

If we fit a value of k to equation (6) for the values of $\log_{10}(R/N_r)$ and $k\sqrt{r} - 0{\cdot}42 - 2 \log_{10}k$ for the values of $r = 1, 2, \ldots. 7$ mm., then from Table I the sums of squares of differences for $k = 0{\cdot}4, 0{\cdot}5, 0{\cdot}6, 0{\cdot}7$ are respectively 0·0581, 0·0184, 0·0124, 0·0710 with a minimum (determined graphically) at $k = 0{\cdot}58$ and

$$\left.\begin{aligned} R/N_r &= 1{\cdot}12 \;.\; 10^{0{\cdot}58\sqrt{r}} \\ \log_{10} R/N_r &= 0{\cdot}05 + 0{\cdot}58\sqrt{r} \end{aligned}\right\} \qquad \ldots\ldots (7)$$

The approximate values of R/N_r for $r = 1, 2, \ldots 7$ mm. as observed and as calculated by Thomson using $R/N_r = 1 \cdot 05 \times 10^{0 \cdot 57 \sqrt{r}}$, and as calculated from equation (7) are given in Table II.

TABLE II—VALUES OF R/N_r

	r or more millimetres of rain						
	1	2	3	4	5	6	7
Observed	4·4	8·2	13	18	23	29	35
Thomson	3·7	6·8	10	15	20	26	34
Equation (7)	4·3	7·4	14	16	22	29	38

It should be noted that a unique value of k cannot really be obtained by curve fitting. Much depends on which part of the curve we are most interested in. For example, the value 0·58 which was obtained for k from equation (7) by fitting the part of the curve for $r = 1, 2, \ldots 7$ mm. would have been changed to 0·63 had the point $r = 0 \cdot 1$ mm. also been included; and another different value would have been obtained by considering the section of the curve for $r > 7$ mm.

The use of equation (3) enables the curve to be fitted more accurately, but there is then a corresponding difficulty in interpreting λ and n, and the bold step taken by Thomson of giving n the fixed value 2 may be considered well worth while.

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1. THOMSON, A. B.; One aspect of the pattern of rainfall. *Met. Mag., London*, **83**, 1954, p. 293.
2. LEWIS, R. P. WALDO; The pattern of rainfall. *Met. Mag., London*, **84**, 1955, p. 366.

[It was because I had myself already worked out the theory given in the beginning of Mr. Jenkinson's note and arrived at his equation (5) that I was led to extend the results given in Mr. Thomson's paper and to write my own note. Equation (5) was subsequently abandoned because it just does not fit the values of C and k obtained in practice. Moreover, I cannot feel that equation (5) has any real theoretical justification. The formula

$$\frac{R}{N_r} = C \times 10^{k\sqrt{r}} \qquad \ldots\ldots \quad (8)$$

appears to fit the facts well for numbers of tabular hours with r mm. or more of rain in each (at least for r up to 10 or 15 mm.), but to change from these essentially discontinuous quantities to smoothly varying rates of rainfall and infinitely divisible periods of time dN_r and then to integrate up to an infinite rate of rainfall is not in any strict sense admissible. The argument has heuristic value, and tells us to look out for a relation not very different from equation (5), but so would an even simpler "dimensional" treatment. The point of my note is quite simple: equation (8) fits the rainfall data for individual stations extremely well and

$$\frac{1}{C} = 3 \cdot 30\, k^2 - 0 \cdot 24,$$

for values of $k > 0 \cdot 5$, fits values of C and k obtained in practice extremely well—much better than equation (5). No theoretical significance is claimed, though it is pointed out that some practical use may be made of the second equation.—R. P. WALDO LEWIS].

COMPARISON OF WEATHER CONDITIONS DURING JULY AND AUGUST 1954 AND 1955

By R. E. BOOTH

The fine weather experienced during July and August 1955 stands out in contrast with the poor summer of 1954. It is noteworthy, however, that the weather in England and Wales during the first half of 1955 followed the same general pattern as it did in 1954, being on the whole cold, wet and unsettled with temperature below, and rainfall above, the average. In both years a cold and rather severe winter was followed by a sunny and very dry April. Each of the succeeding seven months of 1954 had considerably more than average rainfall, and in 1955 May and June were also unusually wet, but in July there was a major change.

In 1954 July and August were windy, cool, dull and wet, but in 1955 these two months were very different; they were quiet, warm and sunny with long periods without rain.

The unusually low temperature experienced throughout England and Wales during July and August 1954 resulted in the mean temperatures for these months being 3·5°F. and 2·3°F. respectively below the monthly averages; the July average was in fact the lowest since 1922. Low day temperatures were mainly responsible. At Kew, the monthly mean daily maximum temperature for July was more than 6°F. below the average, and the highest temperature recorded there during August, 57°F. on the 19th, was the lowest maximum in any August since 1931. At Ross-on-Wye the highest temperature recorded during July 1954, 70°F., was the lowest July maximum since 1880. Rainfall during these two months in 1954 was appreciably above the average, 124 and 139 per cent. for July and August respectively, while the corresponding percentages of sunshine were 70 and 75. It is worth noting that July was an unusually windy month, the windiest July since 1909 at Southport and since 1936 at Kew.

In sharp contrast, the brilliantly fine weather of July and August 1955 broke many records. The mean temperature for England and Wales in July was 1·9°F. above the average, and in August the average was exceeded by as much as 3·5°F.; there were only two warmer Augusts in the present century, those of 1911 and 1947. The mean temperature of the two months taken together was more than 5½°F. above the corresponding figure for 1954. Temperature reached 90°F. in both months for the first time since 1947, 12°F. and 9°F. above the maxima in corresponding months the previous year. July and August had nearly four times as much rain in 1954 as in 1955; taken together these two months in 1955 were the driest in the whole series of rainfall records since 1869. July was drier on only four occasions, 1885, 1898, 1911 and 1935, and there have only been two drier Augusts, 1940 and 1947. Most places were affected to a greater or less extent by lack of rain; the drought period which began in many places on July 4 continued at some until August 8. Camborne in Cornwall had 33 rainless days, July 1–August 2, and a total rainfall during the two months of only 0·36 in. There was more than twice as much sunshine during July in 1955 as in 1954 and August figures in 1955 were half as much again as in the preceding year. At some stations in north-west England it was the sunniest July for 70 years[1].

Throughout July 1954 an anticyclone was situated near the Azores but at no time did it spread over the British Isles sufficiently to establish fine weather; on almost every day part of the country at least was under the influence of a low-pressure system. During August as well, frequent and active depressions from the Atlantic dominated the weather in most parts of the country. In 1955 mainly anticyclonic conditions were experienced over the country for practically the whole of July and the major part of August.

In the upper air, cold troughs moved quickly across the Atlantic to the British Isles during the first few days of July 1954. A pronounced upper cold pool associated with an occluded surface depression remained in the neighbourhood of the North Sea from the 4th to the 7th; scattered thunderstorms occurred during this period, chiefly in eastern districts. The whole system moved towards the Baltic Sea on the 8th allowing the broad westerly flow in middle latitudes of the Atlantic to make some progress across the British Isles, but the flow was blocked over Russia as shown in Fig. 1. Minor upper troughs and ridges in this stream were associated with the frequent passage of small but sometimes active surface secondary depressions or troughs across the country, but from the 13th to the 23rd the perturbations in the zonal flow were of a greater amplitude, and more vigorous surface depressions gave some days of widespread rain particularly on the 17th and 18th. A blocking anticyclone formed over eastern Canada on the 23rd and the flow of cold air down the Davis Strait on its eastern flank eventually gave rise to an extensive upper trough to the south of Greenland (see Fig. 2). An upper cold trough moved slowly eastward reaching the North Sea by the 28th. During this time the weather over the British Isles was very disturbed, with heavy rain, scattered thunderstorms and wind reaching gale force in many places.

The blocking pattern over North America persisted during the first week of August 1954 but had receded to western Canada by the 4th, and a large cold trough then dominated the Atlantic north of 50°N. Atlantic depressions deepened as they moved east; a large and complex low-pressure area remained in the eastern Atlantic from the 4th to the 6th, after which the

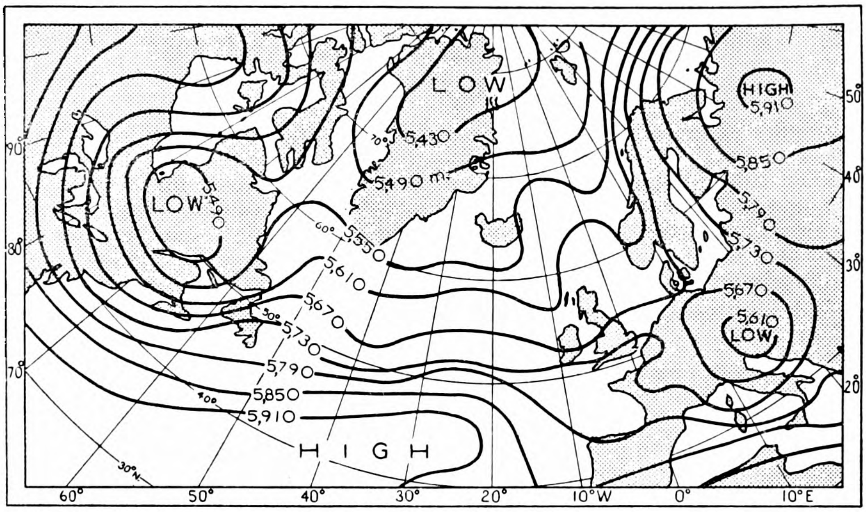

FIG. 1—500-MB. CONTOURS, 1500 G.M.T. JULY 8, 1954

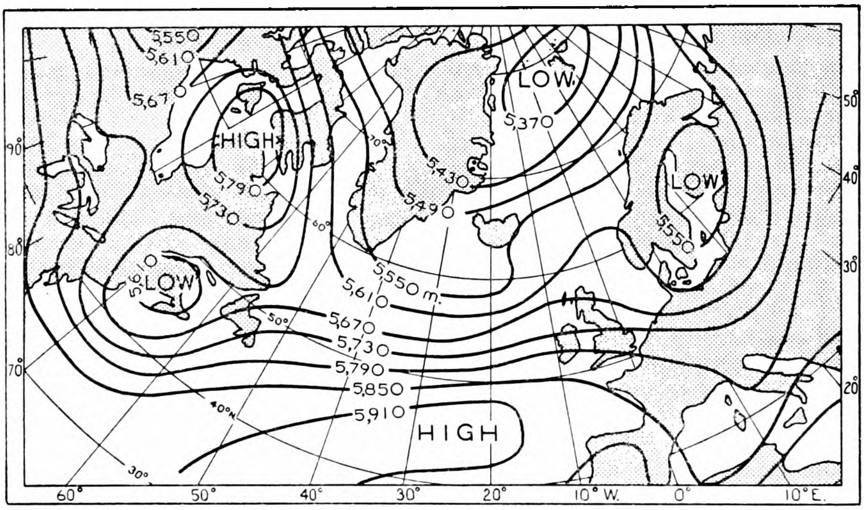

FIG. 2—500-MB. CONTOURS, 1500 G.M.T. JULY 23, 1954

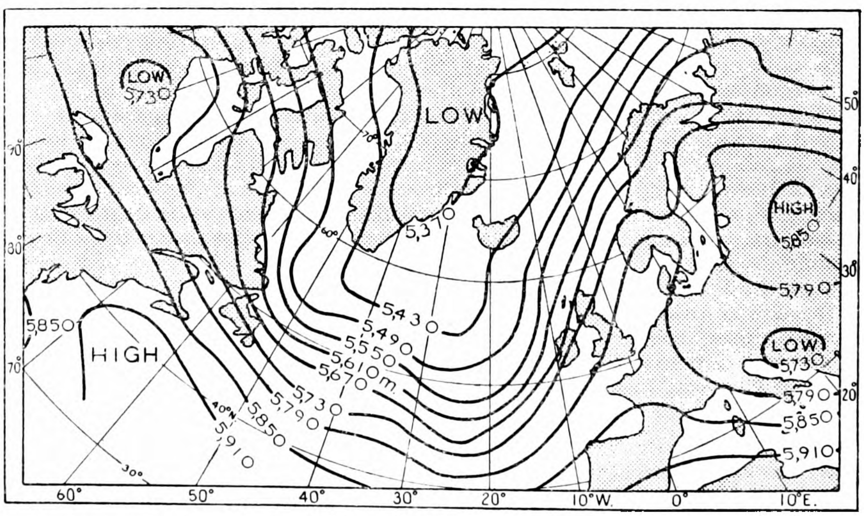

FIG. 3—500-MB. CONTOURS, 1500 G.M.T. AUGUST 16, 1955

lowest surface pressure was slowly transferred to the British Isles. The Atlantic upper trough also moved eastward, and it seemed probable that this was now being maintained by a flow of arctic air from a region east of Greenland. During this time small perturbations developed in the strong zonal field to the south of the upper trough between 40° and 50°N. and moved fairly quickly eastward in company with small surface secondaries. By the 14th the lowest surface pressure had moved eastward to the Baltic and the cold upper trough had given place to a more or less normal ridge and trough pattern over the Atlantic, and this pattern soon extended over North America as well. On the 19th one of these upper ridges became more than usually developed and cut off a small cold pool to the south of Great Britain which intensified and drifted south-eastwards attaining its maximum development over central Europe on the 25th. At the surface an anticyclone developed north-eastwards, and by the 23rd became centred over the Norwegian and Greenland Seas; a NE.–N. arctic air stream was established over the British Isles from the 21st to the 25th. Another upper warm ridge developed north-eastwards on the 27th, and at the same time there was a temporary extension across the southern part of the country of a surface ridge from the Azores anticyclone which gave two or three days of fine weather in the south with temperatures in the lower seventies for the first time since the 5th.

In July 1955 a blocking pattern became established over north-west Europe during the first week and persisted for the remainder of the month. A tongue of cold air penetrated south-eastwards into north-west Germany on the 4th and 5th while a frontal system, with surface pressure rising all round it and a well marked ridge above, moved eastwards towards the British Isles. The upper ridge was quickly followed by a second which amalgamated with it; this augmented upper ridge joined up in the warm air over Scandinavia cutting off a cold pool over east Germany and completing the blocking pattern. From then on the zonal westerlies were mainly near to, or to the north of, Scotland, and for much of the month a cold pool existed over France or Germany and a thermal ridge over the British Isles or Scandinavia. Except for the first few days high pressure persisted from the region of the Azores to Scandinavia, and the weather on most days was fine and warm though light easterly winds brought low cloud inland over eastern districts at night.

At the beginning of August 1955 the British Isles was mainly under the influence of the declining ridge of the blocking pattern of the previous month. This ridge was slowly displaced westwards by an intensifying upper trough which moved south over the North Sea. As the trough moved southward an accompanying surface cold front brought the first appreciable rain for several weeks to north and east England and much cooler conditions. From the 6th to the 9th an upper Atlantic warm ridge intensified considerably and ultimately re-established the blocking pattern which had been present most of July. An upper cold pool was cut off and moved to central Europe. From the 10th to the 15th England remained under the influence of the upper cut-off low which had extended westwards, and thundery rain and thunderstorms extended to most southern and central districts. Scotland, however, remained dominated by the blocking anticyclone. Increased cyclonic activity in the eastern Atlantic from the 14th to the 19th was associated with an intense upper trough which had been developing in mid Atlantic and which approached the British Isles on the 16th and 17th (see Fig. 3). From the 20th to the 25th an upper ridge and anticyclonic conditions were re-established over the country with temperatures rising in the south to between 85° and 90°F. The warm spell was gradually brought to an end by a renewal of thunderstorms over the Midlands and south-east England as a cold pool moved westwards from Germany. A deepening upper trough on the Atlantic approached giving less settled weather during the last two days of the month.

Maps of mean monthly contours at 500 mb., Figs. 4 and 5, give the combined effect of all the upper air developments during July of each year, and show in a striking manner how the main characteristics of the thermal pattern in the neighbourhood of the British Isles in July 1954 were reversed in July 1955. The trough over the North Sea in 1954 was replaced by a ridge the following year; upper winds approaching the British Isles from the Atlantic had a definite northerly component in 1954, whereas in 1955 they had a southerly component and decreased markedly in speed towards the west of Ireland; mean upper winds were light in the region of Iceland in 1954 and were strong further south, whereas in 1955 the position was reversed and they were strong near Iceland and lighter further south. The pronounced trough over the North Sea in 1954 is interesting. An examination of the tracks of depressions during the month showed that the majority moved from a point south of Iceland to southern Scandinavia or else became quasi-stationary off southern Norway, frequently drawing arctic air over the British Isles and the North Sea. Most of the depressions approached the British Isles from a point north of west in the general direction of the isopleths on the mean chart which seems to indicate that thermal steering during the month had some effect. Fig. 5 shows quite clearly the persistent upper ridge over the British Isles during July 1955, and a trough to the south of this ridge—a well recognized blocking pattern; the general track of depressions after the first five days of the month was in fact north-eastwards following the general run of the isopleths on this chart.

From the foregoing it can be inferred that the very fine weather of July 1955 was associated with a sustained blocking pattern over or near the British Isles. Although August 1955 was

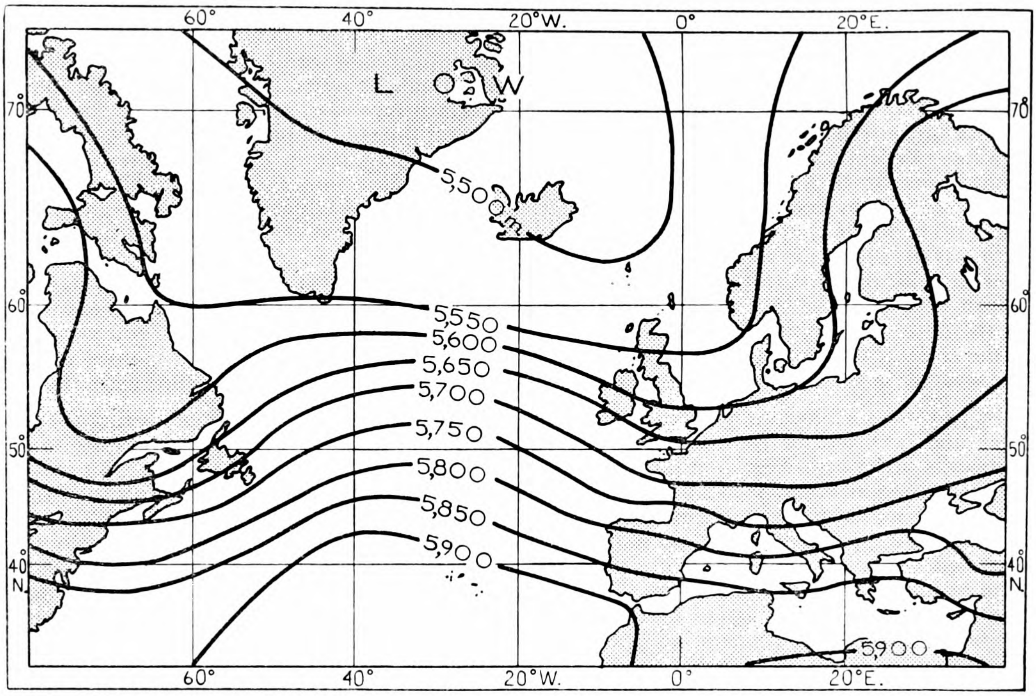

FIG. 4—MEAN 500-MB. CONTOURS FOR JULY 1954

not quite such a good month the blocking pattern was present most of the time, though occasionally interrupted and not so marked as in the previous month. During the cold and wet months of July and August 1954 the upper air pattern was markedly fluid in character throughout the whole period (see Fig. 4); the poor weather can be attributed to the fact that a blocking pattern in the upper air did not at any time become established near the British Isles except during the last few days of August. Blocking patterns over North America or Russia in the general westerly stream sometimes appeared to be linked with increasing cyclonic activity over the British Isles. The block to the zonal westerlies over Russia during July 9–17, 1954 (see Fig. 1) was accompanied by an increase in the activity of very small depressions over the British Isles;

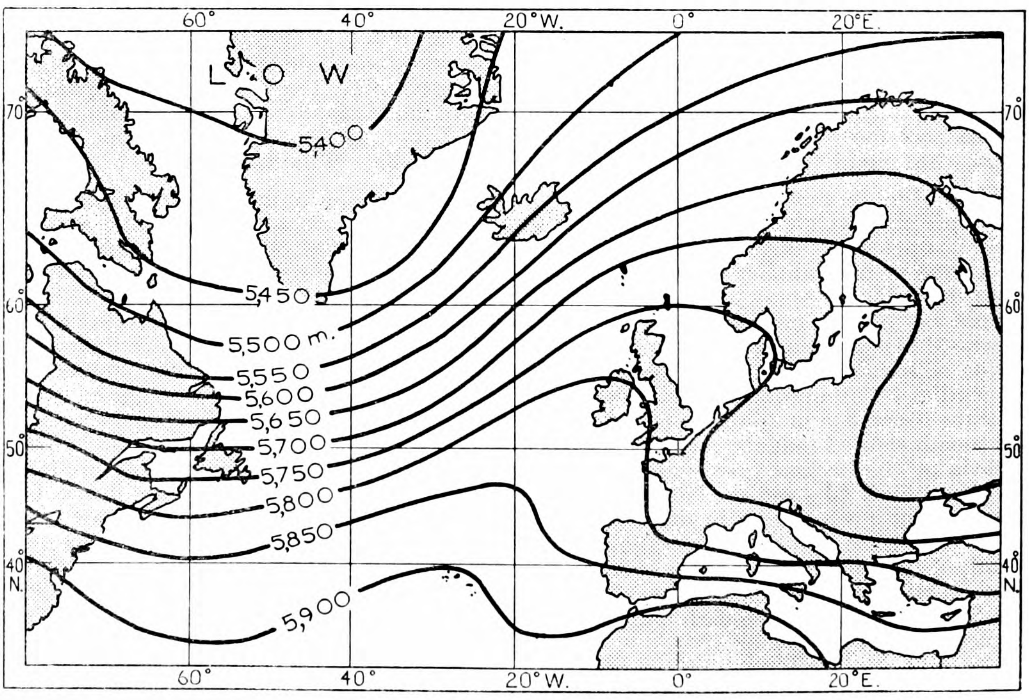

FIG. 5—MEAN 500-MB. CONTOURS FOR JULY 1955

the blocking pattern, which formed over eastern Canada on July 23, 1954 (see Fig. 2), allowed a deep upper trough to be formed east of Greenland with arctic air flowing down the Davis Strait; this in turn gave rise to unusually deep Atlantic depressions which later affected the British Isles.

It would be hard to find two other consecutive years which, after apparently being so similar during their early months, gave such good examples of blocking and fluid thermal patterns respectively as did 1955 and 1954 in July.

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OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

Handbook of meteorological instruments. Part I. Instruments for surface observations.

General instruction in the care and manipulation of instruments at Meteorological Office stations has, until recently, formed part of the scope of the "Meteorological observer's handbook". In a post-war revision of Meteorological Office publications it was decided to reduce the amount of information on instruments in the "Observer's handbook" to that necessary for their routine operation and day-to-day maintenance, and to publish a comprehensive handbook of meteorological instruments giving full information on the design, installation, operation, maintenance and performance of all instruments used at Meteorological Office stations, together with some information about other types of instruments in order to illustrate different principles.

This, the first part of the "Handbook of meteorological instruments", is concerned with instruments for surface observations; further parts will describe instruments for upper air observations and for geophysical measurements.

GEOPHYSICAL MEMOIRS

No. 94—Meteorological results of the Balaena expedition, 1946–47. By H. H. Lamb, M.A.

Part I of this Memoir describes the general organization of the *Balaena* expedition and the meteorological arrangements, including instrumental gear. Certain aspects of the unknown geography of the Antarctic continent and its bearing upon the meteorological work are considered here and in the later sections. Part II presents the meteorological results in terms of observation summaries and such lessons as can safely be learnt from them. The observations themselves are fully tabulated in the Appendices. An important part of the effort on this expedition was devoted to weather analysis over the Southern Ocean and to the experimental provision of a forecasting service for the remote Antarctic whaling grounds in the Indian Ocean and Australian sector. Part III consists of a description of the methods used and an appraisal of this forecasting experiment.

The best maps of Antarctica and the off-lying islands, reefs and ice-shelves, which the reader may find helpful in studying this report of the *Balaena* expedition, are amongst the items listed in the classified bibliography.

LETTER TO THE EDITOR

Dust devil observed at Coalburn, Lanarkshire

At 1400 G.M.T. on April 29, 1956 my attention was attracted by a noise as of escaping steam which appeared to be approaching fairly fast (probably at 15 m.p.h.). Coming towards me from a north-east direction was a whirlwind into which had been sucked grass and light twigs. The largest of these was almost 12 in. in length and ¼ in. in diameter. I estimated the width of disturbance at 5 ft. It passed within a few feet of me and dissipated a few yards further on. At the time it was dead calm and there had previously been bright periods amounting to 4 hr. sunshine. Screen temperature was at the maximum for the day (50°F.).

I estimate the height to which the grass was carried as about 10–12 ft. and I think it had a clockwise motion. The nearest trees, from where the twigs must have come, are 80 yd. from where I was standing. In the vicinity of the trees there is a flat expanse of ashes which might have become heated;

another 20 yd. further away there is a large corrugated iron building. The sky was partly overcast with cumulus, and an hour later the temperature reading was 48·2°F., relative humidity was 41 per cent., with vapour pressure 4·7 mb.

J. ROSS

Coalburn, May 4, 1956.

[A col was centred over Scotland during April 29 lying between an anticyclone centred over the Norwegian Sea and a ridge extending over Ireland from the Azores anticyclone. Polar air covered the North Sea and Great Britain. During the night this air was sufficiently unstable over the sea to allow showers to drift over Leuchars, but during the day subsidence aloft caused an inversion to form at 6,000 ft. thus preventing deeper convection. Below 6,000 ft. the air was unstable, and became more so during the day in the lowest layers with a superadiabatic lapse rate between 1017 and 982 mb.; 3 oktas of cumulus formed at 2,500 ft. spreading out as stratocumulus beneath the inversion. These are fairly typical convection conditions for the time of year. The only unusual feature which could have caused the development of the dust devil was, as Capt. Ross suggests, the exceptionally strong radiational heating over the expanse of ashes.

Dust devils are unusual at such a low temperature, presumably because sufficiently steep lapse-rates are not often produced. F. E. Dixon* recorded the occurrence of dust devils at Dublin Airport on May 12, 1949, a day on which the screen maximum was only 51°F. They occurred then on a dust surface heated to a temperature of about 89°F.—Ed., *M.M.*]

NOTES AND NEWS

Dust cloud in the stratosphere over western Europe July 24—August 4, 1953

The dust clouds at about 49,000 ft. over western Europe in late July and early August 1953 have been described by L. Jacobs[1] and F. Volz[2], while F. Volz[2], G. de Vaucouleurs[3] and S. Fritz[4] have discussed the effects of the cloud on solar radiation.

For completeness of the record it should be added that the *Volcano Letter*[5] gives a full account of the volcanic eruption of which brief mention is made in Jacobs's article. The volcano Mount Spurr, Alaska, 61°18'N., 152°15'W. 80 miles west of Anchorage, Alaska erupted at 5 a.m. on July 9, 1953. The eruptive cloud was seen from aircraft to reach up to 60,000 or 70,000 ft. and to have an estimated diameter of 30 miles. The ash cloud moved eastward and produced complete darkness at Anchorage from 1 to 3 p.m. Ash fell at Anchorage to a depth of ¼ in. The main eruption was confined to the 9th, but the volcano continued in a state of moderate steadily diminishing activity for the rest of the month. The eruption was from a vent at 7,000 ft., and was the first strong activity of the volcano in the 200 yr. of recorded history of the area.

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* DIXON, F. E.; Dust devils at Dublin Airport. *Met. Mag., London*, **78**, 1949, p. 206.

Photograph by the late Mr. M. C. Gillman

CUMULONIMBUS CLOUD BEFORE SUNSET
Taken from Dar-es-Salaam, British East Africa, looking inland.

[*To face p. 216*

Reproduced by courtesy of Capt. T. M. King

LOW-FLYING CANBERRA AIRCRAFT ENVELOPED IN CONDENSATION AURA, FEBRUARY 4, 1956

Aircraft condensation aura

The photograph facing this page was taken by Capt. T. M. King on the occasion of the Queen's visit to the Gold Coast when six Canberra aircraft gave a display of low flying and aerobatics on the morning of February 4, 1956 along the coast between Christiansborg Castle (the Governor's residence) and Accra, a distance of about 2½ miles.

On several occasions during the display an aircraft would suddenly become enveloped in an aura of self-made cloud lasting no more than a second or two. Although Capt. King exposed a complete roll of a film this was the only picture in which he managed to photograph the phenomenon. The photograph was taken looking eastwards towards Accra. The onset was so sudden that, on the first two occasions, some of the crowd thought the aircraft was exploding.

It was a fine morning and at the time of the photograph (1030 G.M.T.) the sky was cloudless with a few patches of haze over the sea. Nevertheless the visibility was more than 8 miles and ships 2½ miles away off Accra could be seen clearly. There are cliffs, 30–40 ft. high, all along the coast with a few slight indentations but no promontories; inland the land is undulating with one or two native huts and some palm trees 100 yd. from the cliff edge. The aura only seemed to occur when the aircraft passed at high speed through a patch of very slight haze at about 100 ft. above sea level approximately over the cliff edge. In interviews afterwards the airspeed was stated to be 550 m.p.h.

The phenomenon is clearly of the same origin as that described by R. F. Jones* in connexion with a similar condensation photographed at Farnborough in September 1954. Areas of low pressure develop on the wing surface which lead to adiabatic cooling in the slowly moving boundary layer in contact with the wing. The depth of the boundary layer and the drop in pressure both increase with increasing airspeed, but each depends very closely on the aerodynamic qualities of the wing. The relation may be expressed very roughly by the formula

$$p - p_0 = \tfrac{1}{2} k\rho u^2$$

where u is the airspeed, p the pressure on the wing surface, p_0 the ambient pressure, ρ the air density and k a function of the shape of the aerofoil and the distance from the leading edge. For straight subsonic flight at zero angle of incidence† k is positive with a value about 1·0 near the leading edge but a short distance away it soon becomes negative, and for most of the distance along the aerofoil would have a value about −0·2, the precise values depending on the wing profile‡. If we assume a value of −0·2 and take the known conditions at Accra [pressure 1000 mb. at a height of 300 ft., airspeed 550 m.p.h. (= 250 m./sec. approximately), surface air temperature 83½°F., surface dew point 72°F.] then the drop in pressure at the wing surface will be 68 mb. This is not quite sufficient for adiabatic condensation in straight flight.

However, the sea temperature off Accra in February is normally above 80°F. and an observation by s.s. *John Holt* in 4°36′N. 3°12′W. the following

* JONES, R. F.; Condensation phenomena at the Exhibition of the Society of British Aircraft Constructors at Farnborough. *Met. Mag., London*, **84**, 1955, p. 93.

† See GOLDSTEIN, S.; Modern developments in fluid dynamics. Oxford, 1938, p. 524.

‡ For higher subsonic speeds the numerical values of k away from the leading edge increase rapidly particularly on the upper wing surface, see HOWARTH, L.; Modern developments in fluid dynamics. High speed flow. Oxford, 1953, p. 622.

day measured a sea temperature of 78°F. So that if we can assume the wet-bulb temperature at least 78°F. with the onset of the sea-breeze bringing patches of moister air (the haze patches described earlier) over the cliffs, condensation would occur with an adiabatic fall of no more than 50 mb. As a rule during the display the airspeed was insufficient or the air too dry for the aura to form. But over the cliff edge where the sea-breeze was just beginning to break through in patches the air would be moist enough to condense about 1½ gm. of water droplets in each cubic metre of air, quite sufficient to produce the observed effect. The effect is accentuated by higher speeds at the end of a dive (when the angle of incidence of the aerofoil is least) or by increased values of *k* during a turn but it is likely that the patchy onset of the sea-breeze was the most important contributing factor.

P. B. SARSON

Night cooling curves for Achnagoichan

Recent suggestions[1] relating to the significance of spring anomalies in the times of the discontinuities (T_r) occurring on clear nights have led to the examination of a Scottish record maintained at high level. The thermograph at Achnagoichan (57°09′N. 3°49′W. height 1,000 ft.) is controlled by the Nature Conservancy on a site which has much in common with Alston, Cumberland where the records have already been analysed. Both are about 1,000 ft. above the sea, and their aspects are similar. The significant difference is that of latitude, and it was considered probable that a northerly station like Achnagoichan might exaggerate the effects determined at English stations because of the greater variations in lengths of daylight.

The exceptional number of clear nights during 1955 has been helpful to this study, and Fig. 1 shows the final plotting. The charts were for weekly periods

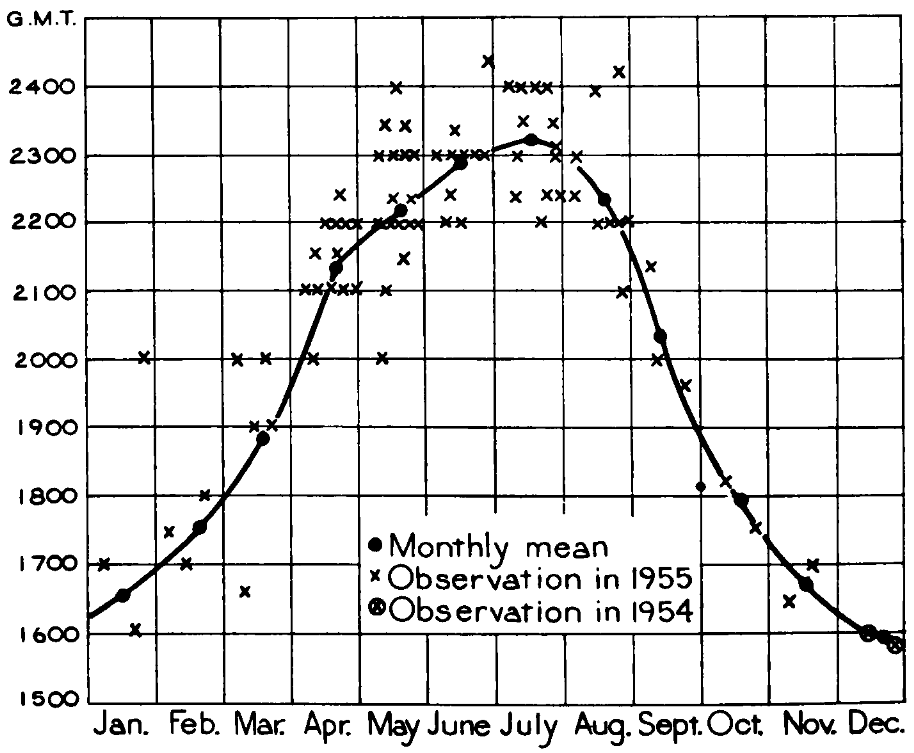

FIG. 1—ANNUAL VARIATION OF TIME OF EVENING DISCONTINUITY OF TEMPERATURE

so that a time unit of 30 min. forms the limit of accuracy. The spring bulge appears to suggest early drying out, but in view of the controversial aspects of this topic stimulated by Bruce[2] it has been deemed proper to reproduce all the points on the graph so that it may be judged that the curve-fitting is in order.

The plotting of the temperatures at the discontinuity against the resulting minima was disappointing since occasions of low temperatures without snow cover were not recorded. As a result the contention arising from the Alston analysis[1] that 15°F. is the absolute minimum under these conditions received no further support. The graph is almost linear and is so disposed as to give

$$T_{min} \simeq T_r - 6$$

throughout the entire winter-summer range of minima between 0°F. and 62°F., irrespective of snow cover.

W. E. RICHARDSON

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REVIEWS

Problems and control of air-pollution. Edited by F. S. Malette. $9\frac{1}{2}$ in. × 6 in., pp. vi + 272, *Illus.* Reinhold Publishing Corporation, New York and Chapman & Hall Ltd., London, 1955. 60*s.*

Atmospheric pollution is a subject which arouses verbosity if not eloquence in a large number of people. The vast quantities of smoke and other impurities discharged each day into the atmosphere inspire well justified anger in all of us, but those who have to make a study of air pollution are also beset by the acres of print that are covered with writings upon this subject. There is clearly much in common between air pollution and sin. Everyone is against them but comparatively few do anything positive about either. One need only spend a foggy morning in an industrial area to become convinced that the one sin calling for urgent and drastic remedies is air pollution.

The literature on atmospheric pollution is so enormous that anyone trying to keep abreast of even a few of the different aspects must occasionally give way to a sense of frustration at the immensity of his task. A special welcome is therefore given to this book which consists of the papers presented at the First International Congress on Air Pollution held in March 1955, and sponsored by the American Society of Mechanical Engineers. The various papers, 25 in all, provide an up-to-date account of many of the most important problems associated with the occurrence of air pollution and with the possibilities of exercising greater control over it.

The first chapter deals with the growth and moulding of public opinion and is by Sir Hugh Beaver, who was Chairman of the Committee on Air Pollution set up by the British Government shortly after the disastrous London smog of December 1952. Then follows a chapter on the responsibilities of management in which it is demonstrated that industrialists, provided they have a social conscience, can do much to reduce the worst effects of pollution without waiting for the compulsion of legislation. These two chapters on the complementary roles of a responsible management and an enlightened public opinion form a social document of the first importance.

The next set of chapters is concerned with the discussion of important gaps in our knowledge of air pollution in such fields as biology, health, meteorology and engineering. Professor Hewson, whose writings are well known to readers of this Magazine, contributes a chapter on meteorology and gives an informative appreciation of the difficult problems of estimating ground concentrations of pollution that still await a comprehensive solution.

An important section of the book is devoted to the question of removing sulphur dioxide from flue gases before their release into the atmosphere. Sulphur dioxide is produced wherever fuel, whether in the form of coal, coke or oil is burnt, and, as the report of the Beaver Committee states, in Great Britain about 5 million tons of this highly toxic gas are discharged to the air each year. The removal of sulphur dioxide is therefore a question of extreme importance but the costs are enormous and it appears that effective measures must await the development of a recovery process that would yield substantial quantities of saleable sulphur and sulphur compounds.

The value of each section of the book is considerably enhanced by comprehensive bibliographies and altogether the organisers of the Congress are to be congratulated on this permanent record of their initiative. In these days it is customary for the reviewer to raise his eyebrows when the price of a book is much in excess of what it would have been if published before the last war. Relative values are not easily assessed but it is considered that the price of this book, taking account of the general contents and the number of illustrations and diagrams, is not unduly high.

P. J. MEADE

Frontiers to space. By Eric Burgess. $8\frac{3}{4}$ in. × $5\frac{1}{2}$ in., pp. xvi + 174, *Illus.*, Chapman and Hall Ltd, London, 1955. Price: 21*s*.

Probably the most significant development in meteorology during the last few years has been the provision and use of routine measurements of wind, temperature and humidity up to considerable heights in the atmosphere. At present the ceiling of the radio-sonde balloon is at least as high as that of aircraft for which forecasts have to be made on a routine basis, and, moreover, it is above 90 per cent. or so of the mass of the atmosphere. Many meteorologists are therefore well content that the study of conditions at higher altitudes should be in the hands of the geophysicists, ionosphericists, and astronomers rather than be treated as yet another branch of meteorology. However, since the basic driving force for our weather is radiation from the sun and long-term forecasts can only follow from a study of solar-terrestrial relations it seems that ultimately the outer atmosphere will have to be studied in detail by meteorologists for this reason alone. Besides being considerably less accessible the outer atmosphere is, however, certainly no easier to study than the troposphere. A large number of new problems such as those of ionization, photochemistry and radiation conditions in the far ultra-violet end of the solar spectrum arise.

In "Frontiers to space" Mr. Burgess has attempted to summarize the present state of our knowledge of the atmosphere from the troposphere to outer space. Although investigations by other methods are not neglected, he is chiefly concerned with rockets, and has collected together in a single account all the information given up to date in many technical papers and reports about the American high-altitude rocket experiments. Extensive bibliographies are included. Some information is also given on the French rocket programme.

The arrangement of the early chapters of the book is to describe the main features of the work in the firing of rockets and how the experiments are made. An outline is given of the main physical features of the outer atmosphere, and then the principal investigations—those of pressure, temperature and composition—are dealt with in turn. Medical experiments with mice and monkeys are also described briefly. A good summary of our knowledge of the ionosphere both as derived from surface experiments and the rocket work is followed by a chapter on solar radiation. The results of the radiation measurements are to the meteorologist perhaps the most interesting section of the book. Before they became available our knowledge of the solar spectrum below 3,000°A. was very slight because of absorption of radiation below 3,000°A. by the ozone layer between about 20 and 60 Km. above the earth's surface. A great deal of information on this subject has been gained in recent years. As well as measurements of the solar spectrum and the ozone layer, information has been obtained on air glow both by day and by night. Finally there are two chapters on investigations of cosmic-ray phenomena and on artificial satellites, which, although more of astronomical or general scientific than of meteorological interest, complete the story of the rocket programme and point to the further work which must be done before space travel can be contemplated.

The general stress throughout the book is on experimental methods and techniques, the description of the phenomena to be investigated and the results obtained tending to be overshadowed by the accounts of the engineering methods in the experiments. The book abounds in excellent photographs of the rockets and the measuring gear, cut-away sections of the installations, and in line and block diagrams. In some respects the detail given appears to be too full for all but rocket enthusiasts. It is not of much interest to the general reader to learn for instance that a given type of rocket fired at a given time had a flight of a given duration, and then to find out that the experiment was a failure because a small part of the apparatus failed to operate. This emphasis on technology is however probably a true reflection of the stage attained at present by the research workers. While most meteorologists will admit that they ultimately owe practically all their present data at lower levels to the achievements of technologists, many are likely to be impatient in reading a book of this type when two thirds or so of it describes experimental methods and the remaining third results. Moreover the scope of the subjects covered is so very considerable that the reader will have to have a very wide field of interest to reap full benefit from all its various sections.

This book, however, should be generally welcomed as the first attempt to condense all the information now available into a short connected account, and can readily be used as a first introduction into the study of the outer atmosphere before a more intensive study of a particular aspect of the work is undertaken. It is not entirely free from errors and obscurities. For example the discussion of winds at high levels on pp. 69–71 does not leave the reader with a clear picture of the general circulations, and the fact that these winds vary with altitude and are subject to tidal influences seems to have been ignored. This is not surprising in a book covering so many facets of the subject, but the few errors that exist are comparatively minor and do not detract from its value to the general reader. Its production and layout are excellent.

R. J. MURGATROYD

HONOURS

The following awards were announced in the Birthday Honours List, 1956:—

C.B.E.

Mr. S. P. Peters, Deputy Director, Meteorological Office

M.B.E.

Mr. G. A. Howkins, Senior Scientific Officer, Meteorological Office

Mr. R. J. Williams, Senior Experimental Officer, Meteorological Office

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Sir Graham Sutton, C.B.E., F.R.S., Director of the Meteorological Office, received the honorary degree of Doctor of Science at Leeds University on Thursday, May 17, 1956.

OBITUARY

Mr. John Ransome Bright.—It is with deep regret that we learn of the death of Mr. J. R. Bright, Senior Scientific Assistant, on May 28, 1956, at the age of 33. He joined the Office as a Temporary Meteorological Assistant in December 1940, and after a course at the training school he served for some time at aviation outstations. Since 1944 he has been employed on radio-sonde and sferics duties. At the time of his death he was serving at Hemsby.

METEOROLOGICAL OFFICE NEWS

Ocean weather ships.— The following is an extract taken from a report of the Master of an ocean weather ship:

O.W.S. *Weather Recorder.*—Voyage 67—On a bright summery day, the first day of British Summer Time, we arrived at the Great Harbour after a voyage which had been truly delightful. With the exception of a couple of days of strong force gale, on the day of the mail drop and the day of relief by the *Cirrus*, the weather has been very kind to us and for the first time in years we were able to have a boat out on a full scale ASR exercise when advantage was taken to try out the "Salvita" boat radio. Later that day rubber dinghy races were arranged between the departments.

The food has been very well cooked and the menu varied. The films have been very good indeed and these films twice weekly certainly break up the monotony of the voyage.

Sports activities.—*Netball.*—The Meteorological Office Ladies Netball team won the Air Ministry tournament on May 26, 1956 for the eighth consecutive year. A team from the Central Forecasting Office, Dunstable gained fourth place.

Chess.—The Air Ministry chess championship of 1955–56 has been won for the third time by Mr. P. M. Shaw; second was Dr. J. Pepper, third Mr. P. B. Sarson. This is the first occasion that all three top places have been attained by members of the Meteorological Office. It is the seventh time in ten years that the Meteorological Office has provided the Air Ministry chess champion.

Contract bridge.—This year's Air Ministry Contract Bridge individual championship has been won by Mr. G. T. Smith. Mr. A. E. Milne was joint runner-up.

WEATHER OF MAY 1956

The month was remarkable for a degree of approach to regular zonal movement of depressions in both Atlantic and Pacific sectors seldom seen in May. In the case of the Atlantic this was clearly associated with greater extent and intensity than usual of the residual cold trough over the north-eastern half of North America (anomaly −5°C. both south-east and south-west of Hudson Bay, but +5°C. over New Mexico). The depressions travelled on tracks well to the north-east, commonly passing through the Denmark Strait and up the east coast of Greenland. There was a remarkable absence of the usual May anticyclones over north Greenland and Iceland. The mean map for the month shows a well developed Iceland low, 8 mb. deeper than usual and displaced far to the north-east from its usual May position off Labrador. The Azores anticyclone was also more intense than usual and displaced 500 miles to the north-east. Maximum anomalies were −12 mb. in north Iceland, north-east Greenland and Jan Mayen and +9 mb. north of the Azores. North-east Siberia was also rather colder than usual (maximum anomaly −3°C., whilst Japan had anomalies of +1° to +4°C.) and the low off south-west Alaska was 5 to 7 mb. deeper than normal on the mean map. The monsoon depression over south Asia was 6 mb. deeper than usual in May and the monsoonal development of low pressure over Siberia also appeared more advanced than usual.

Rainfall was well above normal over central and south-western India, and in a belt from Burma to Indo-China, the Philippines and southern Japan. Ceylon and north-west India and the Punjab however remained dry. Rainfall was also over twice the normal for May in parts of Iceland and west and north Norway. Notably dry weather over eastern Scandinavia and the Baltic accompanied the persistent westerlies in that region.

In the British Isles, May was sunny and very dry. Over a broad area of the Atlantic, to the north-west of the country, there was much cyclonic activity, which frequently affected north-western districts but was of little significance further south. During the first half of the month pressure was high from the Azores to western Europe, and for much of the remainder, a ridge of varying intensity extended from an anticyclone over the Atlantic to the British Isles.

During the first week slight rain or drizzle occurred daily in many places though sunny periods predominated. Temperature rose fairly steadily and by the 5th exceeded 70°F. locally in southern England and was in the middle sixties in Scotland and northern Ireland. London Airport and Mildenhall reached 76°F. on the 6th, but persistent sea fog over parts of the south and west coasts kept temperatures 20°F. lower. At the beginning of the second week frontal activity spread further south and on the 9th there was rain at times over most of the country. The following two days were showery with gales in Scotland on the 11th. Winds were mainly between W. and NW. and the weather showery with sunny periods during most of the third week; on the 16th cooler air spread south and an anticyclone moved eastward in the cold air, becoming centred over Ireland on the 19th. Ground frost was widespread for several nights and there was some slight air frost, but on the 21st a slow southerly drift of wind developed and temperatures rose progressively to reach the middle seventies locally in England on the 23rd. From the 25th to the 27th the Azores anticyclone extended eastward across the British Isles and weather was warm and sunny in most districts; more than 15 hr. of sunshine were recorded at many places and temperature reached 76°F. at Renfrew on the 27th and 28th and 78°F. at London Airport on the 28th. A depression from Portugal moved slowly northwards bringing outbreaks of thundery rain to England on the 29th, but the 31st brought a change to a north-westerly flow over the whole country.

May was the fourth successive month of dry weather in most parts of the British Isles, rainfall in many places over the four months February to May being only about a quarter of the normal amount. Kew Observatory had its driest May since 1896 with only 0·22 in. while at Tynemouth it was the driest since records began in 1864. Rainfall was less than half an inch over a wide area of the Midlands and central southern England. Sunshine was generally well above average. Most areas had 120–130 per cent. of their average, and very few places recorded less than 200 hr. during the month. On the Air Ministry roof more sunshine was recorded than in any month since June 1952. Growth of vegetation, especially grass and corn, was slow because of the continued dry weather. Frosts, particularly during the early hours of the 19th–21st and 27th damaged young potato haulms, beans, strawberry plants, black currants and in some cases top fruit. Forest and heath fires, some very serious, were frequent.

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 ...	82	23	+1·4	−5	39	128
Scotland	78	24	+1·9	+1	101	102
Northern Ireland ...	70	27	+1·8	0	56	95

RAINFALL OF MAY 1956

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	0·43	24	*Glam.*	Cardiff, Penylan ...	1·07	44
Kent	Dover	0·34	20	*Pemb.*	Tenby	1·01	44
,,	Edenbridge, Falconhurst	0·50	27	*Radnor*	Tyrmynydd	0·96	28
Sussex	Compton, Compton Ho.	0·37	17	*Mont.*	Lake Vyrnwy	1·51	47
,,	Worthing, Beach Ho. Pk.	0·34	21	*Mer.*	Blaenau Festiniog ...	5·43	96
Hants.	St. Catherine's L'thouse	0·42	26	,,	Aberdovey	1·90	76
,,	Southampton (East Pk.)	0·28	14	*Carn.*	Llandudno	0·78	44
,,	South Farnborough ...	0·20	11	*Angl.*	Llanerchymedd ...	1·70	72
Herts.	Harpenden, Rothamsted	0·56	29	*I. Man*	Douglas, Borough Cem.	1·48	59
Bucks.	Slough, Upton	0·19	11	*Wigtown*	Newton Stewart ...	1·47	56
Oxford	Oxford, Radcliffe ...	0·33	18	*Dumf.*	Dumfries, Crichton R.I.	...	...
N'hants.	Wellingboro' Swanspool	0·49	25	,,	Eskdalemuir Obsy. ...	3·87	117
Essex	Southend, W. W. ...	0·37	26	*Roxb.*	Crailing...	0·75	37
Suffolk	Felixstowe	0·74	56	*Peebles*	Stobo Castle	1·53	67
,,	Lowestoft Sec. School ...	0·73	45	*Berwick*	Marchmont House ...	0·65	26
,,	Bury St. Ed., Westley H.	0·83	46	*E. Loth.*	North Berwick Gas Wks.	0·52	27
Norfolk	Sandringham Ho. Gdns.	1·04	57	*Midl'n.*	Edinburgh, Blackf'd. H.	0·57	28
Wilts.	Aldbourne	0·45	22	*Lanark*	Hamilton W. W., T'nhill	1·77	74
Dorset	Creech Grange... ...	0·55	27	*Ayr*	Prestwick	1·46	75
,,	Beaminster, East St. ...	0·67	33	,,	Glen Afton, Ayr San. ...	2·83	94
Devon	Teignmouth, Den Gdns.	0·76	42	*Renfrew*	Greenock, Prospect Hill	3·68	113
,,	Ilfracombe	0·91	44	*Bute*	Rothesay, Ardencraig ...	...	...
,,	Princetown	2·01	47	*Argyll*	Morven, Drimnin ...	4·48	139
Cornwall	Bude, School House ...	0·76	41	,,	Poltalloch	2·84	98
,,	Penzance	1·64	74	,,	Inveraray Castle ...	7·36	187
,,	St. Austell	1·02	42	,,	Islay, Eallabus	2·59	98
,,	Scilly, Tresco Abbey ...	1·61	95	,,	Tiree	2·99	120
Somerset	Taunton	0·28	16	*Kinross*	Loch Leven Sluice ...	1·72	70
Glos.	Cirencester	0·68	32	*Fife*	Leuchars Airfield ...	0·63	32
Salop	Church Stretton ...	0·40	16	*Perth*	Loch Dhu	5·56	124
,,	Shrewsbury, Monkmore	0·42	22	,,	Crieff, Strathearn Hyd.	1·64	66
Worcs.	Malvern, Free Library...	0·79	37	,,	Pitlochry, Fincastle ...	1·80	85
Warwick	Birmingham, Edgbaston	0·58	25	*Angus*	Montrose, Sunnyside ...	0·44	22
Leics.	Thornton Reservoir ...	0·59	29	*Aberd.*	Braemar	1·22	51
Lincs.	Boston, Skirbeck ...	0·64	36	,,	Dyce, Craibstone ...	0·52	20
,,	Skegness, Marine Gdns.	0·53	31	,,	New Deer School House	0·71	33
Notts.	Mansfield, Carr Bank ...	0·40	19	*Moray*	Gordon Castle	0·42	20
Derby	Buxton, Terrace Slopes	1·27	41	*Nairn*	Nairn, Achareidh ...	1·02	57
Ches.	Bidston Observatory ...	0·74	39	*Inverness*	Loch Ness, Garthbeg ...	3·04	122
,,	Manchester, Ringway...	0·99	46	,,	Loch Hourn, Kinl'hourn	9·24	172
Lancs.	Stonyhurst College ...	2·33	82	,,	Fort William, Teviot ...	7·68	195
,,	Squires Gate	1·06	51	,,	Skye, Broadford ...	7·45	177
Yorks.	Wakefield, Clarence Pk.	0·58	29	,,	Skye, Duntuilm ...	4·64	163
,,	Hull, Pearson Park ...	0·59	31	*R. & C.*	Tain, Mayfield... ...	1·68	82
,,	Felixkirk, Mt. St. John...	0·63	34	,,	Inverbroom, Glackour...	4·64	155
,,	York Museum	0·91	46	,,	Achnashellach	7·40	175
,,	Scarborough	0·87	46	*Suth.*	Lochinver, Bank Ho. ...	3·49	137
,,	Middlesbrough... ...	0·36	19	*Caith.*	Wick Airfield	1·43	69
,,	Baldersdale, Hury Res.	1·10	44	*Shetland*	Lerwick Observatory ...	2·60	124
Norl'd.	Newcastle, Leazes Pk....	0·37	19	*Ferm.*	Crom Castle	1·42	51
,,	Bellingham, High Green	0·84	35	*Armagh*	Armagh Observatory ...	1·29	54
,,	Lilburn Tower Gdns. ...	0·38	16	*Down*	Seaforde	0·87	33
Cumb.	Geltsdale	1·43	55	*Antrim*	Aldergrove Airfield ...	0·83	37
,,	Keswick, High Hill ...	3·14	98	,,	Ballymena, Harryville...	1·26	44
,,	Ravenglass, The Grove	2·47	88	*L'derry*	Garvagh, Moneydig ...	1·38	54
Mon.	A'gavenny, Plâs Derwen	1·05	35	,,	Londonderry, Creggan	2·36	90
Glam.	Ystalyfera, Wern House	2·59	74	*Tyrone*	Omagh, Edenfel ...	2·20	85

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ICE ACCUMULATION UPON TRAWLERS IN NORTHERN WATERS

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

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

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

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

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

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

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

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

(ii) Accumulation of snowfall

(iii) Freezing of sea spray.

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

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

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

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

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

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

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

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

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

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

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

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

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

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DURATION OF HIGH RELATIVE HUMIDITIES

By L. P. SMITH, B.A.

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

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

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

Values shown in brackets are weighted.

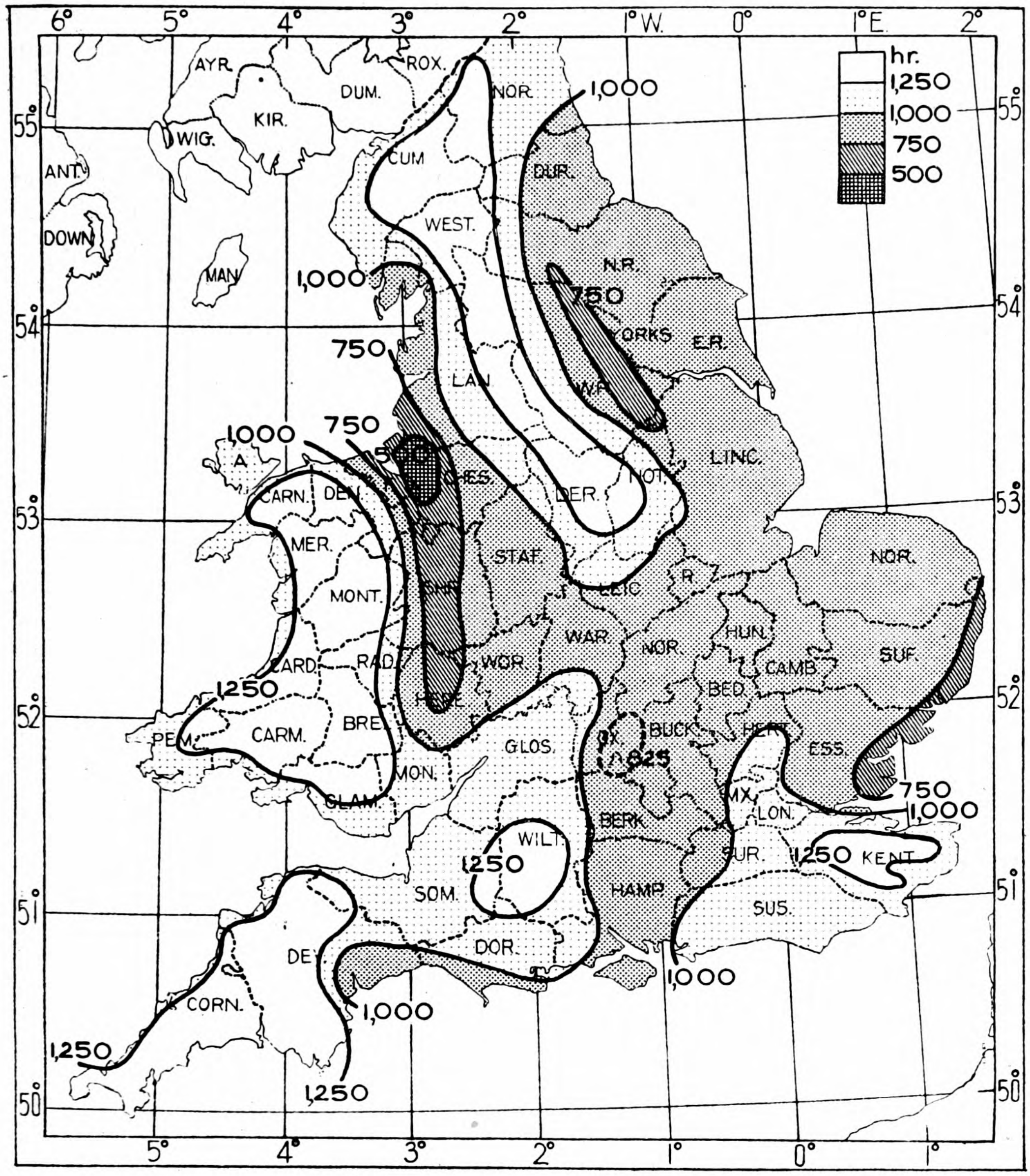

FIG. 1—MEAN SEASONAL (JUNE–SEPTEMBER) TOTAL OF HOURS OF RELATIVE HUMIDITY 90 PER CENT. OR MORE

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

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

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

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

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

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MEAN RANGE IN AN AUTOREGRESSIVE SERIES

By A. F. JENKINSON, M.A.

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

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

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

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

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

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

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

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

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

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

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

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

By J. K. MACKENZIE

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

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

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

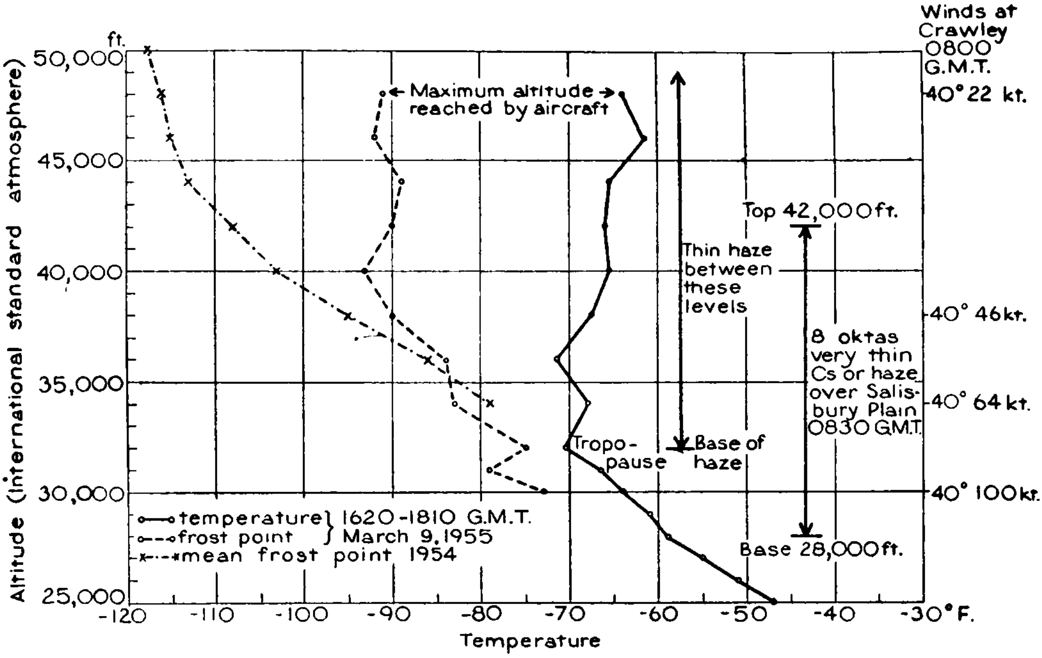


FIG. 1—AIRCRAFT ASCENT OF MARCH 9, 1955 (1620–1810 G.M.T.) COMPARED WITH MEAN FROST POINTS OF 35 CANBERRA ASCENTS MADE IN 1954

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

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

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

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

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

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

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

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

200 mb.

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

300 mb.

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

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

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

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

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

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

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

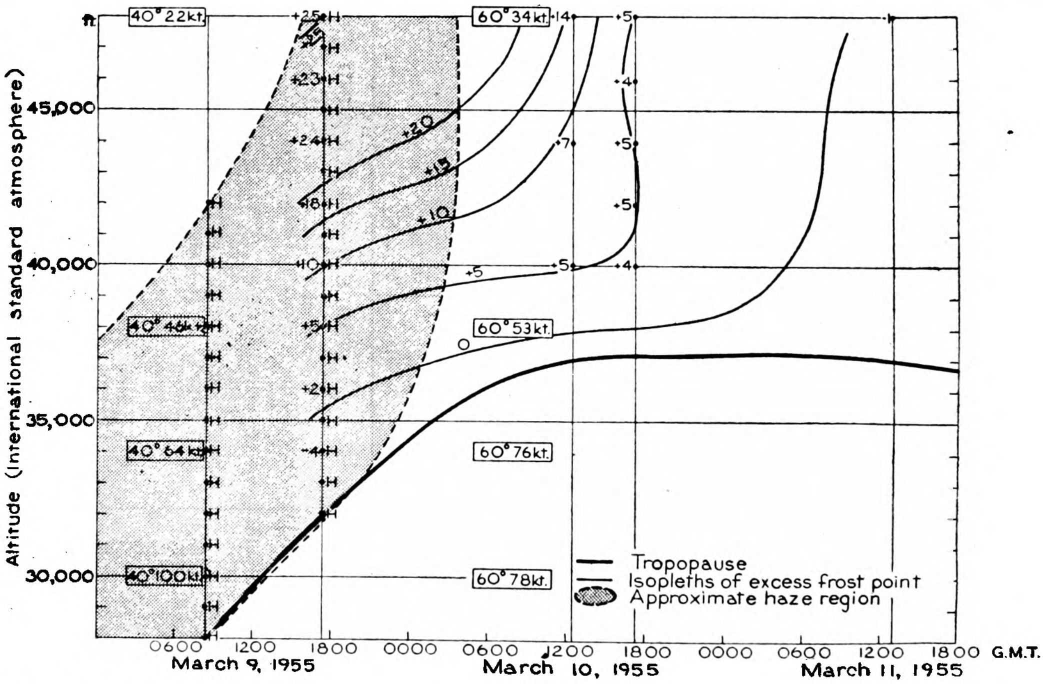


FIG. 2—HAZE AND EXCESS OF FROST POINT ABOVE 1954 MEAN OBSERVED IN THE STRATOSPHERE, MARCH 9–10, 1955

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

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

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

REFERENCES

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

AN UNUSUAL REFRACTION PHENOMENON SEEN FROM A HIGH-FLYING AIRCRAFT

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

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

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

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

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

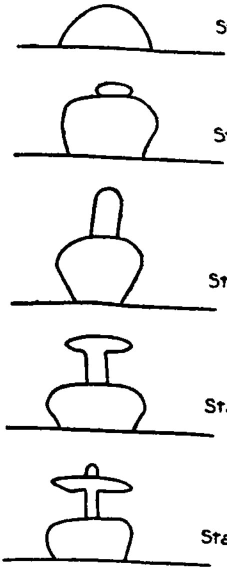


FIG. 1

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

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

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

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

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

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

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

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

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

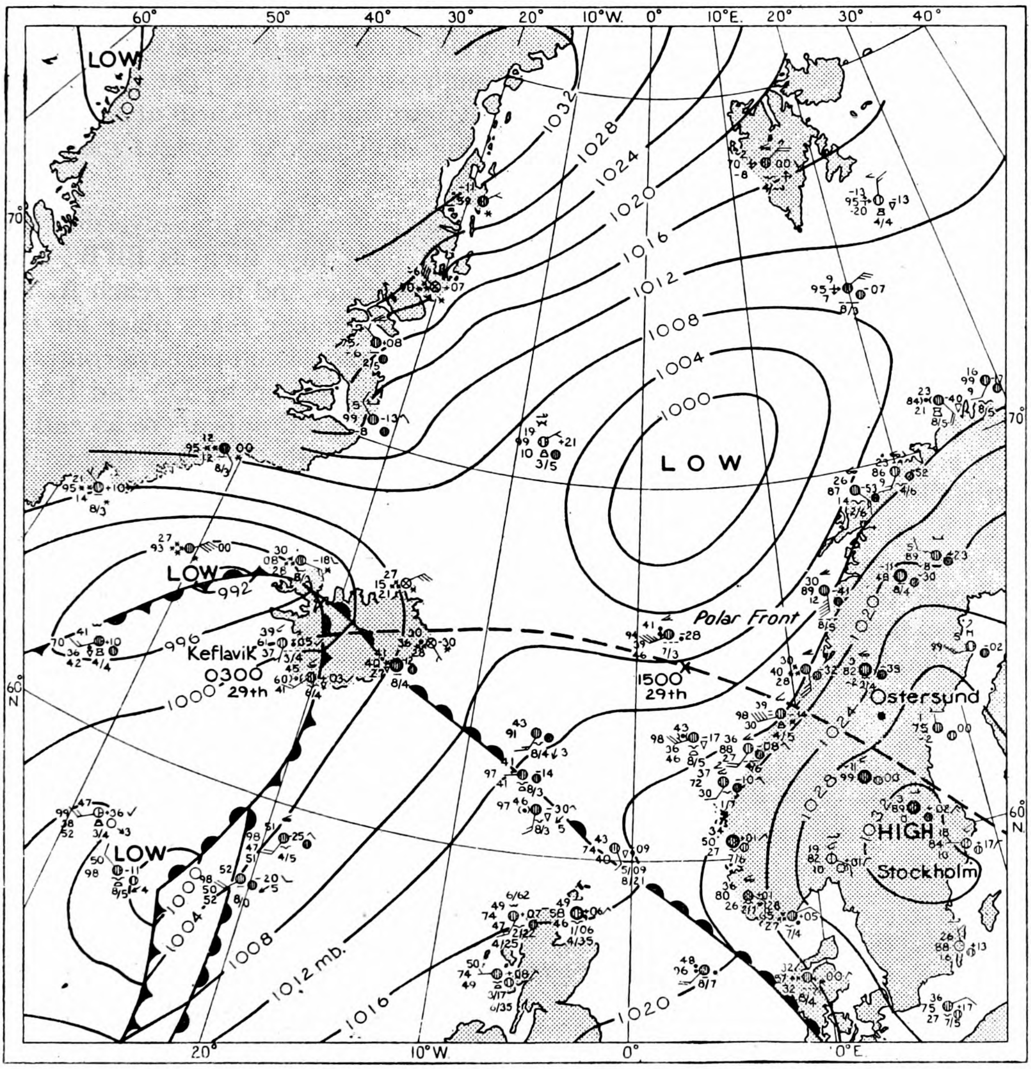


FIG. 2—SYNOPTIC CHART, 1200 G.M.T. NOVEMBER 29, 1955

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

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

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

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

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

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

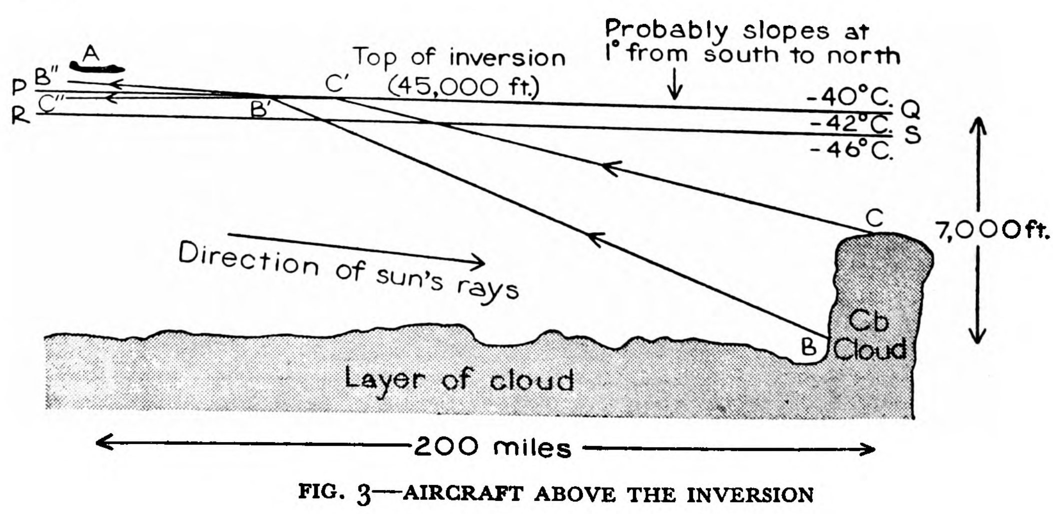
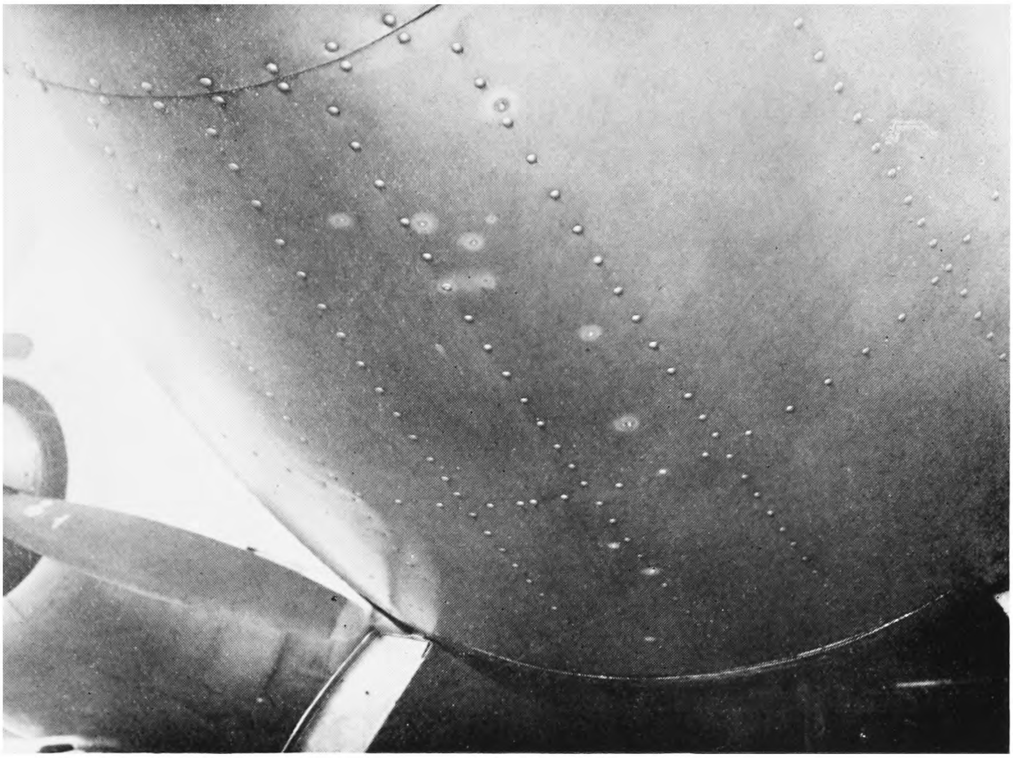
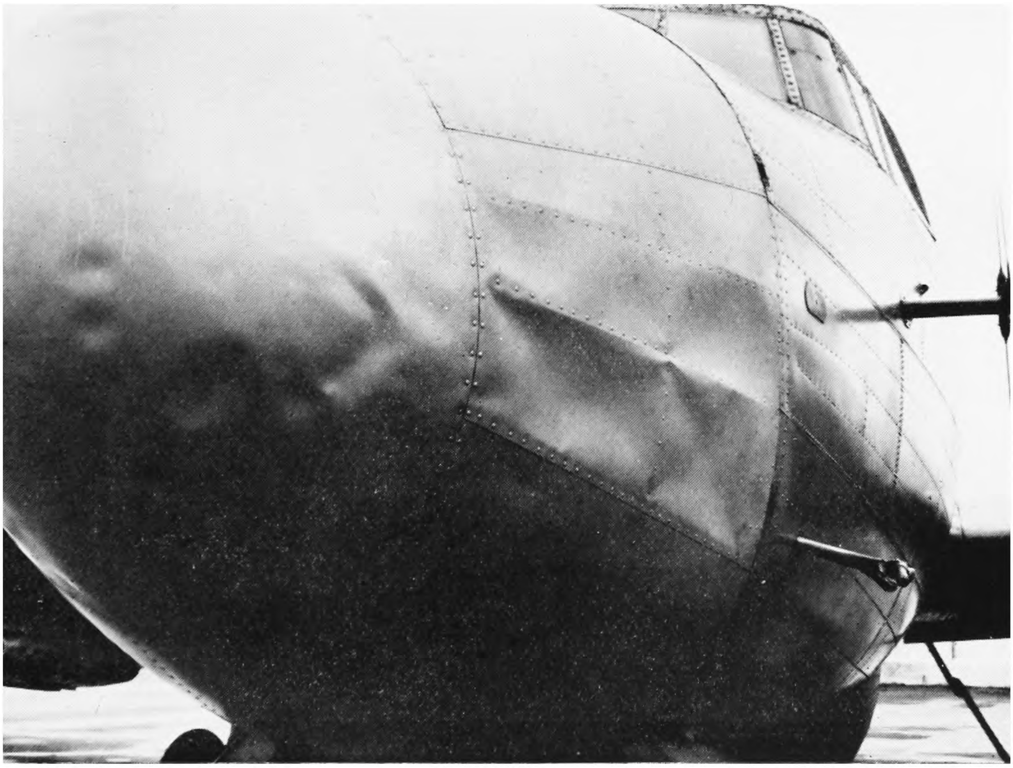


FIG. 3—AIRCRAFT ABOVE THE INVERSION



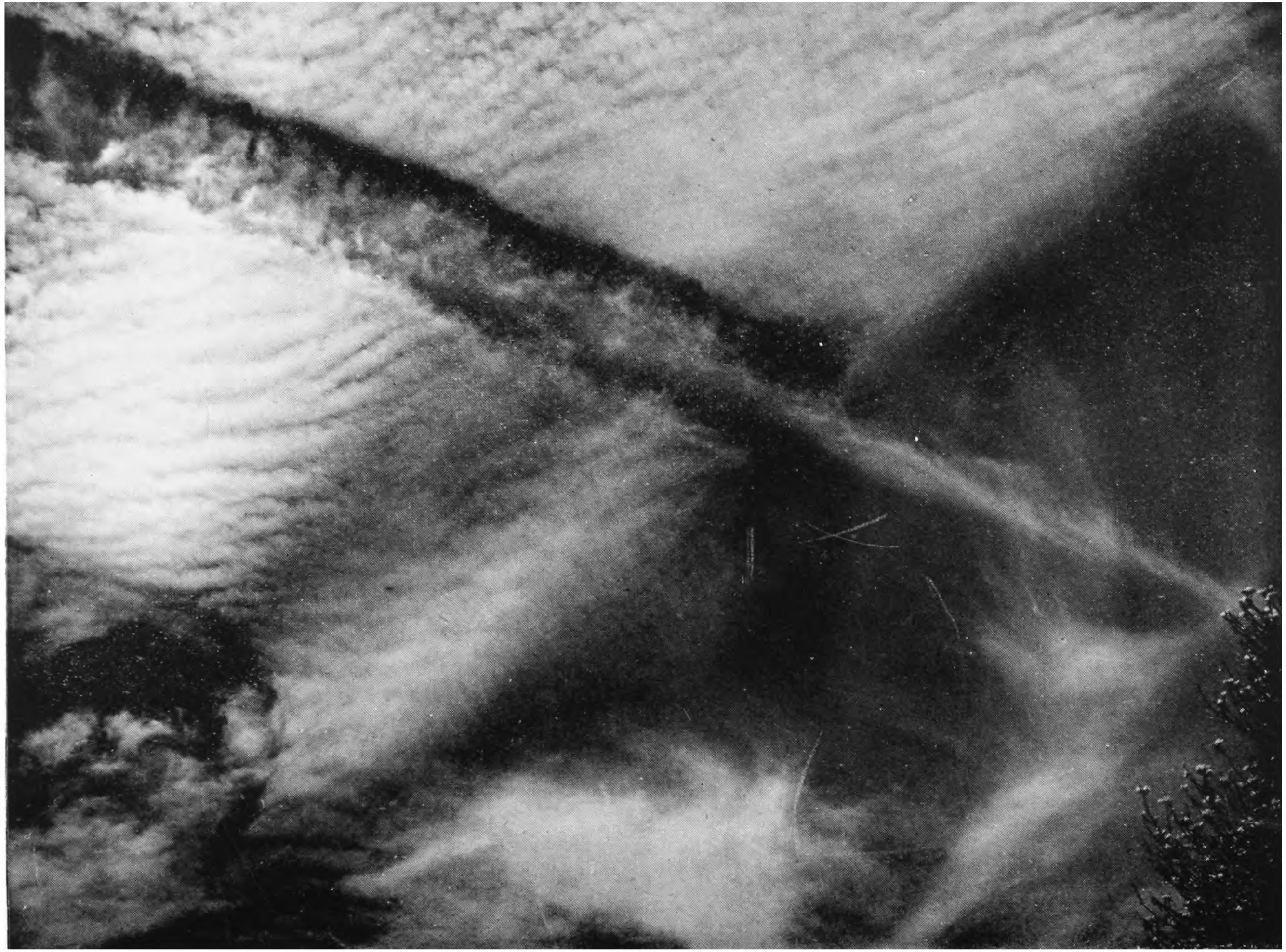
HOLES IN AIRCRAFT CAUSED BY LIGHTNING



BUCKLING CAUSED BY LIGHTNING

EFFECT OF LIGHTNING ON AIRCRAFT

(see p. 248)



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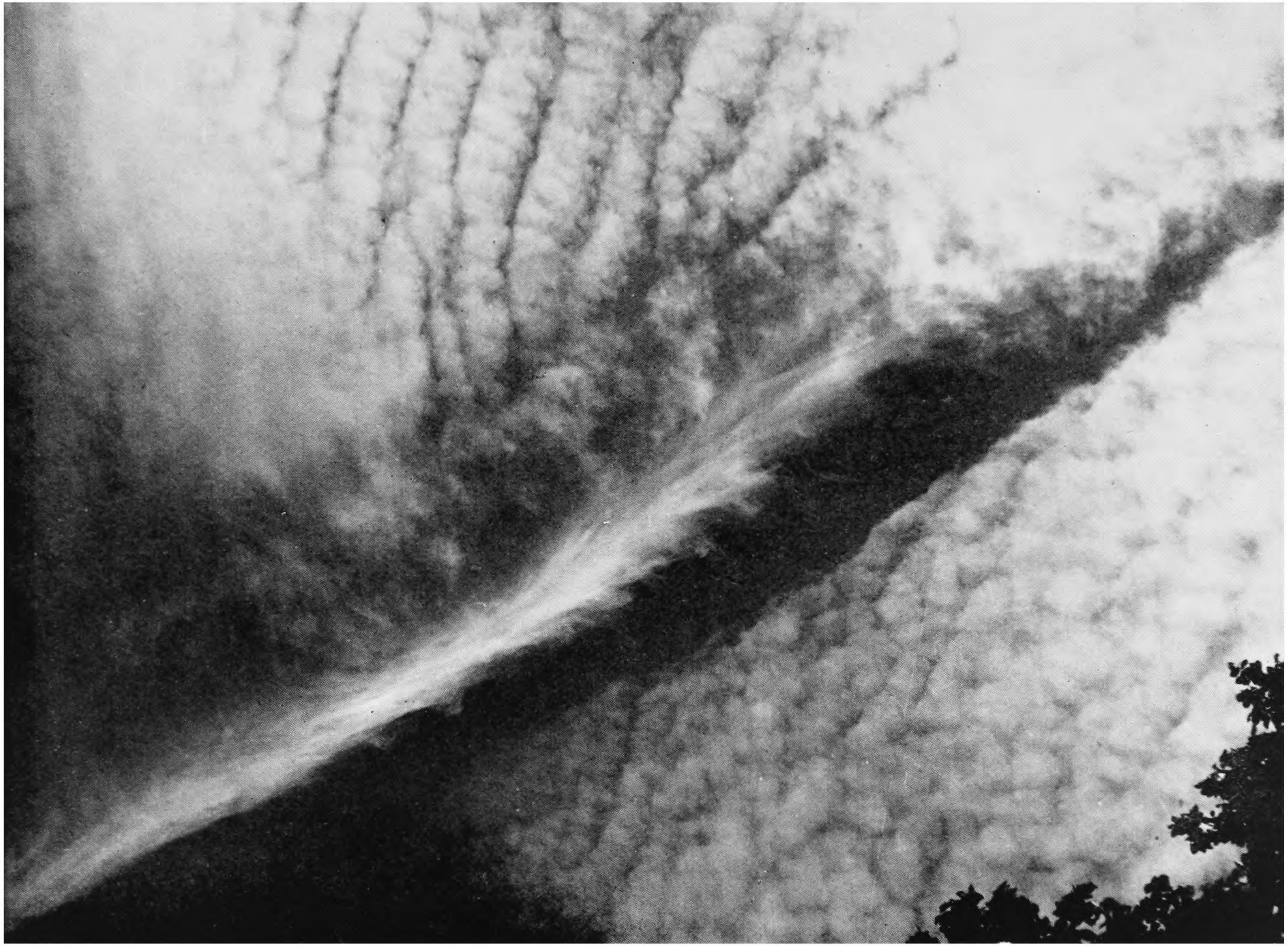
DISTRAIL OBSERVED AT WEMBLEY
(see p. 249)



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DISTRAIL OBSERVED AT WEMBLEY

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

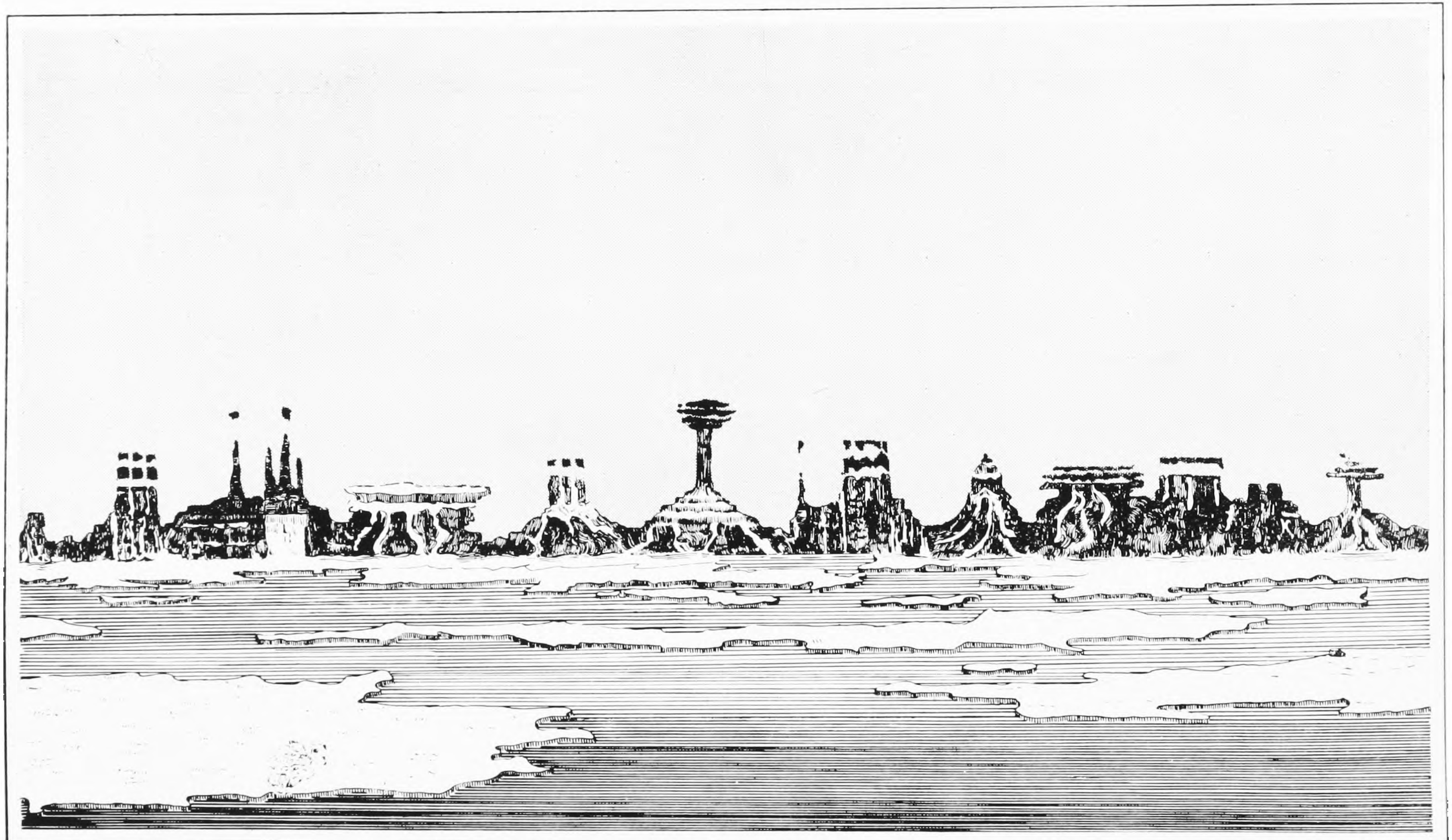

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FIG. 5—TELESCOPIC APPEARANCE OF THE EAST COAST OF GREENLAND, AT THE DISTANCE OF 35 MILES, WHEN UNDER THE INFLUENCE OF AN EXTRAORDINARY REFRACTION JULY 18, 1820 (POSITION 71° 20′N. 17° 30′W.)

(see p. 242)

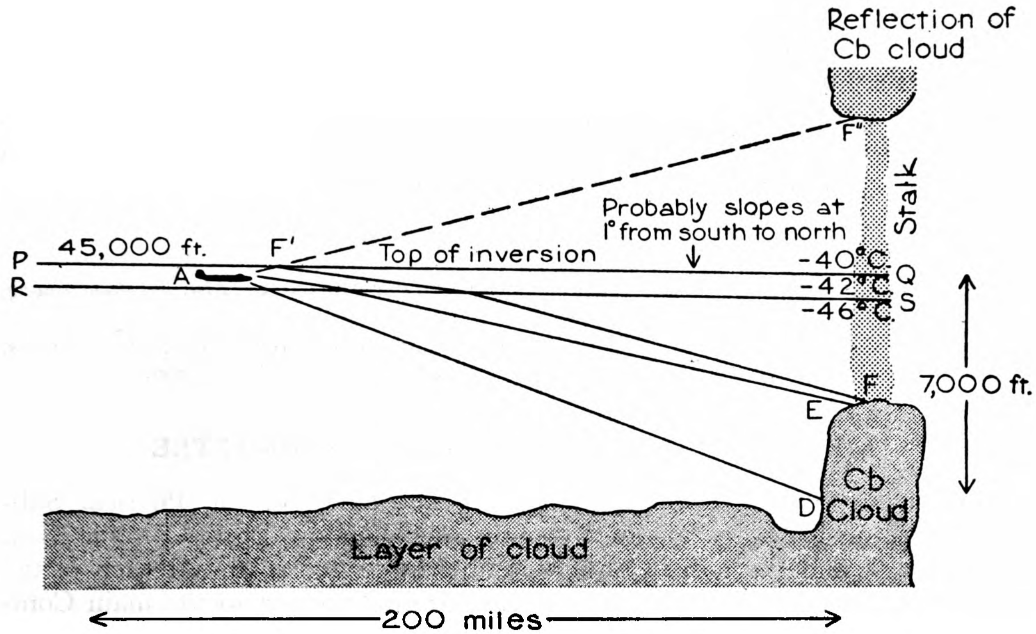

FIG. 4—AIRCRAFT WITHIN THE INVERSION

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

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

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

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

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

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

REFERENCES

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

METEOROLOGICAL RESEARCH COMMITTEE

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

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

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

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

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

ABSTRACTS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

OFFICIAL PUBLICATION

The following publication has recently been issued:-

GEOPHYSICAL MEMOIRS

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

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

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

ROYAL METEOROLOGICAL SOCIETY

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

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

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

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

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

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

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

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

Symons Memorial Lecture

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

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

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

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

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

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

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

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

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

LETTERS TO THE EDITOR

Three aircraft simultaneously struck by lightning

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

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

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

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

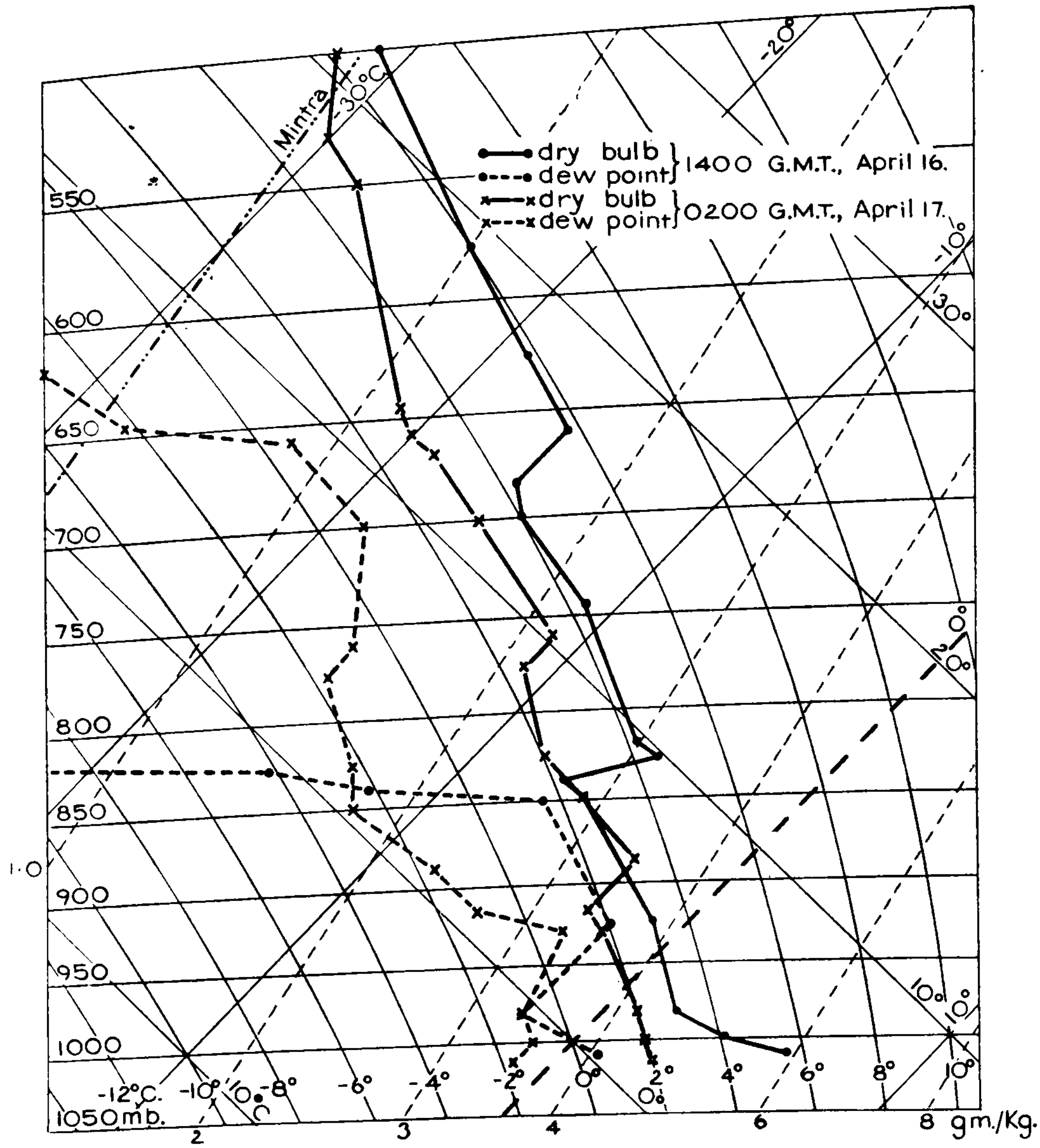

FIG. 1—TEPHIGRAM OF HEMSBY ON APRIL 16 AND 17, 1956

TABLE I—OBSERVATIONS RECORDED AT BINBROOK AT TIME OF INCIDENT

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

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

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

L. L. ALEXANDER

Wittering, April 17, 1956

Aircraft struck by lightning

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

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

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

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

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

G. W. HURST

North Front, Gibraltar, February 20, 1956

NOTES AND NEWS

Distrails

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

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

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

D. T. TRIBBLE

Personal bias introduced during interpolation

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

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

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

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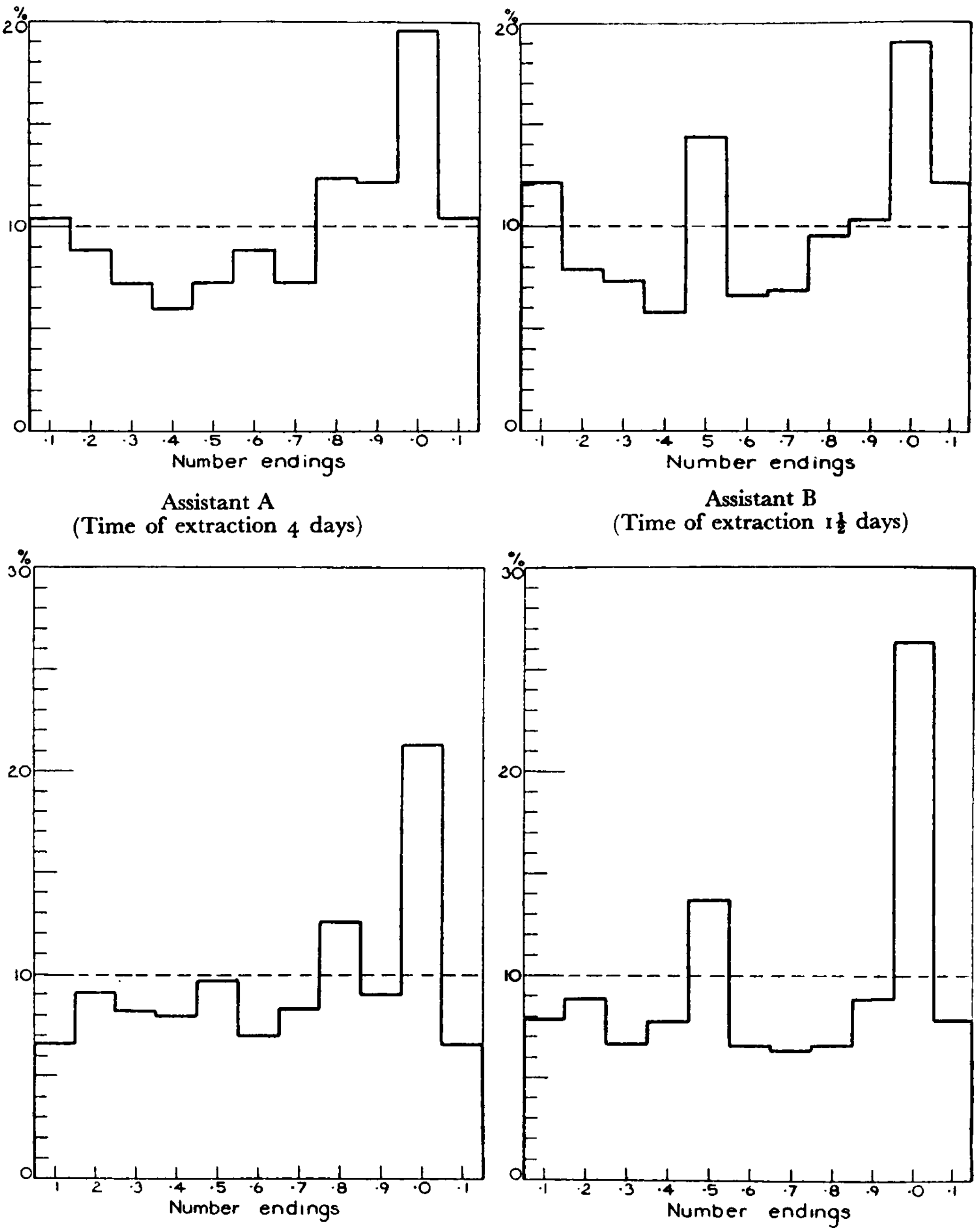
* LUDLAM, F. H.; Fall-streak holes. *Weather, London*, **11**, 1956, p. 89.



Assistant A
(Time of extraction 4 days)

Assistant B
(Time of extraction 1½ days)

Assistant C
(Time of extraction 8 days)

Assistant D
(Time of extraction 8 days)

FIG. 1 FREQUENCY OF READINGS OF LAST FIGURE OF INTERPOLATION

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

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

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

L. FLETCHER

REFERENCES

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

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

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

REVIEWS

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

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

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

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

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

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

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

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

N. BRADBURY

A study of fifty years' rainfall of Mangalore. By K. P. Ramakrishnan and J. Narayanan. *Mem. India Met. Dep., Delhi,* **30,** Pt. III. 12½ in. × 10 in., pp. 52, *Illus.,* Manager of Publications, Delhi. Price: *Rs* 6–14 or 11*s.*

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

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

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

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

R. G. VERYARD

METEOROLOGICAL OFFICE NEWS

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

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

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

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

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

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

WEATHER OF JUNE 1956

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

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

* Hillhead High School, Glasgow.

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

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

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

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

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

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

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

RAINFALL OF JUNE 1956

Great Britain and Northern Ireland

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

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ICE ACCRETION ON AIRCRAFT IN WARM-FRONT CONDITIONS

By A. C. BEST, D.Sc.

Introduction.—Wexler[1] has deduced that only the ice phase exists at temperatures below about $-5°$C. in stratiform clouds from which widespread precipitation of fairly uniform intensity is falling. His method of reaching this conclusion was rather indirect and it seems worth while to derive directly an approximate criterion for the maintenance of a relative humidity of 100 per cent. with respect to liquid water in ascending air which contains ice particles. If this condition is maintained we may expect condensation into liquid water drops to occur and hence the existence of potential icing conditions. The maintenance of 100 per cent. relative humidity with respect to liquid water depends upon the rate of ascent of the air being sufficiently fast for water vapour, surplus to that required for saturation with respect to liquid water, becoming available at a rate equal to the rate of deposition of water onto the ice crystals in the saturated atmosphere.

The rate of release of water vapour in ascending air.—Let us denote the saturation density (with respect to liquid water) of water vapour by ρ_w. As the air ascends the temperature falls and ρ_w decreases. In a particular parcel of air the rate at which water vapour becomes surplus to the amount required for saturation is $-d\rho_w/dt$. According to Dalton's law we may put

$$\rho_w = \frac{M}{R}\frac{p_w}{\theta},$$

where M is the molecular weight of water (18), R the gas constant ($8{\cdot}31 \times 10^7$ erg deg.$^{-1}$ mol.$^{-1}$), θ the temperature (degrees absolute), and p_w the saturation vapour pressure (dynes cm.$^{-2}$).

and so $$\frac{d\rho_w}{dt} = \frac{M}{R\theta}\left(\frac{\partial p_w}{\partial \theta} - \frac{p_w}{\theta}\right)\frac{d\theta}{dt}.$$

If the air is ascending at a rate V(cm. sec.$^{-1}$) and the lapse rate in the cloud is Γ_s(°C. cm.$^{-1}$) we can replace $d\theta/dt$ by $-V\Gamma_s$ and so get

$$\frac{d\rho_w}{dt} = -\frac{M}{R\theta}\left(\frac{\partial p_w}{\partial \theta} - \frac{p_w}{\theta}\right)V\Gamma_s. \qquad \ldots\ldots (1)$$

This is the rate at which water vapour is available for deposition on the ice particles if saturation with respect to liquid water is to be maintained.

Rate of deposition of water vapour on ice particles.—If an ice particle exists in an atmosphere in which the vapour pressure is not equal to the vapour pressure at the surface of the particle, vapour will be conducted to or from the particles by gaseous diffusion. Sublimation or evaporation will occur and, owing to the release or absorption of latent heat, the temperature of the particle will differ from the ambient temperature. The evaporation or growth of the particle in a stationary atmosphere is a problem in gaseous diffusion, the solution to which has been given by Jeffreys[2]. Because the particle temperature differs from the ambient temperature, heat will be conducted to or from the particle by a process analagous to the diffusion of vapour. If a steady state is reached in which the temperature of the particle neither rises nor falls, the sum of the heat conducted to the particle and the heat released by sublimation must be zero. We can describe these processes as follows. Jeffreys's solution[2] for the rate of growth of the particle is

$$\frac{dm}{dt} = 4\pi DCG\,(\rho_o - \rho_s) \qquad \ldots\ldots (2)$$

and the analogous equation for heat conduction is

$$\frac{dH}{dt} = 4\pi kCG\,(\theta_o - \theta_s)\,. \qquad \ldots\ldots (3)$$

The equation representing the steady state is

$$\frac{dH}{dt} + \frac{\lambda}{M}\frac{dm}{dt} = 0\,, \qquad \ldots\ldots (4)$$

where

m = mass of ice particle (gm.)
D = coefficient of diffusion of water vapour in air (cm.^{2} sec.$^{-1}$)
C = electrostatic capacity of a conductor of the same shape as the ice particle
G = coefficient introduced to take account of relative motion between the particle and the atmosphere
ρ_o = ambient vapour density (gm. cm.$^{-3}$)
ρ_s = vapour density at particle surface (gm. cm.$^{-3}$)
H = heat content of particle above some arbitrary level (cal.)
k = thermal conductivity of air (cal. cm.$^{-1}$ sec.$^{-1}$ deg.$^{-1}$)
θ_o = ambient temperature (°C.)
θ_s = particle surface temperature (°C.)
λ = latent heat of vaporization of ice (cal. mol.$^{-1}$)
σ = density of ice (gm. cm.$^{-3}$).

Using Dalton's law to replace vapour densities by vapour pressures and assuming the particles are spherical with an equivalent radius a (see Appendix) so that we can write $m = 4\pi a^3\sigma/3$ and $C = a$ we eliminate dH/dt from equations (2)–(4) and, after a little manipulation, get

$$\Delta\theta = \frac{\lambda\sigma}{kGM}\,a\,\frac{da}{dt} \qquad \ldots\ldots (5)$$

$$p_o - p_s = \frac{R\theta\sigma}{DGM}\,a\,\frac{da}{dt} \qquad \ldots\ldots (6)$$

where $\Delta\theta$ is the excess of particle temperature over ambient temperature. Equations (5) and (6) represent the growth of the (spherical) ice particle at a temperature $\theta + \Delta\theta$ in an environment in which the temperature is θ and the vapour pressure is p_o. The vapour pressure at the particle surface is p_s. We are here interested in the case in which $p_o = p_w$ and, provided $\Delta\theta$ is not too large, we may put

$$p_s = p_i + \Delta\theta \frac{\partial p_i}{\partial \theta}$$

where p_i is the saturation vapour pressure over ice at temperature θ. We then easily obtain from equations (5) and (6)

$$a\frac{da}{dt} = \frac{GMDk\ (p_w - p_i)}{\sigma(R\theta k + D\lambda\ \partial p_i/\partial\theta)} \qquad \ldots\ldots (7)$$

to represent the rate of growth of a single particle.

Condition for maintenance of water saturation.—In order that water saturation may be just maintained we must have

$$4\pi n\sigma a^2 \frac{da}{dt} = -\frac{d\rho w}{dt},$$

where n is the number of ice particles per cubic centimetre. Substituting for da/dt and $d\rho_w/dt$ from equations (7) and (1) respectively we obtain

$$V = B\frac{Gan}{\Gamma_s}, \qquad \ldots\ldots (8)$$

where

$$B = \frac{4\pi kDR\theta\ (p_w - p_i)}{(\partial p_w/\partial\theta - p_w/\theta)\ (R\theta k + D\lambda\ \partial p_i/\partial\theta)}. \qquad \ldots\ldots (9)$$

In order to assess the minimum value of V necessary to maintain liquid water in the cloud we must evaluate the five variables of which V is a function.

Evaluation of B.—The quantity we have denoted by B is a function of temperature. Inserting appropriate numerical values for various parameters (c.g.s. units) we find the following values.

θ(°A.)	273	268	263	258	253	248	243
B	0	1·0	2·2	3·3	4·3	5·1	5·7

Evaluation of Γ_s.—The temperature lapse rate in the cloud is a function of height and temperature but a reasonable approximation to the saturated lapse rate is given by taking $\Gamma_s = 7 \times 10^{-5}$ °C. cm.$^{-1}$.

Evaluation of a.—The evaluation of a, the radius of the equivalent spherical ice particle, is somewhat more difficult. As a preliminary step it is useful to consider the rate of growth indicated by equation (7) and with the assumption that G is unity. If S is the surface area of the ice sphere

$$\frac{dS}{dt} = 8\pi a \frac{da}{dt}$$

$$= \frac{8\pi GMDk\ (p_w - p_i)}{\sigma(R\theta k + D\lambda \partial p_i/\partial\theta)}.$$

Thus dS/dt is a function only of temperature. Inserting appropriate values for the parameters involved and putting $\sigma = 0{\cdot}9$ and $G = 1$ we get

θ	268	263	258	253	248	243
dS/dt	$5{\cdot}6\times10^{-7}$	$8{\cdot}5\times10^{-7}$	$9{\cdot}2\times10^{-7}$	$8{\cdot}4\times10^{-7}$	$7{\cdot}0\times10^{-7}$	$5{\cdot}2\times10^{-7}$

in c.g.s. units. The variation with temperature is thus small and to a close approximation we can put $dS/dt = 8 \times 10^{-7}$ and $S = 8 \times 10^{-7}t$ to give a reasonable approximation to the size of the particle t sec. after it is first formed in an atmosphere saturated with respect to liquid water. From this formula we easily obtain the following values for the radius of the equivalent spherical ice particle

t (sec.)	10	100	1,000	10,000
a (μ)	8	25	80	250

The radius varies as the square root of the time and it is apparent that a reaches a value between 50 and 100 μ within minutes but that hours are necessary for the particle to grow to significantly greater sizes. We shall see below that G is of the order 2·3 so that the assumption of unity for G has led to an underestimation of a by a factor of less than 1·5. Weickmann[3] has provided a number of photographs of ice crystals caught in cirrus cloud. Many of these crystals were in the form of plates or prisms and photographs of 17 were measured and the radius of the sphere of similar surface area computed assuming the prisms to be cylinders and the plates to be discs. For the prisms the resulting value of a was about 80 μ at 233°A. and about 160 μ at 263°A. The plates occurred only at the higher temperatures of course and gave a mean value of about 250 μ for a at 263°A. These values are in agreement with the values to be expected (as regards order of magnitude) from consideration of the rate of growth and we may conclude that a is likely to be between 50 μ and 300 μ.

Evaluation of G.—The best known formula for G is probably that of Frossling[4] who suggested

$$G = 1 + 0{\cdot}23(R_e)^{\frac{1}{2}},$$

where R_e is the Reynolds number of the falling particle. Frossling's result[4] was based upon the evaporation of spherical drops of water. The present writer[5], from a consideration of work including heat transfer as well as vapour transfer, has suggested

$$G = 1 + 0{\cdot}14(R_e)^{0{\cdot}6}.$$

In view of the accuracy with which we can work in the present problem the difference is not significant. For both formulae we must evaluate R_e.

Nakaya[6] quotes the average size of plate crystals as 0·8 mm. and prism crystals as 0·5 mm. The terminal velocities of crystals are not known in detail, but on the basis of the terminal velocities quoted by Nakaya for other types of crystal it seems likely that they are less than 60 cm. sec.$^{-1}$ for the plate and 100 cm. sec.$^{-1}$ for the prism. Taking the kinematic viscosity of air as 0·12 c.g.s. units these figures lead to values of 40 and 42 for the Reynolds number for plate and prism respectively. Whichever formula is used for G we then get a value of about 2·3. The values of a tabulated as a function of time in the preceding section were based upon a value of unity for G. The actual value varies with the crystal size but since $G \simeq 2{\cdot}3$ for the average crystal and since a varies as $\sqrt{G}$ the factor by which the tabulated values are in error is probably less than 1·5.

Evaluation of n.—This is the most difficult parameter to assess. The work of Findeisen and Shulz[7] suggests that the initial formation of ice crystals in rising air may be at the rate of about one per cubic metre at 263°A. and 1 per litre at 243°A. If this is so we should put $n = 10^{-6}$ at 263°A. and $n = 10^{-3}$ at 243°A. Subsequently of course more crystals may be produced by the splintering process and this may be the dominant factor in the later stages of the life of the cloud.

Minimum up-draught to maintain liquid water.—We have seen, equation (8) that,

$$V = B\frac{Gan}{\Gamma_s}.$$

Putting in the values

θ	B	G	a	n	Γ_s
			c.g.s. units		
263	2·2	2·3	200×10^{-4}	10^{-6}	7×10^{-5}
243	5·7	2·3	100×10^{-4}	10^{-3}	7×10^{-5}

we get $1\cdot4\times10^{-3}$ cm. sec.$^{-1}$ and 1·9 cm. sec.$^{-1}$ as the minimum up-draught necessary to maintain a liquid water content at 263°A. and 243°A. respectively. These values of V may occur in association with warm fronts and we may accordingly expect supercooled liquid water drops to occur in the initial stages of such a frontal system and to be more numerous with the greater values of V, i.e. in the more vigorous fronts. It also follows that convective clouds with much greater values of V, will be far more likely to give icing conditions.

In the later stages of the life of the warm-front system we may assume that ice crystals which have formed at the higher levels have fallen to lower levels and that n has been greatly increased by splintering. It is difficult to assess the value of n in these conditions but it seems reasonable to assume that at the lower levels it is not less than the number of raindrops per unit volume nearer the ground. If we assume a rate of rainfall of 2·5 mm. hr.$^{-1}$ some earlier calculations[8] suggest that the number of raindrops is of the order of 3,000 m.$^{-3}$. If we use this value for n at 263°A. we get a critical up-draught of about 4 cm. sec.$^{-1}$. Bannon[9] has computed up-currents in selected cases of rainfall associated with depressions and has obtained values of 10–20 cm. sec.$^{-1}$ with rates of rainfall of about 2·5 mm. hr.$^{-1}$.

Conclusions.—There is considerable uncertainty about the present calculations of the critical up-draught but the significance of the values obtained lies not in the precise speeds but in the fact that, in normal conditions, they can be of the same order as the up-draughts associated with warm fronts. Significant variations in n must occur and it must often happen that the actual up-draught is very near the critical value, sometimes smaller and sometimes greater. With variations in n and in the actual up-draught it is easy to visualize the out-of-balance being in opposite directions at places separated by only a few miles or at the same place during comparatively short periods of time. We should thus expect apparently contradictory icing reports from aircraft flying in apparently similar warm-front conditions. This does not help much with forecasting problems but it may be useful to note two implications. A vigorous up-draught is favourable for icing but the icing risk should have diminished when the rate of rainfall becomes high since, according to the Bergeron-Findeisen theory, this implies a large number of ice crystals.

Appendix

Equivalent spherical ice crystal

Ice crystals may be of various shapes, the particular shape depending upon the conditions of growth. The treatment of the rate of growth of an ice crystal by deposition is facilitated if we can assume the crystal to be spherical. Since evaporation and sublimation are surface phenomena one might speculate that the total rate of deposition on to a non-spherical crystal is very similar to the total rate of deposition on to a spherical crystal having the same surface area. We shall show that for two particular shapes this is a reasonable assumption.

Jeffreys[2] has given the solution to the equation, representing the diffusion of water to or from a droplet or crystal, in a form in which the shape of the droplet or crystal is represented by C, the electrostatic capacity. Thus two crystals of different shapes will increase in mass, in the same ambient conditions, at rates which are proportional to their respective electrostatic capacities. The electrostatic capacity of a sphere is numerically equal to its radius. The electrostatic capacity and surface area of a spheroid generated by an ellipse of eccentricity e are

	Prolate spheroid	Oblate spheroid
Axis of rotation...	Major	Minor
Surface area ...	$2\pi a^2(1-e^2)\left\{1+\dfrac{\sin^{-1}e}{e\sqrt{(1-e^2)}}\right\}$	$2\pi a^2\left\{1+\dfrac{1-e^2}{2e}\log_e\dfrac{1+e}{1-e}\right\}$
Electrostatic capacity ...	$2ae/\log_e\dfrac{1+e}{1-e}$	$ae/\sin^{-1}e$

In these expressions $2a$ is the major axis of the generating ellipse and the minor axis, $2b$, is given by $b^2 = a^2(1-e^2)$.

From these formulae it is a matter of simple arithmetic to compute the ratio of the capacity of a sphere, having the same surface area as the spheroid, to the capacity of the spheroid for various values of the eccentricity e. Some results of such calculations, together with the corresponding values of the ratio of the major to the minor axis of the generating ellipse, are shown in Table I.

TABLE I—RATIO OF CAPACITY OF EQUIVALENT SPHERE TO CAPACITY OF SPHEROID

Eccentricity e	Ratio of axes $\frac{a}{b}=\frac{1}{\sqrt{(1-e^2)}}$	Ratio of capacity of equivalent sphere to capacity of spheroid: Prolate	Oblate
0·9	2·3	0·99	1·006
0·95	3·2	0·97	1·016
0·99	7·1	0·89	1·049
0·995	10·0	0·85	1·061
0·999	22·3	0·71	1·084
0·9999	70·7	0·52	1·101

As e increases to unity, the capacity ratio for the prolate spheroid diminishes to zero and for the oblate spheroid increases to 1·11 ($=\pi/2\sqrt{2}$). It is thus clear that an equivalent sphere can be treated instead of an oblate spheroid with an error not exceeding 11 per cent. and instead of a prolate spheroid with an error which does not exceed 50 per cent. provided the major axis is not more than 70 times the minor axis. It is also reasonable to assume that an oblate spheroid, with e nearly unity, is a good approximation to a flat plate and that a prolate spheroid is a good approximation to a needle or column. For the purpose of calculating evaporation or sublimation we can accordingly replace ice crystals of these three shapes by spheres of equal area.

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A DIRECT-READING GEOSTROPHIC WIND SCALE

By L. S. MATTHEWS

Introduction.—The geostrophic wind scale described below incorporates corrections for the variation of the Coriolis acceleration and of chart scale with latitude. The instrument may be adapted for use on any orthomorphic chart whose scale at a point is a function of latitude alone.

Directions are given for the construction of scales for use on Mercator's conical orthomorphic and polar stereographic projections, which are those adopted for meteorological use[1].

The advantages of this instrument are:

(i) It may be used in very low or high latitudes with equal facility.

(ii) The geostrophic wind speed is obtained directly, no further correction being required.

(iii) A single instrument may be graduated for use on more than one chart projection.

So far as can be ascertained from the available literature[2–7], no single geostrophic scale yet proposed incorporates all these advantages.

Theory and description of the scale.—The equation for geostrophic motion is

$$2\,\omega\, v \sin\phi = -\frac{dG}{dn}, \qquad \ldots\ldots (1)$$

where v is geostrophic wind, ω the earth's angular velocity, ϕ the latitude, dG the geopotential interval between successive contours of an isobaric surface and dn is the corresponding horizontal interval measured along the common normal to the contours. Equation (1) applies to a wind in any direction, the wind being parallel to the contours.

On a map drawn to an orthomorphic projection the angles are conserved, and the scale relation between distances on the map and on the earth is a point function varying over the map but independent of the direction in which the distance is measured. Thus, considering only projections in which the scale is a function of latitude alone, we may write

$$ds = f(\phi)\, dn, \qquad \ldots\ldots (2)$$

where ds and dn are corresponding small distances on the map and on the earth respectively, and $f(\phi)$ is the scale value at latitude ϕ; dG is fixed as the conventional geopotential interval between successive contours.

Equation (1) may be written as

$$v = \frac{k f(\phi)}{(\sin \phi) . ds} \qquad \ldots\ldots (3)$$

where

$$k = \frac{dG}{2\omega} .$$

A scale may be constructed as shown in Fig. 1. A rotating cursor C fixed at O moves over a graduated scale S which is a circle of centre O. The angle θ between the cursor and a fixed initial line OX is a function, to be determined, of the latitude ϕ at which the scale is to be used. The line OX is graduated inversely as the speed v, so that the distance from O of the projection N of a point P on the cursor is given by

$$\text{ON} = \frac{A}{v}, \qquad \ldots\ldots (4)$$

where A is a numerical constant and v is the geostrophic wind speed corresponding to the contour spacing PN, in the latitude ϕ to which the cursor is set on scale S. Eliminating v from equations (3) and (4)

$$\frac{A \sin \phi}{k f(\phi)} = \frac{\text{ON}}{ds} = \cot \theta . \qquad \ldots\ldots (5)$$

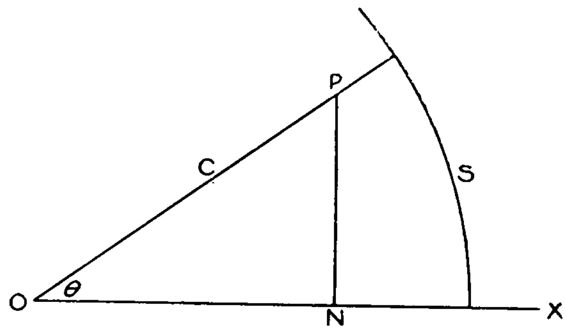

FIG. 1

The scale S may now be graduated in terms of ϕ by using the relation

$$\cot \theta = \frac{A \sin \phi}{k f(\phi)} . \qquad \ldots\ldots (6)$$

The formulae[8] for chart scale $f(\phi)$ are as follows:

(i) Mercator's projection with standard parallels 22½°N. and 22½°S.

$$f(\phi) = \sec \phi \cos 22\tfrac{1}{2}^\circ . \qquad \ldots\ldots (7)$$

(ii) Conical orthomorphic projection with standard parallels 30° and 60°.

$$f(\phi) = \frac{1 \cdot 283 \, [\tan \tfrac{1}{2} (90^\circ - \phi)]^{0 \cdot 7157}}{\cos \phi} . \qquad \ldots\ldots (8)$$

(iii) Polar stereographic projection

$$f(\phi) = \frac{2 \tan (45^\circ - \tfrac{1}{2} \phi)}{\cos \phi} . \qquad \ldots\ldots (9)$$

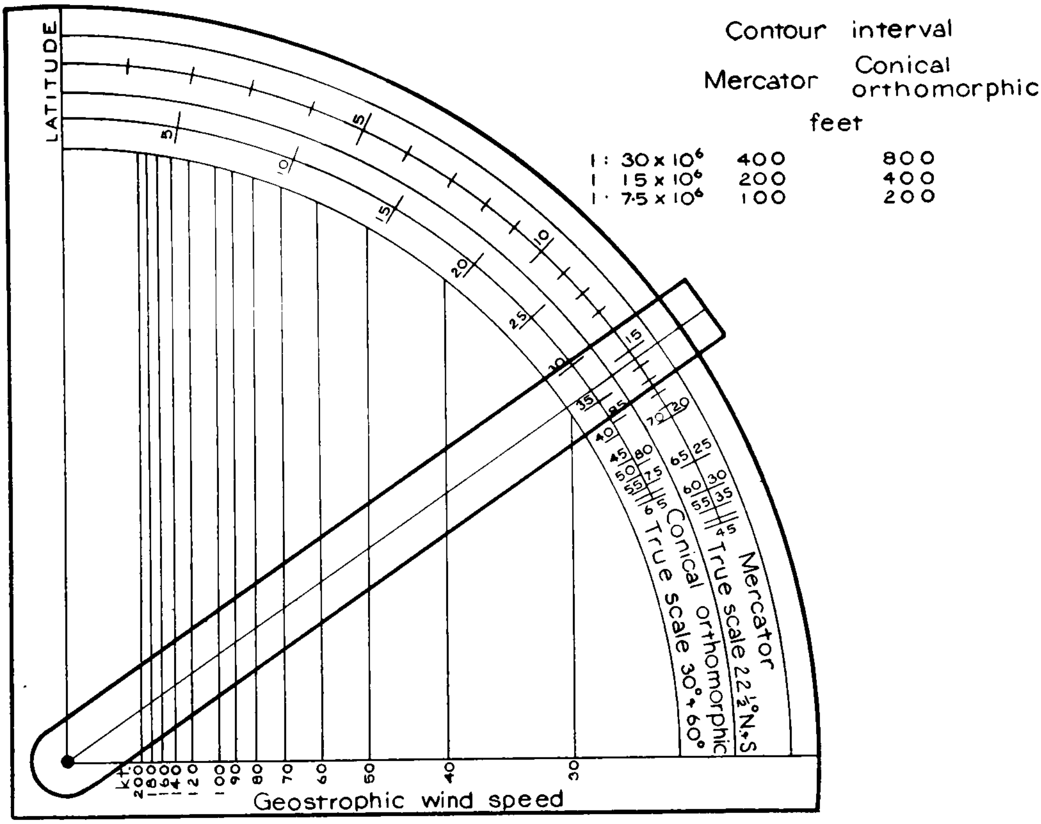

FIG. 2—SCALE GRADUATED FOR USE ON MERCATOR'S AND CONICAL ORTHOMORPHIC PROJECTIONS

Fig. 2 shows a scale graduated for use on Mercator's projection, with standard parallels $22\frac{1}{2}$°N. and $22\frac{1}{2}$°s., and on the conical orthomorphic projection with standard parallels 30° and 60°.

Directions for using the scale.—First draw on the map the common normal P′N′ to two consecutive contours of the isobaric surface at the desired position. Set the cursor to the latitude on scale S, and place the scale on the map, adjusting its position so that N′ lies on OX, P′N′ is perpendicular to OX, and P′ lies on the cursor line. Then PN coincides with P′N′, and the geostrophic wind speed may be read off the scale OX at the point N, since

$$ON = PN \cot\theta \,. \qquad \ldots\ldots \quad (10)$$

With a little practice the scale may be used without actually drawing the line P′N′.

When the contours are orientated north to south, P′ and N′ lie in the same latitude and there is no difficulty in setting the cursor to the correct latitude. When the contours are orientated in any other direction, however, P′ and N′ lie in different latitudes. It can be shown that the best latitude setting in such cases is the mid-latitude between the points P′ and N′.

Considering the extreme case when the contours are orientated exactly west to east, equation (1) may be written

$$2\,\omega\, v \sin\phi = -\frac{dG}{Rd\phi}\,, \qquad \ldots\ldots \quad (11)$$

where R is the radius of the earth,

and $$\frac{dG}{d\phi} = m\, v \sin \phi \,,$$

where $$m = -\, 2\, \omega\, R.$$

Now, assuming that the geostrophic wind speed between the points P′ and N′ is uniform, and writing ϕ_P, ϕ_N for the latitudes of P′ and N′ respectively, and δG for the geopotential interval between the contours,

$$\delta\, G = \int_{\phi_N}^{\phi_P} \frac{dG}{d\phi} \,.\, d\phi \qquad \ldots\ldots (12)$$

$$= m\, v\, (\cos \phi_N - \cos \phi_P)\,.$$

The mean gradient between P′ and N′ is therefore

$$\frac{\delta G}{\delta \phi} = \frac{m\, v\, (\cos \phi_N - \cos \phi_P)}{\phi_P - \phi_N}\,. \qquad \ldots\ldots (13)$$

If the cursor is set to the mid-latitude between P′ and N′, the indicated value v_i of the geostrophic wind speed will be such that

$$2\, \omega\, v_i \sin \tfrac{1}{2}\, (\phi_N + \phi_P) = -\, \frac{\delta G}{R \delta \phi}\,. \qquad \ldots\ldots (14)$$

Substituting m for $-2\omega R$ and expression (13) for $\frac{\delta G}{\delta \phi}$,

$$m\, v_i \sin \tfrac{1}{2}\, (\phi_N + \phi_P) = \frac{m\, v\, (\cos \phi_N - \cos \phi_P)}{\phi_P - \phi_N}\,. \qquad \ldots\ldots (15)$$

Hence $$\frac{v_i}{v} = \frac{\cos \phi_N - \cos \phi_P}{(\phi_P - \phi_N) \sin \tfrac{1}{2}\, (\phi_N + \phi_P)}\,.$$

The expression on the right-hand side of this equation does not differ appreciably from 1 for any value of ϕ_N and for values of $(\phi_P - \phi_N)$ up to at least 10°. This is true even when $\phi_N = 0$.

It follows that if the cursor is set to the mid-latitude between the points P′ and N′, the geostrophic wind speed obtained by the use of the scale approximates very closely to the true value: the only condition is that the wind speed between the contours should be uniform, or nearly so. This condition is fulfilled in practice if the contours are drawn at sufficiently close intervals.

Conversely, the scale may be used to determine the correct spacing of the contours when the wind speed only is known. This property is of particular value when constructing charts covering regions where observations of upper air temperatures and pressures are sparse, as in many parts of Africa and over the oceans.

Practical examples of the use of the scale.—The scale has proved its usefulness at Khartoum in the construction and interpretation of pressure-level contour charts in connexion with Comet flights. The nearest available upper air soundings were those made at Khartoum, Aden, Nairobi, Nicosia, Benina and Cairo. It was therefore difficult to draw accurately the contours between Khartoum and the Mediterranean coast. It was found however that, if the contours near Khartoum and Cairo (or Nicosia, when the Cairo observations were not available), were spaced on the assumption that the winds were geostrophic, at any rate at levels above the 500-mb. surface, the gradient obtained between Khartoum and Cairo gave geostrophic wind speeds which were in good agreement with those observed. Upper-wind determinations at Wadi Halfa, when they were available, were found very useful.

For example, on February 11, 1953, the Comet flying from Cairo to Khartoum reported winds as follows:

At top of climb from Cairo (approx. 30,000 ft.)...	280° 130 kt.
Approx. 26½°N., 33,000 ft.	272° 120 kt.
Approx. 21°N., 35,000 ft.	284° 103 kt.

The geostrophic winds measured from the 200-mb. contour chart were:

Lat. 30°N. 280° 120 kt.	Lat. 22°N. 270° 110 kt.
Lat. 27°N. 270° 120 kt.	Lat. 18°N. 270° 85 kt.

Again, during the afternoon of February 16, 1953, the Comet flying from Entebbe to Khartoum reported winds as follows:

Approx. 7½°N. 34,000 ft. 10° 77 kt. Approx. 12°N. 35,000 ft. 28° 70 kt.

There was unfortunately no upper air sounding at Khartoum on that day, but on the morning of the 17th it was possible to draw contours for 200 mb. from observations made at Khartoum and Aden using radio-sondes, and Wadi Halfa and Wau using pilot balloons, with an interpolated value of pressure level at Nairobi.

The geostrophic winds scaled from this chart gave the following values:

Lat. 7½° N. 20° 80 kt. Lat. 12°N. 20° 65 kt.

The extrapolations in space and time are certainly greater than one would wish, but the agreement between the observed and scaled winds is striking and encourages the hope that at least at these high levels the winds may be found to agree closely with the geostrophic winds, even in very low latitudes.

Acknowledgements.—The writer is indebted to Mr. J. Cochemé, Senior Meteorologist of Messrs International Aeradio, Ltd, and to Mr. U. C. W. Rath, Meteorologist of the Sudan Meteorological Service, for their constructive criticism during the initial stages of the work; and to Mr. A. W. Ireland, formerly Government Meteorologist, Sudan Government, for permission to publish this article, which was prepared while the author was a member of the staff of the Sudan Meteorological Service.

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NOCTURNAL WIND AT THORNEY ISLAND

By B. J. MOFFITT

Geographical situation.—Thorney Island is situated (see Fig. 1) in a land-locked harbour on the south coast: the South Downs run roughly parallel to the coast with their ridge rising some 600 ft. above sea level about 8 miles north-north-east of the station. The coastal water is very shallow and undergoes considerable temperature variation due both to diurnal effects and changes of weather type.

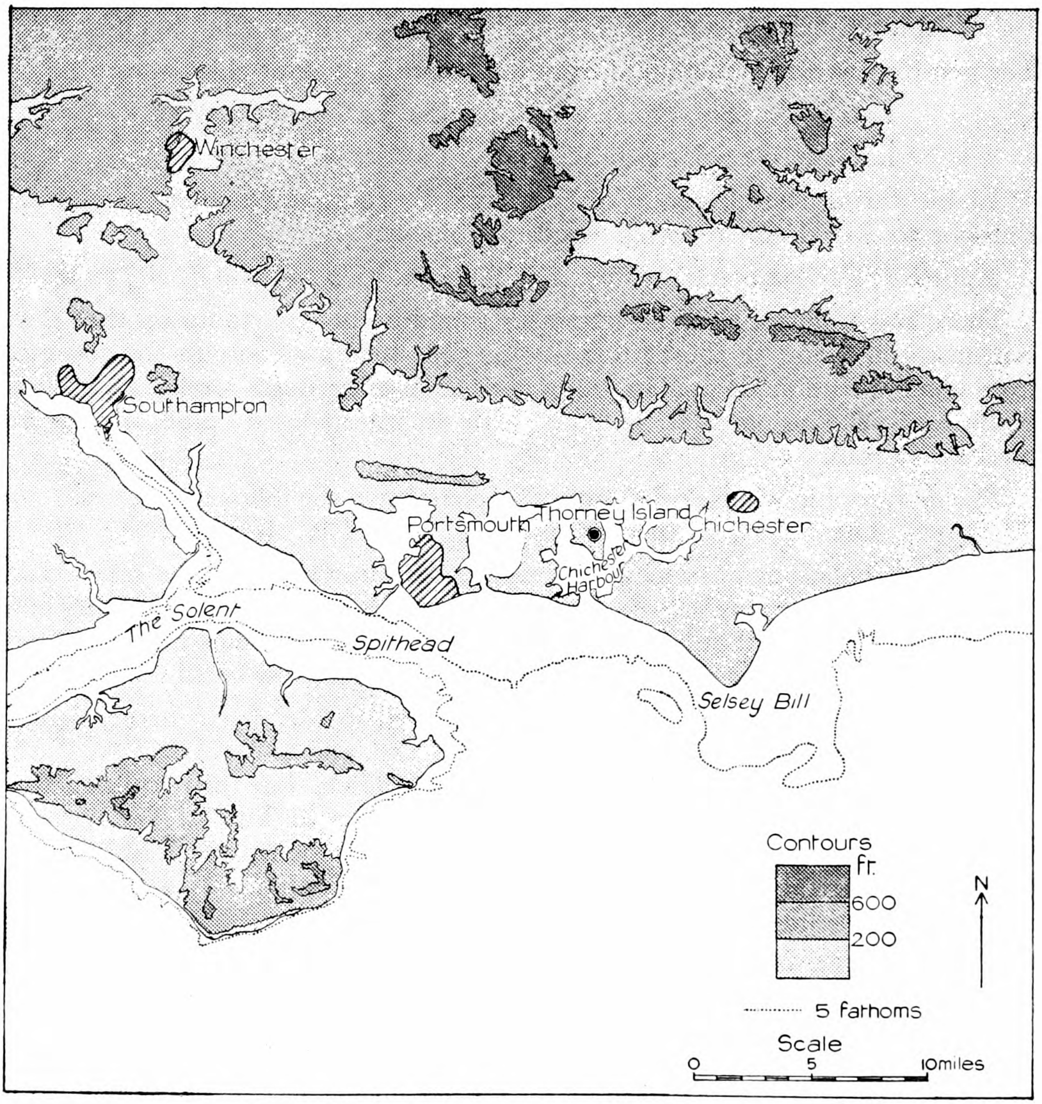


FIG. 1—THORNEY ISLAND AND SURROUNDING DISTRICT

Description of the wind and its importance.—The nocturnal wind at Thorney Island is from NNE. and may occur at any time of the year when clear skies and light winds prevail; with a light on-shore gradient wind there is usually a sudden change of wind direction to about 30° and a sudden temperature fall of some 2°F. The most important effects of the wind are its ability

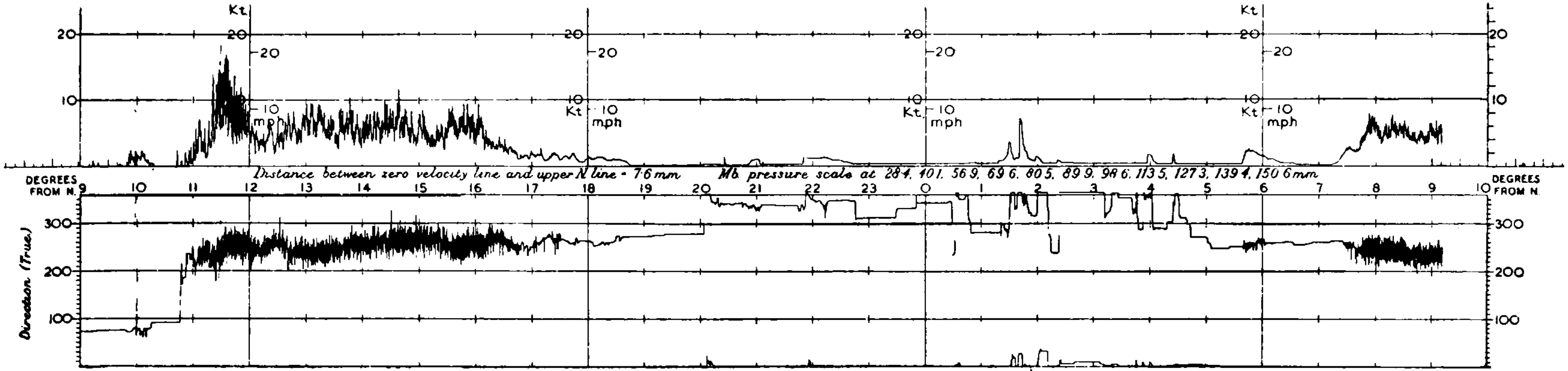


FIG. 2—ANEMOGRAM ILLUSTRATING INTERMITTENT NOCTURNAL WINDS ON NOVEMBER 10, 1953

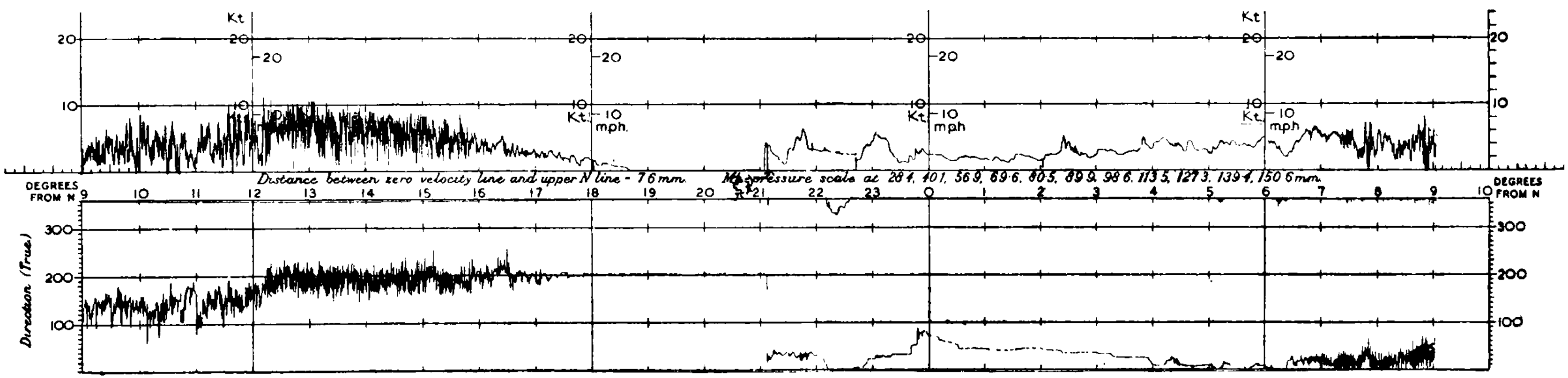


FIG. 3—ANEMOGRAM ILLUSTRATING NOCTURNAL WINDS ON APRIL 9, 1954

to delay considerably the formation of fog, a tendency to improve the visibility and sometimes to disperse fog already formed. It is therefore of considerable operational importance. Anemograms showing two typical occasions of nocturnal wind are illustrated in Figs. 2 and 3.

Controlling factors.—It is considered that the nocturnal wind is primarily of katabatic origin but there is an additional land-breeze effect when the sea is warmer than the land (a common occurrence at the time of onset). It was therefore assumed that the main controlling factors would be the strength of the opposing gradient wind (taken to be at 1,000 ft.) and the degree of nocturnal cooling. Fig. 4 is a graph of estimated wind at 1,000 ft. plotted against temperature difference between the day maximum and the night minimum. On this graph it is possible to draw a reasonably good curve separating occasions of occurrence and non-occurence of the nocturnal wind. During the period 1952–54 all occasions of wind speed less than 30 kt. with an on-shore component were used in this graph. The occurrences which fall above the curve are mainly of two types:

(i) occasions with a large temperature difference between sea and land (sometimes as much as 20°F.)

(ii) occasions of fairly strong gradient wind.

The occasions (ii) are mostly partial occurrences in which the nocturnal wind sets in for a few minutes several times during the night but is continually being dispersed by turbulence created by the relatively strong gradient wind.

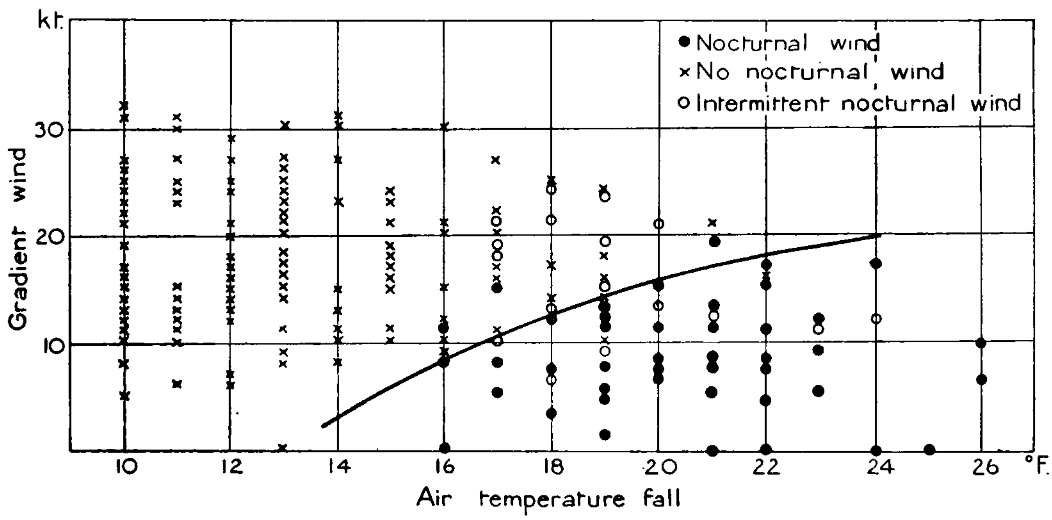


FIG. 4—GRAPH OF GRADIENT WIND AND TEMPERATURE FALL

Time of onset.—In considering the katabatic effect, the rapidity of descent of the cooled air from the South Downs is expected to depend on the rate of cooling of the air in contact with the slope. The land-breeze effect is also enhanced by nocturnal cooling and hence the time of arrival of the nocturnal wind should be dependent on the rate of cooling.

An analysis of 1952–54 data shows that on clear nights 68 per cent. of occurrences arrive 2–4 hr. after sunset but with variable cloud cover over 90 per cent. of occurrences began more than 4 hr. after sunset.

Since the nocturnal wind thus appears to occur much earlier on clear nights than on nights with variable cloud, it is not surprising that nearly all occurrences can be correlated with a particular fall of temperature at Thorney Island. It has been found that 90 per cent. of all occurrences arrive when the temperature at Thorney Island has fallen by 14–16°F. from the day maximum.

Forecasting procedure.—From the above discussion the following rules for forecasting the nocturnal wind at Thorney Island have been deduced:

(i) Forecast the night minimum temperature and hence deduce the expected fall of temperature from the day maximum.

(ii) Forecast the on-shore wind speed at 1,000 ft.

(iii) Plot the temperature fall and the on-shore wind speed at 1,000 ft. on Fig. 4 and read off whether a nocturnal wind is probable, improbable or marginal.

(iv) Consider whether the wind may arrive earlier than 2 hr. or later than 4 hr. after sunset, bearing in mind the coastal sea temperature and the expected cloudiness.

ROYAL METEOROLOGICAL SOCIETY

The Annual General Meeting of the Royal Meteorological Society was held on April 25 with the President, Dr. R. C. Sutcliffe in the Chair. After the formal business the following awards were made:

Buchan Prize: Mr. F. H. Ludlam.
Hugh Robert Mill Medal and Prize: Mr. J. S. Sawyer.
Darton Prizes for 1955:
Home, 1st: Mr. R. J. Murgatroyd.
2nd: Mr. S. E. Ashmore.
Canada, 1st: Mr. Roy Lee.
2nd: Mr. R. Anderson, Mr. B. W. Boville and Mr. D. E. McClellan, jointly.

Dr. Sutcliffe then delivered his Presidential Address.

Presidential Address—Moisture balance of the atmosphere.

Dr. Sutcliffe would have liked to have discussed the general circulation of the atmosphere which was curiously ignored in this country, but this was too wide a subject and he therefore confined himself to a talk about the water circulation in the atmosphere. There were three main parts to the circulation: evaporation, transport in the form of vapour or clouds, and precipitation.

It was convenient to assume that all condensation below the dew point would produce rain although this was clearly not the case. Precipitation, in the macrodynamic as opposed to the microphysical sense, could be classified into three types: orographic, convective (associated with vertical instability and of 1–10 Km. horizontal dimensions) and cyclonic (of 1,000 Km. horizontal dimensions). Little data was available about vertical transport of water on any scale yet this was fundamental in convective precipitation which was the main type in tropical regions. North of, say, 30°N. horizontal transport was predominant and exchange of moisture took place by eddy fluxes on the cyclonic scale.

For the tropics on the other hand, Palmén had shown that a reasonable proportion of equatorial rainfall can be accounted for from the trade-wind influxes, i.e. from mean and not eddy winds. The implication was that the circulation of water vapour in temperate regions occurs because there are eddy systems whereas in the tropics the circulation is due to convection. The tropical cyclone is a hybrid between a temperate-zone depression and a convective cell on a little smaller scale than a temperate-zone depression; it is a type of latent instability due to the release of latent heat. Possibly a small increase in temperature in equatorial regions might, as suggested by Bergeron and Palmén, produce a sequence of tropical cyclones in both hemispheres with a W. wind at the equator. Dr. Sutcliffe then showed a diagram having, on a cosine (equal areas) scale of latitude, isopleths of the distribution of water vapour up to 300 mb., the curves rising steadily at a slope of about 45° from pole to equator. He next showed diagrams of the amount of precipitable water over the Earth in January, maximum 5 cm. over the Amazon and 0·5 cm. over the Arctic and Siberia, and July, maximum 6 cm. over north-east India. These diagrams showed a maximum water content where there was most rain. A table of average amounts of precipitable water showed in January 0·9 cm. over the northern hemisphere, 2·5 cm. over the southern hemisphere and 2·2 cm. over the Earth and for July values of 3·4 cm., 2·0 cm. and 2·7 cm. respectively. As the mean amount of precipitation is 90 cm./yr.

the atmosphere holds only 10 days' supply of precipitation and its stock of water vapour must be renewed at that rate. Hence the main reservoir of water was on the Earth and, over a long time, the atmosphere was not of great account.

Turning to the energy requirements of evaporation Dr. Sutcliffe described the work of Albrecht and Budyko on evaporative energy transfer and pointed out that the energy used in evaporation is only a small part, 18 per cent., of the total energy of insolation.

Finally he showed a slide of Albrecht's figure of areas over which heat was transferred from the Earth to the atmosphere and *vice versa*. Heat was put into the atmosphere from the Earth in the equatorial regions and over the Gulf Stream and taken out of the atmosphere by the Earth in the subtropics. The pattern of input of energy from Earth to atmosphere corresponded with that of rainfall. Dr. Sutcliffe pointed out that the diagram showed it was not realistic to suppose, as was sometimes done, that the air received energy from the Earth all over the tropics and lost energy to the Earth in the temperate and polar regions.

LETTERS TO THE EDITOR

Whirlwind at Mitcham, May 18, 1956

Here are details of the whirlwind which struck my son-in-law's shed, Deer Park Gardens, Mitcham, Surrey on Friday, May 18, 1956. The incident occurred about 9 o'clock in the evening. The whirlwind sounded like an express train and the air was very cold. My son-in-law saw the whirlwind approaching and

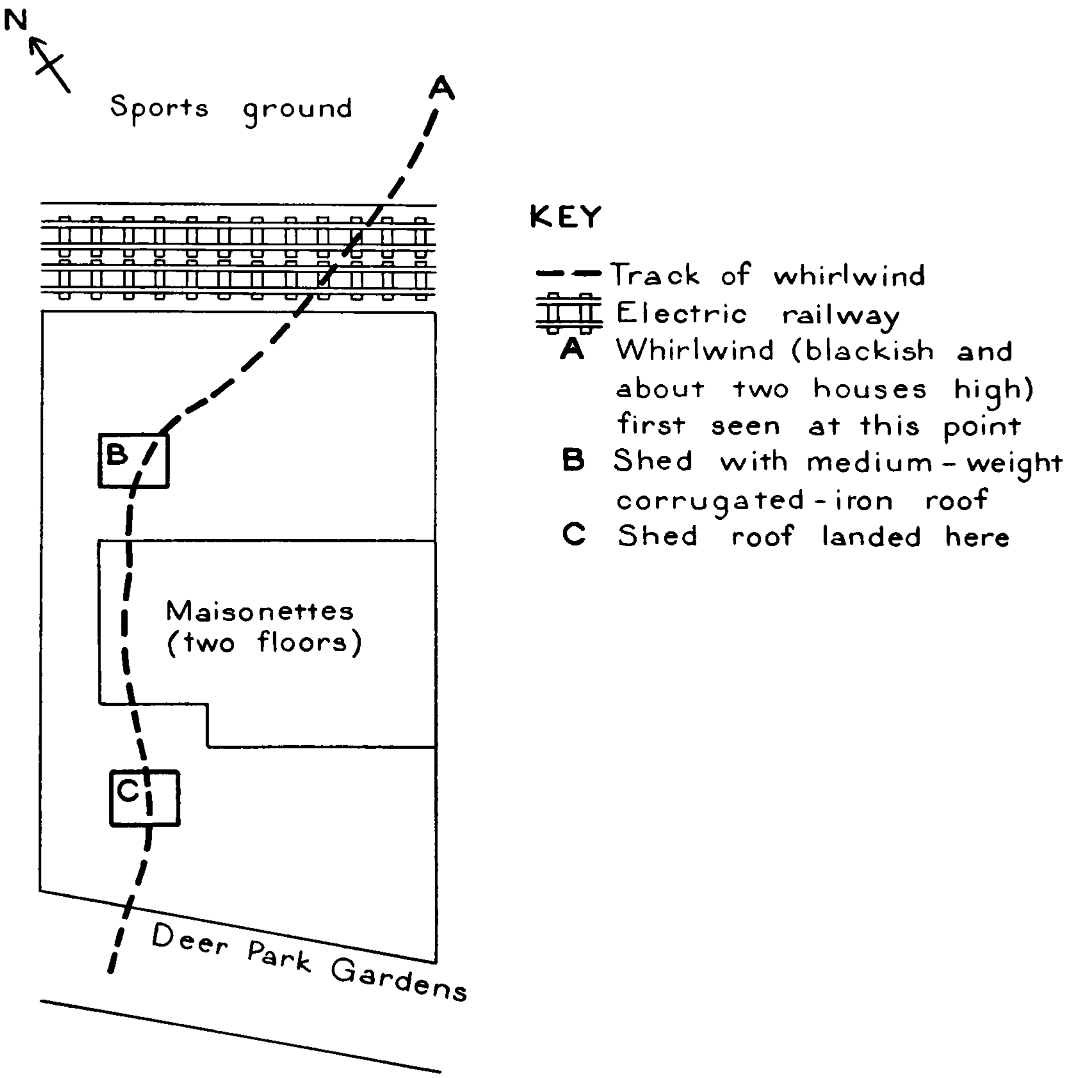
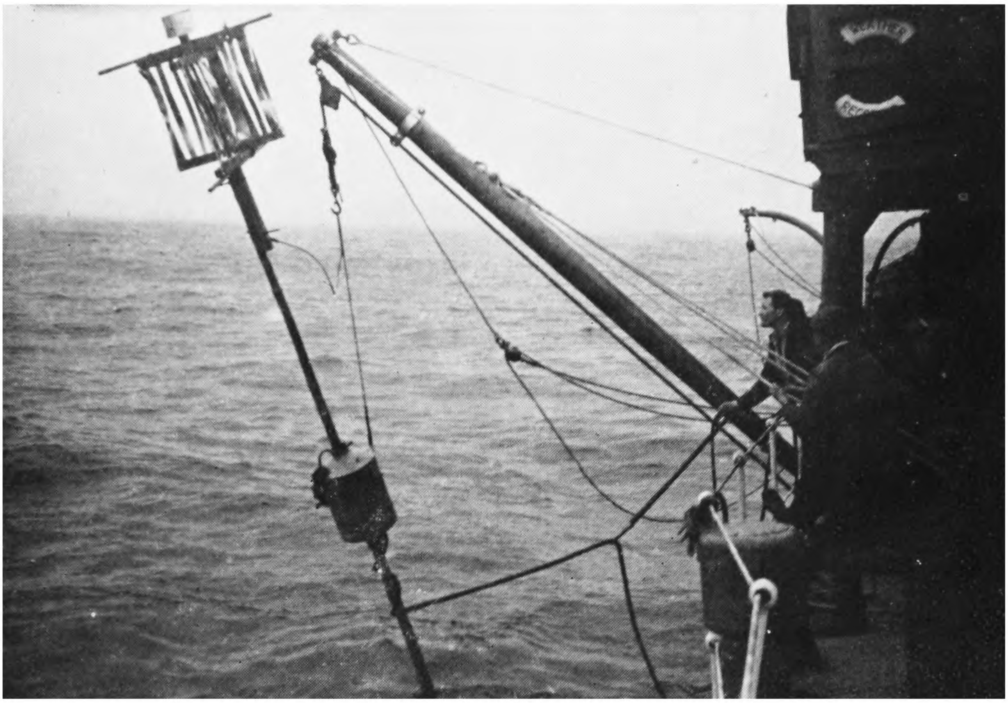
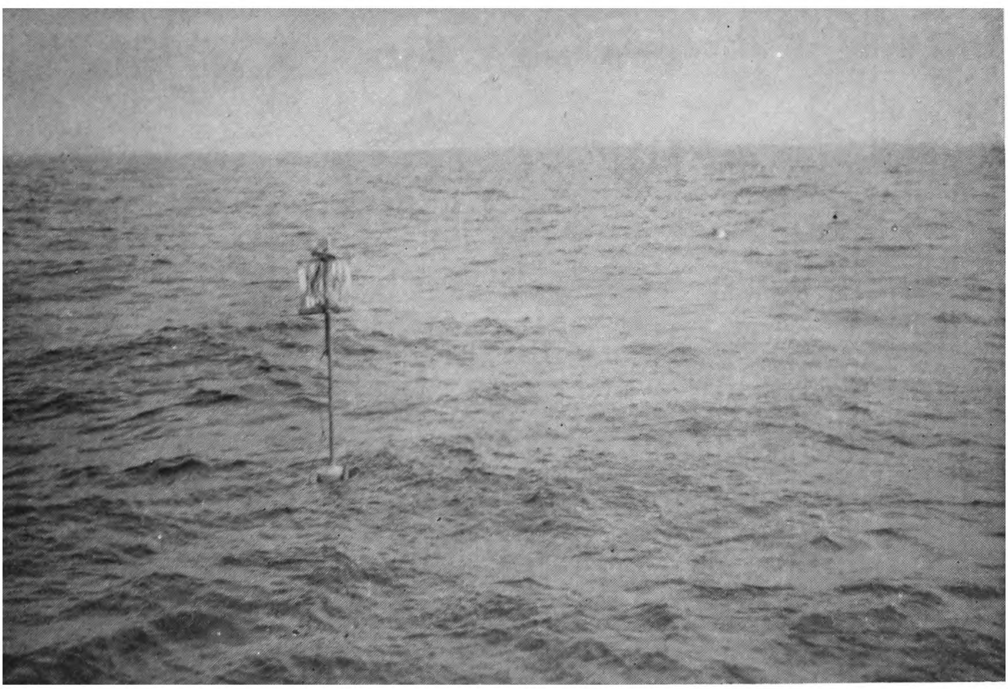


FIG. 1—TRACK OF WHIRLWIND AT MITCHAM

[*To face p. 272*



DAN BUOY BEING HOISTED INBOARD



DAN BUOY AFLOAT

Electrical-resistance thermometers are attached to the Dan buoy in order to investigate air and sea temperature gradients near sea level.

Reproduced by courtesy of E. M. Nicholson

DUST DEVIL, CAVENHAM HEATH, NOON, APRIL 23, 1956
(see p. 273)

Reproduced by courtesy of E. M. Nicholson

DUST DEVIL, CAVENHAM HEATH, NOON, APRIL 23, 1956
Taken near Ash Plantation on Cavenham Heath Nature Reserve looking south-east over Black Ditches.

(see p. 273)

Photograph by H. G. Biggs

SILVER BIRCH TREE STRUCK BY LIGHTNING

The tree, at Whiteley Village, Walton-on-Thames, was struck at 0630 B.S.T. on July 9, 1956 during a severe thunderstorm when 2·47 in. of rain fell. Bark from the tree was scattered round the base, the furthest piece being 12 ft. away. The incident was reported by G. B. Chetwynd-Stapylton, warden of the Whiteley Homes Trust.

threw himself to the ground. When he arose he found the shed roof had disappeared—this he subsequently found in the front garden. The diagram (Fig. 1) may help you to visualize what happened.

C. F. MACLAREN

16 *St. Aidan's Road, East Dulwich, S.E.* 22, *May* 23, 1956

[On May 18, 1956 the air over south-east England was cold and unstable in the lower layers. Winds were light and northerly. A few slight showers of rain were reported and at Kew the duration of sunshine was 6·7 hr.—Ed. *M.M.*]

Low latitude aurorae and the International Geophysical Year

The recent report of the Meteorological Office Discussion on the International Geophysical Year has prompted me to make the following suggestion to readers who live or who will be travelling in the regions named. One of the characteristics of sun-spot maxima is the extension southward of great auroral displays, the absolute records being Singapore (1°N.) and Batavia (6°S.) on September 25, 1909*. May I suggest that those whom duty or business or pleasure take to the East Indies, the Caribbean, and the Canal Zone during the International Geophysical Year keep a special watch for auroral activity.

CICELY M. BOTLEY

2 *Park Road, Tunbridge Wells, May* 29, 1956

NOTES AND NEWS

Dust devil on Cavenham Heath, April 23, 1956

We are indebted to the Director General of the Nature Conservancy for the two photographs in the centre of this magazine which were taken on Cavenham Heath Nature Reserve, Suffolk, at noon on April 23, 1956. The dust devil was moving from a north-easterly direction (left to right on the photographs) and the interval between the two exposures was about one min. At 1200 G.M.T. there was a weak cyclonic circulation of cold air over East Anglia and the screen temperature at Mildenhall (3 miles to the north-west of Cavenham Heath) was 52°F. The average lapse rate of temperature at Hemsby, Norfolk, up to 850 mb. was slightly less than 1°C./100 m.

Beiträge zur Physik der Atmosphäre

In the April number of the Magazine we announced the forthcoming publication of the new periodical, *Beiträge zur Physik der Atmosphäre* and stated the names of the publisher and editors. We are now pleased to report the publication of the first number which contains four major articles.

The first article is a memorial by H. Koschmieder to the scientific and administrative work of Richard Assmann. It includes a tribute to Dr. F. Schmidt-Ott a civil servant who was very instrumental in securing financial support, against his own superiors' wishes, for Assmann's work. Dr. Schmidt-Ott, founder of the *Notgemeinschaft der deutschen Wissenschaft*, died in April at the age of 95.

The research articles are by J. Zierep on the theory of lee waves in the stratosphere and troposphere taking account of suitable boundary conditions at the ground and tropopause, by A. J. Abdullah on dust storms in Iraq showing their occurrence along pre-cold-front pressure-jump lines and describing the

* STØRMER, C.; The polar aurora, Oxford, 1955, p. 17.

storm of March 23, 1954 in detail, and by H. v. Tippelskirch on the reason for the opposite sense of flow in Bénard cells in liquids and gases. The number is very well printed on 54 crown-octavo art-paper pages. The price of a volume of four numbers is 55.DM.

The dry weather in England and Wales during the first half of 1956

The first half of 1956 was notable for a long dry spell of weather which in many places lasted for nearly four months. Absolute droughts were reported as detailed below from a number of districts, principally in southern England. An absolute drought is a period of at least 15 consecutive days to none of which is credited 0·01 in. or more of rain. At first the general pattern of rainfall in England and Wales seemed to be following that of the great drought of 1921 when a wet January was followed by a long series of exceptionally dry months, but fortunately, in 1956, the series did not continue into June, as nearly twice the normal amount of rain fell over the country as a whole during the two weeks ending on the 9th and 16th of that month.

During February rainfall over England and Wales was only about 44 per cent. of the average, and apart from 1952 which had about the same amount of rain during that month, there has been no drier February since 1934. Less than one tenth of an inch was recorded at each of many places along the south-east coast of England and absolute droughts occurred from about the 13th to the 29th in the London area and in south coast counties from Kent to Devon.

March had about the same percentage of the average rainfall as February, and again the southern part of the country was the driest. Much of Kent, Sussex, Hampshire, Wiltshire and Gloucestershire experienced less than a quarter of the usual amounts. Absolute droughts occurred from the 4th to the 19th mainly south of the Thames and south-east of a line from about London Airport to the Isle of Wight.

April had 76 per cent. of the average for the month. Absolute droughts were reported from about March 24 to April 9 along the south coast of England at places extending from Bournemouth to Torquay and also along the south Welsh coast. Droughts also occurred later in the month in Northamptonshire, Huntingdonshire and Norfolk from about April 14–30.

It was the driest May in England and Wales since 1896 with only 41 per cent. of the month's average rainfall. Absolute droughts occurred at many places in East Anglia from about April 14 to May 8, and also locally in the Home Counties from May 10–24.

A map of the amounts of rain measured at a large number of stations during the period February–May 1956 and expressed as a percentage of the 1881–1915 average shows that everywhere in England and Wales for the same four months the rainfall during this period was less than 75 per cent. of the average except locally in Yorkshire. It was locally less than 50 per cent. in the English Lake District and generally less than 50 per cent. over most of England and Wales south of a line drawn approximately from Aberystwyth to Cambridge and thence to Southend, and was locally less than 33 per cent. in the Thames Valley and along much of the south coast. Graphs of accumulated departures from the average amount of rainfall drawn for six representative stations well dispersed over the country show that during the 17 weeks from January 29 to May 26 rainfall was below the average almost every week and that the deficiency amounted to about 4 in. in the south and 3 in. elsewhere in the country. Outstandingly dry places were South Farnborough, which usually has over 7 in. during the periods February–May, with a deficit of 5·4 in., and Princetown (Devon) which recorded 15 in. less than its usual fall of 24 in.

The effects of the dry weather during the first half of 1956 were all the more serious as 1955 was a dry year, especially during the second half when the rainfall over England and Wales was 7 in. below normal; the accumulated deficiency over the 12 months amounted to 4 in. The four months February–May 1956 with only 4·8 in. was the driest period from February–May on record since, at least, 1869; the driest four-month period was March–June 1893 with 4·2 in. The 11 months July 1955–May 1956 with only 23·8 in. (10 in. below the average for this period) was also the driest of any similar period of 11 months since records began in 1869.

Over Scotland as a whole the dry weather of February–May 1956 was not so pronounced as over England and Wales. A large area in the north and west had over 75 per cent. of the average and locally there was a close approach to the average. In many parts of the east and south however, there was only 50–60 per cent. of the averages and in the neighbourhood of Edinburgh in particular the deficiency combined with deficiencies of earlier months to make December 1954—May 1956 the driest 18 months on record.

R. E. BOOTH

Strong winds at high levels in the equatorial zone of the Far East

Strong winds (exceeding 75 kt.) have been noted from time to time in the band between 40,000 and 55,000 ft. in the winds derived from radar-wind-measurement stations in the Far East equatorial zone (regarded as the zone between 10°S. and 10°N. for the purposes of this note). Reference has been made to the winds at these levels by Hay[1].

Since the arrival of Canberra aircraft in Malaya early in 1955, more aircraft reports of winds at heights above 40,000 ft. have become available in addition to the sparse radar observations. From these, we conclude first, that the sparsity of radar wind-measurement stations over a vast area, coupled with the system used in coding the results for transmission which allows for reporting standard heights only, has probably been the cause of many occasions of strong winds being unnoticed; secondly, that somewhere in the layer between 40,000 and 55,000 ft. there often exists a narrow "core" of strong easterlies, often exceeding 75 kt. and occasionally exceeding 100 kt., with comparatively light winds above and below the "core". In fact it is not uncommon at the time of year to which this note relates (late May to July) to find a change to westerlies a few thousand feet above the core of strong easterlies, as shown by Hay[1]. The height of the "core" appears to vary from day to day, as does the orientation of its axis. There are insufficient data to be able to correlate the surface or lower-level streamline charts with the day-to-day movement of the "core".

An example of the existence of such winds which, from available data, would have been impossible to forecast, occurred on a flight by a Canberra from Negombo to Butterworth (overflying Car Nicobar Island) on June 19, 1955. Flying at an indicated height of 46,500 ft. the mean wind found between Negombo and Car Nicobar was 82° 102 kt., with a maximum computed to have been

120 kt. The mean wind between Car Nicobar and the let-down point near Butterworth was 80° 86 kt.

Another example occurred in a flight by another Canberra over the same route on July 26, 1955. Flying at 47,000 ft. the mean wind from Negombo to 250 miles from Butterworth was 75° 80–90 kt. A marked decrease occurred about 250 miles from Butterworth.

A third example occurred in a flight by a Canberra from Changi to Labuan and return on May 27, 1955, spending one hour between 0500 and 0600 G.M.T. over Labuan. Flying at heights between 40,000 and 45,000 ft. (indicated) the mean wind on the outward flight was 85° 50 kt. Flying at 42,000 ft. the mean wind on the return flight was 85° 60 kt. On the outward flight flying at 40,000 ft. two winds of 82° 99 kt. and 72° 105 kt. were computed at 0347 and 0353 G.M.T. respectively. On climbing to 43,000 ft. a wind of 85° 40 kt. was computed at 0413 G.M.T. On further climbing to 45,000 ft. winds of 65° 49 kt. and 85° 70 kt. were computed at 0420 and 0440 G.M.T. respectively.

TABLE I—UPPER WINDS AT STATIONS NEAR THE AIR ROUTES

	May 26, 1955						May 27, 1955					
	Singapore				Songkla		Singapore				Songkla	
	0300 G.M.T.		1500 G.M.T.		0300 G.M.T.		0300 G.M.T.		1500 G.M.T.		0300 G.M.T.	
ft.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.
55,000	110	25	100	48	90	35	...	...	100	18	...	...
50,000	90	30	80	52	100	46	...	...	60	56	90	16
45,000	110	35	90	35	80	52	...	...	50	53	70	33
44,000	...	...	...	...	...	...	80	47	...	...	...	...
43,000	100	44	...	...	...	...	...	...	...	...	...	...
40,000	100	14	110	21	70	35	90	39	70	49	90	25

	June 18, 1955						June 19, 1955					
	Bangkok		Singapore				Bangkok		Singapore			
	0300 G.M.T.		0300 G.M.T.		1500 G.M.T.		0300 G.M.T.		0300 G.M.T.		1500 G.M.T.	
ft.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.
55,000	70	93	90	40	...	...	...	...	20	7	70	36
54,000	...	...	...	...	...	...	...	...	70	26	...	...
53,000	...	...	...	...	...	...	...	...	...	...	60	78
52,000	...	...	...	...	...	...	...	...	70	78	...	...
51,000	...	...	60	74	...	...	...	...	...	...	50	88
50,000	80	67	60	72	...	...	70	106	60	63	50	81
47,000	...	...	...	...	70	69	70	87	...	...	...	...
45,000	90	54	70	47	80	53	70	82	...	...	50	46
40,000	70	45	70	44	80	40	80	49	90	39	70	29

	July 25, 1955								July 26, 1955									
	Bangkok		Singapore				Songkla		Bangkok		Singapore				Madras		Songkla	
	0300 G.M.T.		0300 G.M.T.		1500 G.M.T.		0300 G.M.T.		0300 G.M.T.		0300 G.M.T.		1500 G.M.T.		0300 G.M.T.		0300 G.M.T.	
ft.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.
55,000	90	102	...	...	60	43	10	46	...	...	70	37	90	16	...	...	80	30
51,000	...	...	...	...	70	58	...	...	...	...	...	...	...	...	...	...	...	...
50,000	...	...	90	40	70	52	80	102	90	69	70	44	90	52	...	...	50	91
49,000	...	...	...	...	...	...	...	...	...	...	...	...	100	54	...	...	...	...
48,000	...	...	80	54	...	...	...	...	...	...	...	...	...	...	...	...	...	...
47,000	80	106	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
45,000	...	...	100	40	60	41	60	45	80	63	80	50	90	49	...	...	60	73
40,000	70	69	80	30	70	36	90	33	60	40	80	38	80	39	90	94	90	89

The Canberra aircraft which made the flights from Negombo to Butterworth were able to "pin-point" Car Nicobar. The airspeed indicator and "machmeter" provided a cross check for airspeed. R/T communication was possible with Car Nicobar and Butterworth. The degree of accuracy of the winds computed is calculated to be ± 10 per cent. for speed and ± 10° in direction. The heights are underestimated a little because in this area aircraft altimeters (based on an international standard atmosphere) underread to the extent of 1,000–2,000 ft. between 40,000 and 50,000 ft. The aircraft which made the Labuan flight had the same navigational aids but, in addition, radio "beams" gave first-class fixes throughout the route. A somewhat higher degree of accuracy of computed winds was therefore to be expected.

As experience in the forecasting of high-level winds in the area is limited and a number of different techniques are being compared, the existence and day-to-day movement of the all important "core" of strong winds is a problem of some concern.

Actual winds found by the radar wind-measurement stations situated nearest to the routes are given in Table I.

P. F. EMERY

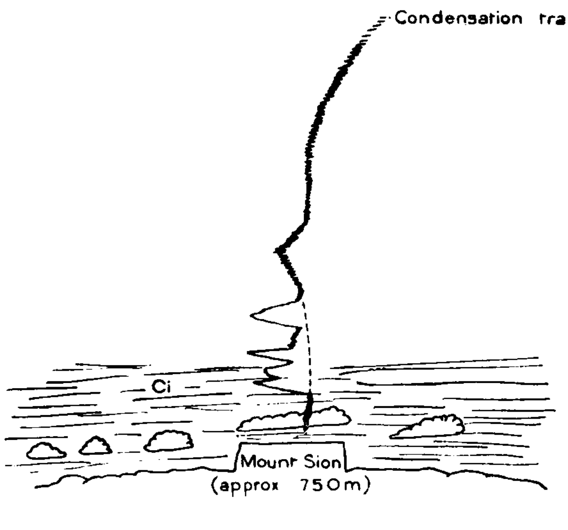
REFERENCES

1. HAY, R. F. M.; Wind at high levels over Singapore 1950–52. *Met. Res. Pap., London*, No. 770, 1952.
2. HAY, R. F. M.; High-level strong easterlies over Singapore and Hong Kong. *Weather, London*, **8**, 1953, p. 206.

An orographically generated jet stream?

The sketch reproduced below shows an unusual condensation trail seen on September 30, 1954 at 1115 near Mount Sion, Haute Savoie, France. A photograph taken of the phenomenon was unsuccessful as the writers had no suitable filter.

The most unusual feature of this condensation trail is the spectacular lateral distortion in the lower portion. This distortion had already taken place when the condensation trail was first seen, and remained virtually constant throughout the period of some 15-20 min. during which it was under observation. It was thought to be associated with high-level wind shear, perhaps caused by a jet stream, but examination of the relevant upper air data by the writers failed to establish any such connexion.



As similar phenomena have often been observed in Switzerland, mostly just under or just above the tropopause, it is thought that it was associated with local effects produced by mountainous terrain. On one occasion a Venom pilot over that country reported severe turbulence in the area of a similar condensation-trail distortion, and concluded from his marked drift that it was produced by a local jet stream. On this particular occasion, June 11, 1954 and some 20 hr. before the arrival of an active warm front, the turbulence was found to be in a thin layer of about 200–300-m. thickness and the width varied from about 20 to 50 Km. The length could only be guessed, but was estimated at 200–300 Km. These phenomena are thought to be associated with local jet streams at heights between 9,000 and 11,000 m. In the course of 12 months' observation by one of the writers the maximum height at which condensation trails formed was 11,500 m. A watch is being kept for further similarly distorted condensation trails.

No attempt has been made to attach heights to the diagram because of the distance at which the condensation trail was observed. It is pointed out that no connexion with the 750-m. mass of Mount Sion is intended, this mountain only appearing to be beneath the condensation trail from the point of observation. It is suspected that the disturbance had its origin in the much higher ground to the north-west where, in the western Swiss canton of Vaud, the Jura Mountains reach 1,500–2,000 m. That high-level turbulence is not an inevitable result of mountains on this scale is shown by an occasion when a condensation trail 40 Km. in diameter at an altitude of 10,000 m. (aircraft measurement) drifted south-eastwards for over an hour without distortion.

The only other examples of marked " kinking" of a condensation trail which can be traced are those noted in the *Meteorological Magazine* for April 1953 and July 1955.

P. ROGERS
J. KELLER-HAMMER

Relation between 0900 G.M.T. cloud amount and sunshine total

The objective was first to establish an empirical relation between average cloud amount (y), in tenths, observed at 0900 G.M.T. and average sunshine (x), expressed as a percentage of possible, at one station, and then to determine whether the results may be satisfactorily applied to another station.

The work was divided into three sections: correlation coefficients and linear regression equations were computed, from monthly means of x and y

(i) using data from Wisley, for the 20-yr. period 1931–50,

(ii) using data from Scilly, Wakefield and Stonyhurst for 10-yr. periods, as available,

(iii) using the same Wisley data, month by month.

Results.—The first stage showed promise, with a reasonably high correlation and equations quite near the ideal of $x = -10y + 100, y = -(1/10)x + 10$, which would imply that the 0900 G.M.T. cloud amount completely represented the mean over daylight hours.

The next step was to find whether stations in other situations would give similar results. Two stations were selected, one in the extreme south-west of England and the other in the north country. The results were against expectation in that Scilly showed a much closer resemblance to Wisley than did

Wakefield. This could be due to smoke at Wakefield, and to check this, data from a third station, Stonyhurst, were treated in the same manner and found to be somewhat closer to the southern stations.

	Period	Correlation coefficient	Mean cloud δy		Mean sun δx		Regression equations	
			tenths		*per cent.*			
Wisley	1931–50	−0·79	7·4	0·96	30·3	11·63	$x=-9{\cdot}71y+102{\cdot}16$	$y=-0{\cdot}066x+9{\cdot}40$
Scilly	1945–54	−0·80	7·4	0·90	37·2	11·55	$x=-10{\cdot}22y+112{\cdot}68$	$y=-0{\cdot}062x+9{\cdot}71$
Wakefield	1931–40	−0·57	7·4	0·72	23·4	10·81	$x=-8{\cdot}52y+86{\cdot}66$	$y=-0{\cdot}038x+8{\cdot}29$
Stonyhurst	1931–40	−0·75	7·4	0·93	27·9	10·63	$x=-8{\cdot}50y+90{\cdot}77$	$y=-0{\cdot}066x+9{\cdot}23$

So far, only the year as a whole had been considered. To determine whether there was an acceptably small variation between the months the 20-yr. Wisley data were used. As may be seen, there was found to be a large variation in the relation with a general tendency to be closer in summer than in winter, possibly due to the differing time of sunrise.

	Correlation coefficient	Mean cloud σy		Mean sun σx		Regression equations	
		tenths		*per cent.*			
Jan.	−0·68	8·1	0·50	17·0	4·12	$x=-5{\cdot}59y+62{\cdot}28$	$y=-0{\cdot}084x+9{\cdot}53$
Feb.	−0·92	7·7	0·89	22·5	8·76	$x=-9{\cdot}04y+92{\cdot}11$	$y=-0{\cdot}094x+9{\cdot}81$
Mar.	−0·72	7·3	0·73	31·5	7·99	$x=-7{\cdot}89y+88{\cdot}76$	$y=-0{\cdot}066x+9{\cdot}36$
Apr.	−0·90	7·2	0·99	36·4	9·59	$x=-8{\cdot}75y+99{\cdot}36$	$y=-0{\cdot}093x+10{\cdot}59$
May	−0·74	7·0	0·77	38·4	7·18	$x=-6{\cdot}89y+86{\cdot}63$	$y=-0{\cdot}080x+10{\cdot}07$
June	−0·84	6·8	0·90	42·5	5·77	$x=-5{\cdot}41y+79{\cdot}29$	$y=-0{\cdot}139x+12{\cdot}71$
July	−0·88	7·1	1·15	38·6	10·09	$x=-7{\cdot}74y+93{\cdot}55$	$y=-0{\cdot}101x+10{\cdot}98$
Aug.	−0·89	6·9	1·04	39·8	7·26	$x=-6{\cdot}19y+82{\cdot}50$	$y=-0{\cdot}128x+11{\cdot}99$
Sept.	−0·90	7·0	0·90	35·0	7·74	$x=-7{\cdot}77y+89{\cdot}39$	$y=-0{\cdot}105x+10{\cdot}69$
Oct.	−0·37	7·5	0·74	27·7	4·25	$x=-2{\cdot}11y+43{\cdot}50$	$y=-0{\cdot}064x+9{\cdot}27$
Nov.	−0·69	7·9	0·65	18·5	4·89	$x=-5{\cdot}22y+59{\cdot}74$	$y=-0{\cdot}091x+9{\cdot}58$
Dec.	−0·69	8·0	0·68	16·3	4·73	$x=-4{\cdot}77y+50{\cdot}46$	$y=-0{\cdot}100x+9{\cdot}63$

The scale of this monthly variation shows that no simple expression can be used. While it is possible to obtain a close correlation between these two variables for any one station, the results cannot successfully be applied to other areas, smoke pollution and latitude probably being large factors in the variation.

D. T. TRIBBLE

REVIEWS

Land, air and ocean. 2nd edn. By R. P. Beckinsale. 8¾ in. × 5¾ in., pp. 370, *Illus.*, Gerald Duckworth & Co., Ltd, London, 1956. Price: 25*s.*

The preface states this book's objective, namely to cater for "the general public who are interested . . . , though it has been written primarily for students at universities and training colleges. . . ." Evidently the earlier edition published in 1943 has found a certain popularity in serving these purposes. The preface to the new edition adds that ". . . recent advances in physical geography, particularly in the study of climate, land-forms and oceans have been incorporated."

It comes as something of a shock to find on p. 82 that climate is defined as nothing more nor less than "the average state of the atmosphere at a given point".

The book has in fact, a number of obvious merits. It covers a wide field of information, providing a wealth of well chosen illustrative material, quoting figures and giving on the whole well chosen diagrams. The text is in the main well written in reasonably simple, direct English. About 100 pages are devoted to climate. The best sections and paragraphs are those which are strictly geographical and wherein some bearing upon adaptation of human activities to environment is explained. Here the writing is imaginative in the best sense and shows real understanding, as for instance on p. 100 "many Swiss villages are perched at considerable altitudes above the valley floor, the two or three hours increase in sunshine thereby gained being deemed a recompense for difficulties in transport". There are also good bibliographies for further reading on the subject matter of each chapter. Many of the diagrams, however, including those reproduced on the paper cover, are without adequate explanation of the symbols used.

The figures quoted in the text are made hard to assimilate by being all in English units. Nowhere will the reader be led to suppose that there are other units for measuring the pressure of the atmosphere or of atmospheric water vapour than inches of mercury. Water-vapour content is given in grains per cubic foot. Surely it is indefensible today to familiarize students with all temperatures, whether of the air or produced by radio-active processes in the earth's interior and in the sun, solely in terms of the awkward Fahrenheit scale. The Celsius scale has crept into the chapter on vulcanism. Really, in spite of the layman's conservative addiction to the *ad interim* temperature scale of Fahrenheit of Danzig, it is precisely the layman who would gain most from the simplicity of the Celsius scale on which the most obviously critical temperature is 0°, 10° represents mild winter days in the temperate zone, 20° marks genial spring warmth (and good water for outdoor bathing) and 30° stands for tropical heat. The reviewer wonders how many readers will be sure what is meant on p. 86 by "below zero".

In the realm of physical description and explanation of atmospheric phenomena some of the statements offered are more seriously clumsy or misleading. There is an odd insistance on p. 103 and elsewhere that katabatic winds are the gentle "creep" of cold air draining into the hollows in the English landscape on radiation nights and are not to be confused with the fierce cold gales off ice caps and other mountain regions. On p. 52 tropical cyclones and tornadoes are equated as "small revolving storms . . . an extremely localized form of convection".

On p. 57 it is asserted that "spring is the snowy season in the British Isles"—an overstatement which makes nonsense. Even in our most maritime western and northern districts the maximum frequency of snow appears to be in late February and early March. Presumably the carry-over of this maximum into March is counted as a technical trespass on the part of the atmosphere! On p. 72 the phrase "from late September onwards, when the overhead position of the sun begins to move southwards . . ." really will not do. On p. 73 the writer shows discernment in linking the mild winter weather of our Atlantic coast districts with dull skies and drizzle; but the comparison on the same page with the "usually intensely blue cloudless sky" in winter in the Mediterranean is less than fair. This is a time-worn misconception which beguiles English travellers into spending money on expensive fares to places in the Mediterranean where the winter rainfall is often double that of London, the number of rainy days about the same and the windiness much greater than in our inland districts. The blue skies are really a predominant feature only in those districts (the French Riviera especially and the south-east coast of Spain) which enjoy orographic shelter from the prevailing winds and in the African interior.

The greatest disappointment is perhaps to find anticyclones and some depressions still explained largely in terms of Abercrombie, though with some slight indication of frontal patterns and behaviour included. It is surely time someone wrote an up-to-date and acceptable account of the general circulation of the atmosphere and development of surface-pressure systems in terms that every serious student can understand. The fundamental concepts of development in association with the accelerations and retardations in the flow of the main streams of upper wind are not difficult. This book, however, does not attempt it.

H. H. LAMB

The theory of hydrodynamic stability. By C. C. Lin. *Cambridge Monogr. Mech. appl. Math.* 9 in. × 5½ in., pp. xii + 156. Illus., Cambridge University Press, Cambridge, 1955. Price: 22*s*. 6*d*.

Meteorologists have to deal with instability at all scales of motion in the atmosphere, starting with the smallest-scale turbulence and ending with the long waves in the westerlies or, perhaps, with the general circulation itself. In between there is a multitude of phenomena: clear-air turbulence and condensation trails, the motion of air above a heated surface and convection cloud, the motion of air past an obstacle and the creation of lee waves spring to mind at once. Usually the interest, meteorologically speaking, lies in the motion after instability has set in; e.g. it is turbulence rather than laminar flow which is important. However, the meteorologist has often to estimate the stability of an air stream from a few gross characteristics (and in fact has often to make one further step and first forecast the gross characteristics and hence the future stability). Some of the problems are successfully attacked and one thinks immediately of the forecasting of thundery rain and showers. Other problems are not nearly so easy, such as the estimation of the characteristics of waves in the lee of a mountain. Any book which deals with hydrodynamic stability must be of practical interest to meteorologists in view of the diversity of the applicaions and the difficulty of most of the problems.

Prof. Lin's book deals with the stability of flow after a small perturbation has been applied so that much of it deals with linearized theory and not with the large-scale departures from the mean field of motion; the meteorological interest lies less in the quantitative prediction, such as the dissipative changes caused by turbulent flow, than in the prediction that a phenomenon will occur, such as predicting that instability will set in in a certain air stream, given that some criterion is satisfied. The fourth chapter is the most important in the book; here the author discusses, with little mathematics, the general theory of hydrodynamic stability using physical arguments and bringing well to the front the role played by viscosity. The ideas expounded have of course already been applied to meteorological problems such as the stability of the westerlies and the formation of waves. Chapter 7 gives examples of stability problems and includes two very important meteorological problems—the stability of zonal winds and the convective motion of a fluid heated from below. In each case the treatment is very short indeed, although references are given to the literature, and the results in the former case might not be accepted by everyone. This chapter could well have been expanded.

From a meteorologist's point of view the other chapters are not so interesting as these two, except perhaps to some specialists dealing with the flows which are treated, because in the atmosphere we rarely find stable flows about to become unstable, but usually find the turbulent state. The first three chapters develop the stability problem from the Navier-Stokes equations for Couette and Poiseuille flow and indicate the methods used in solving the differential equations. The fifth chapter gives the stability theory for boundary-layer flow over a flat plate, with many results including the flow of a perfect gas. The sixth deals with the stability under various boundary conditions, including heating and cooling, injection of fluid and the effect of curvature at the boundary, while the last chapter deals with the mathematical theory of the stability of parallel flows, showing the difficulties that arise. A bibliography completes the book: several meteorological papers are included although they deal with rather different aspects of stability from those treated in the text. There is an author index but no subject index, perhaps because the chapters are set out in well defined paragraphs; nevertheless, a subject index does help the reader who wants to find quickly if and where a problem has been treated.

The printing and the lay-out of the mathematics are of the excellence that one associates with the publishers and the proof-reading seems to have been particularly good. The price of this series of monographs remains reasonable and meteorologists are lucky to find two of the first five volumes devoted to subjects which are important to them.

E. KNIGHTING

The polar aurora. By C. Størmer. *Int. Monogr. Radio.* $9\frac{1}{2}$ in. × $6\frac{1}{4}$ in., pp. xx + 404 + 34 plates, *Illus.*, Oxford: Clarendon Press. London: Cumberlege, 1955. Price: 55*s*.

This book is the fourth in the series "International monographs on radio", which are designed to produce an up-to-date account of the position in a scientific field connected with radio, the field being largely determined by the interests of the author. This is reflected in the volume under review which has been written by an outstanding research worker in the field of auroral studies, one of the first to start the systematic measurement and observation of the polar aurora.

The book is divided into two parts; the first part deals with the results of the observations and measurements of the aurora and thus poses the problem, and the second reviews the attempts which have been made to provide an explanation. Part one begins with a description of the appearance of the aurora and the classification of the main forms which it takes. The difficulties of classifying any particular aurora are not glossed over but the excellent collection of photographs in the book are a great help. This is followed by an account of the geographical distribution of the aurora over the world and of its variations especially during magnetic storms.

The author then describes the method originated and used by himself and his collaborators for measuring the height and position of individual auroral forms by means of photographic triangulation. The large amount of data accumulated by them is described and many interesting features of this work are discussed. Included with this are general hints on photographing aurorae. This is followed by a shorter description of the spectrum analysis of the light from the aurora, and the identification of the main lines is given. Some of the ways by which the emission of these spectrum lines can be caused by particles of high energy falling into the upper atmosphere are discussed. The mechanism of the emission of particles from the sun and the relation of aurora with solar flares and sun-spots is dealt with next, and while there are many aurorae and magnetic storms which seem to be closely linked with individual occurrences on the sun it is pointed out that there are also aurorae which occur when no solar flare is observed and indeed even when there are no sun-spots on the solar disc.

The second part of the book deals with attempts which have been made to explain the way in which aurorae are produced. C. Størmer himself was a pioneer in this field, and he was the first to attempt to calculate the trajectories of charged particles which approach the earth and then come in to the the influence of its magnetic field. The book deals with this problem in some detail and explains fully the various simplifying assumptions that have been made at the various stages and the results obtained. The difficulties in the way of extending the results by eliminating the restrictive assumptions one by one are discussed. These results are then applied to the aurora in an attempt to explain the various forms that occur and to explain the geographical distribution that is observed. It is found that many of the main features are capable of an explanation on this theory but that a number cannot be explained without further development.

The author then goes on to discuss further theoretical work by other workers which deals mainly with the explanation of magnetic storms, or fluctuations in the earth's magnetic field, but which are closely linked with the occurrence of the aurora and which are also thought to be due to particles of high energy entering the upper atmosphere. He deals first with the Chapman–Ferraro theory and a modification of this by D. F. Martyn, and follows this by an account of the electric-field theory by Alfvén and his co-workers in Sweden. The accounts of the last two are given as quotations by the workers concerned and are not critically discussed. The next to last chapter deals with other applications of research into the motion of electric particles in the field of a magnetic dipole which are discussed in earlier chapters.

This book is strongly recommended for anyone who is interested in the subject and needs to find out the basic facts about aurora. The second part is also excellent in the presentation of the work by the author and his collaborators in the explanation of the aurora by means of charged particle trajectories in the earth's magnetic field. It needs however to be supplemented by further reading if a critical knowledge of other theories of auroral formation is required. Full references are however given to enable this to be done. The production and printing of this volume is of the high standard associated with the Oxford University Press. The numerous auroral photographs are excellent.

R. H. COLLINGBOURNE

The Earth as a Planet. Edited by G. P. Kuiper. *Solar system,* Vol. II, 9½ in. × 7 in. xvii + 752, *Illus.,* Chicago University Press, 1955. Price: 94*s.*

This beautifully produced book is the second of an ambitious series of four on the solar system. The first "The sun" was published in 1953 and was very well received. The second maintains the high standard. It was published late in 1954; most of the individual contributions follow developments well into 1953. The dust jacket tells us ". . . it is designed to be both a reference book for the specialist and a source of general information for the reader having some acquaintance with the physical sciences". Specialization is now so narrow and intense that this objective is practically impossible to achieve, but most of the articles will serve as a reference source to all except those in the forefront of progress in the specific subject treated, and by this very fact will call, in the general reader, for a much deeper knowledge of the physical sciences than that usually indicated by the words "some acquaintance".

There are 15 sections each by an author greatly distinguished in his subject. It would be tedious to enumerate them; the standard of scholarship is well illustrated by the first and last "Dimensions and rotation" by Sir Harold Spencer Jones and "Albedo, colour, and polarization" by Prof. André Danjon. The allocation of space will disappoint most meteorologists. The editor, in his preface, says ". . . half the book is devoted to our atmosphere, although its fractional mass is only one millionth. Even so space requirements dictated severe economy. The recent appearance of the 'Compendium of meteorology' made it unnecessary to include many meteorological topics of great potential interest to the planetary astronomer. . . .". We find in fact that Prof. Byers is allowed 70 pages to discuss "The atmosphere up to 30 kilometers", whilst more than 250 pages are devoted to the remainder of the atmosphere. One millionth of the mass has half the book, one part in 107 has a third. The oceans have only 40 pages, contributed by Prof. Sverdrup, so we may expect oceanographers also to feel that quantitative justice has not been granted to them.

Prof. Byers succeeds in his almost impossible task more completely than anyone could fairly expect. He has of course no space for detail, but he gives a rounded picture of the present state of the subject under the headings "Composition and heat balance of the atmosphere", "Distribution of temperature", "Atmospheric circulation", "The secondary circulations", "Tropical cyclones and tropical weather", "Atmospheric electricity", and "Condensation and precipitation". The growing points of the science are indicated, so are, at least by implication, the points which are not responding too eagerly to cultivation. There is no attempt to distribute praise and allocate blame fairly amongst individual workers; this is hardly necessary in an article of this type where space must be put to better use. As a result practically all the literature citations are to American work; the only point on which I suspect an affront to truth, in addition to the many to individual pride, is the quotation of some results of Barrett, Herndon and Carter as the only information on the water content of the stratosphere.

Prof. Sverdrup's article is similar in style to that of Prof. Byers, and since the greater part of it is concerned with the heat budget of the oceans and the surface currents it will be of equal interest to meteorologists. A more detailed and very welcome review by G. E. Hutchinson on "The biochemistry of the terrestrial atmosphere" completes the section devoted to the bulk of the atmosphere. There follow authoritative articles on the absorption and emission spectra of the atmosphere, density, pressure and temperature above 30 Km., and the physics and photochemistry of the outer layers. The great disappointment of the book comes with the chapter "Dynamic effects in the high atmosphere" by M. Nicolet. Nicolet's very distinguished work has been concerned with the fashionable outer fringe, indeed it has done much to set the fashion, and he interprets his title in the light of his own special interest. The chapter comprises a discussion of hydrostatics, gas kinetics, and the inevitable speculative photochemistry, but little or no dynamics. Nicolet says "The motions in the high atmosphere cannot be studied as in meteorology, where the Coriolis force is dominant". This statement deserves, though it does not receive, justification; the more so since the lower atmosphere for the purposes of the book as a whole appears to end at 30 Km., with the implication that the high atmosphere begins there. There is no discussion, worthy of the rest of the book, of upper atmospheric motions, tidal or otherwise.

I would not like to end a notice of such an excellent book in critical fashion, and the last two short chapters give ample scope for enthusiasm. I was glad to see a description of Danjon's remarkable observations in a place where meteorologists are likely to read it, but cannot say I found it easy to follow. There is a use of the word "hence" near the top of p. 733 which is worthy of the attention of a future Fowler. The section to which I have turned repeatedly is however that by C. T. Holliday "The earth as seen from outside the atmosphere" which contains eight pictures of the south-west United States, taken from elevations of about 100 Km., excellently reproduced. The meteorological possibilities opened up by the use of even so simple an instrument as a camera at these levels are clearly enormous. I specially commend to your attention Fig. 5, in which you ". . . note shadows of cirrus clouds on Pacific sea fog. Nearer, thunderheads are forming over mountain ranges, with cloud streets prominent near all mountains. . . .". The day is clearly not far distant when someone will publish a photograph of a mature extratropical cyclone, and it is surely not unlikely that such a photograph will repay careful scrutiny.

G. D. ROBINSON

METEOROLOGICAL OFFICE NEWS

Retirements.—*Cmdr M. Cresswell, R.N.R.*, who has been Port Meteorological Officer at Liverpool for nearly 32 years, retired on June 26, 1956. Despite his retirement he is not severing contact with the Meteorological Office; in August 1956 he takes over the duties of Merchant Navy Agent in the Humber area in succession to Capt. R. E. Dunn who is retiring from that agency. (A Merchant Navy Agent carries out similar duties to a Port Meteorological Officer but, instead of being a full-time employee of the Meteorological Office, he is paid on a "fee" basis).

During his long service at Liverpool Cmdr Cresswell has initiated an enormous number of ships' officers into the intricacies of meteorological observing and the use of synoptic codes at sea. Records show that on an average he visited about 1,000 ships annually during the course of his duties. The quality of the observations received by radio from British Selected Ships and of their logbooks shows how well Cmdr Cresswell and his colleagues at the other ports do their job.

Cmdr Cresswell went to sea in 1907 and served his apprenticeship in the sailing ships *Port Crawford* and *Port Caledonia*. He obtained his Master's Certificate in 1914 and joined the Canadian Pacific Company as a junior officer. During the First World War he was on naval service afloat in various types of vessels. In 1919 he passed his Extra Master's examination (square rigged) and rejoined the Canadian Pacific Company where he rose to the rank of 1st Officer. After a course of meteorological training in London he was appointed Port Meteorological Officer in Liverpool in January 1925 and he has served there ever since.

Mr. F. G. Whitaker, Experimental Officer, retired on July 7, 1956. He first worked as a computer at the Royal Observatory, Greenwich, and after service with the Royal Field Artillery in the First World War, he joined the Office in June 1919 as a Technical Assistant. Apart from a period between 1928 and 1934 in the Marine Division at Headquarters, his work during his 37 years' service has been mainly concerned with meteorological services for the Army at Shoeburyness where he was serving at the time of his retirement.

Horticultural Show.—The Air Ministry Horticultural Society held their annual show at Whitehall Gardens on July 10. The staff of the Office were represented in all three sections—flowers, fruit and vegetables. Miss H. G. Chivers, Mr. B. G. Brame and Mr. H. A. Scotney gained prizes. In addition Miss Chivers and Mr. Scotney were awarded certificates of merit for their exhibits and Mr. Scotney also shared one of the aggregate prizes.

Social Activities.—On July 21 nearly 40 people met for a picnic near Dozmary Pool on Bodmin Moor. This was the culmination of a treasure hunt, the qualification for entry being some connexion with the Meteorological Office, Mount Batten, Plymouth. The party was a great success and will be repeated.

ERRATUM

JULY 1956, PAGE 205. Table I. No breaks within 12 hr., Mean; *for* "28" *read* "18".

WEATHER OF JULY 1956

The most outstanding feature of the month in the British Isles and Western Europe, was the above normal rainfall experienced. For a period of about ten days in the middle of July anticyclonic conditions were unusually persistent in the Spitsbergen area. Consequently, during this period, easterly winds prevailed in the British Isles and depression tracks were further south than normal into western Europe.

The features of this period dominated the mean-pressure map for the month. The normal weak polar anticyclone was displaced to Spitsbergen and was more intense than normal, the pressure anomaly there being of the order of + 7 mb. The area of positive pressure anomaly extended to Iceland (+ 2 mb.) where the mean-pressure map did not show the normal low-pressure area. Pressure was also above normal over most of Canada (anomaly + 5 mb. in the North-West Territories) and a little above normal in the Rocky Mountains area of the United States. From the Azores across Great Britain to Denmark, pressures were 1 mb. or 2 mb. below normal. Zonal flow in the America–Atlantic–United Kingdom Sector was thus weaker than normal.

Temperature was near normal over much of the hemisphere, the major anomalies being $-1°$ C. to $-2°$C. in east Germany and the Baltic and in the Great Lakes area of America, and $+1°$C. to $+2°$C. in the eastern Mediterranean and in the Rockies.

Rainfall was well above normal in other parts of the hemisphere as well as Great Britain and western Europe. More than three times the normal July rainfall was experienced in the north-west of India and Pakistan, and above normal falls were reported in most of the eastern United States and in a belt across Africa in about 10°N.—15°N. With the exception of the north coast, the Mediterranean however had little rainfall, most stations reporting no rainfall during the month.

In the British Isles July was generally changeable and unsettled with thundery rains, except during the fourth week when the weather was largely dominated by an anticyclone, which moved north-east from the Azores.

A vigorous depression over Ireland on the 1st gave cool showery weather over most of the British Isles with thunderstorms in many places during the first two or three days of the month as it moved slowly north. Widespread rain on the 4th and 5th was associated with the passage north-east across the country of a complex depression from the Atlantic; the thundery tendency continued and rain was heavy locally; 3·12 in. fell in 24 hr. at Blaenau Festiniog on the 4th. A ridge of high pressure which followed the depression gave a fine day on the 6th with over 12 hr. sunshine at many places, but warm moist air brought extensive fog to the English Channel and Irish Sea during the next two days and raised temperatures inland to about 80°F. Thunderstorms broke out over a wide area on the night of the 8th—9th. Several places in the Home Counties recorded over 2 in. of rain during 24 hr.; a 'remarkable' fall of 1½ in. in 30 min. was recorded at Sutton, Surrey, while the 2·38 in. measured in 12 hr. at Kew Observatory was the most in a rainfall day since records began there in 1871. Three sunny but cooler days, with local ground frost early, followed the thunderstorms as a shallow anticyclone moved northward over the country. Pressure was highest to the north of the British Isles and winds over the country were mainly from an easterly direction from the 12th to the 20th. On the 13th and 14th rain from the North Sea brought temperatures below their seasonal normal but thereafter weather improved slowly and Scotland and parts of northern England had several warm sunny days. Thunderstorms developed widely again from the 16th to the 19th as a depression off western Ireland moved south-east to the Bay of Biscay and northern France. Storms were particularly heavy on the 18th and 19th and there were many noteworthy falls with considerable flooding; on the 18th 3·71 in. was recorded at St. Ives, Huntingdonshire in 24 hr. and a 'very rare' fall occurred at Harmondsworth, Middlesex when 3·87 in. fell in 114 min., on the 19th. 3·21 in. fell at Liskeard, Cornwall in 24 hr. and there was a 'remarkable' fall of 1·29 in. in 30 min, at Beer, Devon. On the 21st the easterly winds were replaced by a weak westerly flow. The northern parts of the British Isles had slight rain from time to time, but with the approach of an anticyclone from the Azores warm sunny weather spread from the south with temperature exceeding 80°F. in places. On the 27th temperature reached 86°F. at Jersey and 83°F. at Tunbridge Wells, Kent. Early on the 29th a deepening depression from the Atlantic became exceptionally vigorous for the time of year as it approached south-west England. Central pressure fell to 976 mb. equalling the lowest previously recorded during July in the British Isles—at Tynemouth in 1922. Gales were widespread and severe in places over the southern half of England and Wales and rain heavy locally. In Cornwall wind reached 76 kt. in gusts at St. Mawgan and 57 kt. at Culdrose. The previous highest gust in the British Isles during July was 64 kt. at Lympne, Kent in 1938; gusts of more than 55 kt. during this month are rare. Damage during the gales was considerable. Eleven people are reported to have been killed, six by falling trees. The London–Holyhead road was blocked by a landslide in the Nant Francon Pass, Caernarvonshire and among the many tragedies at sea was the capsizing of the *Teeswood* (1,246 tons) off Dungeness, Kent, and the sinking of the sail-training ship *Moyana* off the Lizard. The following day was showery with considerable sunny periods in the south but with heavy rain in Scotland. Brighter but cooler weather extended to most of the British Isles by the 31st.

The outstanding feature of the month was the high rainfall. New rainfall records for July were set up at Pembroke Dock, Valley, Dishforth, Stornoway and Kew. Kew had over an inch more than their previous highest (in 100 yr. of readings) of 4·88 in. in 1880. Sunshine was below average particularly in south-east England and temperature over the month was about average although day maxima were rather below normal.

The violent storms and gales have caused considerable damage to crops. Reports of flooding and damage to grain, particularly barley, have been received, but it is hoped that most of it will still be harvested. Cattle and sheep were killed during heavy thunderstorms in Hereford. The gales of the 29th caused widespread damage over the whole country, and among many reports are some from Kent of top fruit blown down and havoc in the hop fields.

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 ..	86	33	−0·8	137	+1	87
Scotland	79	31	−0·8	160	0	100
Northern Ireland ...	73	38	−0·2	132	+1	100

RAINFALL OF JULY 1956

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	5·90	248	*Glam.*	Cardiff, Penylan ...	2·82	92
Kent	Dover	2·76	131	*Pemb.*	Tenby	4·14	140
,,	Edenbridge, Falconhurst	3·37	146	*Radnor*	Tyrmynydd	4·04	98
Sussex	Compton, Compton Ho.	3·21	113	*Mont.*	Lake Vyrnwy	8·06	226
,,	Worthing, Beach Ho. Pk.	2·74	134	*Mer.*	Blaenau Festiniog ...	12·11	142
Hants.	St. Catherine's L'thouse	1·66	85	,,	Aberdovey	5·48	157
,,	Southampton (East Pk.)	2·26	99	*Carn.*	Llandudno	3·96	177
,,	South Farnborough ...	3·12	153	*Angl.*	Llanerchymedd ...	5·67	198
Herts.	Harpenden, Rothamsted	2·43	106	*I. Man*	Douglas, Borough Cem.	4·25	139
Bucks.	Slough, Upton	3·45	180	*Wigtown*	Newton Stewart ...	5·43	173
Oxford	Oxford, Radcliffe ...	2·43	103	*Dumf.*	Dumfries, Crichton R.I.	5·95	182
N'hants.	Wellingboro' Swanspool	4·33	189	,,	Eskdalemuir Obsy. ...	6·83	167
Essex	Southend, W. W. ...	3·02	152	*Roxb.*	Crailing...	3·67	127
Suffolk	Felixstowe	2·38	122	*Peebles*	Stobo Castle	4·53	156
,,	Lowestoft Sec. School ...	1·78	78	*Berwick*	Marchmont House ...	3·54	116
,,	Bury St. Ed., Westley H.	1·72	69	*E. Loth.*	North Berwick Gas Wks.	4·87	189
Norfolk	Sandringham Ho. Gdns.	3·03	118	*Midl'n.*	Edinburgh, Blackf'd. H.	5·21	185
Wilts.	Aldbourne	2·96	117	*Lanark*	Hamilton W. W., T'nhill	4·94	172
Dorset	Creech Grange... ...	4·67	190	*Ayr*	Prestwick	4·05	165
,,	Beaminster, East St. ...	2·77	107	,,	Glen Afton, Ayr San. ...	5·86	140
Devon	Teignmouth, Den Gdns.	2·56	110	*Renfrew*	Greenock, Prospect Hill	4·89	132
,,	Ilfracombe	4·33	170	*Bute*	Rothesay, Ardencraig ...	..	..
,,	Princetown	7·99	149	*Argyll*	Morven, Drimnin ...	7·84	178
Cornwall	Bude, School House ...	..	..	,,	Poltalloch	6·27	152
,,	Penzance	5·07	186	,,	Inveraray Castle ...	6·92	139
,,	St. Austell	4·32	129	,,	Islay, Eallabus	3·90	114
,,	Scilly, Tresco Abbey ...	3·87	174	,,	Tiree	4·12	114
Somerset	Taunton	2·18	103	*Kinross*	Loch Leven Sluice ...	4·52	157
Glos.	Cirencester	3·06	115	*Fife*	Leuchars Airfield ...	3·91	150
Salop	Church Stretton ...	2·84	108	*Perth*	Loch Dhu	7·26	150
,,	Shrewsbury, Monkmore	3·28	156	,,	Crieff, Strathearn Hyd.	5·00	168
Worcs.	Malvern, Free Library...	2·69	118	,,	Pitlochry, Fincastle ...	4·26	158
Warwick	Birmingham, Edgbaston	3·83	150	*Angus*	Montrose, Sunnyside ...	3·64	138
Leics.	Thornton Reservoir ...	2·53	102	*Aberd.*	Braemar	2·99	116
Lincs.	Boston, Skirbeck ...	2·62	119	,,	Dyce, Craibstone ...	5·76	190
,,	Skegness, Marine Gdns.	2·62	120	,,	New Deer School House	4·89	160
Notts.	Mansfield, Carr Bank ...	3·00	115	*Moray*	Gordon Castle	5·29	165
Derby	Buxton, Terrace Slopes	6·13	156	*Nairn*	Nairn, Achareidh ...	4·66	183
Ches.	Bidston Observatory ...	4·71	182	*Inverness*	Loch Ness, Garthbeg ...	7·25	229
,,	Manchester, Ringway...	4·45	160	,,	Loch Hourn, Kinlochourn	9·89	156
Lancs.	Stonyhurst College ...	5·96	154	,,	Fort William, Teviot ...	5·57	114
,,	Squires Gate	4·70	169	,,	Skye, Broadford ...	7·77	140
Yorks.	Wakefield, Clarence Pk.	4·40	174	,,	Skye, Duntulm ...	6·26	167
,,	Hull, Pearson Park ...	3·66	156	*R. & C.*	Tain, Mayfield... ...	5·90	216
,,	Felixkirk, Mt. St. John...	4·91	180	,,	Inverbroom, Glackour...	7·55	203
,,	York Museum	3·63	144	,,	Achnashellach	6·87	141
,,	Scarborough	3·40	140	*Suth.*	Lochinver, Bank Ho. ...	6·34	209
,,	Middlesbrough... ...	2·37	93	*Caith.*	Wick Airfield	3·62	138
,,	Baldersdale, Hury Res.	3·46	119	*Shetland*	Lerwick Observatory ...	3·85	168
Norl'd.	Newcastle, Leazes Pk....	2·56	100	*Ferm.*	Crom Castle	5·79	166
,,	Bellingham, High Green	2·86	87	*Armagh*	Armagh Observatory ...	3·81	132
,,	Lilburn Tower Gdns. ...	3·32	134	*Down*	Seaforde	3·12	98
Cumb.	Geltsdale	3·43	99	*Antrim*	Aldergrove Airfield ...	2·44	87
,,	Keswick, High Hill ...	7·23	188	,,	Ballymena, Harryville...	4·47	130
,,	Ravenglass, The Grove	5·10	136	*L'derry*	Garvagh, Moneydig ...	5·57	172
Mon.	A'gavenny, Plâs Derwen	3·68	135	,,	Londonderry, Creggan	4·56	124
Glam.	Ystalyfera, Wern House	5·57	122	*Tyrone*	Omagh, Edenfel	5·05	149

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METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

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THE GALE OF JULY 29, 1956

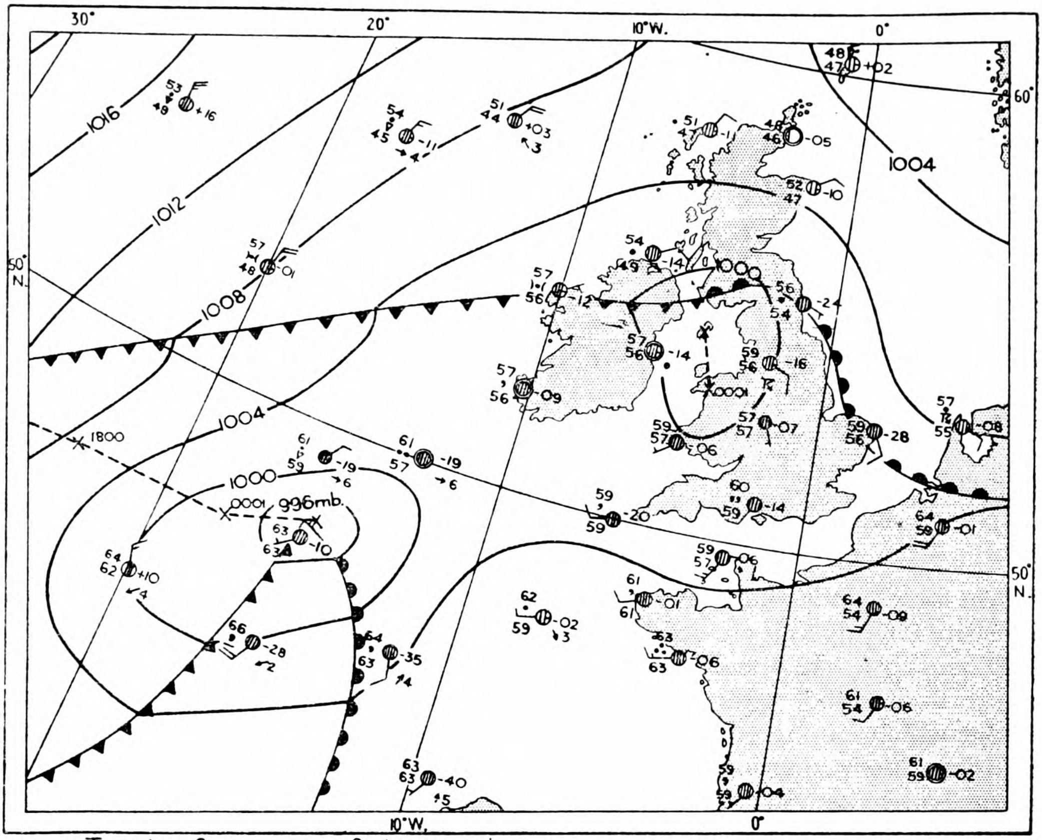
By D. M. HOUGHTON, M.Sc.

Storm force winds and heavy rainfall accompanied a depression of exceptional intensity for July as it crossed England from the Scillies to the Wash on Sunday, July 29, 1956. In the English Channel the ketch *Moyana* on her victorious return from Lisbon after sailing in the Torbay to Lisbon race, was among the yachts which foundered. Many others, in harbours, came to grief as they were torn from their moorings. On land six people were killed by falling trees and many had to be evacuated from camping sites which were flattened by the gale; even caravans were overturned. Severe flooding occurred in north Wales and landslides blocked the London–Holyhead road. Farmers and fruit growers suffered heavily as corn was flattened and fruit trees were stripped.

On Wednesday, July 25 a small frontal wave broke away from a weak parent depression over eastern America and progressed across the Atlantic on the south side of a belt of westerly thermal winds. For three days it travelled almost due east along latitude 47°N. at a speed of about 30 kt. with central pressure between 1000 mb. and 1004 mb.

The 500-mb. charts show a large-scale trough intensifying to the west of the British Isles and by 0300 G.M.T. on Saturday, July 28 it had a well defined axis from Iceland to the Azores. As it developed further the axis swung eastwards, pivoting on Iceland, and at 0300 G.M.T. on the 29th it lay from Iceland to Cape Finisterre. Though the flow around the trough was fairly strong for a summer situation it was in no way unusual and cannot have been solely responsible for the extraordinary features of the subsequent surface developments.

While the wave was crossing the Atlantic much of the British Isles was under the influence of a declining anticyclone whose centre was moving eastwards across northern France. By Friday morning the pressure was almost uniform over the whole country and a quasi-stationary front was giving rain over southern Scotland. Pressure continued to fall steadily over the whole country and by early on Saturday a small depression had formed over northern England with widespread and severe thunderstorms. Pressure remained relatively high to the south of Greenland and as the pressure fell over the British Isles increasing northerly winds brought cold air southwards over the eastern Atlantic. Late on Friday the 27th the wave passed the axis of the thermal trough associated



x--x Track of centre of depression

FIG. 1—SYNOPTIC CHART, 0600 G.M.T., JULY 28, 1956

with the large-scale upper trough in the east Atlantic and began to turn east-north-east deepening slowly in the weakly cyclogenetic area on the forward side of the trough. Figs. 1 and 2 show the 0600 G.M.T. surface chart and the 1000–500-mb. thickness chart for 0300 G.M.T. on Saturday.

The character of the air in the lowest few thousand feet which was over the British Isles as the depression approached south-west England may have been important. Prolonged thundery rain and thunderstorms over Scotland, northern England and Northern Ireland resulted in almost saturated air in the lower troposphere with a wet-bulb potential temperature of about 14·5°C. This was almost stagnant. Somewhat similar air over central and southern England drifted away into the North Sea and was replaced by drier and more stable air ahead of the warm front. The relevant ascents show that the fronts associated with the depression were little more than discontinuities in surface dew point. The Camborne 1400 G.M.T. ascent on 28th shows no warm frontal stability aloft. This is borne out by the absence of any well defined belt or area of rain to the south of the depression centre. Also the low remained on the warm side of the belt of strong 1000–500-mb. thickness gradient and created little distortion in it.

Some of the colder air to the west of Ireland was drawn into the circulation late on Saturday and by midnight the low had deepened to about 980 mb. By this time the gradient wind had increased to about 50 kt. over a radius of about 200 miles around the centre. Between 1800 G.M.T. on 28th and 0600

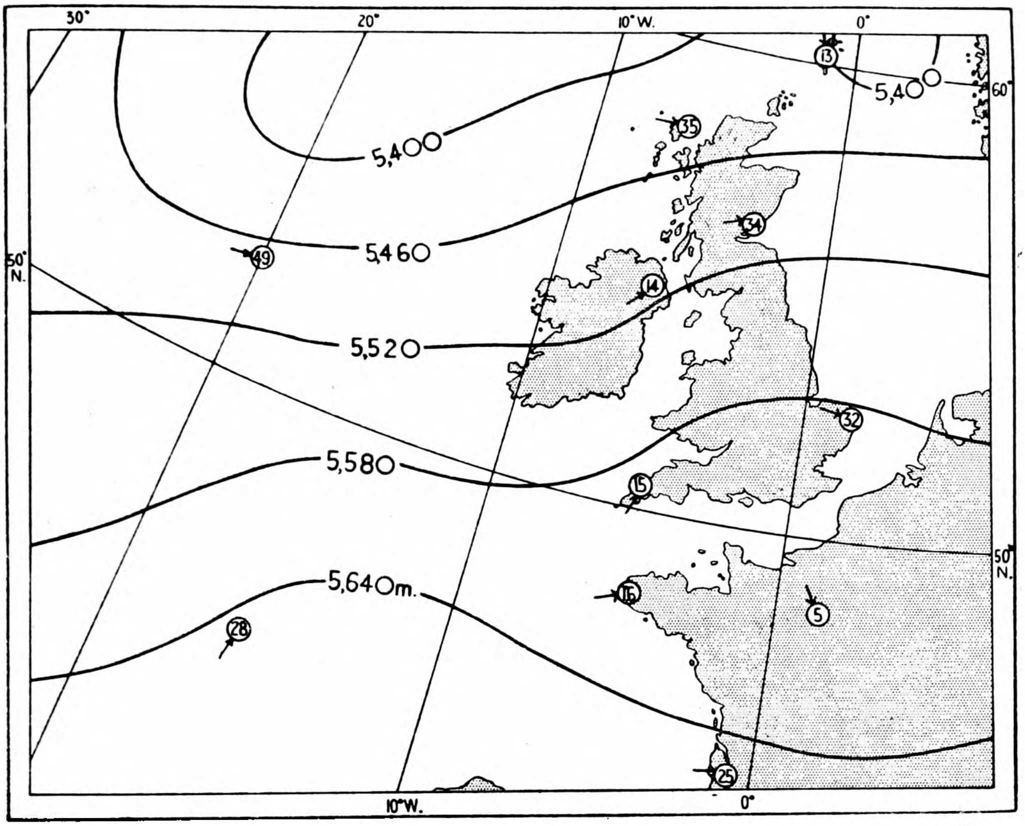


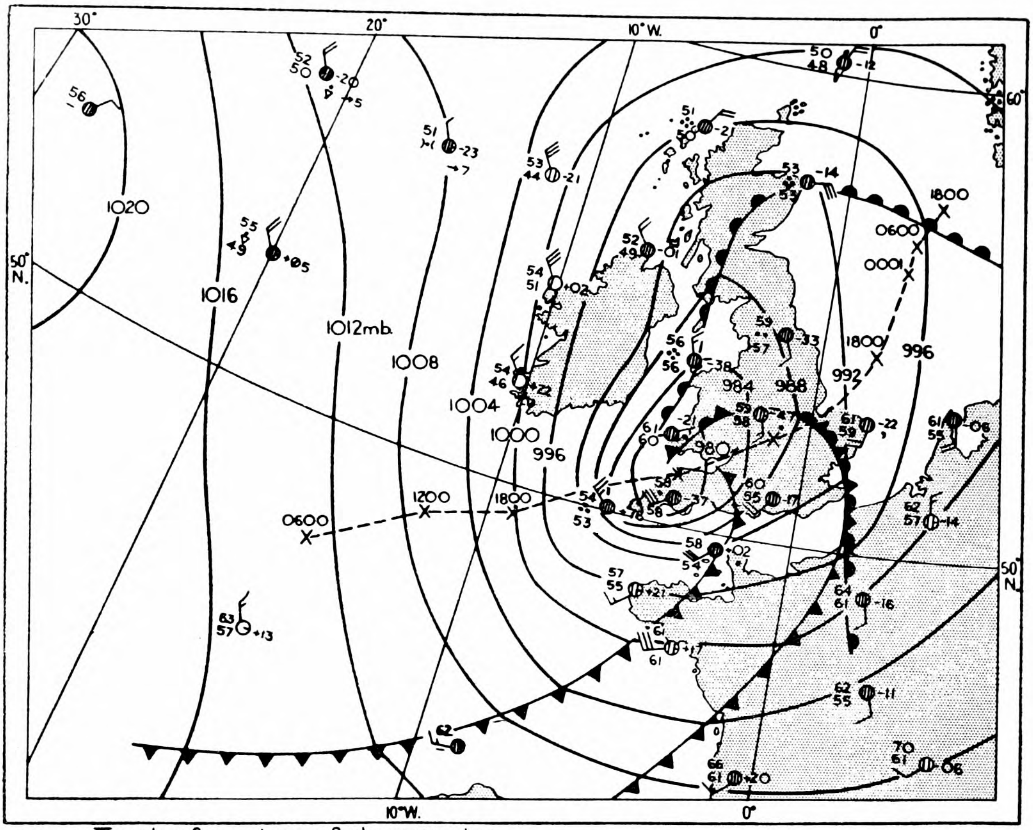
FIG. 2—1000–500-MB. THICKNESS CHART, 0300 G.M.T., JULY 28, 1956

The directions and magnitudes (in kt.) of thermal winds are indicated by arrows and encircled numbers.

G.M.T. on the 29th when most of the deepening occurred the speed of the depression decreased to about 17 kt. As it entered the Bristol Channel an area of heavy rain developed over west Wales as the warm moist surface air was drawn southwards. This air was warm with respect to the air at higher levels and it may have been partly responsible for the rapid developments during Sunday morning. The very heavy rain in the rear of the depression and exceptionally severe gales on its western and southern flanks are suggestive of unusual convergence of air in the lower layers just west or south-west of the centre.

Just before the depression reached its maximum depth (about 974 mb.) at about 0800 G.M.T. on 29th a very rapid rise of pressure set in over a confined area in its wake. The first sign of such a rise was at Scilly at 0600 G.M.T. when an hourly figure of 2·8 mb. was reached. During the next few hours tendencies of over 10 mb. in three hours were reported at almost all stations in south-west England. At Exeter three-hourly tendencies reached 13·1 mb. and in one hour (0800 to 0900 G.M.T.) the pressure rose by 5·3 mb. The severe gales which accompanied these developments reached 58 kt. at 0600 G.M.T. at the Lizard with a gust to 87 kt. At St. Mawgan a gust of 76 kt. was reached at 0600 G.M.T. and at Culdrose a mean hourly wind of 46 kt. with a gust of 74 kt. occurred at the same time.

The depression continued in its east-north-easterly track across England and by 1400 G.M.T. was over the Wash and had filled to 980 mb. The winds were



x---x Track of centre of depression

FIG. 3—SYNOPTIC CHART, 0600 G.M.T., JULY 29, 1956

still blowing at above gale force to the south and south-west of the centre, and over south-east England gusts exceeded 60 kt. in several places. The maximum recorded at Shoeburyness was 52 kt. at 1200 G.M.T. with a gust to 66 kt. The rain in the rear of the depression eased during the forenoon and by 1400 G.M.T. only sporadic outbreaks of moderate rain were being reported. The remainder of the depression track into the North Sea is shown in Fig. 3.

The lowest pressure reported was at Yeovilton at 0800 G.M.T. when the barometer (reduced to M.S.L.) read 976·6 mb. Since the depression was some 30 miles to the north at the time the central pressure probably fell to about 974 mb. The only July depression of comparable depth this century crossed central and northern districts of England on July 6, 1922 and the record minimum of 976·0 mb. was recorded at Tynemouth. Owing to the more southerly track of the later depression the pressure at Kew reached a new low record for July. A mean-sea-level pressure of 981·7 mb. was recorded at 1050 G.M.T. on the 29th. The previous lowest in records dating back to 1869 was 983·5 mb. in July 1922.

Winds on July 29, 1956 were far in excess of any previously recorded in the British Isles in the month of July. The highest gusts recorded on July 6, 1922 were 68 kt. at Scilly and 66 kt. at Calshot.

Rainfall between 2100 G.M.T. on 28th and 0900 G.M.T. on the 29th was 41 mm. at Valley, 32 mm. at Pembroke Dock and 24 mm. at St. Mawgan.

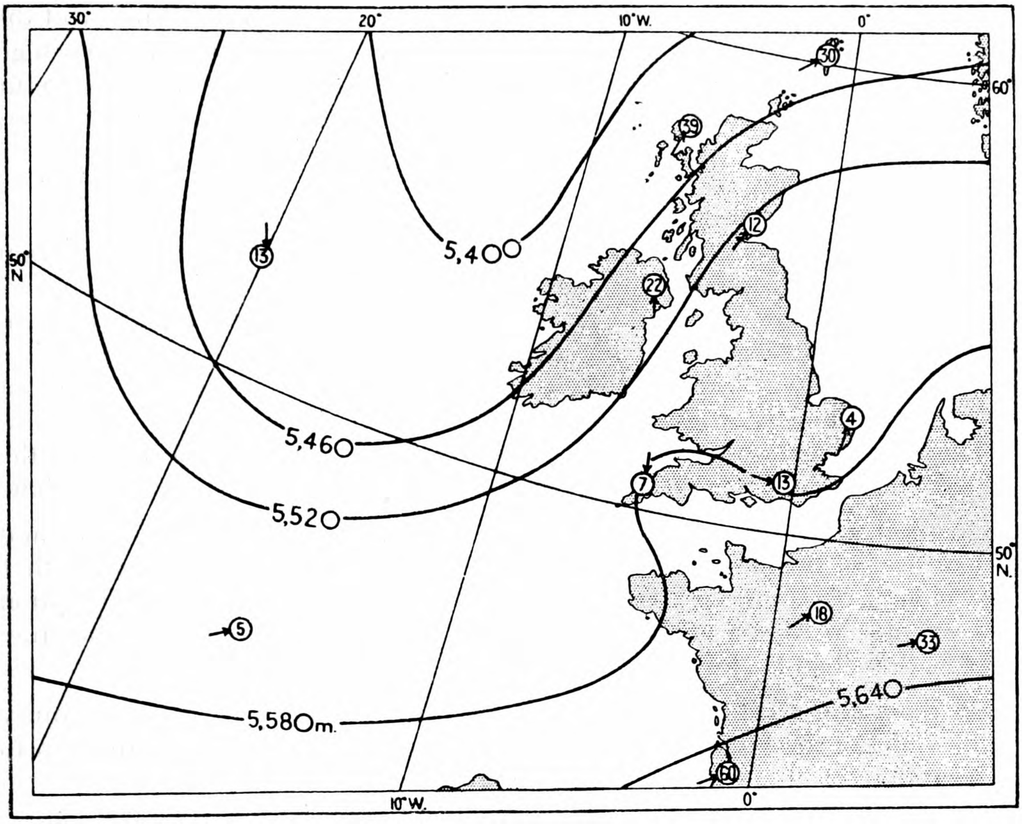


FIG. 4—1000–500-MB. THICKNESS CHART, 0300 G.M.T., JULY 29, 1956

The directions and magnitudes (in kt.) of thermal winds are indicated by arrows and encircled numbers.

The picture would not be complete without mention of the floods in north and east Scotland on the following day. During the 24 hr. from 2100 G.M.T. on Sunday a rainfall of 65 mm. was measured at Kinloss, 57 mm. at Cape Wrath and 42 mm. at Aberdeen. Bridges were washed away, homes flooded and road and rail services dislocated.

DUST IN THE STRATOSPHERE OVER WESTERN BRITAIN ON APRIL 3 AND 4, 1956

By G. A. BULL, B.Sc., and D. G. JAMES, Ph.D.

Between 1000 and 1045 G.M.T. on April 3, 1956, Wing Cmdr Martin, Chief Test Pilot of the Gloucester Aircraft Company and his navigator Mr. Varley observed from 50,000 ft. a layer of "cloud" estimated to be at 55,000 ft. The cloud was observed to cover the whole of the south-west part of England and to be in bands or streaks running north to south with minor ripples on the underside running north-east to south-west. The colour of the "cloud" was off-white; viewed from directly below it was transparent and the disc of sky above seemed a vivid blue. The underside of the cloud closely resembled an oily sea. On a flight on April 4 the same pilot passed through a layer of cloud 50 ft. thick at 40,000 ft. which was considered to be rather more lumpy in appearance than on the previous day. The tropopause was at a height of 11 Km. (36,000 ft.) so this "cloud" was well in the stratosphere.

During the period 1850–2010 G.M.T. on April 3, 1956 Mr. B. Ramsey of the Meteorological Office, Aldergrove, Northern Ireland observed a very high "cloud" layer . The weather was fine with visibility 30 miles and, mainly to the eastward, a little cumulus and stratocumulus at 2,500 ft. Sunset was at 1904 G.M.T. at azimuth 275°, civil twilight at 1942 G.M.T. and at 2010 G.M.T. the sun was about 15° below the horizon. The "cloud" showed a strong "dead" grey white appearance and its steely colour was apparent from north-north-west to south-south-west. By about 2000 G.M.T. when it had almost faded from sight the tops turned a deep but rather flat rose colour. The sheet had a solid appearance. Its underside was by no means smooth and had irregular undulations like estuary sand seen at low tide after being swept by strong currents or like rough-set concrete. When first seen, the near edge of the sheet was at about 40° elevation and it gradually lowered to about 5° before fading from view, looking to a casual observer rather like a receding cirrostratus sheet. After the "cloud" had completely gone there was a persistent and strong twilight glow.

On receipt, through the Senior Meteorological Officers at Gloucester and Aldergrove, of this information at the Meteorological Office it was clear that the "cloud" observations were similar to those of the dust from the eruption of a volcano in Alaska on July 9, 1953 seen over the British Isles in late July 1953 as described by Jacobs[1].

No reports of recent volcanic eruptions had been received but on inquiry of the Chief of the United States Weather Bureau he kindly drew attention to an eruption of the volcano Bezymannaya Sopka (55°57′N., 160°32′E.) in Kamchatka which was stated in a news bulletin broadcast by Moscow Radio as having occurred at 1711 L.S.T. (0611 G.M.T.) on March 30, 1956. The Moscow report, some further details of which were obtained from the British Broadcasting Corporation, stated that the volcano in question erupted suddenly at the time given and that a cloud of ashes rose to a height of 20 Km. (67,000 ft.), accompanied by thunder and lightning lasting for 4 hr., and that an appreciable fall-out of volcanic ash had been registered at a distance of nearly 80 Km. from the volcano. After the end of the fall-out the air remained filled with volcanic dust. On the morning of March 31 the fall-out had been nearly 30 Kg. of volcanic ash per square metre near a vulcanological station some 40 Km. from the volcano. A second explosion occurred on April 1 with gases and ashes shooting up to 10 Km. A 1500-micron displacement of the earth's crust was recorded.

The Chief of the United States Weather Bureau stated in his letter that the dust was not seen over the United States but that a report of a heavy haze layer on April 3 at 10,000 ft. over Anchorage, Alaska had been received. By and large, however, Alaska was cloud covered.

The problem of determining from information on upper winds, the possibility of the "cloud" over the British Isles having been dust from the Kamchatka eruption was then studied in the Forecast Research Division.

It was reasonable to suppose that the "cloud" observed from Aldergrove was the same as that over Gloucester and its height was assumed to be near that of the 100-mb. level.

100-mb. charts were accordingly drawn for 0300 and 1500 G.M.T. for each of the days March 30 to April 3 inclusive. Unfortunately no data at 100 mb.

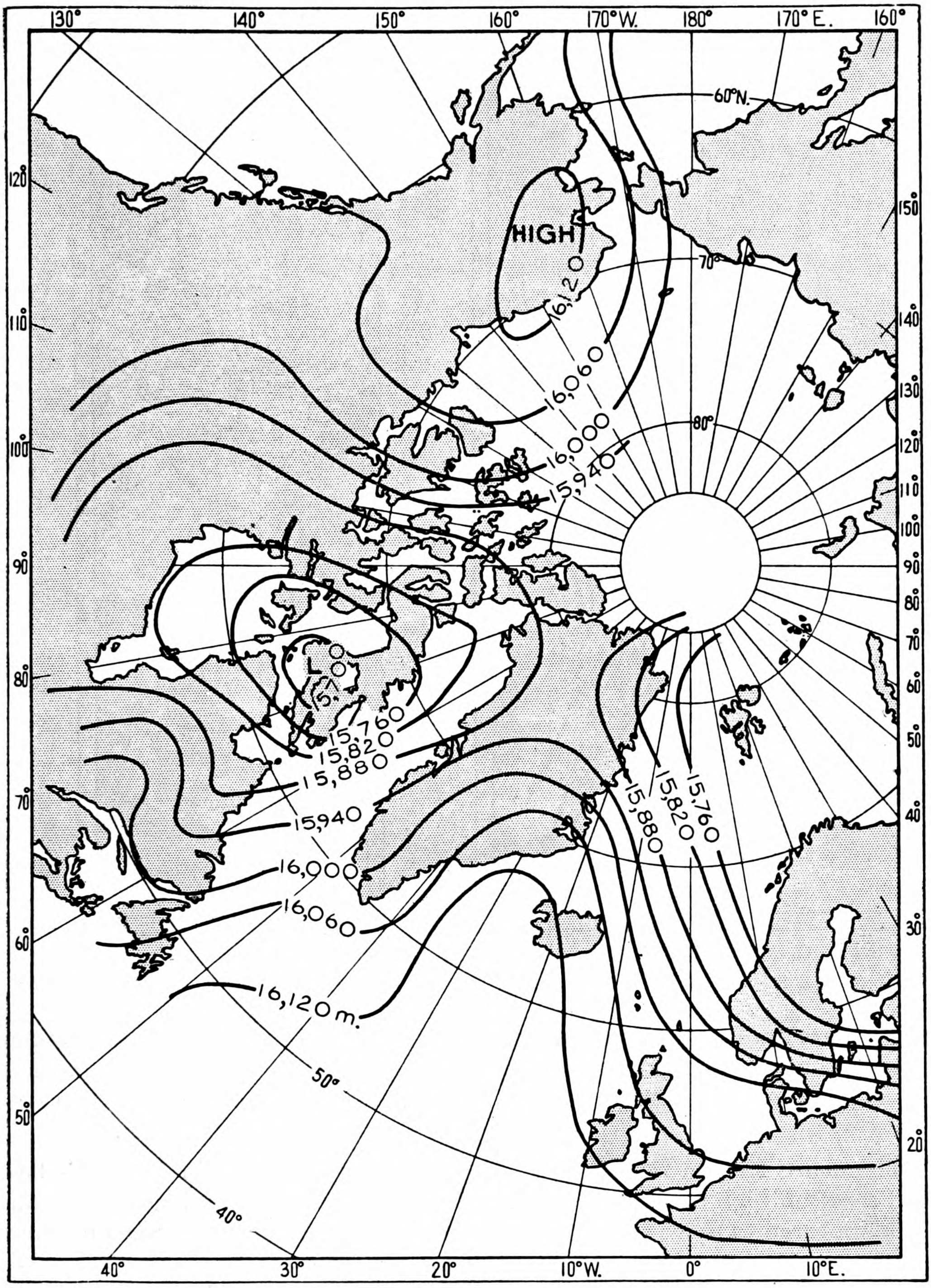


FIG. 1—PATTERN OF CONTOURS OF THE 100-MB. SURFACE NORTH OF 50°N. AT 1500 G.M.T., MARCH 31, 1956

were available from the Kamchatka–North Pole–Greenland area for the construction of the charts. Figs. 1 and 2 show the main features of the pattern of contours of the 100-mb. surface north of 50°N. at 1500 G.M.T. on March 31 and April 2 respectively.

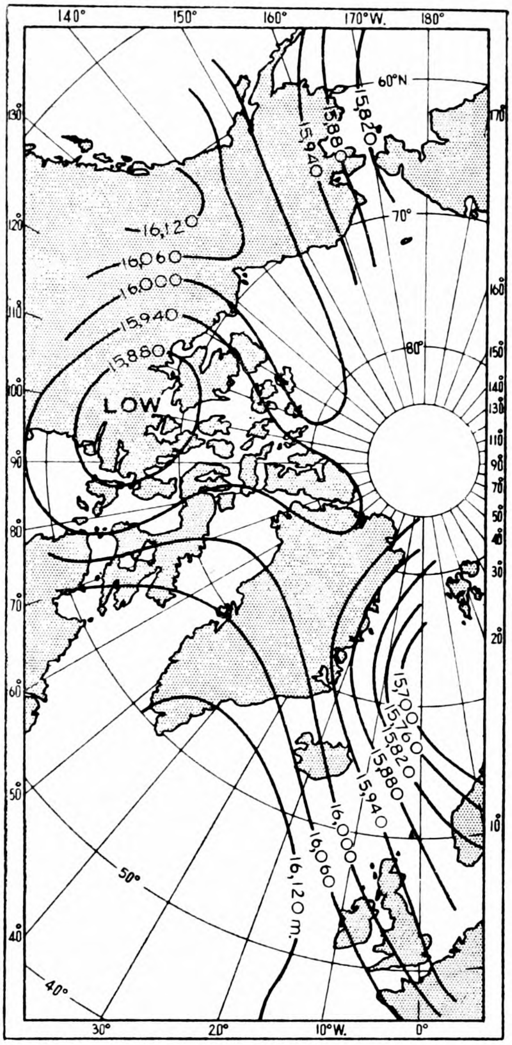


FIG. 2—PATTERN OF CONTOURS OF THE 100-MB SURFACE NORTH OF 50°N. AT 1500 G.M.T., APRIL 2, 1956

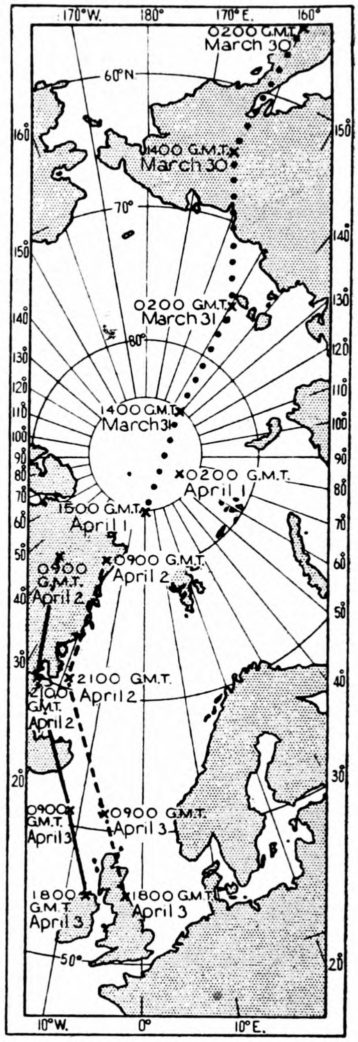


FIG. 3—AIR TRAJECTORIES TRACED FORWARD FROM KAMCHATKA (MARCH 30–APRIL 1, 1956) AND BACK FROM ALDERGROVE (APRIL 2–3, 1956)

The charts show a ridge in mid-Atlantic, a cut-off low near Hudson's Bay and a cut-off high over Alaska. This pattern in the Greenland–north Canada area appeared to move somewhat westwards during the period. Starting from Aldergrove at 1800 G.M.T. on April 3 the air can be traced back to 77°N. 40°W. by 0900 on the 2nd as is shown in the full-line trajectory in Fig. 3. The exact position of the last point is subject to more than normal error because of confluence in the flow pattern over Greenland. A trajectory starting from 5° east of Aldergrove would not be subject to the same doubt and gives a position at about 80°N. 20°W. at 0900 on April 2, as shown in the trajectory (pecked) in Fig. 3.

The great-circle distance from the volcano in Kamchatka to 80°N. 40°W. is rather more than 3,000 miles and the time interval available is about 75 hr.

This time interval is far too short to allow of travel round the upper low in the Hudson Bay area and so if the "cloud" originated in the eruption it must have come directly across the Polar basin at an average speed of about 40 m.p.h.

As noted already no information is available on winds at 100 mb. over Kamchatka but at 200 mb. over that area on March 30 the wind was southerly, 60–70 m.p.h. A trajectory at 200 mb. computed from this information is also shown (dotted) on Fig. 3 from which it is clear that if the winds at 100 mb. from Kamchatka to the Pole were not very different from those at 200 mb., air at 100 mb. would have crossed the Pole and reached a point north of Greenland by 1500 G.M.T. on April 1. As already stated a trajectory drawn back from Aldergrove at 100 mb. starting at 1800 on April 3 does reach a point in north Greenland by 0900 on April 2.

Allowing for errors of observation and analysis it it clear that the end points of the two trajectories are near enough together to give the fairly sure result that the dust seen over western Britain on April 3 could have originated in the volcanic eruption in Kamchatka on March 30.

REFERENCE

1. JACOBS, L.; Dust cloud in the stratosphere. *Met. Mag., London*, **83**, 1954, p. 115.

SEVERE HAILSTORM AT TUNBRIDGE WELLS ON AUGUST 6, 1956

By R. E. BOOTH

After its worst hailstorm for more than 30 yr., Tunbridge Wells on August 6, presented a scene more like midwinter than August Bank Holiday, with hailstones in parts of the town shovelled up to 6 ft. high looking like snowdrifts.

A polar depression near Iceland on the 3rd was brought southward in an arctic air stream and became situated off the Hebrides by midday the following day. About that time tornado-like "funnels", always an indication of very disturbed conditions, were observed at Earls Colne near Colchester reaching down to the ground from a dense bank of cloud. A similar phenomenon was seen at Ramsgate at about noon the next day, the 5th; the cloud was then described as "looking rather like a parsnip with the tail swinging about". On Sunday, August 5 the polar low deepened considerably as it moved south from Northern Ireland to become centred over the Lizard at noon and over northern France 24 hr. later. Associated with the surface low there was a cold vortex in the upper air at 500 mb. This cold vortex moved slowly eastward with the surface low; 1000–500-mb. thickness values reached the minimum recorded for the month since 1949 while the thickness at Brest at 0300 G.M.T. on the 6th was an August extreme minimum. The tephigram (Fig. 1) shows the 0200 and 1400 G.M.T. ascents for Crawley. It will be seen that, during the early hours, the environment below 700 mb. was extremely unstable and very dry; and remained so, although to a somewhat reduced extent, during the afternoon. From the 3rd to the 5th there were showers and scattered thunderstorms over most of the British Isles, and early on Bank Holiday Monday thunderstorms broke out along the south coast from Kent to Devon and spread northward during the morning.

The storm which struck Tunbridge Wells was one of these and began about mid-morning with heavy rain and thunder. The hail started a little before noon

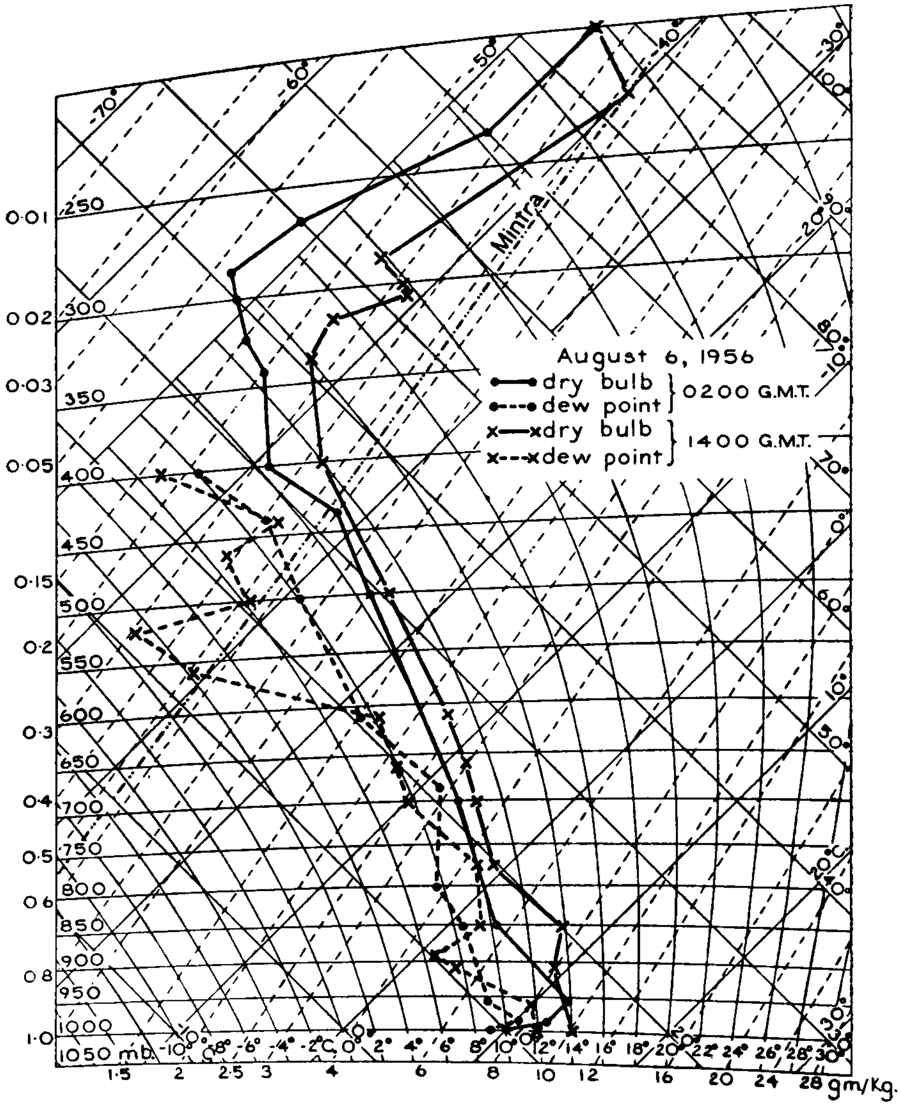


FIG. 1—TEPHIGRAM OF CRAWLEY ON AUGUST 6, 1956

and poured down with an unremitting and sustained intensity which was quite remarkable. Roads were soon blocked by hailstones; hailstones carried by rain-water quickly choked the drains and flood water rose rapidly (see photograph facing p. 304). The effects of the storm appeared to be greatest in the lower or "Pantiles" quarter of the town which resembles a basin and into which four wide main roads converge. Here hailstones and flood water were at times 3 ft. deep and there were hailstones in drifts of up to 4 ft. Bulldozers and mechanical shovels worked for 4 hr. to clear a passage for the traffic and when a way was cleared, cars had to pass between piles of frozen hailstones up to 6 ft. high. Undrifted hailstones covered most of the ground in the neighbourhood to a depth of 2 in.; they varied from ¼ in. to ⅝ in. in diameter.

In spite of the intensity of the storm, structural damage appeared to be comparatively slight although St. James' Church was struck by lightning and hailstones broke through the roof of the Nevill Arms Hotel and went right through the ceiling into the bar. There was extensive flooding; a cinema which was flooded was unable to open on time, and at the Castle Hotel hail was piled 6 ft. in the cellars and the draught beer is said to have been frozen solid.

The damage to growing crops was disastrous. Lettuce leaves were slashed and reduced to a quarter of their normal size and cabbages were cut to ribbons. Peas, beans and tomatoes were stripped of their leaves and pea pods were severely bruised and cut about. Hops over the whole storm area were hanging on the strings by bare stalks. Oats were literally threshed by the hail so that only the bare stalks remained and grain lay in piles on the ground. Fruit on trees hung bruised and cut, surrounded by torn and broken leaves (see photograph facing p. 305).

FREQUENCIES AND CORRELATION IN UPPER AIR DATA

By N. GOLDIE, B.Sc.

Introduction.—The subject of this article is a combination of upper air climatology and statistics. First, fundamental concepts in each of these are outlined briefly; then discussion proceeds to correlations in upper air data and frequency distributions of temperature, wherein probability paper is described, and thence to normal correlation surfaces and frequency distributions of wind vectors.

Troposphere and stratosphere.—The two lowest layers of the earth's atmosphere are known as the troposphere and stratosphere. The troposphere, in which, above the first 300 ft., temperature generally decreases with height, extends from the earth's surface to the tropopause, the latter being the boundary between troposphere and stratosphere. On the temperature record obtained from a single ascent of a sounding balloon, the tropopause usually shows up as a well marked discontinuity at which the fall of temperature with height either becomes suddenly much smaller, ceases or becomes negative. In fact it is very common to find in the lower stratosphere a complete reversal of the lapse rate characteristic of the troposphere. Average values of atmospheric pressure at the tropopause over a few stations in different latitudes are shown in Table I, with equivalent heights in feet and in kilometres.

TABLE I—AVERAGE LEVEL OF THE TROPOPAUSE

		Average tropopause level	Approximate equivalent height	
		mb.	ft.	Km.
Arctic Bay, Canada	73°N. 84°W.	302	29,000	9
Lerwick, Shetland	60°N. 1°W.	254	33,000	10
Larkhill, Wiltshire	51°N. 2°W.	233	36,000	11
Habbaniya, Iraq	33°N. 44°E.	Lower 220—180	40,000	12
		Upper 100— 85	55,000–60,000	17–18
Nairobi, Kenya	1°S. 37°E.	93	57,000	17

Poleward of latitude 45°, a single tropopause is generally evident which shows, on average, a gradual slope upwards from arctic through temperate latitudes. Within 25° or so of the equator, the tropopause is very much higher; and, between 25° and 45° of latitude, two tropopauses are apparent, presumably due to the overlapping of the polar and tropical tropopauses.

Discussion here is limited to the portions of the atmosphere in which observations of temperature and wind are made daily in many parts of the world, i.e. to the troposphere and lower stratosphere. Rough averages of the heights of selected pressure levels in these layers are shown in Table II.

TABLE II—AVERAGE HEIGHTS OF PRESSURE LEVELS IN LATITUDES 33°N.–60°N.

	Pressure (mb.)					
	1000	500	300	200	150	100
Rough average height ft.	300	18,000	30,000	39,000	45,000	53,000
Km.	...	5½	9	12	13½	16

Frequency diagrams.—The basic concepts considered in statistics are the frequency diagram and the correlation coefficient.

Suppose we have a set of upper air temperature observations ranging from, say, −75°F. to −25°F. We can group them into classes according to each 2°F. say of the range, and draw for each class a column to represent the number of occurrences. The result might be something like that shown at the bottom of Fig. 1. This type of frequency diagram is known as a histogram. If it is symmetrical and bell-shaped, one is tempted to fit to it a "normal" frequency curve. This has been done in Fig. 1. The superimposed curve represents the "normal" frequency distribution which has the same mean or average value as the observations and the same standard deviation.

The "normal" distribution, based on the theory of errors and known sometimes as the Gaussian distribution and sometimes as the Maxwellian, is used as a standard by which we may judge any linear distributions of frequencies. These may be either skew, humped or flat-topped (see Fig. 2). Where a set of observations conforms very closely to the normal distribution, it is as if there were a certain characteristic value approximated by the average, individual observations being random shots at this characteristic or "true" mean value.

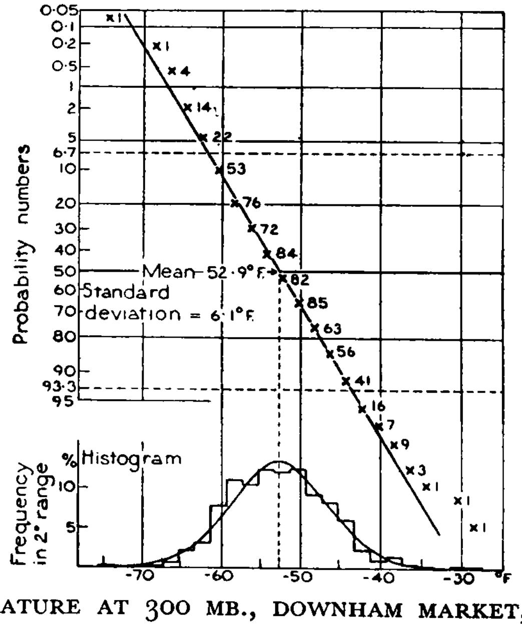


FIG. 1—TEMPERATURE AT 300 MB., DOWNHAM MARKET, APRIL 1946–51
Number of observations = 692

The standard deviation is a measure of the scatter of the observations about the mean value. If, for any observation X, we write $X = \bar{X} + x$, where $\bar{X}$ is the mean or average, then the root-mean-square of x is known as the standard deviation; that is

$$\text{standard deviation of } X = \sqrt{\left(\frac{1}{N}\sum x^2\right)},$$

where N is the number of observations.

Correlation.—If we have a related series of observations, Y, we may similarly write $Y = \bar{Y} + y$

and $$\text{standard deviation of } Y = \sqrt{\left(\frac{1}{N}\sum y^2\right)}.$$

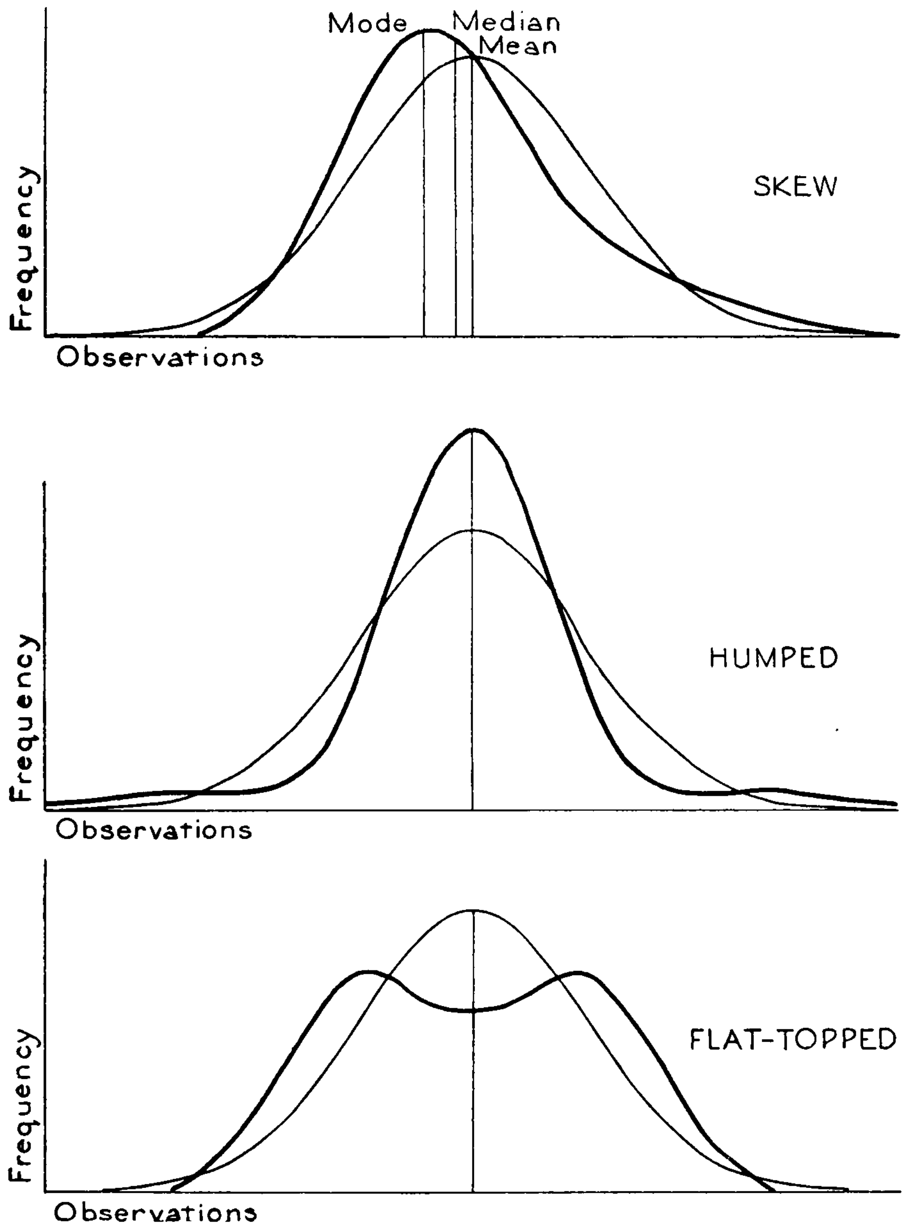


FIG. 2—TYPES OF FREQUENCY DISTRIBUTION COMPARED WITH NORMAL

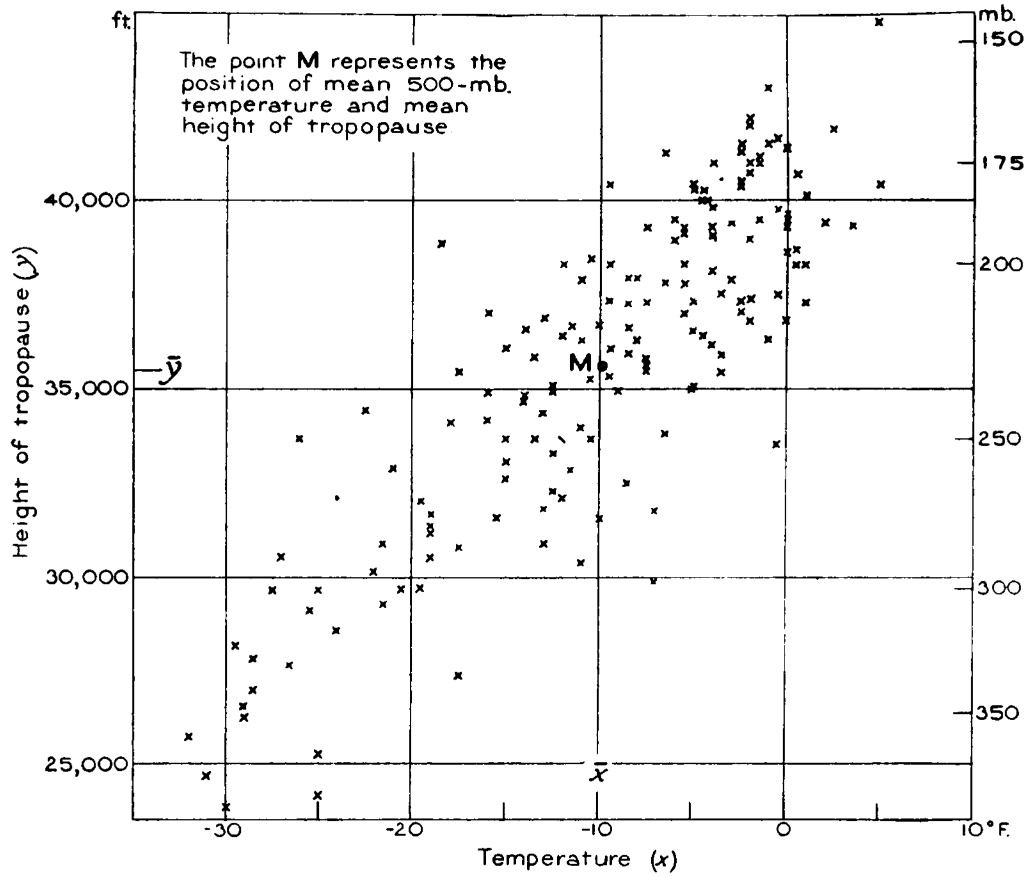


FIG. 3—SCATTER DIAGRAM. TEMPERATURE AT 500 MB. AGAINST HEIGHT OF TROPOPAUSE

When we plot Y against X, we get a cloud of points as shown in Fig. 3. Here X represents temperature at 500 mb. over Larkhill in January and Y the height of the tropopause on the same occasion. If there is a rough linear relation between X and Y as in this example, the cloud will tend to be elliptical in shape: the narrower the ellipse, the closer the relation.

A plot of individual values of 500-mb. temperature against height of tropopause gave a rather crowded picture and so, in Fig. 3, the number of observations has been halved. Each cross shows, not an individual value of temperature, but the mean of two observations which corresponded to as nearly as possible the same height of tropopause.

The origin of co-ordinates may be transferred to point M ($\overline{X}$, $\overline{Y}$), and then the co-ordinates become x and y. A measure of the relation between X and Y is given by the correlation coefficient:—

$$r = \frac{\Sigma(xy)}{\sqrt{\{\Sigma(x^2)\,.\,\Sigma(y^2)\}}} = \frac{(1/N)\Sigma(xy)}{(\text{standard deviation of } X)\,(\text{standard deviation of } Y)}$$

The products xy are summed algebraically and this sum gives the sign of r. The coefficient r varies from -1 to $+1$; $r = \pm 1$ denotes an exact relation between X and Y, or between x and y. More often the magnitude of r lies between unity and zero. A value of $r = 0{\cdot}7$ indicates that half of the variation of Y is dependent upon that of X and, conversely, that half of the variation of X is dependent upon Y; r $= 0{\cdot}5$ shows that one quarter of the variation of Y depends upon X; and generally, we may write

$$\sigma_y^2 = r^2\sigma_y^2 + (1-r^2)\,\sigma_y^2$$

where σ_y denotes the standard deviation of Y. The term $r^2\sigma_y^2$ is closely related to the variation of X; the term $(1-r^2)\sigma_y^2$, the remaining part of σ_y^2, can be shown to be entirely independent of X.

Application to upper air work.—Frequency curves and correlation coefficients have been familiar to meteorologists during the past 50 years. The earliest reference in meteorological literature to the fitting of a normal frequency curve that the author could find is in a paper dated 1906. In this Van der Stok[1] compares a frequency polygon of 22,188 pressure values at the Helder, Holland, in January and February 1843–1904, with the equivalent normal curve. Correlation occurs at least as early as 1907 when Hooker[2] published results of his studies of relations between crops and weather. Application of correlation to upper air data comes only a few years after, the pioneer in such work being W. H. Dines. He was not the first to make systematic soundings of the upper air, although his work followed very soon after that of Rotch in America and Teisserenc de Bort and Assmann in Europe; but, as far as can be gathered, he was the first to examine relations which he detected between different elements in the free air and to test them statistically. The largest of Dines' correlation coefficients are given in Table III. They relate height (H_c) of the tropopause to

(i) temperature (T_c) at the tropopause level
(ii) conditions in the troposphere
(iii) pressure (P_s) at the earth's surface.

The values shown are from a Memoir[3] published in 1919 but they differ very little from earlier values[4] published in 1912.

TABLE III—CORRELATION COEFFICIENTS IN UPPER AIR DATA

	T_c	P_9	T_m	P_s	H_{1000}	H_{300}	T_{500}	Authority
				correlation coefficient				
H_c	−0·68	+0·84	+0·79	+0·68	...	...	...	W. H. Dines
H_c	−0·47	...	...	...	+0·49	...	...	C. H. B. Priestley
P_c	...	...	...	...	...	−0·75	−0·75	J. K. Bannon and A. Gilchrist

Data used: Dines, European, 1902–13, scattered days; Priestley, Larkhill, 1944, all months; Bannon and Gilchrist, Larkhill, 1948–50, January, April, July and October.

The negative relation between height and temperature at the tropopause shown by the first coefficient listed, is not unexpected. It arises partly from the conception of the troposphere as a layer of atmosphere in which temperature falls at a fairly steady rate with increasing height: the higher the tropopause the greater the fall in temperature from near-surface air to air at the tropopause. The pressure (P_9) at 9 Km. and the mean (T_m) of temperatures at 2·5, 5·0 and 7·5 Km. are related very closely. Dines[3] writes, "Whatever the reason for the curious division of the atmosphere into two parts may be, it is the value of the air pressure at about 9 Km. height which regulates the position of the boundary"; but nowadays it is thought rather that it is the temperature of the troposphere which governs the height of the tropopause; for high tropopauses are associated with warm air, the tropopause in temperate latitudes being higher in air of tropical origin than in air of polar origin.

The coefficient relating height of tropopause with surface pressure (P_s) is consistent with the study of depressions and anticyclones by later workers who find that the tropopause tends to be lower than average over depressions and higher than average over anticyclones.

Dines' results are confirmed numerically by Priestley[5] and by Bannon and Gilchrist[6] (Table III). Priestley uses height (H_{1000}) of the 1000-mb. level instead of surface pressure; Bannon and Gilchrist, instead of height of tropopause worked with the pressure (P_c) at the tropopause, correlating this with height (H_{300}) of the 300-mb. level and with temperature (T_{500}) at 500 mb. The last is shown by both Dines and Priestley to give a good approximation to the mean temperature of the troposphere. The coefficients given by Bannon and Gilchrist are much nearer in magnitude to those of Dines than are Priestley's, but Priestley's are computed from only one year's observations.

Perhaps the chief value of the work by Bannon and Gilchrist[6] is that it covers a variety of latitudes, the following stations being examined:

			Period
Arctic Bay	73°N.	84°W.	1948–50
Lerwick	60°N.	1°W.	1948–50
Larkhill	51°N.	2°W.	1948–50
Malta	34°N.	14°E.	1948–51

For Arctic Bay in July, for Lerwick, for Larkhill in January, April and October and for Malta in January and April, the correlation coefficients are very much of the same order as the mean values shown for Larkhill. The values for Larkhill in July and for Arctic Bay in other months are rather lower and those for Malta in July and October very much lower; in fact those for Malta in July are too small to be significant.

Frequency distributions of temperature.—The form of the relation between any two elements correlated can be gathered from the pattern exhibited by their combined frequencies; but, before considering this, it seems logical to discuss more fully the frequency distributions characteristic of a single element, upper air temperature.

A detailed picture of variations in upper air temperature can be gleaned from recent publications of radio-sonde data for stations in the British Isles and the Middle East[7] by the Meteorological Office. Each of these publications includes histograms for the four mid-season months, January, April, July and October at the pressure levels 700, 500, 300, 200, 150 and 100 mb. For the most part, the frequency distributions portrayed do not appear to deviate much from the "normal"; but, at 200 mb. over stations north of 33°N. in January and April, there is a marked widening of the range of temperature accompanied by a flattening of the histograms (see Fig. 2). At Larkhill (51°N.), these seem to be bi-modal, i.e. there are two temperature values at which the frequency rises to a maximum. Examples of the two salient types of histogram of upper air temperature are given in Figs. 1 and 4, with empirical curves superimposed. The "normal" curve of Fig. 1 was described earlier. The histogram in Fig. 4 shows frequencies of temperature at 200 mb. over Larkhill during the winter months December to January; and to these data is fitted the sum of two normal frequency curves. These correspond to two different régimes

[To face p. 304

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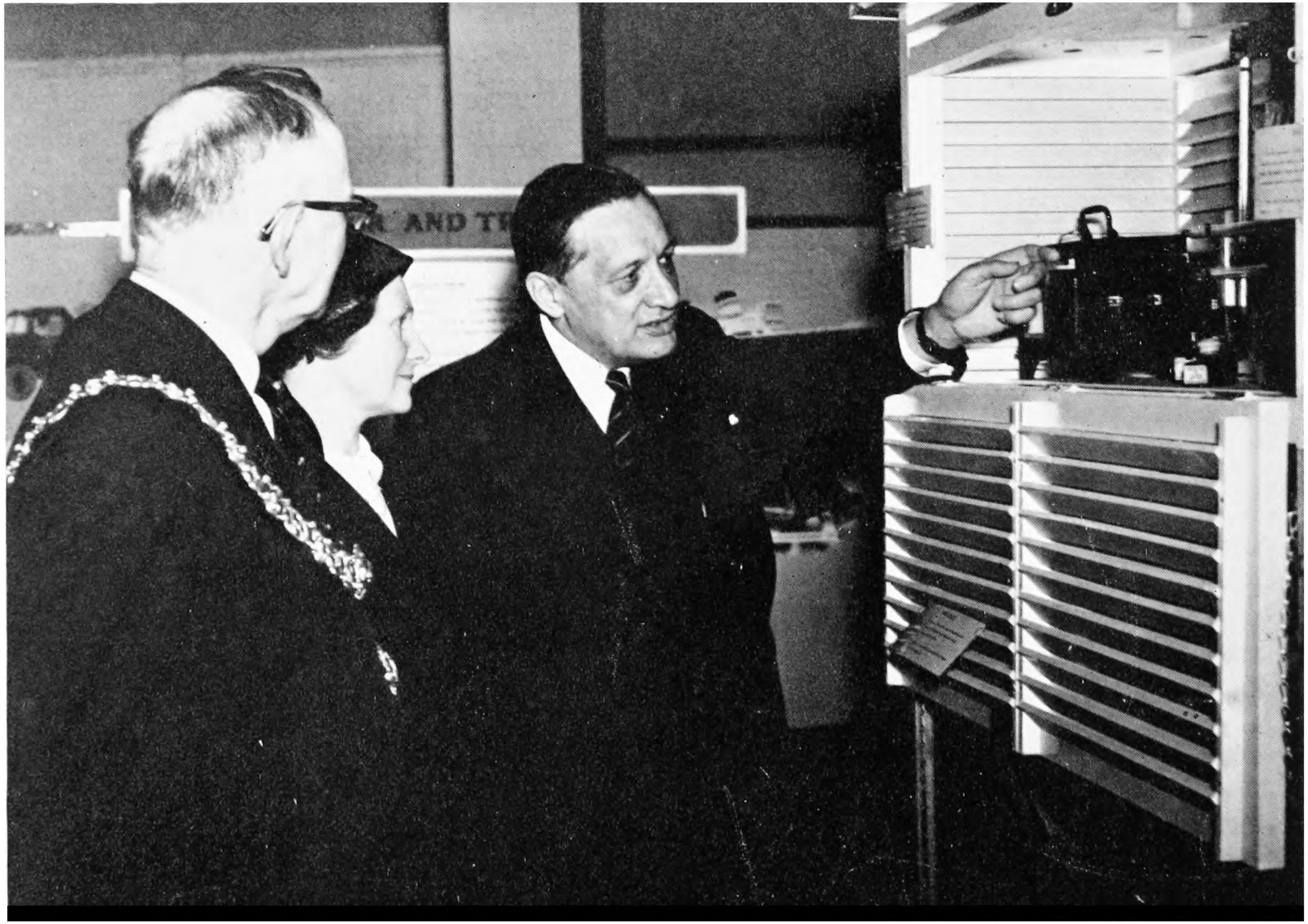
HAILSTONES AT TUNBRIDGE WELLS

(see p. 298)



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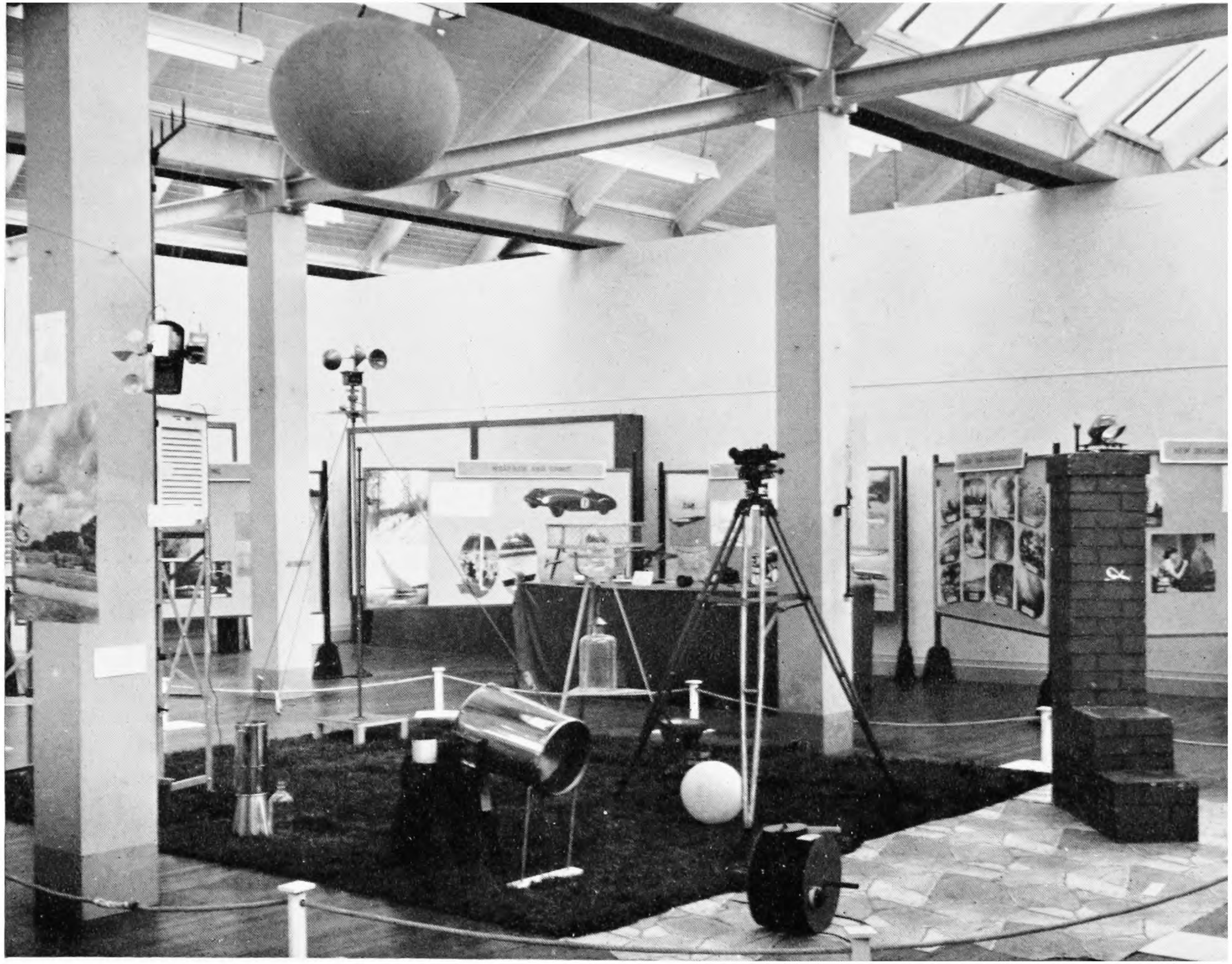
THE DIRECTOR OF THE METEOROLOGICAL OFFICE AT THE ITINERANT METEOROLOGICAL EXHIBITION AT LEICESTER, AUGUST 3, 1956

The Lord Mayor of Leicester and a member of the Leicester City Council are on the Director's right.

(see p. 314)



ITINERANT METEOROLOGICAL EXHIBITION DISPLAYED IN LEICESTER MUSEUM, AUGUST 3–26, 1956

(see p. 314)

Reproduced by courtesy of The Grower

APPLES DAMAGED AND LEAVES TORN BY HAILSTONES

(see p. 299)

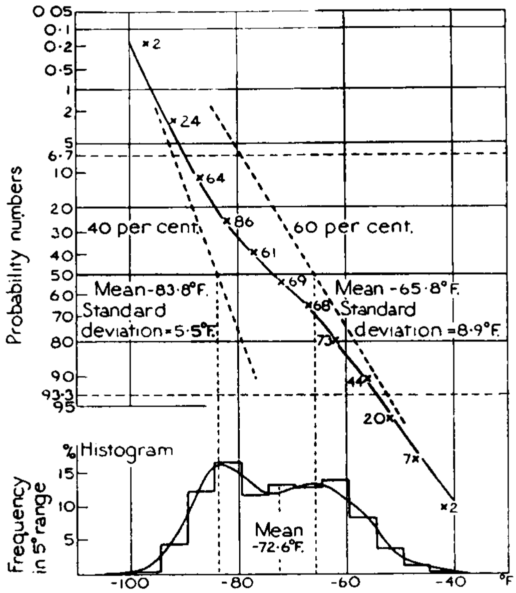


FIG. 4—TEMPERATURE AT 200 MB., LARKHILL, DECEMBER–FEBRUARY 1942–44
Number of observations = 520

of temperature; the left-hand curve, with mode at −84°F., appears to correspond to temperature of air within the troposphere or very near the tropopause, that on the right, with mode at −66°F., to stratospheric air. The method of fitting is by means of "probability" paper.

Probability paper.—This is a special type of graph paper. The co-ordinates are rectangular; one scale is linear and the other is the probability scale. Fig. 5 shows a normal distribution of frequencies; the shaded portion under the frequency curve to the left of *X*, represents the total frequency of values of observations which are less than the value *X*. In plotting such a frequency distribution on probability paper, the value *X* is taken as abscisse along the linear scale; and the corresponding percentage cumulative frequency, i.e. the shaded portion of Fig. 5, expressed as a percentage of the whole area under the curve, is taken as ordinate along the probability scale. This scale is so designed that if the frequency distribution is exactly normal, then the plotted points all lie exactly along a straight line. The ordinate may be termed the "probability number". Hints on plotting were given in an earlier article[8].

The probability-plot of a frequency distribution which is nearly normal is given in Fig. 1. The crosses represent the cumulative frequencies corresponding to the middle points of the steps of the histogram shown below, and the small

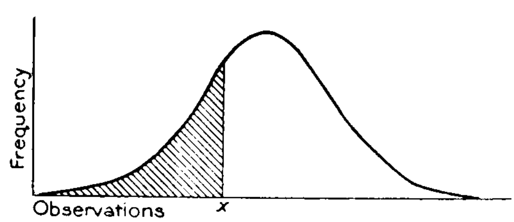


FIG. 5—NORMAL FREQUENCY DISTRIBUTION
The shaded portion is the cumulative frequency corresponding to the value *X*

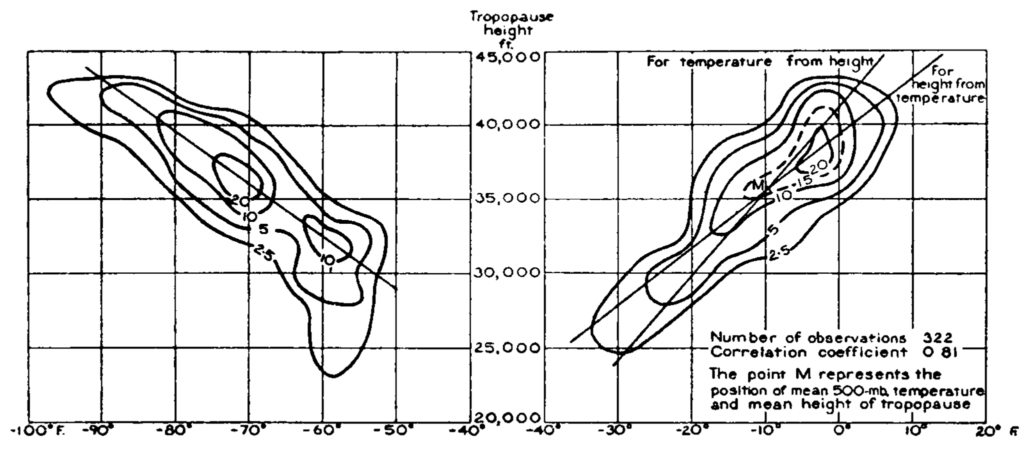
figures indicate the number of observations contributed by each successive step; the straight line represents the fitted normal curve. It will be seen that the actual 300-mb. temperature distribution deviates but little from the straight line. The steepness near the top of the diagram indicates a greater clustering of observations in the range $-70°$ to $-60°$F. than is expected from the normal distribution; also, the highest temperatures (bottom right-hand corner) are more extreme. These features both intimate that the observed distribution is positively skew (see Fig. 2), but in this example the skewness is only slight.

The 50 per cent. line on probability paper indicates the position of the mean on the normal distribution, here $-52{\cdot}9°$F. The standard deviation may be obtained by reading off the temperature values corresponding to the 6·7 per cent. and 93·3 per cent. positions on the normal distribution and dividing the difference by 3. Thus from Fig. 1,

$$\text{standard deviation} = \frac{1}{3}\left\{(-43{\cdot}8) - (-62{\cdot}0)\right\} = \frac{18{\cdot}2}{3} = 6{\cdot}1°\text{F.}$$

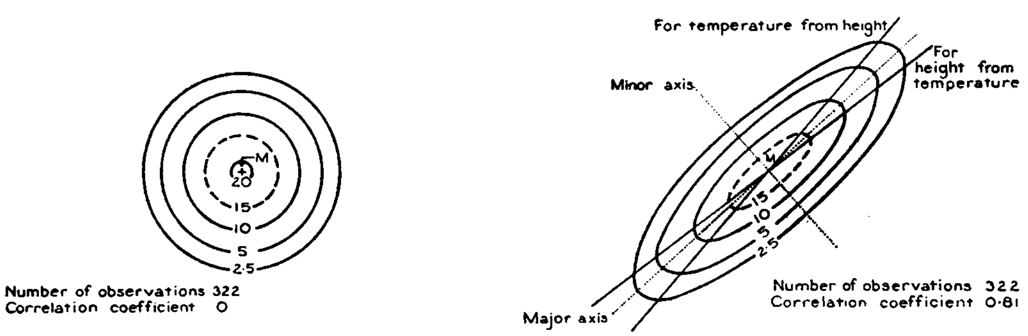
In Fig. 4 the crosses again show cumulative frequencies corresponding to the middle points of the steps of the histogram below; and the full line through the crosses represents the same compound distribution as is shown by the curve superimposed on the histogram. The curve was fitted by a very simple method given by Harding[9]. The crux of his method lies in estimating the proportion of the total frequency to be assigned to each component "normal" distribution. A first shot is made by judging the point of inflexion of a curve drawn by eye through the plotted points; and the division which gives the best fit is then determined by further "trial and error". For the data of Fig. 4, the point of inflexion appeared to be not far from the 50-per-cent. line and so, to begin with, it was supposed that half the frequencies should be allocated to each component. The two components are determined from the tails of the total distribution. The four points nearest the top of Fig. 4 were replotted with their probability numbers doubled and a straight line was drawn by eye as nearly as possible through the new points. This represented one normal component distribution. The six points nearest the right-hand side were replotted with $(100 - P)$ doubled, P being the probability number, and a straight line through these new points gave a first shot at the second component distribution. When these two 50-per-cent. distributions were combined, half weight being given to each, the resulting compound distribution appeared on the probability paper similar to the full line shown in Fig. 4; but, near the centre, the line representing the sum of the 50-per-cent. distributions lay slightly to the left of all the plotted crosses. This suggested that too much weight had been given to the left-hand component, and so, in a second trial, the proportions 40 per cent. and 60 per cent. were adopted. This time, for the left-hand points the probability numbers were multiplied by 100/40 and, for the right-hand, $(100 - P)$ had to be multiplied by 100/60—instead of each by 100/50 as in the first trial. The resulting combination is the one seen in Fig. 4. The proportions 35 per cent. and 65 per cent. also were tried but the fit was slightly less good than that given by 40 per cent. and 60 per cent.

Correlation surfaces.—After this interlude on linear frequency distributions and probability paper, we return to the discussion of correlated elements. The data from which Fig. 3 was derived are shown in a different manner in



(*a*) Correlation surface of tropopause height with 150-mb. temperature

(*b*) Correlation surface of tropopause height with 500-mb. temperature



(*c*) Normal circular frequency surface.

(*d*) Normal correlation surface

FIG. 6—CONTOURS OF FREQUENCY SURFACES, LARKHILL, JANUARY 1948–50

Frequencies are given for 4°F. of temperature by 2,000 ft. of height

Fig. 6(*b*). The roughly elliptical lines are contours of a frequency surface vertical sections of which are not unlike the curves fitted to the histograms in Figs. 1 and 4. The figure labelling each contour gives the actual number of observations contained in a cell representing 4°F. of temperature at 500 mb. by 2,000 ft. of height of tropopause, the contours having been slightly smoothed in the drawing.

A surface which shows the distribution of frequencies of two related variables is known as a "correlation" surface. If all vertical sections of the surface are normal frequency curves, then it is a "normal" correlation surface. Contours of such an idealized frequency surface are shown in Fig. 6(*d*). This diagram has been computed from the values of correlation coefficient and standard deviation pertaining to the "observed" contours of 6(*b*). If X is 500-mb. temperature in units of 4°F. and Y is height of tropopause in units of 2,000 ft., then

$$r = +0{\cdot}81, \qquad \sigma_x = 2{\cdot}33, \qquad \text{and } \sigma_y = 2{\cdot}14.$$

In normal correlation, each of the related variables is normally distributed and the relation between them is linear. The correlation between the height of tropopause and the 500-mb. temperature is seen, from Figs. 3 and 6, to be roughly linear but the frequency distributions both of height of tropopause and of temperature at 500 mb. are decidedly skew.

In Fig. 6 (*a*) the relation is shown between height of tropopause and temperature at 150 mb., a level which at Larkhill is generally within the stratosphere. The contours are those of a somewhat irregular frequency surface. It looks as if there may be an almost linear, but negative correlation in the upper part of the diagram where the 150-mb. temperatures refer either to the troposphere or to the lowest part of the stratosphere, but where the 150-mb. level is well above tropopause level, which happens when the height of the tropopause is less than 33,000 ft. (i.e. tropopause pressure 260 mb. or more), then the 150-mb. temperature seems to be independent of tropopause height and the temperature observations fall relatively closely about a mean temperature of -59°F.

The main ridge of the surface in Fig. 6(*a*) is not far from perpendicular to that of Fig. 6(*b*). This suggests that there is a significant negative correlation between temperature at 150 mb. and that at 500 mb.; but this correlation may, of course, be due chiefly to the fact that both temperature at 150 mb. and 500 mb., in opposite senses, are closely related to the height of the tropopause. Actual computation gives a "total" correlation between 150-mb. and 500-mb. temperatures of $r = -0{\cdot}66$; but, when the effect of height of tropopause is eliminated from each of the elements, temperature at 150 mb. and 500 mb., the "partial" correlation between them is found to be zero. (Correlation between 150-mb. temperature and height of tropopause is $r = -0{\cdot}82$.)

The point M near the middle of Fig. 6(*b*) gives the position of mean 500-mb. temperature ($-9{\cdot}9$°F.) and mean height of tropopause (35,600 ft.) and the straight lines through this point can be used, one to estimate the most likely temperature at 500 mb. for a given height of tropopause and the other to estimate the most likely height of tropopause when the temperature at 500 mb. is known. These two lines are misnamed "regression" lines. The term "regression" was introduced (*circa* 1886) in a problem on heredity studied by Sir Francis Galton and the term has persisted generally. Papers by Galton are cited by Yule and Kendall[10]. The regression lines are distinct from one another so long as the correlation is not unity; they are more and more divergent the nearer r approaches zero, being parallel to the axes of X and Y when the correlation between them is zero; but they coincide when $r = \pm 1$. Formulae for the regression lines are derived in most textbooks of statistics.

The normal correlation surface shown in Fig. 6(*d*) may be regarded as a smoothed and simplified form of Fig. 6(*b*). In Fig. 6(*c*) the contours have been smoothed to an even greater extent; this diagram shows the normal frequency surface that would result if the correlation were zero and the standard deviations of X and Y were equal. All the contours are circles. Such a circular distribution is believed to be characteristic of homogeneous collections of winds in the upper air.

Wind.—The elements considered up to now, temperature, pressure and height, have been scalar quantities. Wind, being a vector (i.e. a quantity having direction as well as magnitude) requires a somewhat different treatment. Any vector can be resolved uniquely into components in three fixed directions mutually at right angles; in a statistical examination of winds, however, the vertical component may be neglected and thus any wind observation is considered as the resultant of two horizontal components each of which can be treated as a scalar element. This means that winds may be plotted in a correlation diagram like that of Fig. 3, X being the easterly component and Y

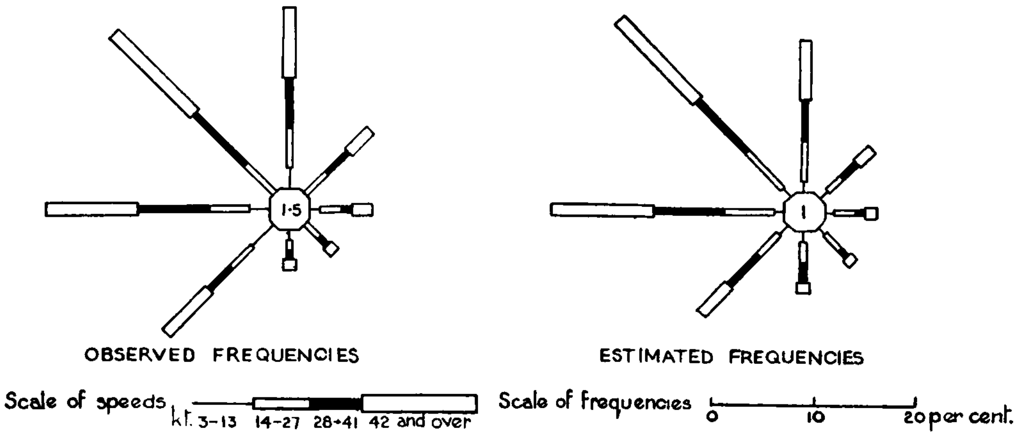


FIG. 7—WINDS AT 500 MB., LARKHILL, DECEMBER–FEBRUARY 1939–40 TO 1944–45

Frequencies are given only to the nearest per cent. (except in the case of calms)
Figures inside the central octagons indicate percentage frequency of calms
Number of observations = 483 V_R = 18·1 kt. V_s = 37·6 kt.

the northerly. The main difference between a correlation diagram of upper air winds and that given as Fig. 3 will be in the configuration of the points plotted. Whereas the present temperature-height diagram shows something of an elongated ellipse, the wind-components diagram might be almost circular in shape with the plotted points distributed radially about a point representing the vector mean wind.

Actual examination of homogeneous sets of observations of winds in the upper air confirmed three important characteristics: first, the easterly and the northerly components are "normally" distributed; secondly, there is no appreciable correlation between these components; and, thirdly, their standard deviations are equal. This meant that the winds examined did in fact conform to normal circular frequency distributions, such as that illustrated in Fig. 6(*c*). (This will not often be true of winds within about 1,000 ft. of the earth's surface; nor is it true of winds at higher levels unless they are strictly homogeneous. For example, Scott[13] finds that a distribution comprising winds throughout September, October and November at 50,000 ft. above Singapore is strongly elliptical; but other evidence, for example Hay[14], suggests that these winds are not confined to a single régime.)

The closeness with which the empirical model fits the actual observations may be gathered from Figs. 7 and 8, reproduced from a Memoir by C. E. P. Brooks and others[11]. Here the data are in the form of wind roses and so the centre of the circular distribution lies not in the central octagon but at a distance from it representing (on the scale of speeds) the magnitude of the vector mean wind. The parameters used in computing the "estimated" frequencies were the direction of the vector mean and its magnitude (V_R), the average speed (V_S) and the number of observations. Details of computation are given in the Memoir[11].

One advantage of the agreement between the simple normal circular frequency surface and actual distributions of upper air winds is that components

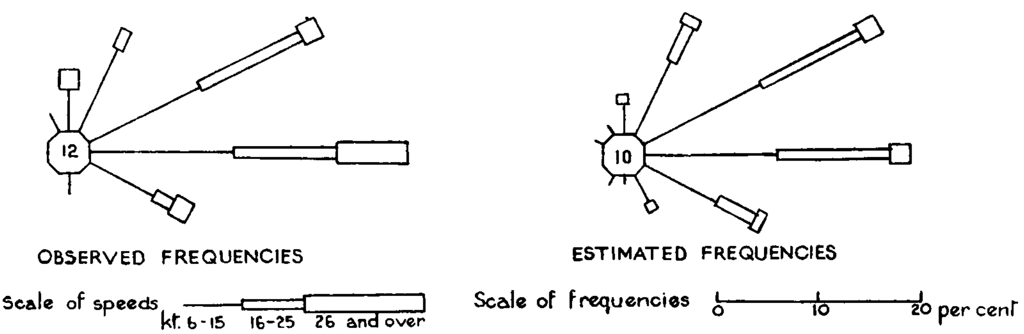


FIG. 8—WINDS AT 14,000 FT., MOMBASA, DECEMBER 1943 AND JANUARY 1944

Frequencies are given to the nearest per cent.

Figures inside the central octagons indicate the percentage frequencies of speeds 0–5 kt.

Number of observations = 52 $V_R = 7 \cdot 6$ kt. $V_s = 14 \cdot 1$ kt.

in any specified direction may be assumed to be distributed normally and so probability paper again is of use in making further deductions, (see Goldie[8]).

Practical applications.—Where frequency distributions of temperature or of wind have been shown to be "normal" this fact has, in a number of instances, been applied to practical problems.

One illustration may suffice. A normal circular wind rose can be computed where the only data available are the vector mean wind and the average wind speed, or even where there are no wind data at all so long as estimates of the vector mean wind and of some measure of the scatter of individual winds about it are possible. The computed wind rose can then be used to estimate probabilities of high winds in specified directions. This is the sort of information that was continually being asked of the Meteorological Office, as far back as the beginning of 1945, in connexion with the planning of post-war civil air routes; and it was this that prompted, first, an investigation into frequency distributions of upper winds[12] and later, the charting of the necessary parameters (estimated where necessary) for the greater part of the globe[11].

The tropopause height used is not an exact height but is the result of converting actual values of pressure at the tropopause to a height scale based upon the average heights (1946–50) of the principal isobaric surfaces.

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ERRORS IN THE ESTIMATION OF GEOSTROPHIC WINDS

By A. F. CROSSLEY, M.A.

A method is described of computing the standard error in the estimation of geostrophic winds from given charts of isobars or pressure contours and an application is made to 500-mb. contour charts.

Theory.—In geostrophic motion the equation of continuity, apart from a small effect due to variations in density which will be ignored, is

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \qquad \ldots\ldots (1)$$

where u and v will be regarded as the components of geostrophic wind from W. and S. respectively. If true values of components of the gradient of the geostrophic wind could be obtained from a series of charts, the correlation coefficient between $\partial u/\partial x$ and $\partial v/\partial y$ would have the value -1, so that

$$R = \frac{\overline{\frac{\partial u}{\partial x}\,\frac{\partial v}{\partial y}}}{\sqrt{\left\{\overline{\left(\frac{\partial u}{\partial x}\right)^2}\;\overline{\left(\frac{\partial v}{\partial y}\right)^2}\right\}}} = -1, \qquad \ldots\ldots (2)$$

where a bar denotes a mean value. Now suppose the gradients are replaced by differences at finite intervals which are the same in all cases. If the geostrophic winds refer to four fixed points A, B, C, D equidistant from a central point and bearing north, south, west and east respectively, then equation (2) may be written

$$R = \frac{\overline{(u_D - u_C)\,(v_A - v_B)}}{\sqrt{\left\{\overline{(u_D - u_C)^2}\;\overline{(v_A - v_B)^2}\right\}}} = -1. \qquad \ldots\ldots (3)$$

The result of inserting estimated components of wind (denoted by primes) in equation (3) is to give

$$R' = \frac{\overline{(u'_D - u'_C)\,(v'_A - v'_B)}}{\sqrt{\left\{\overline{(u'_D - u'_C)^2}\;\overline{(v'_A - v'_B)^2}\right\}}} \qquad \ldots\ldots (4)$$

in which the value of R' will be numerically less than unity. The relations between the estimated and true geostrophic components are written as

$$\left.\begin{aligned} u'_D &= u_D + \varepsilon_D, & u'_C &= u_C + \varepsilon_C, \\ v'_A &= v_A + \varepsilon_A, & v'_B &= v_B + \varepsilon_B, \end{aligned}\right\} \qquad \ldots\ldots (5)$$

where the ε's are the errors in the estimated components. These errors are not expected to be correlated with the geostrophic components and if the space intervals used are sufficiently large, then the errors would not be correlated with each other. In their work on electronic computation of thickness charts, etc., Bushby and Hinds[1] use a grid length of about 140 n. miles; an interval of this order appears adequate to ensure mutually independent errors. With these assumptions it is easy to deduce from equation (5) that

$$\left.\begin{aligned} \overline{(u'_D-u'_C)(v'_A-v'_B)} &= \overline{(u_D-u_C)(v_A-v_B)}, \\ \overline{(u'_D-u'_C)^2} &= \overline{(u_D-u_C)^2} + \overline{\varepsilon_D^2} + \overline{\varepsilon_C^2}, \\ \text{and} \quad \overline{(v'_A-v'_B)^2} &= \overline{(v_A-v_B)^2} + \overline{\varepsilon_A^2} + \overline{\varepsilon_B^2}. \end{aligned}\right\} \quad \ldots (6)$$

Further there seems no reason to expect the mean square errors to differ significantly among themselves provided the number of observations is sufficiently large and provided there is no large gradient of mean wind across the grid of points A, B, C, D. The latter was investigated and found to be small. The suffixes may therefore be omitted from the mean square errors. Then from equations (3), (4) and (6) we obtain

$$\begin{aligned} R' &= R \Bigg/ \sqrt{\left\{1 - \frac{2\overline{\varepsilon^2}}{\overline{(u'_D-u'_C)^2}}\right\}} \Bigg/ \sqrt{\left\{1 - \frac{2\overline{\varepsilon^2}}{\overline{(v'_A-v'_B)^2}}\right\}} \\ &= R(1 - 2\,\overline{\varepsilon^2}/a^2) \end{aligned}$$

approximately, where

$$\frac{1}{a^2} = \frac{1}{2}\left\{\frac{1}{\overline{(u'_D-u'_C)^2}} + \frac{1}{\overline{(v'_A-v'_B)^2}}\right\} \quad \ldots\ldots (7)$$

so that

$$\overline{\varepsilon^2} = \tfrac{1}{2}a^2(1 - R'/R). \quad \ldots\ldots (8)$$

Putting R equal to -1, this becomes

$$\overline{\varepsilon^2} = \tfrac{1}{2}a^2(1 + R'). \quad \ldots\ldots (9)$$

whence the standard vector error is

$$\sigma_\varepsilon = a\sqrt{(1 + R')}. \quad \ldots\ldots (10)$$

It is to be remarked that the approximations involved in disregarding variations of density, equation (1), and in using finite differences, equation (3), both tend to decrease the numerical value of R. If a value of R slightly less numerically than unity is used in equation (8) then the computed value of $\overline{\varepsilon^2}$ is decreased. Thus the value of $\overline{\varepsilon^2}$ and hence of σ_ε corresponding to $R = -1$ should be regarded as an upper limit to the true value.

Application.—Measurements of the geostrophic wind were made at four points over England and the North Sea, namely at A and B on the Greenwich meridian at 55½°N. and 51½°N. respectively, and at C and D on latitude 53½°N. and longitudes 3½°W. and 3½°E. respectively. The half-distance between each pair of points is 120 n. miles. Working charts of 500-mb. contours were used for December 1954, January and February 1955 at 0300 G.M.T. and 1500 G.M.T. each day, a total of 180 charts. In order to ensure that the measurements were unbiased by plotted reports of observed winds, tracings of the original contours were used. The results of the computations based on these measurements are given in Table I.

For the three months taken together, the computed correlation coefficiens (R') between the measured geostrophic gradients is $-0\cdot85$. Confidence limitt for R' at the 5 per cent. level of significance were computed by means of Fisher's z' transformation[2]. The root-mean-square vector error (σ_ε) of the estimations of geostrophic wind is found to be 5 kt. for an average wind speed of 39 kt. This result may be compared with one obtained by Murray[3] by quite a different method. Two analysts made measurements of the geostrophic wind independently on the same series of charts and the differences in the results indicated a value of σ_ε of about 6 kt. Both the number, N, of pairs of measurements and the mean wind speed were almost identical with those of the present investigation. The "standard error" of either value of σ_ε, given by $\sigma_\varepsilon/\sqrt{(2N)}$, is 0·3 kt. The good agreement between the present estimate and Murray's suggests that no appreciable correction is required on account of the approximations used, for it has already been remarked that any correction could only decrease the value of σ_ε and so increase the difference from Murray's figure. An application of "Student's" t test shows that the two values of σ_ε are not significantly different. Hence if the two methods are given equal weight, the best estimate of the standard vector error of estimation of geostrophic wind is 5½ kt. for a mean speed of 40 kt.

It is to be expected that the error should tend broadly to increase with the wind speed. As the mean speed at the four points decreased from 49 kt. in December 1954 to 36 kt. in January 1955 and 29 kt. in February 1955, the value of the error was also determined for each month separately. Although the February figure is the smallest and corresponds with the lighest winds, the figures for the other two months come out equal and the evidence for increase of error with speed cannot be regarded as significant on the data available.

TABLE I—ERRORS OF ESTIMATION OF GEOSTROPHIC WIND

	December 1954	January 1955	February 1955	3 months
Number of charts, N	62	62	56	180
Correlation coefficient, R'	−0·86	−0·80	−0·89	−0·85
5 per cent. limits of R'	−0·92, −0·78	−0·87, −0·68	−0·94, −0·82	−0·89, −0·81
		knots		
Measure of wind differences, a	14·3	11·8	12·7	13·3
Standard vector error of estimation, σ_ε	5·3	5·3	4·2	5·1
Standard error of σ_ε	0·5	0·5	0·4	0·3
Mean scalar speed	49	36	29	39

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OFFICIAL PUBLICATION

The following publication has recently been issued:—

GEOPHYSICAL MEMOIRS

No. 95.—*Wind and temperature to* 50 *Km. over England. Anomalous sound-propagation experiments, 1944–45.* By R. J. Murgatroyd, B.Sc. (Eng.).

This report describes the results of experiments made in England during 1944–45, when recordings of sound received by anomalous paths from large explosions were utilized in an attempt to obtain data on wind and temperature at great heights. The methods used and their limitations are outlined and the results of the calculations presented. The principal results are:—

(i) In England the wind in winter at heights of 30–45 Km. is usually between SW. and NW. with speeds of 40–80 m./sec. In summer the directions are between NE. and SE. and the speeds less than 20 m./sec.

(ii) The temperature between 35 and 50 Km. appears to increase to values approaching surface values. This increase is not as great in winter as in summer, and a 20–40°C. variation of temperature between summer and winter is likely at these levels.

LETTER TO THE EDITOR

Paraselenae

On Sunday, May 20, 1956 at 2354 G.M.T. paraselenae were observed from Acklington, Northumberland. Both mock moons were white in colour and situated at approximately 22° horizontally on either side of the moon, but there was no halo. Visibility was 10 miles. There was almost complete cover of thin cirrostratus with about 5 oktas of stratocumulus at 3,500 ft.

This phenomenon occurred on the same day as a period of solar halos and parhelia, lasting from 0827 G.M.T. to 0954 G.M.T. Parhelia, similar to those shown in the photograph on page 136 of the *Meteorological Magazine* for May 1956, were observed from 0627 G.M.T. to 0754 G.M.T. During this period, visibility was over 15 miles and the cloud increased from 4 to 7 oktas of thin cirrus.

Acklington, Morpeth, Northumberland, May 21, 1956.

W. J. STEWART

[The absence of a halo indicates the refracting edges of the ice crystals were predominantly vertical.—Ed., M.M.]

NOTES AND NEWS

Itinerant Meteorological Exhibition

The first display of the Itinerant Meteorological Exhibition for Museums was opened by Sir Graham Sutton at Leicester Museums and Art Gallery on August 3, 1956 in the presence of the Lord Mayor of Leicester and an invited audience.

The exhibition at Leicester (see photographs in centre of this Magazine) was the first of a series which has been planned to visit museums in the north Midlands and later, museums in other areas. The displays will remain open to the public for periods varying from four to eight weeks at each town or city before travelling on to the next. This should provide opportunity for townsmen and citizens to acquaint themselves at their leisure with its contents i.e. everyday instruments and equipment for observational work, diagrams and photographs describing observations, a complete set of working charts for one day from the Central Forecasting Office, a series of large panels showing how the work of the Meteorological Office enters into the daily life of the community and, for those Museums with the proper outdoor space, a working instrument enclosure.

The idea of this travelling exhibition originated partly with the Centenary Forecast Display of 1955 which visited the six largest cities of the United Kingdom and partly with a meteorological display which was concurrently exhibited in Derby Museum. The popularity of the exhibit at Derby, arousing as it did the interest of other museums, suggested a way of reaching other areas. So the Meteorological Office in conjunction with Air Ministry Information Division built a new display, specially suited to Museums, using much of the existing material from the two previous exhibitions. With the assistance of the Keeper in Geology at Leicester Museums and Art Gallery an itinerary was then arranged which has subsequently developed into a tour that so far, will be continuous till July 1957. If the total of 16,091 visitors to the Leicester Museum in three weeks is any guide to the value of this Meteorological Exhibition it should have a useful life.

W. R. HANSON

International cloud atlas

Readers will be pleased to learn that the new "International cloud atlas" is now being published by the World Meteorological Organization. The atlas will be available in the following volumes:

	Title	Expected date of issue
(1)	INTERNATIONAL CLOUD ATLAS—COMPLETE (in two volumes)	
	Volume I } these two volumes are sold separately	Autumn 1956
	Volume II }	August 1956
(2)	INTERNATIONAL CLOUD ATLAS—ABRIDGED ATLAS	Autumn 1956
(3)	INTERNATIONAL CLOUD ATLAS—ALBUM	End of 1956
(4)	INTERNATIONAL CLOUD ATLAS—BARE PLATES OF VOLUME II	August 1956
(5)	INTERNATIONAL CLOUD ATLAS—BARE PLATES OF THE ABRIDGED ATLAS	Autumn 1956
(6)	INTERNATIONAL CLOUD ATLAS—BARE PLATES OF THE ALBUM	End of 1956

Volume I of the "International cloud atlas" contains a detailed descriptive study of clouds and "meteors" and Volume II contains 224 plates, 103 of which are in colour, to illustrate the text of Volume I. The "Abridged atlas" contains 72 plates and the "Album", which is specially intended for the use of pilots and airborne observers, 32 plates.

A detailed prospectus of the atlas can be obtained on application to the World Meteorological Organization, Campagne Rigot, Avenue de la Paix, Geneva, Switzerland.

REVIEW

Weather analysis and forecasting. 2nd edn. Volume I. Motion and motion systems. By S. Petterssen. 9¼ in. × 6½ in., xx + 428, *Illus.* McGraw-Hill Book Co. Inc., New York, Toronto and London, 1956. Price 64*s.*

The first edition of "Weather analysis and forecasting" described the state of forecasting knowledge at the outbreak of the Second World War. In its preface we read that "recent advances . . . have led to actual application of the principles of physics and mathematics in the forecasting of weather". That statement, more than the date of publication, reminds us of the progress that has been made since 1940. The author, anticipating the question of why so many years separate the second edition from the first, writes in his new preface that "progress in meteorological research has been so rapid that it has not been possible to provide a reasonably stable revision at an earlier date". While Dr. Petterssen considers past achievements to be adequately consolidated he gives no indication that he recognizes any flattening in the curve of progress. On both counts a textbook of this kind fulfils a major requirement, and meteorologists will welcome this most lucid and readable manual.

At the time of writing only the first of the two volumes of "Weather analysis and forecasting" has been published, but the other is expected shortly. This first volume is about as long as the complete first edition of the book. Its subtitle is "Motion and motion systems" and it deals with the dynamics of atmospheric processes. Volume II, called "Weather and weather systems" places the emphasis on thermodynamics and will include weather features associated with smaller-scale atmospheric movements.

By way of introduction, Dr. Petterssen makes an interesting comment on the role of the forecaster when machine-made forecasts are in regular use. He makes the point that the computed prognosis must fall short by an "unexplained residual" because it works on idealized models. It is for the forecaster to remedy this weakness, using theoretical knowledge and the insight that comes from experience, both of which must be maintained at a high level. This function is additional to the essential daily task of translating into a forecast the output of the machine. Dr. Petterssen has set out to provide a text for the training that is required, and in doing so he aims to reduce the gap between synoptic and dynamic meteorology.

The first half of the first edition dealt largely with air-mass features. In so far as the two editions can be related, the second begins half-way through the first. An opening chapter on basic equations is followed by kinematics of quasi-horizontal motion. Chapter 3, kinematics of the pressure field, is based (like most of Chapter IX in the first edition) on the author's papers of 1933 on the movement of surface isobaric systems. A section is included extending the method to forecasting the intensification of pressure centres, but it concludes with a warning that this approach, being based on extrapolation of the instantaneous pressure and tendency fields is not recommended except for changes over short periods.

Chapter 5 remedies a curious omission from the earlier edition by providing a brief account of the influence of surface friction. This perhaps foreshadows the consideration of frictional effects not mainly as by-products of the existing flow but as factors imposing calculable modifications on the circulation.

It is something of a surprise to discover that Chapter 6, on the vertical structure of wind systems, had no counterpart in the earlier edition, until one recalls that only 15 years ago there was no network of upper air stations, and the existence of jet streams was a matter for little more than speculation, supported mainly by the mean distribution of upper air temperature. The next four chapters, too, are new, for they deal with vorticity applications and long-wave theory from the development of the basic Rossby formula up to the present time. Excellent examples are given showing the extent to which these and other methods can be used to estimate the movement of pressure systems.

Some similarity to the first edition appears in Chapters 11–13, which deal with frontogenesis and the structure and behaviour of cyclones and anticyclones. There is, nevertheless, much new material, as is indicated by the fact that 35 of the 41 references at the end of Chapter 13 refer to post-war publications.

Dr. Eliassen has written Chapter 15, on instability theories of cyclone formation. This reviews the work on wave development in an air stream which results from the existence of vertical and horizontal gradients of wind speed.

Next, the development of cyclones (with passing reference to the difficulty of assessing anticyclonic development) is dealt with on Sutcliffe lines. Synoptic examples include that of the hurricane "Hazel" of October 1954, whose re-development and acceleration when over the eastern United States appear to have been forecast with marked success.

Dr. Eliassen contributes a further chapter in introducing the subject of numerical forecasting and includes a detailed account of the computation process for the barotropic model. Dr. Petterssen follows this with a description of the graphical method of Fjörtoft, as well as that of Estoque, which, with substantial simplifications, treats graphically both the 500-mb. and the 1000–500-mb. thickness patterns. The concluding remarks of Dr. Petterssen, written after the publication of Fjörtoft's extension of his theory to the baroclinic model, are of particular interest at a time when the function of objective methods is a matter for speculation among forecasters. The author writes as follows: "It is foreseeable, therefore, that graphical integrations based on the more complete treatment by Fjörtoft will become a mainstay in the forecasting of motion systems. While none of the models proposed for numerical or graphical integration has been tested extensively, it is foreseeable that no single model will be capable of giving satisfactory results in all cases, and it is likely that a family of models will be needed. In each case the choice, based upon experience, must be made."

The arrangement of the book is clear-cut, and the cross-references in the text are particularly helpful in showing the basis for statements which depend on what has gone before. The diagrams and general presentation are of the high standard one is accustomed to in McGraw-Hill publications. The reader who hesitates over the cost should bear in mind that after reading the first volume he is certain to want to possess the second.

C. J. BOYDEN

OBITUARY

Mr. Thomas Lawrence Arthur Waite.—It is with deep regret that we learn of the sudden death on July 22, of Mr. Waite at the age of 39.

Mr. Waite joined the Office in January 1940 as a Meteorological Assistant, but he was reappointed a Temporary Forecaster II in April 1940. After a course at the Training School he was posted to an aviation outstation and, apart for a period in 1947 at radio-sonde units and in 1949–50 in an ocean weather ship, he has been mainly concerned with forecasting for the Royal Air Force. At the time of his death he was serving at Watnall.

He is survived by a widow and a son and daughter to whom the sympathy of all who knew him in the Office is extended.

METEOROLOGICAL OFFICE NEWS

Retirements.—*Mr. D. F. Bowering, M.B.E.*, Senior Experimental Officer, retired on August 31, 1956. He joined the Office as a Staff Assistant in January 1920 after service in the Royal Naval Air Service and the Meteorological Section, Royal Air Force during the First World War. Apart from a period between 1927 and 1931 in the Forecast Division at Headquarters, the whole of his 37 years' service has been spent at aviation outstations, including a tour of duty in Iraq. Since 1947, until his retirement, he has been the officer-in-charge of the Meteorological Office at Croydon Airport. He was appointed a Member of the Order of the British Empire in the New Year Honours List of 1954.

At a ceremony in the Conference Room in Victory House on August 31, Mr. W. H. Bigg made a presentation to Mr. Bowering on behalf of his colleagues.

Mr. B. A. Copping, Experimental Officer, retired on August 31, 1956. He joined the Office in September 1920 as a Technical Assistant and during his service has served both at Headquarters and outstations. From 1946 until his retirement he has served at Thorney Island except for periods of temporary duty elsewhere.

Academic successes.—Information has reached us that the following members of the staff have been successful in recent examinations; we offer them our congratulations.

B.Sc. (General): S. G. Cornford (Second Class Honours).

City and Guilds Intermediate Certificate in Telecommunications Engineering: R. G. Flavell.

General Certificate of Education (Advanced Level): P. F. Abbott, J. M. Bayliss, Miss C. Bulpin, V. H. Farr, D. Gibbons, M. D. Gladstone, J. C. Howe, B. F. James, P. N. Mann, P. D. J. Rae, Miss M. Redding, Miss M. V. Roberts, L. P. Steele, E. H. Tucker, G. W. Tugwell, D. G. Ward and V. A. Winslow.

They all passed in one or more subjects.

Visit to Bracknell.—On the application of the Director, official permission was given for two visits by coach of representative members of the Headquarters staff and their wives to Bracknell, where the new Headquarters of the Office is to be built, to see the town and the types of houses and plots of land available. In a very wet summer both parties (one of non-industrial staff from Victory House, Harrow, Dunstable and Stanmore on August 20, and one of industrial staff from Harrow on August 23) were fortunate to have a fine afternoon for the trip. The Housing Manageress of the Bracknell Development Corporation personally conducted each party round the town and after tea, kindly provided by the Corporation, answered various housing questions.

WEATHER OF AUGUST 1956

As in July 1956 the Iceland "low" was missing from the pattern of mean pressures during August. The North Atlantic depressions travelled east on tracks passing across the British Isles and through the Baltic towards northern Russia. Pressure was high (1013–1015 mb.) over Greenland and Iceland (greatest anomaly +5 mb. near Reykjavik) and above normal in longitudes 20°–40°W. over the Atlantic. Pressures were below normal all over Europe, anomalies exceeding −5 mb. over a wide area of the Baltic, southern Sweden and Finland and locally in Britain and northern Italy. Over North America pressures were near normal, though depressions passed farther south than usual for August across Canada and there were pressure anomalies of +2 mb. to +4 mb. in the Canadian Archipelago.

There were no noteworthy anomalies of temperature over North America (generally ±0° to 1°C.), but temperatures appear to have been below normal over the Atlantic north of 50°N. and over all Europe north of a line from Gibraltar to the Alps (greatest anomaly −3°C. over the north European plain). Most of the Mediterranean, south-east Europe and Turkey were near normal or very slightly above. Temperatures were 1° to 2°C. below normal at nearly all Arctic stations.

There was above normal rainfall over most of Europe from the Alps northward, some places reporting the wettest August for up to 200 yr. (e.g. Geneva). Over twice the normal rainfall occurred in places as far apart as Bordeaux, Brest, Salzburg, Poland and Helsinki; whilst in Spain the totals ranged from 330 per cent. of normal on the north coast to much higher percentages in the usually dry southern districts (especially in the south-west). There was another belt of excess rainfall, though with smaller anomalies, stretching right across North America in 45°–50°N. south of the Canadian depressions. Rainfall was generally somewhat below normal over southern United States, also in Norway and in south-east Europe. Less than a third of the normal rainfall fell in parts of Iceland and Greenland and locally in south-east Spain.

In the British Isles fronts and depressions moved across the country in succession throughout the month and there was a marked absence of anticyclonic activity.

On the 1st moderate to heavy rain spread from the south-west across most of the country and wind reached gale force in the English Channel as a deepening depression crossed northern England. In the polar air behind the depression, which persisted for about four days, showers and scattered thunderstorms occurred in most districts and were particularly heavy and frequent on the 5th and 6th. The 6th was the coldest August Bank Holiday at Kew for 30 yr., and during an unusually heavy hailstorm at Tunbridge Wells on that day, hailstones accumulated to a depth of 4 ft. in parts of the town during the course of an hour. The next few days were dry and sunny as the Azores anticyclone spread its influence north-eastwards; temperatures exceeded 70°F. in many places in southern England reaching 77°F. at Southend and 75°F. at Herne Bay. The warmer weather was short-lived, however, for a depression off Greenland deepened considerably as it moved towards Iceland and brought a return of dull cool weather to the British Isles on the 10th with widespread rain and occasional thunder. A succession of depressions from the Atlantic maintained generally unsettled weather until the 18th. A particularly vigorous one, which moved north-east across Northern Ireland and Scotland on the 13th, was accompanied by winds at gale force in the north and heavy rain in many places; nearly 2 in. of rain fell at Tiree during the night of the 12th–13th. A weak ridge of high pressure on the 14th brought a temporary return of sunny weather except in eastern Scotland, but temperatures, already below normal, became cooler still on the 16th as a trough, accompanied by widespread rain, moved eastward across northern districts. There was heavy rain again on the 18th (1·67 in. fell at Valley, Anglesey, from 0900 to 2100 G.M.T.) and gales occurred in the English Channel, associated with the progress of a further disturbance across the country. During the next two or three days pressure was lowest in the region of Scandinavia and winds over the country became generally north-westerly with frequent showers, occasional thunderstorms and some sunny periods, but on the 21st and 22nd a depression from the central Atlantic brought dull weather with periods of rain to southern England. The depression subsequently moved into northern France. Further disturbances gave two days of rain to most of the country although there were long sunny periods on the south coast on the 23rd, but on the 25th an influx of deep cold air from the north brought frequent thunderstorms to nearly all districts and for several days temperatures fell well below the normal. A secondary to the Scandinavian depression brought another two days of disastrous rain to north Wales and north-east England; there was a landslide down the Great Orme, Llandudno, and the worst floods for 40 yr. in the Colwyn Bay district according to local calculations, but perhaps the worst flooding occurred in the north of England and the Border Country where hundreds of acres of farmland were under water, road and rail communications were cut and houses and farms had to be evacuated. A northerly air stream developed over the country on the 31st and there were long sunny periods in the south.

The outstanding feature of the month was the high rainfall and this was accompanied by maximum temperatures which were 4°–6°F. below the average. Most places in the north of England had more than twice their normal amount of rain and in the north-west during the week 12th–18th there was more than four times the average amount. Bidston Observatory reported its highest total rainfall of any month since records began there in 1869. A "very rare" fall occurred at Arundel Castle, Sussex, on the 20th when 1·78 in. of rain fell in 18 min. Taking England and Wales as a whole it was the wettest August since 1917, and it has been the wettest summer (June, July and August taken together) for 25 yr.

In most areas the harvest was seriously delayed by the wet weather and was two or three weeks late. Incessant rain and heavy flooding caused a great deal of damage to corn land especially in the north, and hay lay rotting in the fields after it had been cut.

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 ...	77	31	−3·9	179	+6	89
Scotland	72	30	−3·8	151	+1	92
Northern Ireland ...	69	34	−3·5	167	+2	94

RAINFALL OF AUGUST 1956

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	5·05	229	*Glam.*	Cardiff, Penylan ...	5·49	130
Kent	Dover	2·41	104	*Pemb.*	Tenby	4·02	106
„	Edenbridge, Falconhurst	2·86	109	*Radnor*	Tyrmynydd	7·64	142
Sussex	Compton, Compton Ho.	6·76	219	*Mont.*	Lake Vyrnwy	8·14	153
„	Worthing, Beach Ho. Pk.	2·56	113	*Mer.*	Blaenau Festiniog ...	17·90	160
Hants.	St. Catherine's L'thouse	4·73	246	„	Aberdovey	6·63	149
„	Southampton (East Pk.)	3·50	134	*Carn.*	Llandudno	8·07	286
„	South Farnborough ...	2·72	123	*Angl.*	Llanerchymedd ...	8·59	237
Herts.	Harpenden, Rothamsted	5·02	198	*I. Man*	Douglas, Borough Cem.	7·96	209
Bucks.	Slough, Upton	3·60	166	*Wigtown*	Newton Stewart ...	6·83	164
Oxford	Oxford, Radcliffe ...	4·52	198	*Dumf.*	Dumfries, Crichton R.I.	7·80	193
N'hants.	Wellingboro' Swanspool	4·47	188	„	Eskdalemuir Obsy. ...	8·88	172
Essex	Southend, W. W. ...	3·16	172	*Roxb.*	Crailing...	8·34	283
Suffolk	Felixstowe	3·88	222	*Peebles*	Stobo Castle	6·17	173
„	Lowestoft Sec. School ...	3·86	175	*Berwick*	Marchmont House ...	10·86	328
„	Bury St. Ed., Westley H.	4·63	178	*E. Loth.*	North Berwick Gas Wks.	6·17	198
Norfolk	Sandringham Ho. Gdns.	5·45	202	*Midl'n.*	Edinburgh, Blackf'd. H.	6·79	212
Wilts.	Aldbourne	4·02	145	*Lanark*	Hamilton W. W., T'nhill	5·16	151
Dorset	Creech Grange... ...	3·52	123	*Ayr*	Prestwick	6·27	197
„	Beaminster, East St. ...	5·93	190	„	Glen Afton, Ayr San. ...	8·26	153
Devon	Teignmouth, Den Gdns.	3·03	134	*Renfrew*	Greenock, Prospect Hill	5·40	105
„	Ilfracombe	5·07	141	*Bute*	Rothesay, Ardencraig ...	5·91	121
„	Princetown	7·36	108	*Argyll*	Morven, Drimnin ...	6·18	117
Cornwall	Bude, School House ...	...	...	„	Poltalloch	6·10	124
„	Penzance	3·18	100	„	Inveraray Castle ...	6·43	98
„	St. Austell	4·43	123	„	Islay, Eallabus	4·51	103
„	Scilly, Tresco Abbey ...	2·85	104	„	Tiree	7·59	181
Somerset	Taunton	2·04	86	*Kinross*	Loch Leven Sluice ...	6·34	166
Glos.	Cirencester	4·76	153	*Fife*	Leuchars Airfield ...	5·46	177
Salop	Church Stretton ...	5·17	155	*Perth*	Loch Dhu	8·51	126
„	Shrewsbury, Monkmore	4·74	171	„	Crieff, Strathearn Hyd.	6·73	160
Worcs.	Malvern, Free Library...	3·93	136	„	Pitlochry, Fincastle ...	5·88	166
Warwick	Birmingham, Edgbaston	4·98	167	*Angus*	Montrose, Sunnyside ...	4·80	172
Leics.	Thornton Reservoir ...	4·21	150	*Aberd.*	Braemar	6·64	195
Lincs.	Boston, Skirbeck ...	3·89	163	„	Dyce, Craibstone ...	3·31	109
„	Skegness, Marine Gdns.	3·14	129	„	New Deer School House	3·25	110
Notts.	Mansfield, Carr Bank ...	6·66	239	*Moray*	Gordon Castle	3·64	115
Derby	Buxton, Terrace Slopes	10·67	244	*Nairn*	Nairn, Achareidh ...	4·40	181
Ches.	Bidston Observatory ...	8·71	283	*Inverness*	Loch Ness, Garthbeg ...	7·25	223
„	Manchester, Ringway...	7·93	241	„	Loch Hourn, Kinl'hourn	7·24	89
Lancs.	Stonyhurst College ...	11·57	229	„	Fort William, Teviot ...	4·05	65
„	Squires Gate	9·41	275	„	Skye, Broadford ...	6·11	95
Yorks.	Wakefield, Clarence Pk.	5·32	205	„	Skye, Duntulm ...	4·55	102
„	Hull, Pearson Park ...	5·21	179	*R. & C.*	Tain, Mayfield... ...	4·31	160
„	Felixkirk, Mt. St. John...	8·19	288	„	Inverbroom, Glackour...	7·90	189
„	York Museum	6·15	244	„	Achnashellach	6·76	107
„	Scarborough	4·80	173	*Suth.*	Lochinver, Bank Ho. ...	4·48	134
„	Middlesbrough... ...	6·62	242	*Caith.*	Wick Airfield	2·76	100
„	Baldersdale, Hury Res.	7·66	232	*Shetland*	Lerwick Observatory ...	2·37	79
Norl'd.	Newcastle, Leazes Pk....	7·30	259	*Ferm.*	Crom Castle	6·76	163
„	Bellingham, High Green	7·86	233	*Armagh*	Armagh Observatory ...	6·28	173
„	Lilburn Tower Gdns. ...	9·44	335	*Down*	Seaforde	7·90	211
Cumb.	Geltsdale	11·40	277	*Antrim*	Aldergrove Airfield ...	6·32	176
„	Keswick, High Hill ...	10·65	204	„	Ballymena, Harryville...	6·53	153
„	Ravenglass, The Grove	9·21	202	*L'derry*	Garvagh, Moneydig ...	6·54	167
Mon.	A'gavenny, Plâs Derwen	3·66	111	„	Londonderry, Creggan	5·91	128
Glam.	Ystalyfera, Wern House	8·38	136	*Tyrone*	Omagh, Edenfel ...	6·94	163

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THE METEOROLOGICAL MAGAZINE

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WATERSPOUTS OFF THE STRAITS OF GIBRALTAR

By G. W. HURST, B.Sc.

Whilst flying about 60 miles west of the Straits of Gibraltar on November 21, 1955, Wg-Cmdr J. D. E. Hughes and Flt-Lt A. R. Jackson of 224 Squadron noted a number of waterspouts which appeared to lie in a line, and were up to two miles apart; at least four were seen. It is felt that a record of this occasion is worth while, both because it occurred close in time and place to an upper air sounding and to surface observations, and because a number of quite good photographs were taken; the best of these are reproduced.

The photograph in the centre of this magazine was taken at 1150 G.M.T. and shows a spout from the surface to about 500 ft. into a cumulonimbus from a distance of about half a mile. The direction of view is towards the south-east, and the slope of the spout from west (at the base) to east. Movement is with the winds towards the north-west. Interesting features of this print are the shoulders surrounding the spout at the cloud base, the slight curvature of the column, the area of disturbance on the sea surface (which shows clearly a movement on the surface towards the camera, and to the right) and the dark central core of the main-spout column; the lightness of the outer core, lit directly by the sun, and the darkness of the centre show strongly the hollow nature of the column. The aircraft was at 300 ft., and the dimensions of the spout are 500 ft. high, 30 ft. in diameter, with a central core of about 5 ft. The surface water is disturbed over an area some 50–100 ft. across. The wind at sea level is obviously not more than moderate, as the sea is little more than gently rippled. There is an active shower to the east.

The upper photograph facing p. 337 was taken a few minutes later, and shows a second spout from rather closer and nearer the sea surface. Very similar characteristics to the first are evident, and again the shoulders are clearly visible. The lighting is not so good as in the first case, and the indirect illumination shows the central core as lighter than the main body of the column. The line running across the foreground is a real phenomenon, and was noted by the crew of the aircraft. It may have been an oil streak, or less likely the wake of a ship, or the track of an earlier spout.

The lower photograph facing p. 337 is a close-up from about 150 yd. of the sea surface in spout conditions; the aircraft was at about 100–150 ft. when it was taken. In this case there was no actual spout above the sea disturbance; it could not be kept in view long enough to decide whether or not it was the beginning, or less probably, the termination of a spout. The direction of movement is clearly from right to left with the wake to the right (the view is now to the west or north-west), the spray from the sea disturbance reaches a height of fully 50 ft., and judging by its appearance the sense of the rotation is anticyclonic. This photograph brings out vividly the very localized nature of these disturbances, as the sea immediately adjacent shows no signs of agitation, and appears gently rippled, as in the other two prints. The writer has seen very similar effects with much rougher sea to the lee of the Rock of Gibraltar in strong west-south-westerly winds; in these cases too, no spout was seen, though they are not uncommon in such circumstances.

The meteorological situation on November 21 was typically that for waterspout formation west of the Straits, and a portion of the 1200-G.M.T. chart surrounding the area is reproduced as Fig. 1. There was a well developed levanter blowing to the east of Gibraltar, and the northern Straits and Cadiz Bay were in this régime. Further south there was a ridge, and the flow to the south-west of the Straits area was mainly southerly. The 1500 G.M.T. radio-sonde ascent for Gibraltar, shown in Fig. 2, was most unstable with practically a dry adiabatic lapse rate from the surface to over 1,700 ft., even with a surface temperature as low as 59°F. The air was very moist from the surface up to the 10,000-ft. level, and the day was one of exceptionally heavy rain at Gibraltar itself, with measurements for 24 hr. varying from 4·02 in. at North Front to over 7 in. at different parts of the Rock. It happened that

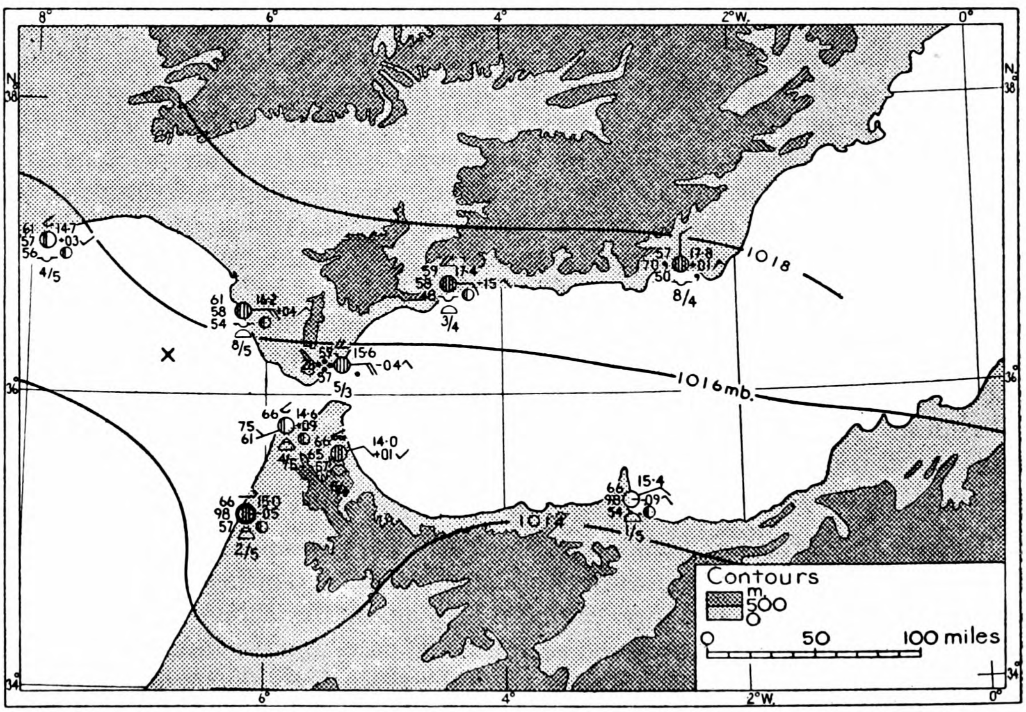

FIG. 1—SYNOPTIC CHART 1200 G.M.T. NOVEMBER 21, 1955 SHOWING VICINITY OF WATER SPOUTS (X)

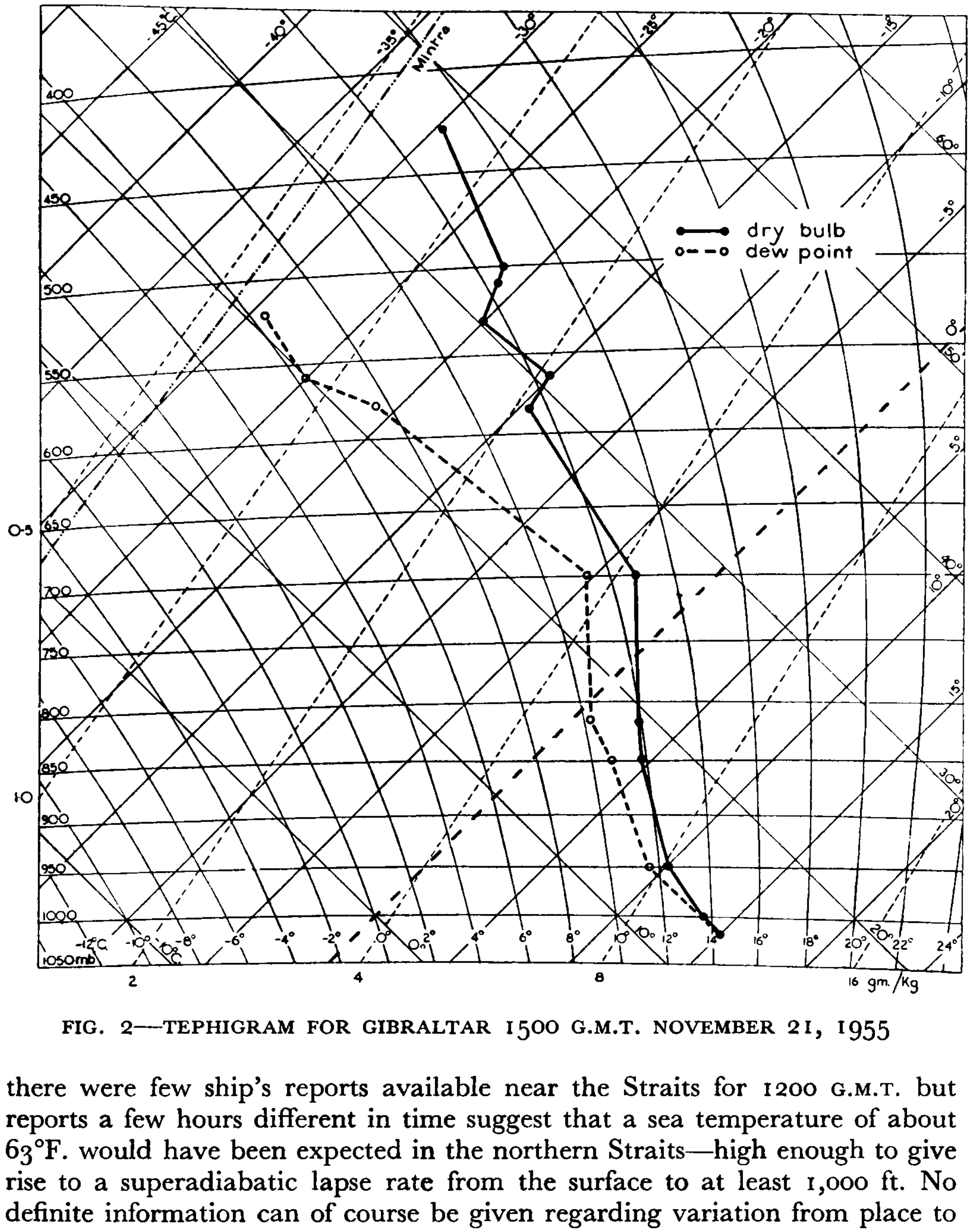

FIG. 2—TEPHIGRAM FOR GIBRALTAR 1500 G.M.T. NOVEMBER 21, 1955

there were few ship's reports available near the Straits for 1200 G.M.T. but reports a few hours different in time suggest that a sea temperature of about 63°F. would have been expected in the northern Straits—high enough to give rise to a superadiabatic lapse rate from the surface to at least 1,000 ft. No definite information can of course be given regarding variation from place to place of sea or air temperatures as discussed by Gordon[1], but the conditions were obviously most favourable for such differences to exist, with easterlies to the north of the spout area, and southerlies to the south. The direction of slope of the spout would be consistent with a decrease in the easterlies with height; the Gibraltar winds cannot be broken down into detail at heights appreciably less than 3,000 ft. above the surface, but the winds at 0900 G.M.T. of 110° 22 kt. at the surface, 110° 25 kt. at 3,000 ft., and 130° 18 kt. at 5,000 ft. suggest that allowing for the surface frictional layer, the easterly was strongest near the surface.

It is interesting to compare these photographs with the close-up of a water spout discussed by Johnson[2]. Most of the characteristics which he deduced for the spouts in the eastern Mediterranean applied in this case, as far as examination is possible with differing distances from the spouts and differing view-points, but two points of difference are that the hollow core does not appear to extend to the lower diffuse region of broader diameter, seen faintly in the first photograph up to about a quarter of the spout height, and the shoulder seen in the first two photographs were not features of the earlier spouts. It is thought probable that the shoulder is in fact a hollow cone, the section of which is seen in silhouette. This may well have formed by the vortex action at the point of exit of the spout from the cloud dragging down part of the cloud in its vicinity along the line. The shoulder is of restricted length with the dissipation in the drier air below cloud.

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PROLONGED HEAVY RAIN AT GIBRALTAR, NOVEMBER 20–26, 1955

By G. W. HURST, B.Sc.

Introduction.—During the period of a week starting at 0900 G.M.T. November 20, the total rainfall measured at North Front, Gibraltar, was 14·97 in., which is the highest fall recorded in one week for at least this century; earlier readings for a seven-day period were 15·17 in. in December 1861, and 17·17 in. in November 1858, both of which were taken west of the Rock in the town area. The average rainfall for November (the wettest month) is 6·28 in. Considerable damage to property and telephone installations due to flooding occurred on the 21st and again in the shorter but very intense fall on the 26th; even more serious damage was reported in Spanish towns near Gibraltar, where bridges were carried away, new roads subsided and houses were demolished. Figures for the daily rain (with the conventional day 0900–0900 G.M.T.) at several stations in the town are given in Table I.

TABLE I—DAILY RAINFALL MEASUREMENTS AT VARIOUS STATIONS IN GIBRALTAR NOVEMBER 20–26, 1955

Date	North Front	Convent Garden	City Hall	Moorish Castle	Green Lodge	Willis Gate
1955				*inches*		
Nov. 20	2·62	4·38	3·59	2·31	2·53	2·48
Nov. 21	4·01	7·02	5·53	5·49	5·89	5·48
Nov. 22	2·21	2·32	2·34	2·53	2·39	2·36
Nov. 23	1·01	1·02	1·00	1·13	1·13	1·13
Nov. 24	0·63	0·68	0·67	0·71	0·75	0·66
Nov. 25	2·18	2·62	2·12	2·20	2·10	2·11
Nov. 26	2·31	2·98	3·00	3·42	3·00	3·22
Total	14·97	21·02	18·25	17·79	17·79	17·44

Of these stations, North Front is the R.A.F. Station a few feet above sea level to the north of the Rock, Convent Garden and City Hall are also low-level stations near each other in the town to the west of the Rock, and Moorish Castle is on the north-west slope of the Rock at a height of 260 ft. The other two stations are 810 ft. and 460 ft. above sea level respectively, both to the north-west of the main body of the Rock. As discussed later there is reason to

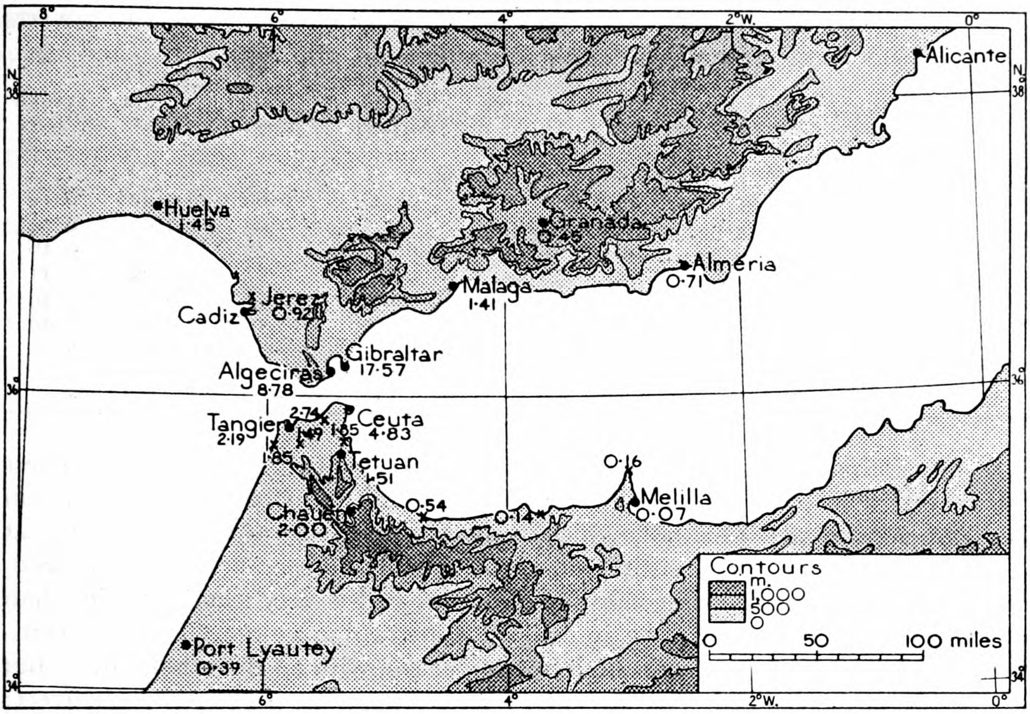

FIG. 1—TOPOGRAPHY AND RAINFALL OF THE GIBRALTAR-STRAITS AREA

Sites indicated by crosses are rainfall stations. Rainfall amounts shown are in inches.

believe that the North-Front site is not always typical of conditions in the town and it is probable that rain at South Bastion, the locale of the earlier records quoted above, would have been of the same order as that at City Hall, and that Gibraltar town suffered appreciably more rain in a week than had fallen in the same period for at least 100 yr. In fact the whole of the North-Front fall of 14·97 in. fell in the exact six-day period 1300 G.M.T. November 20–26.

Rainfall data have been obtained for a number of places in the Straits area, and these are shown as totals for the week 20th–26th on Fig. 1. It is immediately obvious that rainfall at Gibraltar was far in excess of any other recorded rainfall, Algeciras, less than 6 miles to the west across the bay, receiving just under half the Gibraltar fall, and other stations very much less. The increase in rainfall westwards along the narrowing channel is also marked, with maximum falls at Gibraltar and Ceuta, opposite each other across the Straits. Rainfall further west was very low. In Table II daily rainfall totals are given for a number of stations within reach of Gibraltar; the fall for Gibraltar itself is a weighted mean, giving equal weights to data for North Front, City Hall, Moorish Castle and Willis Gate, and half weight to the Convent-Garden and Green-Lodge readings as the data for these two stations are not felt to be quite so representative as those for the other stations.

It is seen that in the vicinity of Gibraltar the very heavy fall of the 21st was reflected clearly at Algeciras and Ceuta, but negligibly so at places even as near as Tangier, Tetuan and Malaga. In fact, throughout the whole week, only on one day, the 24th, was Gibraltar rainfall not far in excess of other regions; even on this day, only Algeciras and Tangier Airport recorded heavier falls.

TABLE II—DAILY RAINFALL MEASUREMENTS AT VARIOUS STATIONS IN THE STRAITS OF GIBRALTAR AREA NOVEMBER 20–26, 1955

Date	Gibraltar	Algeciras	Malaga	Jerez	Tangier Airport	Tangier Town	Ceuta	Tetuan
1955				*inches*				
Nov. 20	2·89	1·97	0·10	...	0·12	0·66	0·32	0·12
Nov. 21	5·39	2·97	0·03	0·09	Tr.	0·03	2·81	0·04
Nov. 22	2·36	0·52	0·09	...	0·19	0·17	0·73	0·16
Nov. 23	1·07	0·63	0·05	...	0·54	0·65	0·22	0·11
Nov. 24	0·68	1·30	0·47	0·23	0·87	0·58	0·47	0·49
Nov. 25	2·19	1·39	0·36	0·48	0·13	0·10	0·24	0·49
Nov. 26	2·99	...	0·31	0·12	...	Tr.	0·04	0·10
Total	17·57	8·78	1·41	0·92	1·85	2·19	4·83	1·51

It is interesting to compare the falls at Gibraltar on the 21st with the heaviest fall recorded in over a century for a conventional 24-hr. period: 7·31 in. on November 7, 1858. This fall, which from a note in the *Gibraltar Chronicle* at the time took place almost entirely at night, must have been very heavy indeed, as it dwarfs the North-Front value of 4·01 in., and is very much heavier than the City-Hall reading of 5·53 in. on an autographic gauge. The Convent-Garden value of 7·02 in. seems high in comparison with all the other values, but the gauge is in a well protected site, and the reading may well have been correct; the gauge itself is standard, and of reasonable exposure, but it is possible that in really heavy rain there might be a slight splash-back from nearby vegetation.

Precipitation during the week is shown graphically in Fig. 2. The fall, very heavy at times, occurred during five periods varying in length from 18 to 31 hr., and in amount from 0·82 to 5·78 in. It will be seen that nearly 40 per cent. of the fall (5·93 in. in fact) fell in a total of 8 hr. The longest break in precipitation was 15 hr. in mid-week, and the heaviest fall in 60 min. was 1·18 in. on the 26th, 1045–1145 G.M.T. Close examination of the anemograph and other

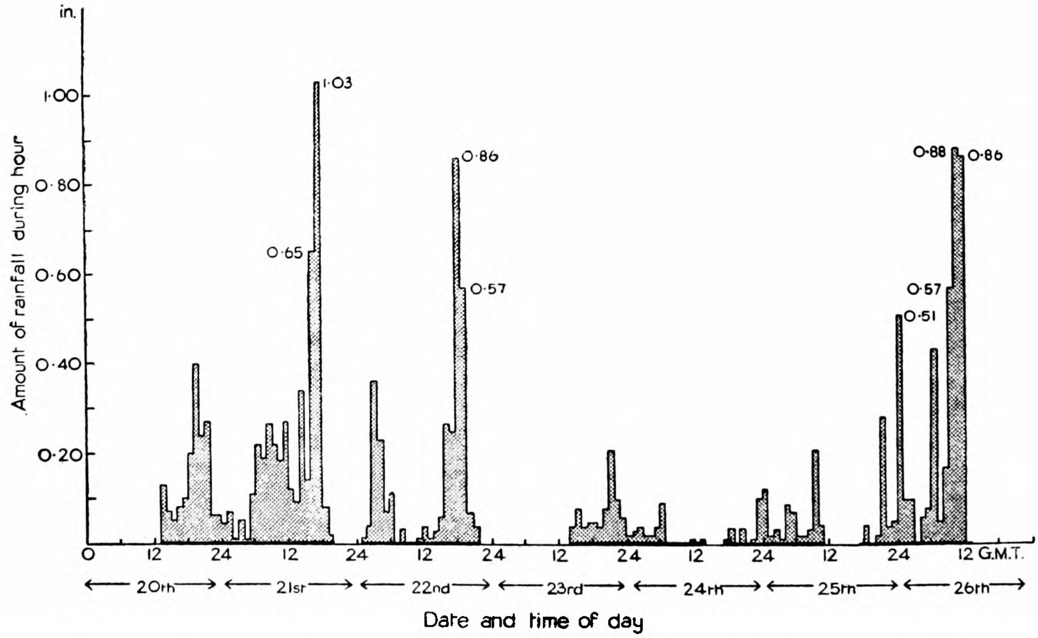

FIG. 2—HOURLY RAINFALL AT NORTH FRONT, GIBRALTAR, NOVEMBER 20–26, 1955

records was made, particularly during the incidence of heavier falls. There was a distinct and sharp veer of wind from 050° to 080° at 1655 G.M.T. on the 21st; no front could be traced on the chart, and there was no apparent modification in the surface air. Similarly at 1815 G.M.T. on the 22nd there was a rather less sharp veer from 050° to 110°, though again with no evidence of a front on the chart. Both these occasions coincided with some of the heaviest rain in the period, and probably represented minor troughs moving across the Straits. Precipitation on the evening of the 20th was accompanied by thunder. A weak warm front was traced through Gibraltar about 2100 G.M.T. on the 23rd; there was a slight veer from 110° to 130° at the time, and the rain, though it continued after 2200 G.M.T., was of decreased intensity. Other temporary anemograph discontinuities were associated with some of the heavier hourly downpours, but the 3-hr. period of really heavy rain on the 26th showed no anemograph discontinuity, nor was thunder heard.

Synoptic situation.—There was little change in the surface chart as it affected Gibraltar in the whole period, 18th–28th, with low pressure to the west or south-west of Gibraltar, and an anticyclone over or to the west of north-west Europe. On the 18th and 19th small amounts of rain fell in the Gibraltar area, but the weather experienced on the 18th could be regarded as typically cloudy with slight rain at times. The significant feature from the 19th to the 20th was the rise in dew-point as the low-level winds backed slightly and the sea track lengthened; temperatures at Gibraltar at 0600 G.M.T. from the 18th to 21st were: 60°–48°F., 63°–52°F., 63°–56°F. and 63°–58°F. The latter temperatures were maintained with minor variations for the remainder of the week. Sea temperatures in the Straits area and immediately to the east were reported in the range 62°–67°F.; probably 62°–64°F. would be representative in the west of the Mediterranean area.

The chart for 1200 G.M.T. on the 21st showed several interesting features, can be regarded as fairly typical of the period, it is seen (Fig. 1, p.322) that there is a good feed of easterlies along the western Mediterranean to the Straits, and that there is a slight tendency to blocking west of the Straits with a southerly component across. There is heavy continuous rain at Gibraltar, with no other station in the vicinity reporting anything other than slight drizzle. The great majority of the rain which fell was non-frontal in character: the only front which passed through was the warm front at 2100 G.M.T. on the 23rd with relatively slight precipitation.

The flow at 500 mb. was dominated on the 16th by a low near Sicily and another near the Azores, resulting in a north-westerly air stream in the Gibraltar area. The Atlantic low naturally became the dominant feature and from the 20th to 24th there was an upper Atlantic feed from the west-south-west to the Straits area; there was slight troughing from Portugal towards French Morocco. The air aloft which thus affected the Straits was of a long sea fetch, and of cold origin with showers at times in the Azores from the 16th to 20th. There was little significant change in the situation until after 26th. Typical upper winds reported from Gibraltar itself in the period are given in Table III.

It is seen from this table that the height of the overrunning south-westerlies varied during the week; variation was between about 4,000 and 8,000 ft. The

TABLE III—UPPER WINDS AT GIBRALTAR, NOVEMBER 18–26, 1955

Height	1500 G.M.T. Nov. 18		0300 G.M.T. Nov. 21		1500 G.M.T. Nov. 23		0300 G.M.T. Nov. 26		1500 G.M.T. Nov. 27	
ft.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.
25,000	250	21	250	23	240	66	270	20	280	17
18,000	240	15	230	18	230	61	240	11	270	13
10,000	200	9	220	8	240	39	220	15	190	8
5,000	100	22	190	8	200	21	180	13	100	16
3,000	100	25	110	25	120	14	130	16	100	22
Surface	100	22	090	21	080	12	060	10	100	22

only important change which took place was the temporary increase in mid-week in the strength of the south-westerlies at 10,000 ft. and above, with the corresponding fairly strong vertical wind shear.

Study of the upper air ascents for Gibraltar, Madeira and Port Lyautey showed varying conditions during the period. The Gibraltar ascent on the 18th was unstable above 700 mb., but was very dry. By the 19th, the south-westerlies above 5,000 ft. were very much moister, and scattered showers might be expected. There were in fact outbreaks of slight rain at Gibraltar throughout the day. By the 20th however, the ascent was completely unstable for surface temperatures 63°–58°F., and with very moist air to 400 mb., heavy precipitation would be expected. The tephigram on the 21st was even more unstable, but from the 22nd to the 24th, the conditions were far less unstable, and on the 24th, 800 mb. was about the limit of convection. The ascent on the afternoon of the 25th indicated an inversion at 930 mb., with instability from 800 to 400 mb. The ascent in the afternoon of the 25th was much more stable, and rain had virtually died out by then. Port Lyautey reflected a similar picture, increasing humidity and instability from the 17th to 19th, with, on the 20th, instability from 860 to 300 mb.; a thundery situation. Again during mid-week, drier air had come in above 900 mb., with less instability, but the early morning ascent on the 26th suggested instability from 950 to 250 mb. Madeira was similar, with a cooling of 10°F. or more in two days from the 18th to 20th in the 7,000–20,000 ft. zone.

Mechanism of fall.—Gibraltar is, fortunately for the water engineers, uniquely placed in that a combination of events will provide rainfall of tropical intensity and persistence, although places only a few miles distant may be clear. It happened on several occasions during the almost sunless period at Gibraltar of the 20th to 26th that skies at Tangier were broken or almost clear, and aircraft flying between the two places on more than one occasion reported a complete break-up of cloud near Tarifa, about 10 miles south-west of Algeciras. The rainfall can almost be regarded as monsoon both in its origin and in its intensity.

Such a combination probably arises on many occasions each decade, though its persistence on this occasion was very unusual. The fundamental requirements for such heavy rain in the Gibraltar neighbourhood are:

(i) warm moist easterly wind to a few thousand feet with a fairly long Mediterranean fetch

(ii) overrunning moist unstable south-westerly wind.

Both these requirements were met in the period 20th–26th, the former continuously, and the latter from the 20th to the 22nd, and on the 26th; on these occasions air was unstable to great heights.

The peculiar geographical situation of Gibraltar and district is shown on the map in Fig. 1. It will be seen that from Almeria to east of Melilla there is a chain of hills almost unbroken to the Gibraltar Straits to a height of 500 m., and without important gaps to a height of 1,000 m. At the former level the channel therefore narrows from 140 miles near Almeria to about 40 miles in the west; there is similar narrowing at 1,000 m. from 160 to about 70 miles. Clearly then with easterly winds, a considerable degree of convergence is being imposed upon the air in its passage of 170 miles from Almeria to Gibraltar. This convergence will express itself both in greater wind speeds in the Straits area, and also in forced ascents. It is not easy to assess accurately the increase in wind speed, as North Front is very open indeed to winds from the east, whereas observations from really well exposed places are not frequent on the south-east Spanish coast. Comparison of the Malaga and Gibraltar wind ascents for the only two occasions the former were received are given in Table IV.

TABLE IV—COMPARISON OF UPPER WINDS AT MALAGA AND GIBRALTAR

Height	1500 G.M.T. Nov. 18, 1955 Malaga		Gibraltar		1500 G.M.T. Nov. 19, 1955 Malaga		Gibraltar	
ft.	°	kt.	°	kt.	°	kt.	°	kt.
8,000	360	21	200	9	110	7	110	9
3,000–2,000	360	20	100	25	...	...	090	22
1,000	360	20	...	...	110	7	...	...
Surface	010	20	110	22	110	8	090	18

No other observations above the surface were available from Spanish stations in the south-east during the period. The observations plotted on Fig. 1, p. 322 however paint a typical picture, Almeria 360° 6 kt., Oran 110° 6 kt., Melilla 070° 6 kt. and 070° 5 kt. at Tetuan, compared with 090° 15 kt. at Gibraltar. It is a feature of this chart that winds to the south-west of the Straits (Tangier etc.) were light, whilst those to the north-west were strongish easterly; this is a natural result of the southerly drift to the west of the Straits area.

Vertical convergence was in this period aided by several other factors. The Rock itself, nearly 1,400 ft. high, presents a formidable barrier to the easterlies in their sweep, coming as it does more or less centrally between adjacent higher ground; the effect was most noticeable in the rainfall on this occasion, as the precipitation was distinctly higher in the town than at North Front. The presence of the Rock, with air flow round and over it, must make itself felt over a range of a mile or two, but "triggering" effects are most felt over and to the immediate lee of the Rock, the ridge of which is only 300–500 yd. from the east coast. Thus fresh or strong low-level winds from east or a point just north deliver somewhat more than the normal convergence rainfall to the North-Front site, but carry additional orographic rain formed over the Rock itself to the town area just to its lee. Much more carry-over from the Rock to North Front occurs with winds south of east. Thus on the 20th and 21st, the winds were from 070–090° about 20 kt., so that a considerable difference might be expected between North-Front and town falls; the percentages of rainfall at North Front to a weighted-mean town fall were 88 and 70 per cent. respectively, with rather more north in the winds on the 21st. From the 22nd to the 25th, the percentage ranged between 92–100 per cent., and the North-Front wind during nearly all the periods of rain was from a point south of east, and was considerably lighter than earlier in the week. On the 26th, the percentage was only 73 per cent., again with winds of about 20 kt. from east or a point just north.

Another factor which was present to a greater or lesser degree during the week was slight blocking action to the west of the Straits, where the light low-level southerly drift which was maintained most of the week acted as a further bar to the free passage of the Mediterranean easterlies. This shows up on Fig. 1, p. 322 to a limited extent in the light winds to the south, and the stronger easterly winds to the north.

A further favourable circumstance for the heaviness of the rain on the 20th, 21st and 26th was the lack of vertical shear in the upper winds, so that developing cumulonimbi were not distorted before they had attained full stature. In the middle of the week, vertical shear alone militated against prolonged heavy rain.

Conclusion.—By reason of geographical circumstances, with marked orographic tendencies, Gibraltar receives about 50 per cent. more rain than most places nearby on the Spanish coast, and twice as much as places inland. The period from November 20th to the 26th brings out the tremendous effect of topography in favourable meteorological conditions.

DAMAGE TO AIRCRAFT BY HEAVY HAIL AT HIGH ALTITUDE

By T. N. S. HARROWER, M.A., B.Sc. and D. C. EVANS

Introduction.—Not more than ten years ago a civil airline pilot would have taken every possible step to avoid flying into an area of cumulonimbus activity but in recent years, with the increased efficiency of de-icing equipment and the improvement of instrument-flying techniques, civil aircraft are, when necessary, flown through thundery areas in which hail, turbulence, icing and lightning are encountered. For such flights by pressurized aircraft it is normal procedure to enter a cumulonimbus at maximum altitude and at minimum air speed, but on some occasions an aircraft will encounter hazardous conditions, and it is thought that a report of one such incident will be of value.

Narrative of the incident.—Captain Marks was the pilot of a British European Airways Ambassador-Elizabethan class aircraft (see photograph facing p. 336) which left Nice at 1417 G.M.T. on August 14, 1954, on a scheduled flight to London. At 1507 near Lyons, at the head of the Rhône valley, while flying in thick cloud at an indicated altitude of 20,500 ft. (450 mb.) and at an indicated air speed of 140 kt., the aircraft encountered a heavy thunderstorm and flew into cumulonimbus cloud. The reported outside air temperature was -10°C. Although the pilot closed the throttles, the aircraft gained both altitude and air speed, the rate-of-climb indicator showing a climb of 4,000 ft./min. and the air speed indicator showing 190 kt. Only moderate turbulence and light rime icing were experienced but extremely heavy hail shattered the outer lamination of the wind-screens, and damaged propeller bosses and engine cowlings. An emergency descent was commenced in case of explosive decompression and the flight was continued at 8,500 ft., unpressurized, to Paris. Further damage to the nose and tail was discovered after landing.

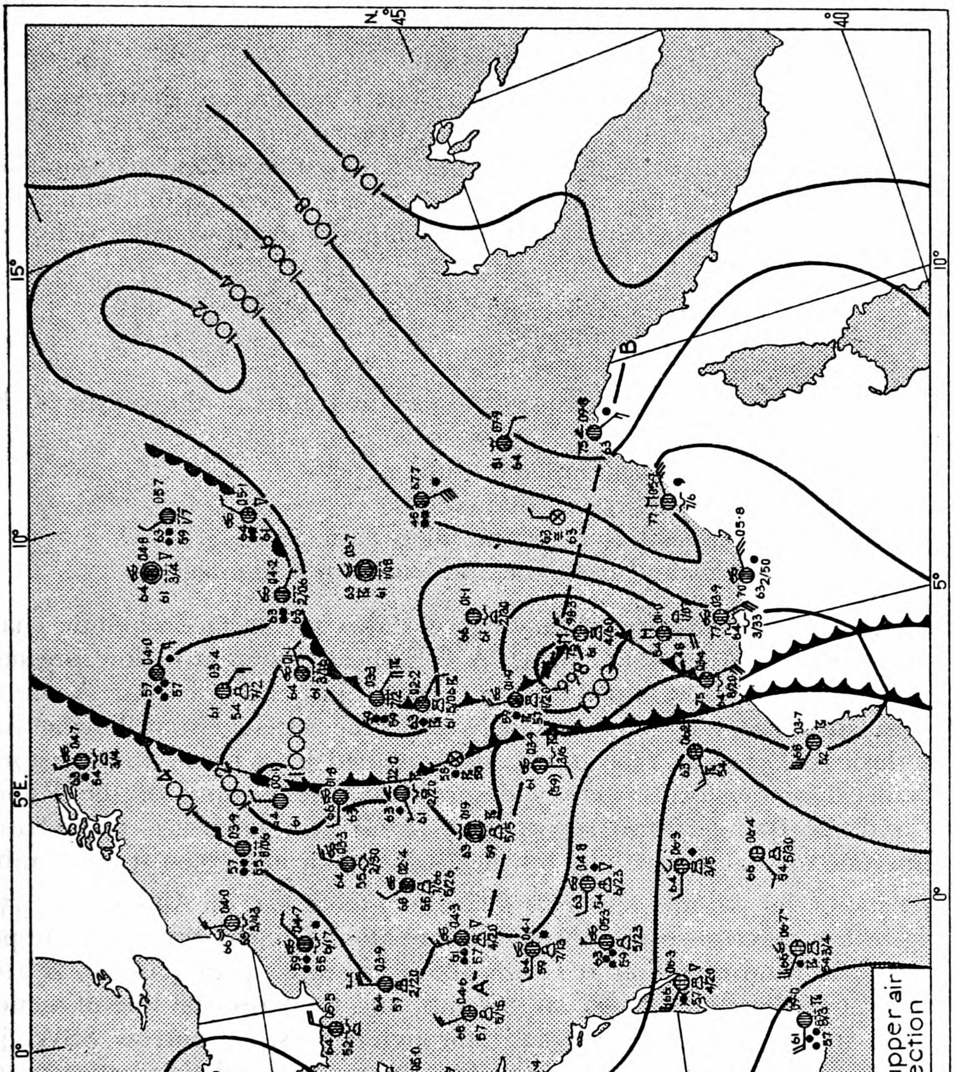

FIG. 1—SYNOPTIC CHART, 1500 G.M.T. AUGUST 14, 1954

Damage to the aircraft.—The following is a full list of the damage sustained by the aircraft

(i) Nose of aircraft holed in three places (see photographs in the centre of this magazine); (the nose is constructed of three 1/16-in. plywood sections bonded together)

(ii) Both pitôt-head attachments dented

(iii) Port and starboard wind-screens, outer laminations shattered

(iv) Cabin hooding and fuselage dented in various places

(v) Tailplane fins and rudder leading edges damaged and rivets missing (see photographs in the centre of this magazine) (central-fin leading edge 0·028-in. aluminium alloy, outer tailplane-fin leading edge 0·036-in. aluminium alloy)

(vi) Tailplane leading edge damaged (0·036 aluminium alloy)

(vii) Engine cowlings damaged

(viii) Indentations on propeller blades

(ix) Propeller spinners damaged (see photographs in the centre of this magazine)

(x) Rivets sprung on mainplane leading edges

(xi) Navigation light screens shattered

(xii) Centreplane leading edge and fillets damaged

(xiii) Aerial shields and tailplane anti-icing intake damaged.

The meteorological situation.—Fig. 1 shows the surface synoptic chart for 1500 G.M.T. on August 14, 1954. A complicated system of low pressure covered France and a low of 998 mb. was centred just east of Lyons. A double cold-front structure was moving slowly east, the surface front having just passed through Lyons at 1500 G.M.T. accompanied by a heavy thunderstorm with hail. Thunderstorms were widespread in the vicinity of the Rhône valley and the thunderstorm reported at Lyons at 1500 G.M.T. is probably the same one as that flown into by the Elizabethan at 20,500 ft. (450 mb.)

Fig. 2 shows the 500-mb. upper air chart for 1500 G.M.T. on August 14, 1954, and Fig. 3 shows a cross-section through Lyons along a line normal to the upper air flow. The wind direction at Lyons above 750 mb. up to 400 mb. is 210° apart from one direction of 200° at 500 mb. and therefore the line of section was taken in the direction 300°–120° through Lyons. A narrow SSW. jet stream was flowing over the Rhône valley, the main core being between 400 and 350 mb. with a speed of about 120 kt. A secondary core appears at 500 mb. with a speed of 100 kt. and another at 650 mb. with a speed of about 90 kt. The latter appears at an exceptionally low altitude for a jet-stream core and it is thought that it is either due to the effect of local topography or due to errors in the wind finding at Lyons where conditions must have been difficult for radio theodolite tracking at that time. The Lyons upper-wind report is given in Table I.

TABLE I—LYONS ASCENT AT 1500 G.M.T. AUGUST 14, 1954

Pressure (mb.)	976	950	900	850	800	750	700	650	600	500	400
Wind direction (°)	180	190	190	190	190	210	210	210	210	200	210
Wind speed (kt.)	6	11	23	38	45	47	75	88	75	81	83

There is an additional report of 210° 81 kt. at a height of 695 mb. The position E at which the Elizabethan encountered the strong up-current and the severe

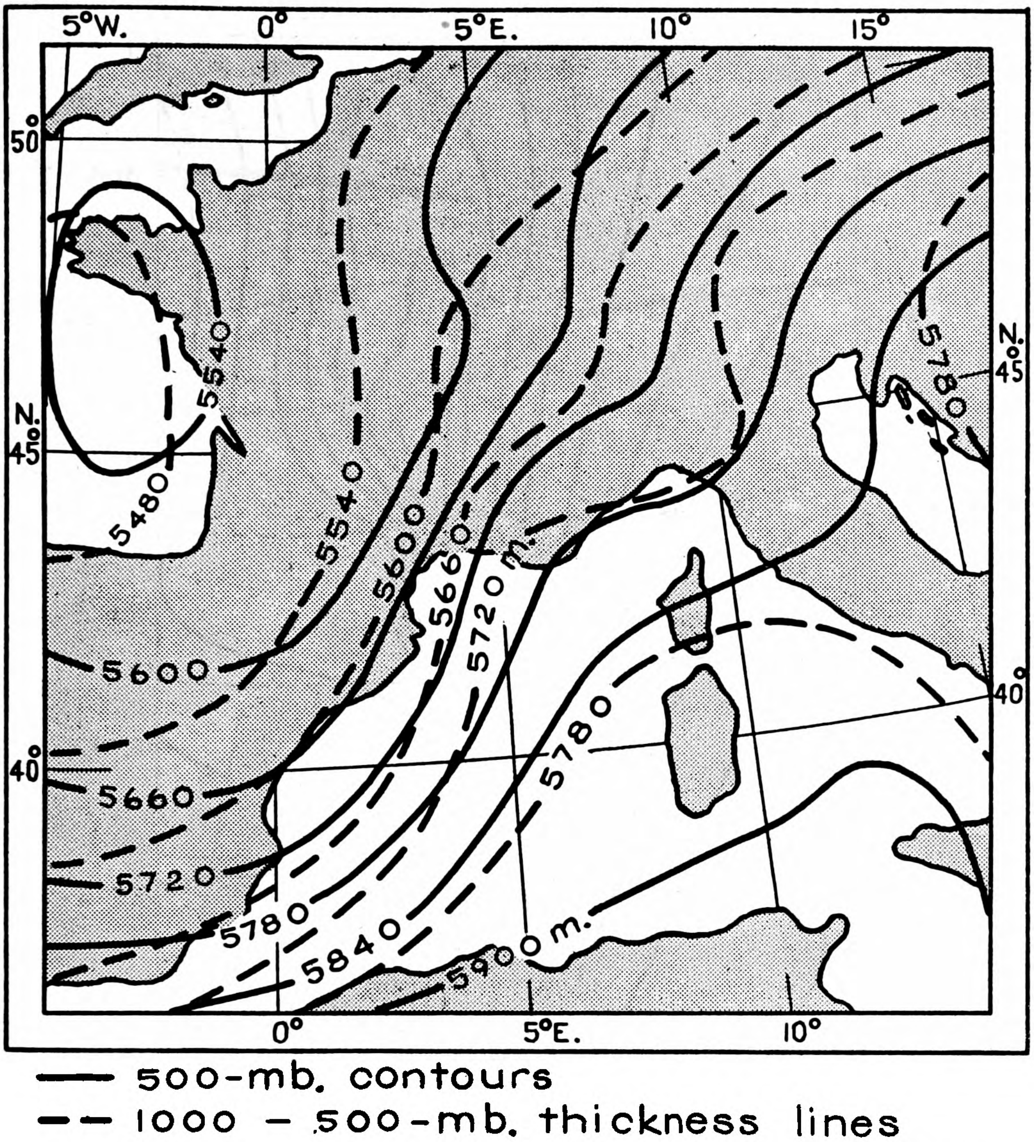

FIG. 2—500-MB. CONTOUR CHART FOR 1500 G.M.T. AUGUST 14, 1954

hail is shown at 450 mb. on the "cold" side of the jet. There is marked horizontal shear but no indication of vertical shear.

Severe turbulence was encountered elsewhere within this jet stream at a position marked B, by a B.O.A.C. aircraft at about the same time. This aircraft was flying at 19,500 ft. on track from Paris to Nice and reported by radio "severe to very severe turbulence, moderate to heavy icing, occasional hail and lightning, outside air temperature −17°C., wind 230° 100 kt.". Several other aircraft reports indicated cloud tops to at least 30,000 ft. above the Rhône valley with severe to very severe turbulence but exact positions are not known.

Fig. 4 indicates the upper air ascents from Nîmes and Payerne made on the afternoon of August 14. The ascent at Nîmes is warmer at all levels and much drier aloft and this is to be expected from the relation of the ascents to the main jet stream. It is obvious that the instability of the Nîmes ascent would be

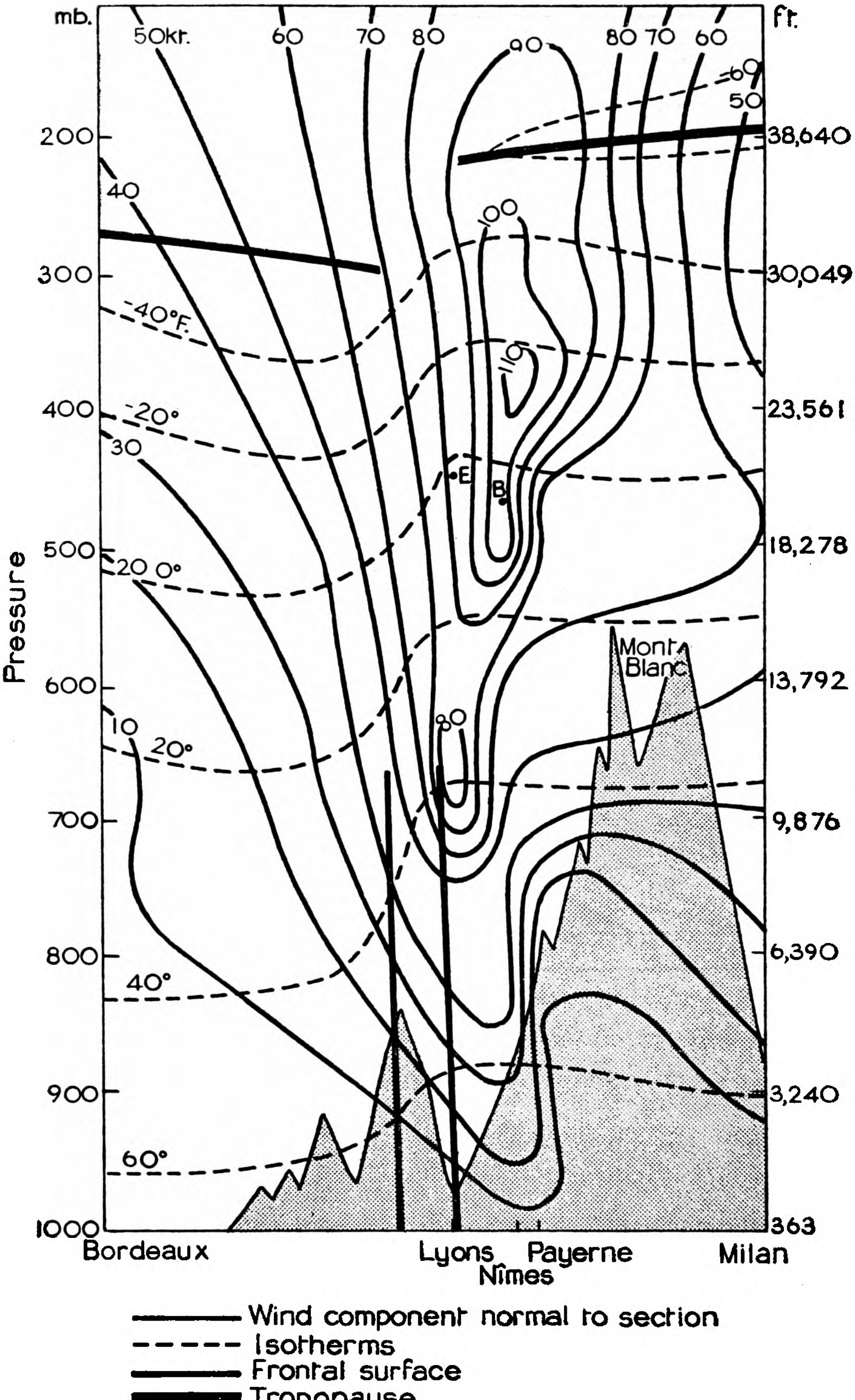

FIG. 3—CROSS-SECTION THROUGH LYONS, NORMAL TO UPPER AIR FLOW, AT 1500 G.M.T. AUGUST 14, 1954

The approximate profile of highest ground within 30 miles of line of section (marked AB in Fig. 1) is shown in the background.

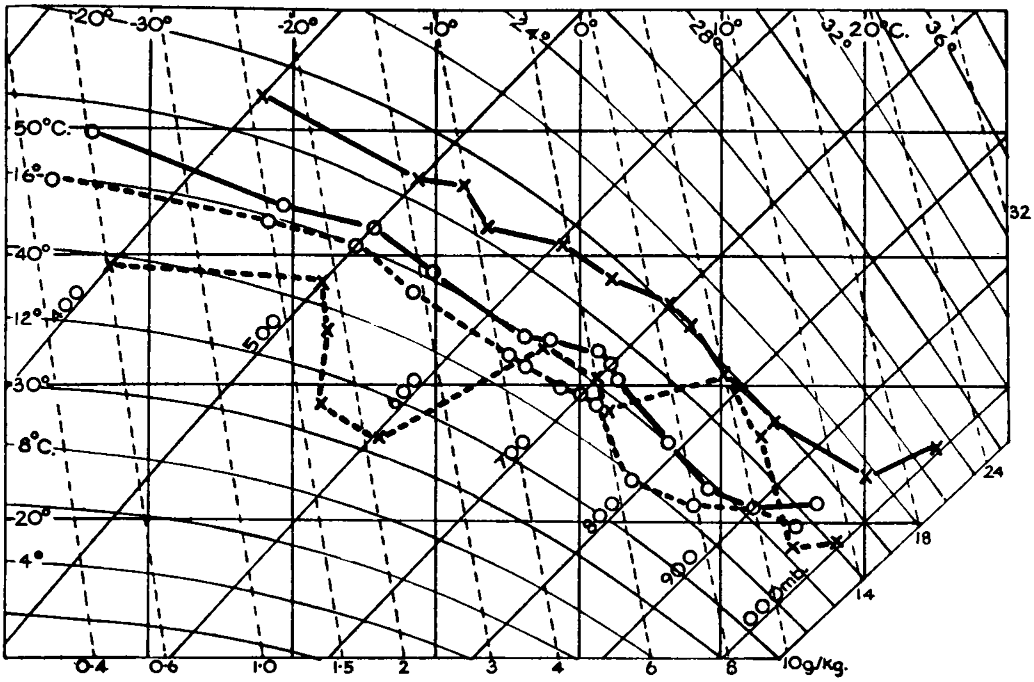

FIG. 4—UPPER AIR ASCENTS FROM NÎMES AND PAYERNE 1400 G.M.T. AUGUST 14, 1954

Nîmes x———x Dry bulb	x- - - - -x Dew point
Payerne o———o Dry bulb	o- - - - -o Dew point

greatly increased by any lifting of the layers between 780 and 600 mb. where the wet-bulb potential temperature decreases with height and this potential instability is undoubtedly the cause of the widespread thundery activity over the high ground. There also must have been considerable channelling and subsequent lifting of the warm southerly air stream in the lower layers by the narrowing of the Rhône valley, but it is impossible to assess the vertical rate of ascent of air due to the topography. However, as an average uplift of only 50 ft./min. results from the steady flow at 30 m.p.h. up a slope which rises 5,000 ft. in 50 miles, it is difficult to imagine that purely topographical effects can account for much of the uplift of over 4,000 ft./min. which was experienced. It seems therefore that a large up-current over 4 miles wide within the cumulonimbus was responsible for the forced ascent.

All factors in this situation combined to produce severe activity over the upper reaches of the Rhône valley and we have, in this relatively small area, the rather unusual combination of a jet stream with severe thunderstorms with heavy hail, very severe turbulence, heavy icing and strong smooth up-currents.

Discussion of the Elizabethan case in relation to existing literature.—Capt. Marks reported the hail which damaged his aircraft to be the size of small eggs.

The most comprehensive literature on the subject of hail damage to aircraft is contained in a publication by Souter and Emerson[1], which includes a summary of hail literature and the effect of hail on aircraft in flight. This is undoubtedly the document which should be studied by anyone interested in this subject. There is an analysis of 131 cases of hail damage to aircraft together with a comprehensive series of photographs.

When the Elizabethan encountered the hail at 450 mb. originally, the true air speed was 200 kt. rising to 280 kt. during the forced ascent of 4,000 ft. If we take a mean true air speed of 250 kt. during the encounter and taking into account the thickness of the surfaces damaged and the experimental evidence given in the United States report, we arrive at a hailstone diameter of about 1·6 in. which agrees well with the estimated size of "small eggs" reported by Capt. Marks.

The outside air temperature reported also indicates that the aircraft must have been caught in a rising bubble of air warmer than the general surroundings. The outside air temperature which might have been expected would have been about −16°C. and the height above mean sea level 21,280 ft. Freezing level was about 14,000 ft.

Only one case can be found in the literature where severe hail (1·6 in. ±0·2) was encountered higher than this. This was on June 17, 1948, in a thunderstorm in Nebraska at 25,000 ft. and at a temperature of −28°C.

In a review of hailstone sizes in the central U.S.A., the United Air Transport Corporation Inc.,[2] found that hailstones over 1 in. in diameter only occur in about 1 out of 800 thunderstorms.

Very little data are available on the distribution of hail in the vertical. The Thunderstorm Project[3], although not carried out in areas of maximum hail occurrence, presents some facts. During 511 cloud traverses in thunderstorms or potential thunderstorms over Florida in 1946 hail was reported in 4 per cent. of the cases. In Ohio in 1947 in 812 traverses hail was reported in 6 per cent. of the cases. Hail was encountered most often at 16,000 ft. over Florida and at 10,000 ft. over Ohio. It appears that the region of hail in any storm and the duration of hail in that region are relatively small.

Generally it appears that hail occurs in very narrow bands within thunderstorm clouds and occurs less frequently above 20,000 ft. In fact in these 1,333 traverses no heavy hail was ever encountered at 20,000 ft. or above.

Souter and Emerson, on the basis of all the evidence available, state that the largest hailstones likely to be encountered in flight would be about 2 in. in diameter.

Studies were conducted to ascertain the weather factors associated with hail encountered by aircraft. The thunderstorms associated with the American encounters were classified as to type; cold front, warm front, or air mass. Of the cases of severe hail encountered 59 per cent. could be attributed to cold-front action, 28 per cent. to air-mass activity, the remaining 13 per cent. to warm-front thunderstorms. This analysis will not be strictly applicable to Europe but it would indicate that pilots should be particularly cautious when flying in or near cold-front thunderstorms, particularly in the summer months. The Rhône-valley thunderstorm which we are discussing comes into this category.

In all the American cases investigated when severe hail was encountered a thunderstorm was present or in the vicinity.

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ELIZABETHAN AIRCRAFT IN FLIGHT
(see p. 330)

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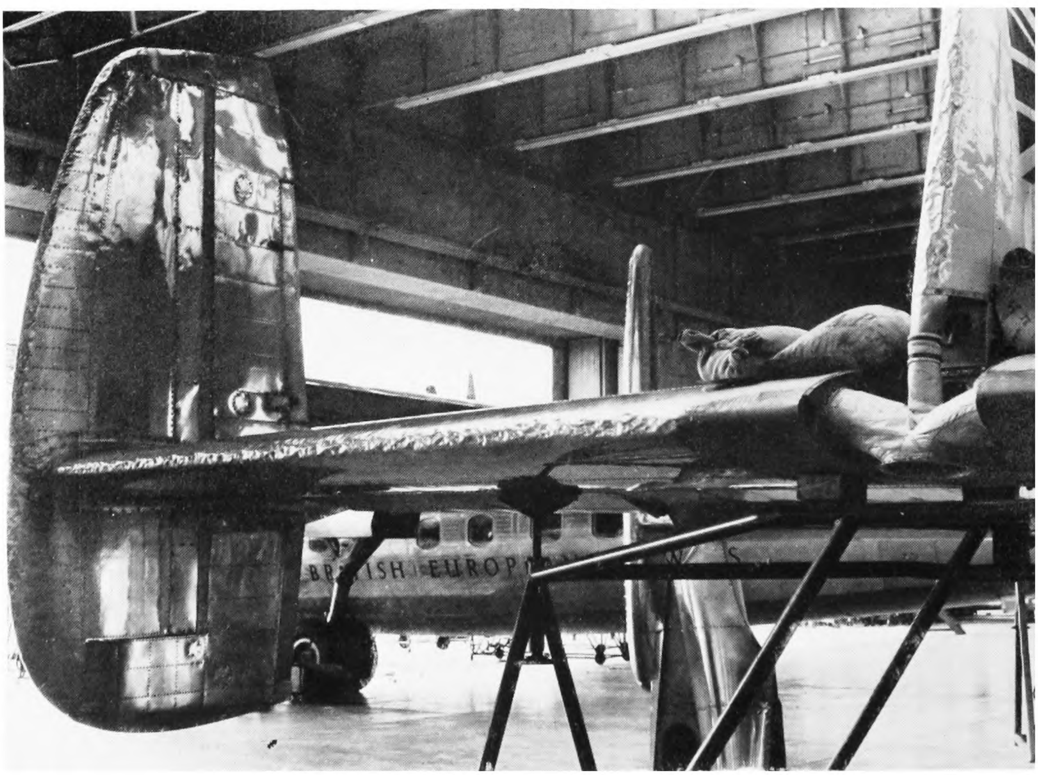
DAMAGE TO NOSE OF AIRCRAFT



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DAMAGE TO LEADING EDGES OF TAILPLANE, CENTRAL FIN AND STARBOARD FIN (see p. 332)

Reproduced by courtesy of British European Airways

DAMAGE TO PROPELLER SPINNERS

(see p. 332)

Photo by R.A.F.

WATERSPOUT SEEN OFF THE STRAITS OF GIBRALTAR, NOVEMBER 21, 1955

1150 G.M.T.

(see p. 321)

To face p. 337]

Photo by R.A.F.

Photo by R.A.F.

WATERSPOUTS SEEN OFF THE STRAITS OF GIBRALTAR, NOVEMBER 21, 1955

(see p. 321)

Souter and Emerson, give much useful advice on the general features in relation to hail, airline operation and hail and the question of forecasting this phenomenon.

Frost[4] reports little difficulty from hail encounters during flights through cumulus and cumulonimbus cloud over Malaya although an up-draught of 53 ft./sec. was recorded on one occasion.

In a review by Browne, Palmer and Wormell[5], it is mentioned that Weickmann suggests an approximate formula for the terminal velocity of hail-stones; $V = 200\, D^{\frac{1}{2}}$ where V is in cm./sec. at ground level and D is the diameter in mm. Allowing for the necessary change in V with increase in height, at 20,000 ft. in an up-draight of 66 ft./sec. measured by the Elizabethan aircraft this would give a size of stone of average density, which could be supported, of 1·7 in. diameter.

According to Gaviola and Fuertes[6], in the Rhône-valley cumulonimbus, which may have extended to over 30,000 ft. the free fall of a particle from the upper layers, could produce hailstones up to the suggested diameter of 1·6 in. by the time it reached 21,000 ft.

In addition to the literature quoted, there are included in the Bibliography further references[7–16] to some works of interest to those who wish to pursue this subject which is of increasing concern to commercial aviation as major structural damage can be caused by brief encounters with large hailstones. Nearly all external components of an aircraft, especially the nose section and leading edges, are subject to damage and encounters with hail lasting only 10 to 30 sec. have caused damage severe enough to warrant scrapping very expensive aircraft. Wind-screens may be shattered completely by hail and this is particularly dangerous in that explosive decompression may take place in high-flying pressurized aircraft.

Conclusions.—From experience of forecasting for the Rhône-valley area it is suggested that the frequency of the occurrences of hazardous thundery conditions is greater in this area than in the area of the U.S.A. dealt with in The Thunderstorm Project and in the United Air Lines report on thunderstorms and it is considered that in similar synoptic situations the occurrences might be frequent.

One of the findings of The Thunderstorm Project was that "in general, the worst conditions were encountered at the altitude at which modern airplanes with supercharged cabins are most frequently flown". Until airborne radar is installed as a means of picking a safe path between thunderstorm cells, it is important that the forecaster should be aware that the forecast of an area of thunder activity will seldom cause a pilot to alter his planned route and flight altitude drastically, and that only by emphasis of the hazards, when necessary, can he contribute towards the safety of the intended flight.

Acknowledgement.—We wish to thank British European Airways for permission to include in this report details of this incident and for supplying and giving permission for the publication of the photographs.

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METEOROLOGICAL RESEARCH COMMITTEE

At the 38th meeting of the Physical Sub-Committee held on July 10, 1956, the first three papers considered were from the Meteorological Research Flight. The frost-point observations, obtained to heights of about 50,000 ft. by the Canberra aircraft during 1955[1] broadly confirm those obtained in 1954 and show that frost-point tends to a constant value of about −117°F. (−83°C.) at about 50,000 ft. It is proposed to obtain corresponding observations at considerable distances to north and south of the British Isles, but it is to be hoped that other countries will undertake similar high-altitude exploration in meteorological régimes differing from those normally experienced in the British Isles. Mr. G. J. Day summarized the report[2] on the main features of the instrumental and other observations obtained during a series of flights through large cumuliform clouds on nine occasions in 1953. There was discussion on the representativeness of the data presented on cloud-droplet size and on the significance of the model proposed for the distribution of the liquid-water content within the type of cloud examined. Mr. W. G. Durbin presented his analysis[3] of droplet samplings made in cumulus cloud on ten occasions in 1951. An interesting point is that the constants in A. C. Best's expression for the relation between liquid-water content and droplet-size distribution appear to depend on the maximum droplet diameter present. Mr. B. C. V. Oddie said that the value of visibility in cloud as calculated from the droplet-size distributions presented in the paper markedly exceeds the observed visibility at the lowest (and presumably more accurate) observed visibilities. A similar discrepancy was noted by Mr. Day. Dr. Best suggested that the discrepancy might be due in part to non-allowance for the effect of variation, with visibility, of the threshold contrast of the human eye. Mr. W. G. Harper[4] described the quantitative use of 3-cm. radar at East Hill in the study of rainfall. In the work cited it was found that on occasions of widespread moderate rain there is little vertical variation in the drop-size distribution in precipitation below the level at which snow-flakes have melted and achieved their terminal velocity. This is contrary to the conclusions, from computations, of some other workers that growth of drops should occur in cloud below the melting level and below the cloud. A deduction in the paper is that below a warm front the cloud below the melting point level is thin i.e. of small liquid water content. In the discussion it was accepted that there are still uncertainties in the use of radar for the absolute measurement of rainfall. It is hoped to obtain more information on this point from radar observations on rain falling into a network of recording rain-gauges at Cardington. The Sub-Committee also discussed proposals concerned with cloud seeding and a suggestion that chemical sampling of air and rain-water should be undertaken at additional stations in the United Kingdom.

The 40th meeting of the Synoptic and Dynamical Sub-Committee was held in the Napier Shaw Laboratory, Meteorological Office, Dunstable, on July 19, 1956. After corporate consideration of three scientific papers, members of the Sub-Committee discussed work in progress with members of the Forecast Research Division and visited other Departments of the establishment at Dunstable. The most interesting preliminary study by Mr. G. A. Corby[5] of the evidence, obtained from the data of routine radio-sonde—radar wind soundings, of the occurrence of atmospheric waves generated by the effects of mountains on air flow was warmly welcomed. Some of the deductions from the data considered confirm conclusions from perturbation theory. There was discussion on the possibility of modifying the rate of ascent or the drag of the balloon assemblage to achieve greater accuracy in the determination of wave amplitude on investigation of the extent of the waves across wind and on the application of deductions from radio-sonde data to operational forecasting. Mr. F. H. Bushby then described further trials in the Meteorological Office on the objective analysis of pressure-contour charts for 500 mb. with the aid of an electronic computer[6], with the aim of preparing charts (much more quickly and with no less accuracy than by conventional analysis) for use in the production of forecast charts by the process of numerical integration. The Sub-Committee concluded that the technique used was well justified and suggested that effects of variation of density of observations in the area of interest (e.g., as between the Atlantic and Europe) might be further examined. The paper presented by Mr. P. Graystone[7] dealt with a statistical method for the fairly rapid computation of the frequency distribution of equivalent headwinds on variable flight tracks, from knowledge of mean vector wind and standard vector deviation. Illustrations were given for the London to New York route, comparing the merits of two, and three tracks. In the discussion, it became evident that the procedure described in the paper will be valuable in civil aviation planning and the adaptation of the method to machine computation was suggested.

1. HELLIWELL, N. C.; MACKENZIE, J. K. and KERLEY, M. J., Further observations of humidity up to 50,000 feet made from an aircraft of the Meteorological Research Flight in 1955. *Met. Res. Pap., London*, No. 976, S.C. III/205, 1956.

In continuation of M.R.P. 877, 1954, observations, with a pressurized frost-point hygrometer and flat-plate thermometer around and over the British Isles, are tabulated for 45 occasions, 5,000–50,000 ft. Means and standard deviations are given for 1954 and 1955. The mean frost point decreases about 3½°F./1,000 ft. from 20,000 to 40,000 ft. and then more slowly to approach −117°F. at 50,000 ft. With a high tropopause frost point is generally lower than with a low tropopause.

2. DAY, G. J., Further observations of large cumuliform clouds by the Meteorological Research Flight. *Met. Res. Pap., London*, No. 980, S.C.III/207, 1956.

A number of observations in flights through upper parts of cumulus clouds are tabulated (maximum and mean water content, icing, height, temperature, excess temperature in cloud, and turbulence). Cells were about 2½ miles across, with cloud asymmetric around them. Life cycle of a cell was 20–25 min. The structure accords with the bubble theory; interaction with environment is weak, with little entrainment. Droplet size was 40μ at first, increasing to 120μ; the suggested rain-producing mechanism is Bergeron below 10°F., coalescence above 20°F., and a combination in 10–20°F. Vertical motion, turbulence, water content, temperature and electrical activity are also dealt with in this exhaustive discussion.

3. DURBIN, W. G., Droplet sampling in cumulus clouds. *Met. Res. Pap., London*, No. 991, S.C. III/211, 1956.

Samples of droplets obtained by aircraft impactor were analysed photographically. Results are tabulated in full. Clouds 750–2,500 ft. and 3,850–7,000 ft. thick are discussed separately. The droplet sizes were arranged in 10 categories (5·28–119μ). There was great variation in range of drop diameters in different flights, but mode was 7½–9μ with in some cases a secondary maximum at 15μ. The water content of the different categories is examined in detail. It tends to increase with height and to be larger in thicker clouds averaging 0·5 gm./m.^{3} below 2,500-ft. thickness, 1·0 gm./m.^{3} above, but up to 5 gm./m.^{3} content is generally below adiabatic value. Mean diameter increased from 1–13μ at base to 23–27μ at top of cloud, but no systematic variation of number of droplets (100–300/cm^3) was found. B. C. V. Oddie discusses discrepancy between estimated visibility and that calculated from droplet-size distribution.

4. HARPER, W. G., Variation with height of rainfall below the melting level. *Met. Res. Pap., London*, No. 984, S.C. III/209, 1956.

Slant radar echoes at East Hill from 500–6,000 ft. (i.e. below freezing level) in widespread warm-front rain were converted to rates of rainfall. Theory and correction factors are set out. The calculated rate was only 0·01–0·21 of that given by the rain-gauge; the reason is discussed and a factor 0·2 is applied. No trend towards increase or decrease of rainfall with height was found; this suggests that cloud-water below freezing level was much less than 0·2 gm./m^3.

5. CORBY, G. A., A preliminary study of atmospheric waves using radio-sonde data. *Met. Res. Pap., London*, No. 985, S.C. II/211, 1956.

Rates of radio-sonde ascents at Leuchars, Stornoway, Aldergrove and Liverpool, November 1953–April 1954 were computed and variations exceeding 300 ft./min. plotted against height. On 48 occasions (27 at Leuchars), of which 34 were at 1400 G.M.T. and 14 at 0200 G.M.T. these showed a pattern of vertical currents, mostly $<$ 500 ft./min. but one $>$ 1,000 ft./min. The amplitude was generally greatest at 5,000–10,000 ft. The associated wind speed and direction (mostly over high ground) at 900 mb. are shown. The wave-length was 2·6–14·4 miles, average 6–7 miles. The distortion of the temperature structure is discussed. An appendix assesses the errors in evaluating the rate of ascent.

6. BUSHBY, F. H., The objective analysis of some 500-mb. charts. *Met. Res. Pap., London*, No. 986, S.C. II/212, 1956.

An experiment was made in analysing the 500-mb. field by electronic computer direct from the observed 500-mb. heights or winds, as a basis for time integration. The method is to find the quadratic or cubic surface which best fits the observations. Three situations were analysed (N. Atlantic and W. Europe). It appears that the objective technique can produce sufficiently smooth and accurate results more quickly than manual plotting; the quadratic surface is considered better than the cubic.

7. GRAYSTONE, P., Equivalent head-wind statistics for variable tracks. *Met. Res. Pap., London*, No. 987, S.C. II/213, 1956.

For practical reasons aircraft must fly the most favourable of several tracks from the point of view of headwinds, instead of the actual minimal track. A statistical method is given for rapid computation of the frequency distribution of equivalent headwinds along two or three alternative tracks in temperate latitudes, and so assessing the relative merits of the different tracks. The frequency distribution is computed for three routes London–New York. Errors of wind prediction are not considered.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on May 16, 1956, the President Dr. R. C. Sutcliffe in the Chair, papers were read on local temperature variation in the Reading area, the temperature profile above bare soil on clear nights and on the space and time distribution of showers in a tropical region.

*Parry, M.—Local temperature variations in the Reading area**

The first paper was read by Dr. Parry and gave a comparison of temperature observed at twelve stations in Reading and the surrounding rural areas at heights ranging from 120 to 200 ft. above mean sea level. Mean temperatures showed the urban heating effect to amount to about ½°F. Maximum temperatures varied very little. Minimum temperatures showed two distinct patterns of distribution, one associated with cloudy disturbed weather and another with anti-cyclonic weather. On nights with the first kind of weather there was little variation. On most clear quiet nights there was an inversion giving minimum temperature differences of up to 8° between the high- and low-level rural stations but in the centre of Reading the inversion usually did not exist. Some radiation nights which gave no inversion were probably nights of deep inversion undetected because of the lack of stations high enough up on the Chilterns.

Curves of minimum temperature differences for specified wind forces show that a force 4 wind and sometimes even a force 3 wind can entirely destroy the urban warming effect.

Lake, J. V.—The temperature profile above bare soil on clear nights.†

Dr. J. V. Lake described observations of the temperature profile over bare earth on radiation nights made with thermistors and spirit-in-glass minimum thermometers at heights of 0·0, 0·1, 0·5, 1·5, 2·5, 3·5 and 54·0 in. The observations were made under very calm conditions over level ground at a distance of 120 yd. from the nearest boundary. The striking result was the existence of a very steep fall of temperature, of the same order of magnitude as that occurring on sunny days between the surface and heights ranging between 2·5 and 6·0 in. At greater heights temperature increased with height. On one occasion the temperature fell from 18·6°F. at 0·1 in. to 16·6°F. at 1·5 in. increasing to 16·8°F. at 3·5 in. Such a difference corresponds to a lapse rate about 2,000 times the dry adiabatic value and 800 times the auto-convective value. Analysis of the time variation of the lowest value showed the fall was closely proportional to the square root of the time as is to be expected from Brunt's theory of the fall of surface temperature on clear nights which is based on a balance between outgoing radiation and upward conduction of heat in the soil neglecting any contribution of heat from the air. Such a temperature profile had been reported before by several workers but had not hitherto been regarded as a normal feature. The results, said Dr. Lake, showed the air must lose heat on a clear night by some mechanism other than convection and conduction to the surface and he suggested that the explanation lay in radiation. On the question of radiative heating and cooling of the layers concerned Dr. Robinson showed that heating at the rate of about 1°C./hr. could occur by radiative effects but he was doubtful about the development and persistence of a sharp lapse rate because of the unstable nature of the stratification. Dr. Monteith said he had observed a lapse rate developing over grass at a rate approaching 1°C./min.

Soane, C. M. and Miles, V. G.—On the space and time distribution of showers in a tropical region.‡

The third paper, by two members of the staff of the Rhodesian Meteorological Service, was read by Dr. A. G. Forsdyke. It described radar observations of the movement of rain showers near Salisbury, Southern Rhodesia. The authors found that the majority of echoes occurred in groups, called progressives, in elongated areas which moved at right angles to the length. Individual echoes lasted for about an hour and new ones continually formed in the moving area. Occasionally isolated echo points formed. No connexion could be established between the movement of a progression and the upper wind, in fact on one occasion two progressions moved towards each other in opposite directions. Since the published paper was written, however, the authors had obtained evidence that the progressions tended to move with the wind at 10,000 ft. With the approach of a progression the surface wind changed to blow from the approaching rain and minor cold-front phenomena occurred at the passage of the group. No conclusive evidence of the mechanism of the group was found.

There was a short Special General Meeting of the Society on June 20, 1956, to elect officers for the coming year. At the Ordinary Meeting which followed, with the President, Dr. Sutcliffe,

* *Quart. J. R. met. Soc., London*, **82**, 1956, p. 45.
† *Quart. J. R. met. Soc., London*, **82**, 1956, p. 187.
‡ *Quart. J. R. met. Soc., London*, **81**, 1955, p. 440.

in the Chair, it was announced that the first winner of the Napier Shaw Memorial Prize, on this occasion for an original essay on "The energetics of the general circulation", would be Dr. N. A. Phillips of the Institute for Advanced Study, Princeton. Dr. Phillips then read his paper.

*Phillips, N. A.—The general circulation of the atmosphere: a numerical experiment.**

In the past, experiments with a rotating fluid heated differentially in a cylinder or ring have shown flow patterns very similar to those encountered on weather maps. Dr. Phillips's paper attempts the same sort of experiment for the atmosphere using similar calculations with the same quasi-geostrophic equations as those used in numerical forecasting. To make his equations tractable at the two working levels of 250 and 750 mb. Dr. Phillips makes the following assumptions among others: the working area is rectangular, 6,000 Km. from east to west and 10,000 Km. from north to south; the Coriolis parameter is constant over the whole area; there is cyclic continuity, i.e. the motion is the same in an infinite number of exactly similar rectangular regions placed side by side; the north and south walls have the properties that at them there is no change in horizontal vorticity and no normal geostrophic motion; the atmosphere is heated non-adiabatically with a linear variation from south to north, being zero in middle latitudes; and the thermal stability, defined as the difference of potential temperatures at 250 and 750 mb. divided by the potential temperature at 500 mb. is constant. Surface friction was allowed for. The calculations are made by finite-difference methods using an electronic computer, the grid intervals being 375 Km. longitudinally and 625 Km. latitudinally.

Starting with the atmosphere at rest with uniform initial temperature and assuming there are no changes longitudinally, integration at intervals of a day produced after a 4-month season of 130 days a nearly uniform temperature gradient from north to south, a zonal easterly surface wind about 1 m./sec., a broad westerly stream at 250 mb. with a maximum of 36·3 m./sec. in middle latitudes and a minute southerly drift of about 0·3 m./sec. in most latitudes at 250 mb. A random disturbance (with root-mean-square velocity 8·8 m./sec.) was then imposed identically at 750 and 250 mb. and the subsequent motion calculated in 2-hr. steps. After 5 days the main features of the flow were a high and a large central low moving eastwards at 1,800 Km./day and having many of the features such as jet streams and V-shaped troughs typical of reality. After 26 days truncation errors, inherent in finite-difference calculations, vitiated any further progress—the resultant motion then being unreal.

Prof. Sheppard, among other questions, asked if it would not have been better to start from some real atmospheric situation rather than from rest. Dr. Phillips said that Dr. Charney had suggested starting from a sinusoidal motion but it was thought to be artificial. Dr. Eady thought that starting from a given real situation would not show much; it was desirable not merely to get the answer right but also to find out how the atmosphere works and therefore it was right to start from rest. It was difficult in meteorology to perform a laboratory experiment in which to separate the wood from the trees.

Dr. Scorer asked why the situation produced by the truncation errors which terminated the experiment could not be treated as another random disturbance. Dr. Phillips said that although the field of flow at the end looked random presumably it was not random. Mr. Sawyer drew attention to the calculated meandering jet stream and the "subtropical" jet stream. Although sharp troughs had been produced he had not noticed the corresponding sharp ridges and thought this might be explained by the cross-isobar flow at the surface due to friction. Dr. Phillips pointed out that the equations were symmetrical and demonstrated by reversing one of the slides that the ridges were just as sharp as the troughs. Dr. Sutcliffe did not find the preliminary calculations very exciting because of the insistence on uniform winds; he also thought it hardly fair to base the general circulation on one high and one low. He wondered too if the heating and friction terms really contributed anything to the solution; would not a similar flow equally result from a disturbance of merely zonal flow? Dr. Phillips stressed that if there was an initial flow pattern there was always a doubt that the derived theory might be biased. Friction had an effect on the momentum process at the ground. Dr. Forsdyke and Mr. Mason wondered if some of the short-comings of the solution might not be accounted for by latent heat but Dr. Phillips did not hold out much hope of taking a latent-heat term into his equations.

LETTER TO THE EDITOR

Night cooling under clear skies

Using a relationship between T_r and T_{min} (T_r being the temperature at the time of the evening discontinuity and T_{min} the minimum temperature during the following hours) to predict the lowest minimum temperature possible at a given place, W. E. Saunders[1] gives 16° or 17°F. for Northolt in the absence of snow-cover. W. E. Richardson[2] gives about 15°F. for Alston, and later[3] appears

* *Quart. J. R. met. Soc., London,* **82**, 1956, p. 123.

to imply that this figure is likely to apply anywhere in the British Isles without snow-cover. Dr. J. Glasspoole is cited as having corroborated this during recent severe spells. However, I found it difficult to accept this limit without further evidence. Investigation of the records at Wrexham nevertheless failed to provide evidence to the contrary; but this was not unexpected, as the severe spells under consideration are so often accompanied by snow-cover, as even a light snowfall will persist night and day. In the meantime Mr. E. L. Hawke was kindly investigating the Rickmansworth records for 1930–44 and he found 13 minima of 12°F. or below, all in the complete absence of snow-cover. The lowest was 7°F. and the investigation was such that the list was not guaranteed complete. The site at Rickmansworth was in a notable frost-hollow, but it would appear that the possibilities of Alston, in an elevated valley, are not much inferior. However I sought information elsewhere and referred to the *Monthly weather report*, and chose, more or less at random, a cold month, February 1929. Daily values of snow-cover are not given in the report, but I found about a dozen stations at which there was no snow lying at the morning observation at any time during the month, which would imply that none had lain during the night either. Of these, seven, including Bournemouth, gave at least one minimum below 15°F., the lowest being 10°F. The report does not enable one to say how many further minima below 15°F occurred at these, or at other stations during that month.

This evidence, all from standard instruments and nearly all of it from official records, makes it clear that it is quite wrong to suppose that the lowest possible minimum without snow-cover is about 15°F. It would appear that evaluation of this figure has been based on an over-simplification of the relationship between T_r and T_{min} (see Saunders[1], p. 610–11) and on a too bold extrapolation on a graph containing rather too few points (see Richardson[2], p. 303).

11 Percy Road, Wrexham, North Wales, June 10, 1956. S. E. ASHMORE

[The implication that the graphs in my recent contribution[2] suggested that an air minimum below 15°F might be impossible if snow cover was absent was intended to be provoking rather than conclusive. I am very grateful therefore to S. E. Ashmore for the information forwarded. However, it would appear worthwhile to point out that the fault in the suggestion was not so much the result of an over-simplification of the relationship between T_r and T_{min} and the extrapolation which followed, as a wrong interpretation of the graph itself. It was suggested by my graphs that around 15°F. T_r and T_{min} were about equal, but as S. E. Ashmore has pointed out in private correspondence there is no reason why T_r itself cannot be less than 15°F. Nevertheless to achieve T_r below 15°F. demands conditions which must be quite rare. For example, by using Saunders' formula. to gain the 7°F, of the Rickmansworth record an afternoon maximum of 21°F. with 11°F, dew point would give the required minimum if a constant of −9°F. were used. This is approximately the constant for Alston when inversions occur below the 850-mb. level, so that these extremes are still consistent with Saunders' work.

S. E. Ashmore's letter concludes discussion of the point that temperatures below 15°F. are impossible without snow-cover, for he has shown that records of the phenomena do exist. However, this does not prove that the "fall-away" shown in the Alston graphs[2] is faulty. He may be correct in his censure of the bold extrapolation but not only do the curve fittings for the observations to date seem justified, but the "fall-away" is consistent with the physics of thermal conductivity without snow-cover. Alston is the only station which has contributed sufficient snow observations to use for this problem, and the possibility of two separate curves for the different snow conditions is a necessary extension of the research into night cooling if a minimum forecast system is to be complete.

W. E. RICHARDSON.]

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NOTES AND NEWS

Damaging hailstorms

Hailstorms reported to have caused damage or sufficiently severe to be likely to have caused damage to crops or glass-houses, and which were mentioned in the various volumes of *British Rainfall* and the *Meteorological Magazine*, for the years 1906 to 1955, have been listed under calendar days. The total number of occasions for the 50 years was 169 and the monthly distribution is given in Table I.

TABLE I—DAYS WITH DAMAGING HAILSTORMS IN ENGLAND, SCOTLAND AND WALES, 1906–55

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
No. of days	2	2	1	9	25*	44	41	25	14	4	2	0	169

* 10 of the 25 days for May fell in the last week, 25th–31st.

The type of damage was also noted and of those storms listed as causing severe damage, the majority occurred during the three months May to July, on 14 days in May, 20 in June and 28 in July.

Under the classification using calendar days, storms as far apart as Devonshire and Ayrshire were credited to the one occasion since they occurred on the same day and were associated with the same unstable airstream. A further grouping was made of the location of the storms by listing them under counties, but the number per county depends on three factors, the county area, the efficiency of reporting and the extent to which damage was possible—a hailstorm in the Peak District or on Salisbury Plain, however severe, might not do any damage. This last factor is largely eliminated since the investigation is concerned with damaging hailstorms. With regard to the second factor, efficiency of reporting, we can only accept the data now available, based on accounts from rainfall and climatological observers and on newspaper reports, the amount of information depending on the interest of the observers, the network of stations and the news value of a storm. The variations in county areas were compensated by computing the frequency of hailstorms per 100 square miles.

The distribution of damaging hailstorms per 100 years per 100 square miles, on a county basis, is shown in Fig. 1. The frequencies are clearly greatest in

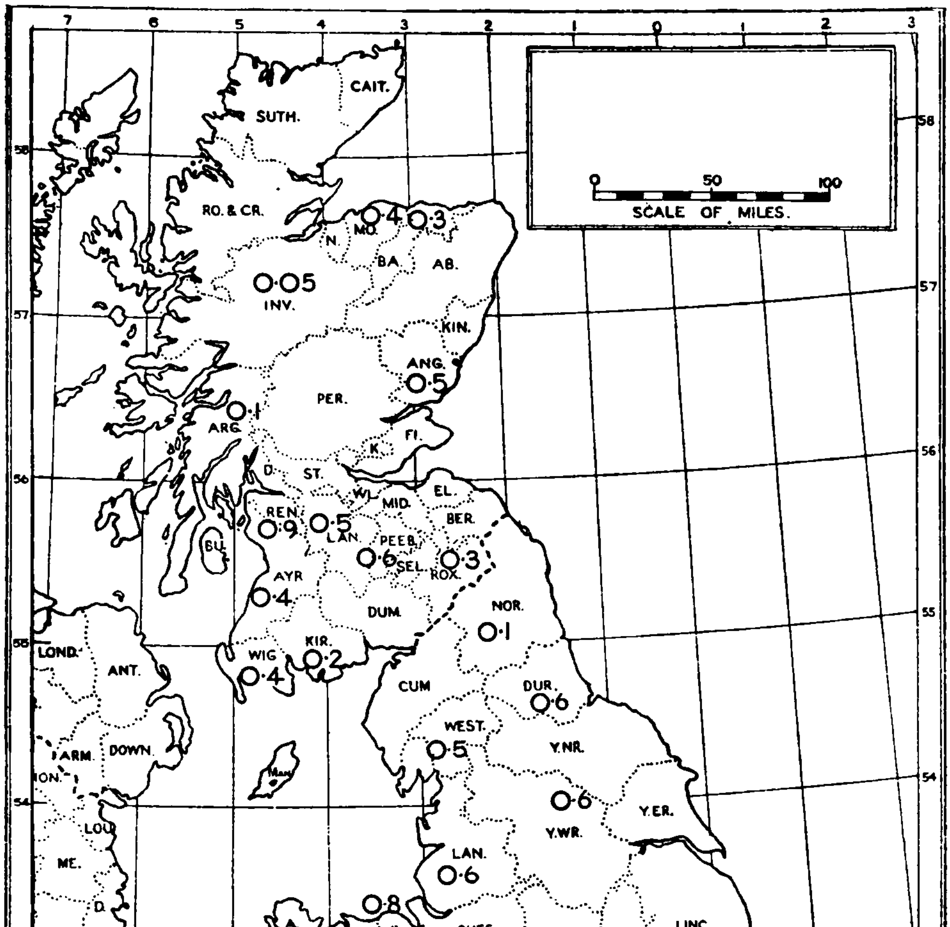

FIG. 1—DISTRIBUTION OF DAMAGING HAILSTORMS PER 100 YR. PER 100 SQ. MILES

the Home Counties and in Hampshire, Bedfordshire, Oxfordshire and Cambridgeshire; the Buckinghamshire value seems too small; the Oxfordshire value may be too big. The high frequencies for London and Middlesex and for Surrey are probably a result of exaggerated reports, but on the other hand a damaging type of hailstorm over these two counties could hardly fail to find a target of gardens, glass-houses and lights. Two other areas of secondary maxima are in the north-east Midlands and over the lower valley of the Severn and around the Bristol Channel.

Allowing for the fact that not every hailstorm which has caused severe damage has been recorded, the risk of any place being extensively damaged twice in a lifetime is small but since in 1955 the damage on one farm alone was reported to be £15,000, this is small consolation to the victims.

E. H. ROWSELL

High-level icing

A case of clear-air icing at low temperatures has been reported by Sqd.-Ldr C. B. Owen, D.S.O., D.F.C., A.F.C., who is on a conversion course at the R.A.F. station, Bassingbourn, Hertfordshire. The aircraft concerned was a Canberra and the icing occurred at approximately 1030 G.M.T. on December 6, 1955.

Sqd.-Ldr Owen reports that he was climbing on a heading of 290° from Bassingbourn, and the icing was first noticed on the front of the canopy near the top of the climb between 35,000 and 40,000 ft. At 40,000 ft. the aircraft levelled out and made a high-speed run on a northerly heading changing to a south-easterly heading. During the northerly run the ice on the canopy thickened appreciably, became thick enough to obscure visibility and persisted on the south-easterly run. Sqd.-Ldr Owen states that the ice was confined to the front of the canopy, and that the sides of the canopy remained completely clear. The icing disappeared during a maximum-rate descent and had all gone by the time the aircraft was down to 25,000 ft. All told the icing lasted for about 10 min.

At the time of the occurrence a cold front lay west to east across Scotland with broad westerly warm-sector conditions over England and Wales. The afternoon ascents from Hemsby, Crawley and Shoeburyness are probably most representative of the air in which the icing occurred, and detailed temperatures are given in Table I.

TABLE I—UPPER AIR TEMPERATURES REPRESENTATIVE OF AIR IN WHICH ICING OCCURRED

	Liverpool		Crawley		Hemsby		Shoeburyness
	0200 G.M.T.	1400 G.M.T.	0200 G.M.T.	1400 G.M.T.	0200 G.M.T.	1400 G.M.T.	1400 G.M.T.
	Tropopause						
ft.	42,000	39,000	44,000	44,000	44,000	41,000	42,000
°C.	−68	−63	−69	−68	−68	−63	−70
ft.	*degrees Celsius*						
40,000	−63	−63	−63	−63	−61	−61	−66
35,000	−52	−54	−50	−52	−51	−51	−54
25,000	−28	−28	−26	−27	−28	−28	−28

Although temperatures were generally low at 40,000 ft., there was a difference of 5°–7°C. between Hemsby and Shoeburyness from 36,000 to 42,000 ft. with Hemsby the warmer.

In the *Meteorological Magazine* for September 1954 Mr. G. W. Hurst has put forward an explanation of a case of clear-air icing. The Hemsby–Shoeburyness temperature gradient and the increase of ice on the northerly run are consistent with this explanation. What is more interesting, is that the ice first formed when the aircraft was climbing from warmer air to colder air.

W. B. PAINTING

[Mr. R. F. Jones points out that the high speed and low temperature at which the ice formation on the canopy reported by Sqd.-Ldr Owen occurred make it improbable that the formation can be ascribed to either impact and freezing of supercooled water droplets or to hoar frost. Mr. Jones considers it significant that many of the icing encounters at low temperatures report icing on the canopy only. He suggests that the aircraft reporting ice accretion at very low temperatures were, in fact, flying in thin cirrus—it is known from the experiences of the Meteorological Research Flight that it is very difficult to distinguish when an aircraft is in thin cirrus—and that the canopy, which is made of insulating material, is frictionally charged so that the ice crystals striking the canopy are held to it by electric force.

In this connexion it is noteworthy that Norinder and Siksna[1,2] in their papers on the electrification of snow found that an air blast containing snow crystals produced a positive charge on a plexiglas surface.

The canopy of the Canberra aircraft is made of polymethylmethacrylate and we are informed by the Government Chemist's Department that plexiglas (which is the United States term for "perspex") is a plastic of the methacrylate class.

Mr. R. Davis, Electricity Division, National Physical Laboratory informs us that the Aerodynamics Division, N.P.L. have experienced trouble, attributed to electrification, with perspex in wind tunnels.

Norinda and Siksna found the snow crystals carried away after impact to be positively charged. Chalmers[3] found the friction of ice on ice in absence of an air blast gives rise to a negative charge on the ice which agrees with the ice-friction theory of Simpson and Scrase[4] for the upper electric dipole of the thundercloud. Possibly the ice crystals striking the canopy were, if the electrical explanation is correct, already negatively charged and the adhesion between the negatively charged crystals and the positively charged canopy is responsible for the phenomenon.

Ed., *M.M.*]

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REVIEWS

Theoretical Hydromechanics. Pt. I, 5th edn. In Russian. By N. J. Kotschin, I. A. Kibel and N. W. Rose. 8½ in. × 5⅝ in., pp. 560, *Illus.*, Gos. Izdat. Tekh-Teoret. Lit., Moscow, 1955. Price: 11 *roubles* 70 *kopecks.*

The German translation by J. Sauer of the 4th edn of this book was reviewed by Sir Graham Sutton in the January 1955 number of the *Meteorological Magazine.*

We have now received from the authors a copy of the 5th edn. A number of additions have been made to the text and two of them are of meteorological interest. The first is an account of Dorodnitsyn's theory of the flow of a compressible fluid over infinitely long ridges at right angles to the wind, neglecting the rotation of the Earth. This has hitherto not, so far as the writer knows, been available in Great Britain. It is similar to Scorer's theory with the important difference that the wind is taken as constant with height. The boundary conditions of flow over an arbitrary surface are set up and elaborate formal solutions given. The description would have been greatly improved and comparison with British work facilitated if diagrams of the flow over ridges of definite shape had been included. The second is an account of Blinova's theory of the mean distribution of pressure at the earth's surface as a function of temperature, described as a theory of the "Centres of action", Icelandic low pressure, etc. Here again we have an elaborate formal theory lacking entirely in vividness by the absence of any diagrams or tables of numerical values to show how theory corresponds with fact. G. A. BULL

Atmospheric pollution: its origins and prevention. 2nd edn. By A. R. Meetham, 8½ in. × 5½ in., pp. x + 304, *Illus.*, Pergamon Press Ltd., London and New York, 1956. Price: 63*s*.

The fact that this book, which first appeared in 1952, should qualify for its second edition within four years is remarkable testimony to the growing awareness of atmospheric pollution as a problem which can and must be controlled. The author may also claim that the book is meeting successfully his main objective in writing it—to provide a comprehensive technical account of air pollution, with particular reference to Great Britain.

In the relatively short time since publication of the first edition, much has happened in connexion with pollution both in the research field and in the readiness of our legislators to introduce measures designed to abolish or reduce the worst effects. The London smog of December 1952 resulted in the formation by the Government of a committee of inquiry to examine the nature, causes and effects of atmospheric pollution and to make recommendations. The report of this committee led to the passing of the Clean Air Act and to a number of steps initiated by local authorities to keep specified areas free from industrial smoke. On the research side technical conferences in this country, in the United States and elsewhere have helped in the pooling of information and have been productive of a wealth of new ideas. In this second edition of his book, it is clear Dr. Meetham has taken account of all this new material not only in revising the original book but also in an additional chapter which contains, among other matters, a brief discussion of pollution from nuclear reactors.

The new edition is therefore thoroughly up to date and covers a wide range—the origin and use of fuels, domestic fires and industrial furnaces, the nature of pollution, its measurement and prevention, the meteorological and health aspects, the law and its administration. Each chapter is followed by a list of references to important papers and a classified bibliography is given at the end of the book. The printing, the diagrams and the photographs are of high order.

The book is warmly recommended to all whose work has a bearing on atmospheric pollution.

P. J. MEADE

HONOURS

Awards to civil airline personnel

It was reported in the July 1955 number of the *Meteorological Magazine* that in recognition of the value of weather reports from civil aircraft on standard routes the Air Ministry had decided to institute a number of awards to civil airline pilots providing the best series of such reports.

Captains A. Caesar-Gordon and F. A. Tricklebank, both of British European Airways Corporation, are the first recipients of these awards. They were presented with brief cases by the Director of the Meteorological Office at a ceremony held by the Guild of Air Pilots and Navigators at Londonderry House on July 24, 1956. Both Captains fly Viscount aircraft to most parts of Europe.

OBITUARY

Gustav J. H. Swoboda, Ph.D.—It is with very deep regret that we learn of the death in Geneva on September 4, 1956, after an operation, of Dr. Gustav J. H. Swoboda, recently Secretary-General of the World Meteorological Organization, and famed international figure in meteorology.

Dr. Swoboda was born in Prague in 1893 and was awarded his Ph.D. there in 1920. For the next 18 years he served as chief of the forecasting services in the State Meteorological Institute in Prague. He also lectured to the Technical College in Prague on meteorology. He made numerous contributions to scientific journals, mainly on synoptic meteorology. His best known work is probably "Wellen und Wirbel an einer quasistationären Grenzflache uber Europa" which was undertaken with T. Bergeron. He subsequently completed a translation into German of Khromov's classical textbook "Einfuhrung in die Synoptische Wetteranalyse".

Dr. Swoboda soon became associated with international meteorology. He was a member of the International Meteorological Organization Commissions for Synoptic Weather Information and for Aeronautical Meteorology. This experience together with his unusual linguistic ability and other qualifications well fitted him to succeed Dr. Cannegieter in 1938 as Chief of the Secretariat of the International Meteorological Organization which at that time had its Headquarters at De Bilt in Holland. Soon after taking up his appointment he carried out the plan already agreed by the International Committee to transfer the headquarters from De Bilt to Lausanne, Switzerland. As a consequence of this transfer Dr. Swoboda took up Swiss nationality.

After the Second World War the old I.M.O. which was a non-governmental organization composed of the Directors of the various national meteorological services, was transformed into the World Meteorological Organization, a specialized agency of the United Nations Organization, possessing official governmental status. It was natural that Dr. Swoboda should be appointed the first Secretary-General of this new organization.

For the next four and a half years Dr. Swoboda successfully guided the Organization from birth to its present maturity. In 1953 he was awarded the

Buys Ballot Medal by the Royal Netherlands Academy of Sciences. He retired as Secretary-General in August 1955 and was appointed professor of Meteorology in the Technical University of Istanbul.

Those of us who knew and worked with Dr. Swoboda will always remember those kindly and lovable personal qualities which so endeared him to all who had the privilege and pleasure to work with him. The helpful friendliness which he showed to all who sought his advice irrespective of race or nationality, and his rare charm will never be forgotten by his staff at the Secretariat who were not only his colleagues, but also his friends.

A. H. GORDON

METEOROLOGICAL OFFICE NEWS

Ocean weather ships.—The following are extracts from the Master's report of Voyage 72 of the *Weather Observer*.

There has been quite a lot of swimming and the usual whist drives, and the following classes are in progress; meteorology, radio, French, cinematograph operation, navigation, mathematics, photography and first aid. These classes are always popular in good weather.

August 7, 1956, 2100–2200. Ship's company exercised at "Night Air/Sea Rescue Drill", during which a flare path was laid, a lifebuoy dropped to represent survivors and a lifeboat recovered the "survivors". This was a very good exercise. The visibility was only 500 yd. at the time which added to the natural hazards. The lifeboat steamed down the flare path to recover the lifebuoy and used a compass on the way back. It was a pleasure to see the way in which the ship's company entered into the spirit of the exercise.

Note: During this voyage the ship's radar became defective owing to a damaged valve. A R.A.F. aircraft of Coastal Command during an air/sea rescue exercise successfully dropped a new valve in a watertight canister attached to a parachute (together with some newspapers) and the radar was soon serviceable again. This is the first time a parachute has been used for the purpose of dropping "spares" from aircraft to weather ships; if a parachute is not used the valves are invariably damaged.

WEATHER OF SEPTEMBER 1956

Mean pressures for the month showed departures up to −5 mb. in 50°N. 20°W. over the Atlantic and +3 to 4 mb. over eastern Europe, where a 1020-mb. anticyclone appeared near the Russo-Polish frontier. Pressure was lowest (1006 mb.) over the Atlantic south-west of Iceland. The pattern so defined differs considerably from the normal over the eastern Atlantic, where a fairly sharp trough occurred, and western Europe where there was a mean pressure gradient for rather weak southerly winds. Over north America the pattern and the pressure values were close to normal.

The September distribution also marked a radical change from August in the nearer parts of the hemisphere. As early as August 24 the anticyclone which had been prominent over Greenland began to move south-east towards Europe: this cell became stationary off Ireland about the turn of the month and depressions continued to affect Britain and central and southern Europe during the first part of September. Further anticyclonic cells moved from northern Greenland to central Europe, and two more moved east from the Atlantic. By about the middle of September slow-moving anticyclones were dominating most of Europe and continued to do so till almost the end of the month. This was the first real break in the wet weather of the summer in many parts of the region.

Temperature averages were slightly above normal for September over nearly all western and central Europe, being warmer than August 1956 in some places especially in the west. Canada and the eastern half of the United States were generally cooler than normal (anomaly −3° to −5°C. between the Great Lakes and Hudson's Bay: the axis of the cold region in terms of surface temperatures was about 80°W.).

Rainfall was below normal over the eastern half of Europe. In the western half the distribution was more patchy with over twice the normal over central France, Brittany and parts of south-west England. There was also above-normal rainfall in north-west and north-east Canada (over 400 per cent. at St. John's, Newfoundland). Most of the United States and central Canada were dry, widely scattered points having almost no rain.

In the British Isles the weather during the first 17 days of the month, apart from a few days around the 12th, was dominated by shallow depressions off the south-west coasts; the remainder of the month was generally dry and mild, although the last four days were cooler and rather stormy.

The first week was dull and in places very wet. A shallow depression, which was situated over the Bay of Biscay on the 1st, moved slowly northward until it was centred over Cornwall on the 3rd; outbreaks of thundery rain occurred extensively in England and Wales with scattered thunderstorms; rain was heavy at times particularly in the south. On the 4th a depression from the Atlantic moved east-north-east to the Irish Sea where it became very active the following day as it was joined by a cold-front wave depression from the Bay of Biscay. Rain, heavy locally, was widespread on the 5th and 6th (2¼ in. fell at Aberdeen in 24 hr.) and on the 7th showers were frequent as the depression moved eastward to the North Sea. The second week was drier though the weather remained dull. Easterly or south-easterly winds were maintained over the British Isles, with occasional slight rain or drizzle, principally in the south during the 8th and 9th by a quasi-stationary depression off the south-west coasts which later moved southwards to Madeira. On the 11th the Azores anticyclone began to spread eastwards, but there was widespread rain over the British Isles as a trough, associated with a complex depression in the region of Iceland, crossed the country. By the 13th the anticyclone from the Azores was centred over north-west France and tropical air spread over the British Isles from the south-west as a low-pressure system, which had developed from a tropical storm off the United States, approached Iceland. There were severe gales in the north of Scotland but temperatures in England exceeded 70°F. at a number of places and reached 76°F. at London Airport and Dishforth, Yorkshire. Humidities were high and fog was persistent along the eastern coasts of England and Scotland and developed at times in the English Channel. On the 14th, a depression which had been off the south-west coasts on the 8th returned to that area after an excursion in the meantime to Madeira, and for the next few days pressure remained low to the south-west and high over the north of the British Isles. Most of the third week was cloudy in the south with a little rain here and there and fog at sea, but in the north weather was mainly dry and sunny with 10 hr. of sunshine on some days in northern England and southern Scotland. Pressure was low in the eastern Atlantic from the 18th to the 23rd and winds over the country were mainly from the south or south-east. Warm air spread slowly northwards and fairly widespread morning fog became a daily feature, and there was an increasing tendency for thunderstorms. After nearly two weeks with only slight rainfall, thundery rain broke out on the 21st and continued for several days in some western districts, but weather remained mainly dry in the east and Midlands for much of the fourth week. Temperatures rose again to the middle seventies locally on the 22nd–25th and remained above 60°F. at night in many places in England and Wales on the 21st and 23rd. On the 25th fog was widespread over much of the country although parts of East Anglia remained fine and warm. Wind freshened and rain spread from the Atlantic across the British Isles on the 27th; rainfall was heavy locally with falls of more than 2 in. in some places; wind reached gale force with gusts of 50–60 kt. A strong south-westerly and showery air stream covered the country during the last few days of the month.

Rainfall was heaviest during the first week being three times the average in the south of England, but taking the month as a whole it was above the average over most of the country except in east coast regions from Kent to Durham, much of East Anglia and the east Midlands, Cumberland and north-west Scotland. It was twice the average over a large part of south-west England. Many places in southern England reported a period of absolute drought from the 12th to the 26th and many others only missed recording one because of local thunderstorms on the 21st. Except for the first week, temperatures were generally above normal. Sunshine was almost everywhere below average and generally amounted to only three-quarters of the normal. At Pembroke Dock it was the dullest September since records began in 1892. The warm dry period during the latter part of the month was the first break in the very wet weather which prevailed throughout most of the summer, and has enabled farmers to finish work on what might otherwise have been a disastrous harvest. The late summer rainfall has ensured good vegetable crops for the early winter.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	80	30	+1·1	146	0	75
Scotland	76	26	+1·1	131	0	73
Northern Ireland ...	72	36	+0·9	122	+3	69

RAINFALL OF SEPTEMBER 1956

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·14	118	*Glam.*	Cardiff, Penylan ...	5·46	179
Kent	Dover	2·21	96	*Pemb.*	Tenby	4·69	149
,,	Edenbridge, Falconhurst	3·04	134	*Radnor*	Tyrmynydd	6·54	169
Sussex	Compton, Compton Ho.	4·71	49	*Mont.*	Lake Vyrnwy	5·20	144
,,	Worthing, Beach Ho. Pk.	3·17	148	*Mer.*	Blaenau Festiniog ...	9·60	122
Hants.	St. Catherine's L'thouse	3·68	154	,,	Aberdovey	5·16	161
,,	Southampton (East Pk.)	4·38	201	*Carn.*	Llandudno	2·63	124
,,	South Farnborough ...	3·50	183	*Angl.*	Llanerchymedd ...	4·83	164
Herts.	Harpenden, Rothamsted	2·14	110	*I. Man*	Douglas, Borough Cem.	4·45	136
Bucks.	Slough, Upton	2·58	146	*Wigtown*	Newton Stewart ...	4·72	138
Oxford	Oxford, Radcliffe ...	2·36	138	*Dumf.*	Dumfries, Crichton R.I.	5·10	188
N'hants.	Wellingboro' Swanspool	1·70	94	,,	Eskdalemuir Obsy. ...	4·79	129
Essex	Southend, W. W. ...	1·73	104	*Roxb.*	Crailing...	1·89	93
Suffolk	Felixstowe	1·48	89	*Peebles*	Stobo Castle	2·99	119
,,	Lowestoft Sec. School ...	1·13	58	*Berwick*	Marchmont House ...	3·42	142
,,	Bury St. Ed., Westley H.	1·74	87	*E. Loth.*	North Berwick Gas Wks.	3·49	169
Norfolk	Sandringham Ho. Gdns.	1·48	71	*Midl'n.*	Edinburgh, Blackf'd. H.	3·83	187
Wilts.	Aldbourne	3·60	171	*Lanark*	Hamilton W. W., T'nhill	4·48	167
Dorset	Creech Grange... ...	5·91	216	*Ayr*	Prestwick	3·58	139
,,	Beaminster, East St. ...	6·50	254	,,	Glen Afton, Ayr San. ...	5·08	130
Devon	Teignmouth, Den Gdns.	5·80	296	*Renfrew*	Greenock, Prospect Hill	4·75	106
,,	Ilfracombe	5·32	198	*Bute*	Rothesay, Ardencraig ...	5·30	131
,,	Princetown	12·96	254	*Argyll*	Morven, Drimnin ...	5·24	93
Cornwall	Bude, School House ...	...	...	,,	Poltalloch	5·27	115
,,	Penzance	6·67	228	,,	Inveraray Castle ...	7·54	117
,,	St. Austell	5·95	187	,,	Islay, Eallabus	4·31	103
,,	Scilly, Tresco Abbey ...	4·38	171	,,	Tiree	4·22	114
Somerset	Taunton	4·93	248	*Kinross*	Loch Leven Sluice ...	3·82	149
Glos.	Cirencester	4·18	183	*Fife*	Leuchars Airfield ...	4·19	217
Salop	Church Stretton ...	3·77	179	*Perth*	Loch Dhu	8·13	142
,,	Shrewsbury, Monkmore	2·36	145	,,	Crieff, Strathearn Hyd.	6·00	210
Worcs.	Malvern, Free Library...	3·86	200	,,	Pitlochry, Fincastle ...	5·78	230
Warwick	Birmingham, Edgbaston	2·88	146	*Angus*	Montrose, Hospital ...	4·35	219
Leics.	Thornton Reservoir ...	2·47	137	*Aberd.*	Braemar	4·36	174
Lincs.	Boston, Skirbeck ...	1·44	82	,,	Dyce, Craibstone ...	4·79	198
,,	Skegness, Marine Gdns.	1·22	67	,,	New Deer School House	2·51	100
Notts.	Mansfield, Carr Bank ...	2·76	150	*Moray*	Gordon Castle	2·26	90
Derby	Buxton, Terrace Slopes	4·11	127	*Nairn*	Nairn, Achareidh ...	2·95	140
Ches.	Bidston Observatory ...	2·94	122	*Inverness*	Loch Ness, Garthbeg ...	5·15	167
,,	Manchester, Ringway...	2·10	93	,,	Loch Hourn, Kinlochourn	8·72	98
Lancs.	Stonyhurst College ...	4·86	127	,,	Fort William, Teviot ...	7·79	122
,,	Squires Gate	2·93	108	,,	Skye, Broadford ...	5·69	82
Yorks.	Wakefield, Clarence Pk.	2·53	158	,,	Skye, Duntulm ...	4·33	94
,,	Hull, Pearson Park ...	1·39	81	*R. & C.*	Tain, Mayfield... ...	3·53	154
,,	Felixkirk, Mt. St. John...	2·44	134	,,	Inverbroom, Glackour...	2·57	58
,,	York Museum	1·86	114	,,	Achnashellach	6·01	87
,,	Scarborough	1·24	69	*Suth.*	Lochinver, Bank Ho. ...	2·38	68
,,	Middlesbrough... ...	1·43	86	*Caith.*	Wick Airfield	1·89	76
,,	Baldersdale, Hury Res.	4·45	174	*Shetland*	Lerwick Observatory ...	2·39	79
Norl'd.	Newcastle, Leazes Pk....	3·05	154	*Ferm.*	Crom Castle	4·31	154
,,	Bellingham, High Green	2·75	115	*Armagh*	Armagh Observatory ...	3·17	129
,,	Lilburn Tower Gdns. ...	2·65	112	*Down*	Seaforde	4·67	170
Cumb.	Geltsdale	2·69	96	*Antrim*	Aldergrove Airfield ...	2·34	94
,,	Keswick, High Hill ...	4·10	97	,,	Ballymena, Harryville...	2·55	82
,,	Ravenglass, The Grove	3·06	91	*L'derry*	Garvagh, Moneydig ...	3·68	124
Mon.	A'gavenny, Plâs Derwen	5·18	202	,,	Londonderry, Creggan	4·08	124
Glam.	Ystalyfera, Wern House	8·09	185	*Tyrone*	Omagh, Edenfel ...	3·08	101

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SNOW SURVEY OF GREAT BRITAIN

Season 1955–56

The basic material for this report has been obtained, as in previous years, from returns made by voluntary observers who have provided, month by month, daily records of snowfall and of any snow cover in sight. These records, from a network of stations distributed over the country, are augmented by data extracted from the regular monthly returns from official weather stations and from voluntary climatological stations reporting to the Meteorological Office. Without the co-operation of all those responsible for these voluntary observations, this report could not have been prepared in anything like its present detail.

The measurements of snow depth are given in inches and refer in general to 0900 G.M.T. or thereabouts.

Summary of 1955–56 season.—Snowfall was about average, taking the season as a whole, and occurred mainly during January and February. There was little snow in November or after March except in Scotland. During January snow was most frequent in Scotland, but in February it was almost as frequent in the Midlands and eastern England as further north. Figs. 1 and 2 show the number of days of snow falling and snow lying respectively during the season and are based on observations from some 450 stations. Snow fell on more than 70 days in the Grampians, 50 over the high ground in the Southern Uplands, 40 in the Pennines and 30 over most of the country north of a line roughly from Aberystwyth, Cardiganshire, to Felixstowe, Suffolk, except western coastal districts, areas around the Humber basin and a broad belt across the country from the Firth of Clyde to the Firth of Forth. Few places had less than 10 days of snow and these were mainly along the south-west coast. The number of days with snow lying (at 0900 G.M.T.) during the season exceeded 60 in the Grampians, 50 in the Cheviots and northern Pennines, and 40 around Buxton, Derbyshire, the Yorkshire Wolds, the North Yorkshire Moors and in parts of Ross and Cromarty, Scotland. Snow lay for less than 10 days in most south and west coastal areas. For most of the country snow was deepest around February 21 (Fig. 3). Undrifted snow had on that day accumulated to a level depth of more than 10 in. in Kent, 8 in. in parts of East Anglia, Lincolnshire and Durham, and more than 12 in. in parts of the East Riding of Yorkshire and around the Cairngorms.

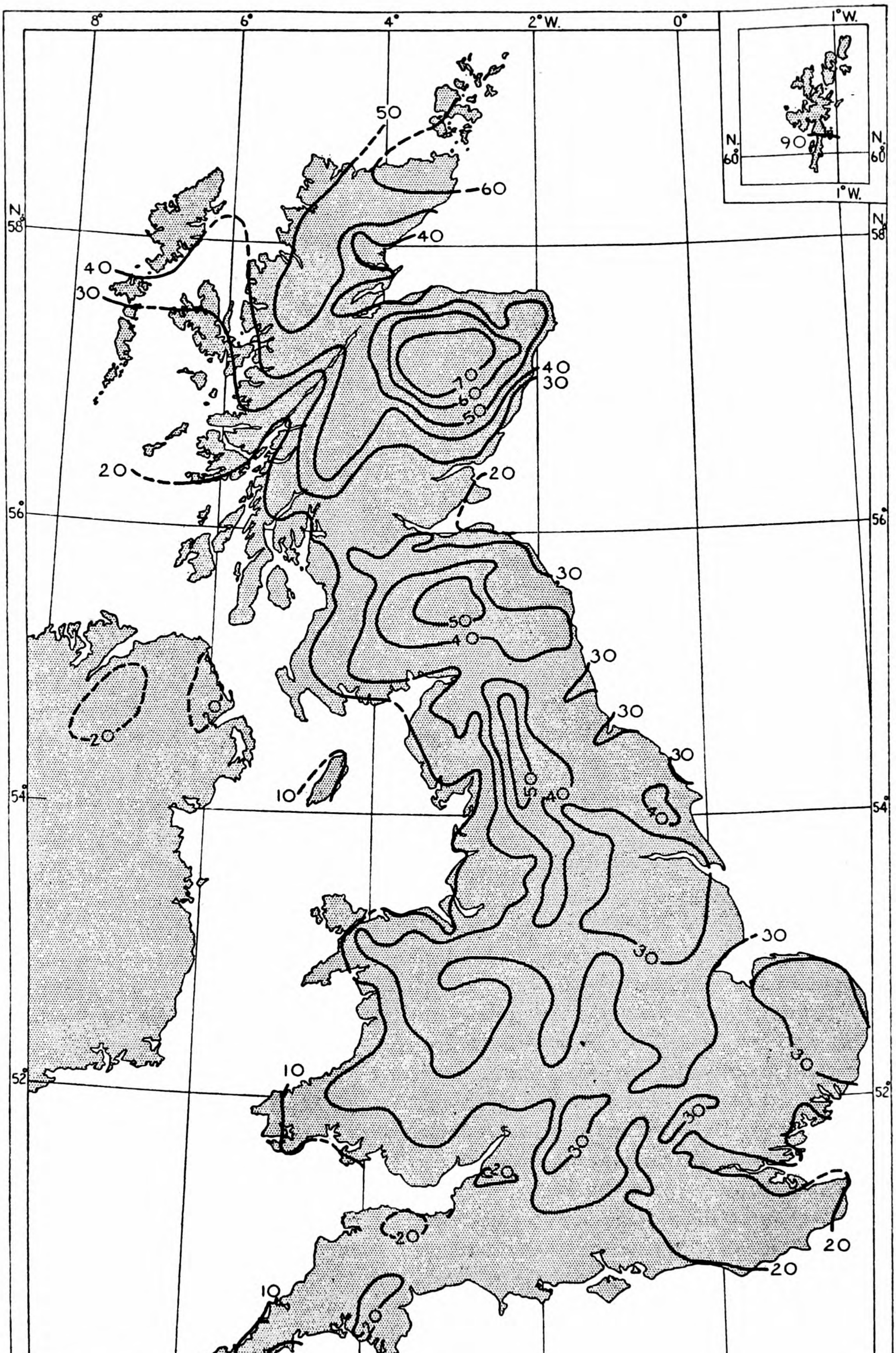

FIG. 1—NUMBER OF DAYS OF SNOW FALLING SEPTEMBER 1955 TO MAY 1956

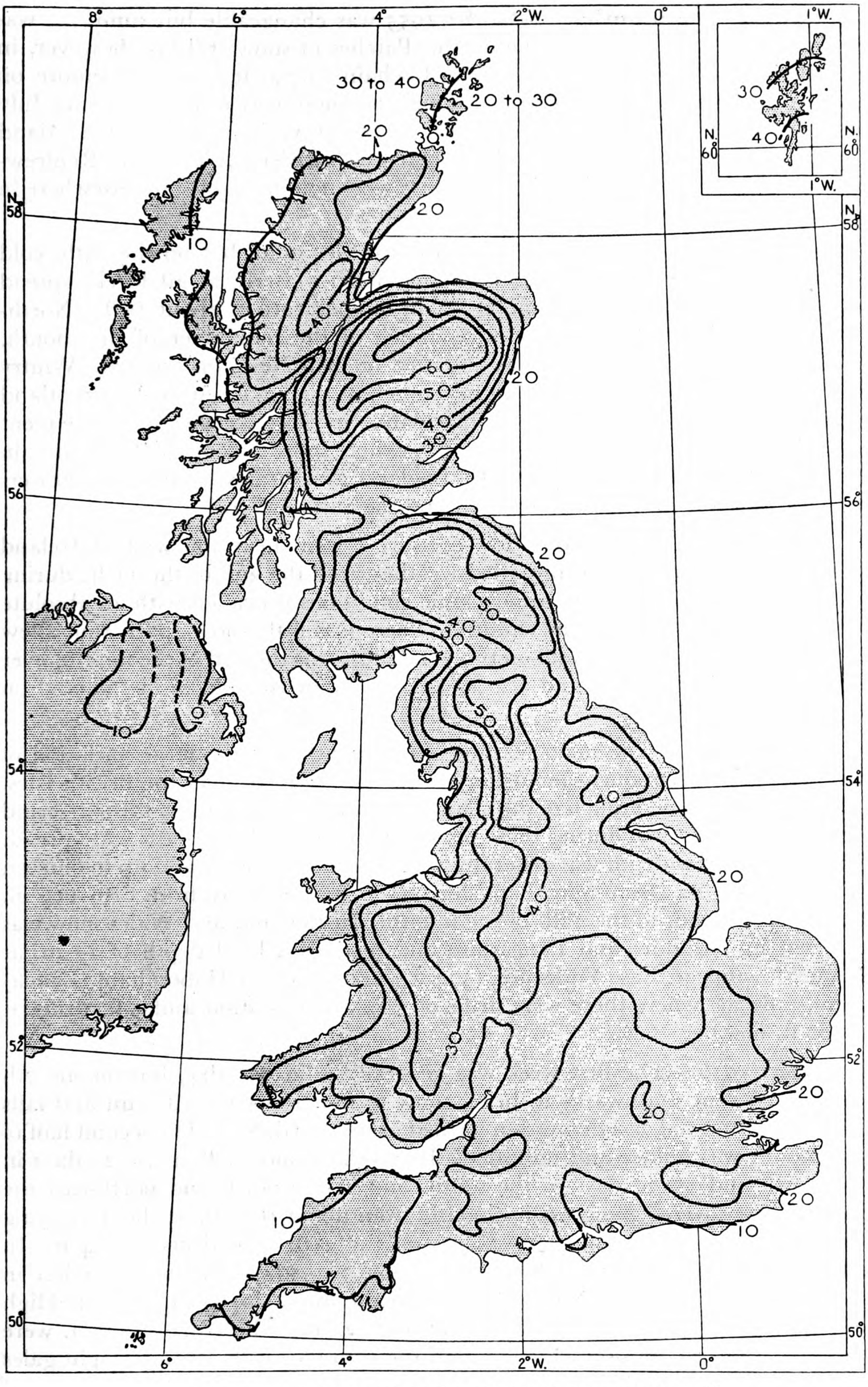

FIG. 2—NUMBER OF DAYS WITH SNOW LYING
SEPTEMBER 1955 TO MAY 1956

Notes on the months.—*September 1955* was changeable but sunny; it was rather warm, particularly in the north. Patches of snow still lay, however, in sheltered areas around Loch Coire an Lochain (3,750 ft.) near Aviemore on the River Spey, Inverness-shire, although no snow was reported during July and August. Slight snow fell on eight days at various places in Scotland including Kinlochewe (Ross and Cromarty), Aberdeen, Greenock (Renfrewshire), and Hawick (Roxburgh), but there were no reports of snow elsewhere in the British Isles.

October 1955.—The first two weeks were rather mild, but on the 15th, cold polar air, with wind direction becoming north-westerly at all levels, spread over the country causing a general fall of temperature of about 15°F. North-westerly winds predominated during much of the remainder of the month. The first snow of the winter was observed on Ben Nevis on the 3rd. Wintry showers occurred around the 16th and much of the higher ground in Scotland was continuously under snow from that date. Snow showers were also frequent during the last few days of the month when snow lay on high ground in Scotland to a depth of 1–3 in. In England and Wales local snow showers occurred mainly in the north-west around the 16th and 26th.

November 1955.—A complex low-pressure system near the west of Ireland maintained generally mild unsettled weather from the 2nd to the 11th; during the remainder of the month anticyclonic conditions prevailed with an absolute drought in many parts of the country. There was little snow apart from a few slight showers on the 2nd, and on three days towards the end of the month, over high ground in Scotland and also locally at one or two places in England on the 2nd and 24th.

December 1955.—The main feature of the month was the large variation of temperature with frequent incursion of polar or arctic air over the British Isles. This cold air affected much of the country on the 7th, 10th–12th, 17th–21st and 30th–31st, and it was during these periods that snowfall was most widespread. In Scotland snow depth was generally 1–2 in. in the lowlands and up to 6 in. on high ground. At Drummuir, Banffshire, (500 ft.) snow lay from 6 to 11½ in. deep from the 9th to the 28th of the month. In England and Wales snow was heaviest in Yorkshire and Lancashire and reached a level depth of 13 in. at High Mowthorpe, East Yorkshire, (574 ft.) and 12 in. at Habergham, Lancashire, (780 ft.) where there were drifts of 3 ft. at the station and 5-ft. drifts at 1,000 ft. nearby.

January 1956.—The first week was generally mild and dry, but on the 7th arctic air swept southwards to bring snow to much of Great Britain and falls became substantial as a depression formed in the North Sea. The second half of the month was milder and unsettled. In Scotland snow fell on 20–25 days in the north and 15–20 days in the south, and in the north and north-east the ground was covered almost continuously from about the 7th to the 31st, lying to a depth of 8–12 in. in many places on the 24th with drifts of 3–4 ft. In England and Wales snow fell in general on 7–15 days and was heaviest in north-east England and North Wales. On the 8th it lay 9 in. deep at High Mowthorpe (574 ft.) and 8–9 in. at Lincoln (22 ft.) where drifts of 4 ft. were reported. The depression which crossed the country on the 10th brought gales and widespread snow. Heavy continuous snow fell for 11 hr. in parts of Lincolnshire and lay to a depth of 15 in. Heavy falls of snow occurred on the

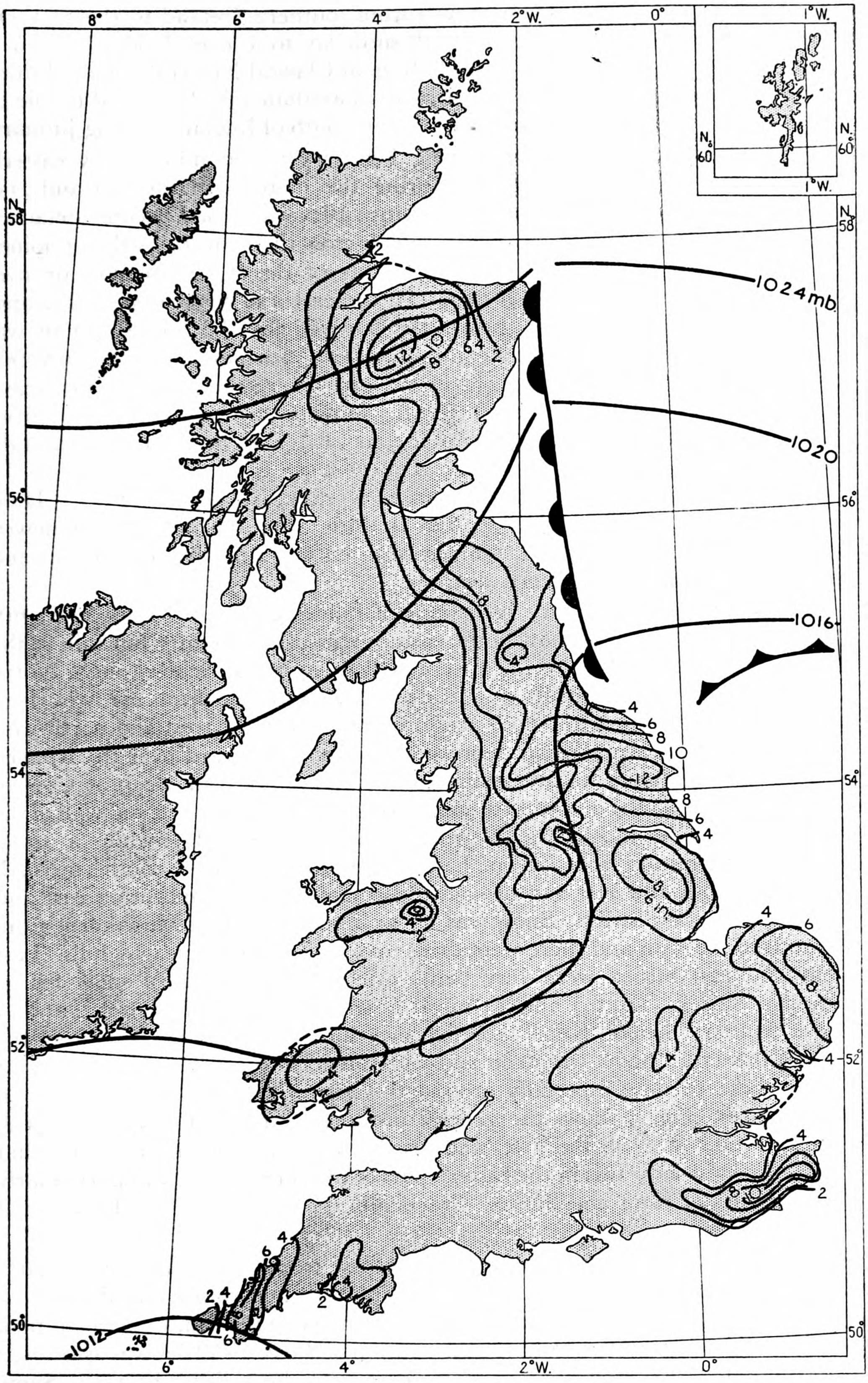

FIG. 3—SNOW DEPTHS AT 0900 G.M.T. AND PRESSURE DISTRIBUTION AT 1200 G.M.T., FEBRUARY 21, 1956

22nd and 23rd as a depression moved from southern Ireland to the southern North Sea. From the 23rd to the 25th snow lay to a level depth of 10 in. at Hirnant, Radnorshire, (1,250 ft.) and 18 in. at Clawdd-Newydd, Denbighshire, (998 ft.), where there were drifts nearby of more than 3 ft. Snow did not lie on the ground to any great extent in the extreme south of England during January.

February 1955.—The weather during February was dominated by easterly winds from the continent. Twice during the month, on the 9th and 21st, anticyclones over or to the west of the British Isles which had become detached from the continental high, formed a ridge across the country as they rejoined the major system, bringing renewed bursts of direct continental air over England with frequent snow showers. In the east and south-east of England, where temperature was 9°F. below the average for the month, there was widespread snow with periods of continuous frost. Scotland was not so severely affected as during January, except in the east where there were some heavy falls. At Balmoral, Aberdeenshire, (927 ft.) snow lay 10 in. or more deep from the 19th to the 22nd. At Drummuir (500 ft.) and Sourhope, Roxburgh, (900 ft.) it accumulated to a depth of more than 8 in. about the 21st. In England snow lay 2 in. deep at Sprowston, Norfolk, (93 ft.) and 7 in. at Hull, East Yorkshire, (8 ft.) on the 1st. On the 9th, with the advent of renewed continental air over England, temperature fell generally below freezing and snow became heavy in eastern districts.

Associated with temporary incursions of milder air on the 12th and 16th there were further falls of snow in the eastern part of the country but rain in the west. On the latter date 10 in. of snow fell in 24 hr. at Scarborough, North Yorkshire, (118 ft.) and drifts 3–4 ft. deep were reported from many parts of Yorkshire. On the 19th and 20th pressure was high to the west and north-west of the British Isles while small depressions moved southward over the western part of the country in an arctic air stream. Snow lay 8 in. deep at Cowpe, Lancashire, (1,000 ft.) on the 21st and Cornwall had its heaviest snowfall of the winter with 8–10 in. in the Newquay–Lizard area. Meanwhile a small secondary depression from Europe had become situated in the southern North Sea on the 20th and 21st and brought deep snow to Kent and other east and south-east coastal districts. Snow was 12–14 in. deep at High Mowthorpe from the 20th to the 24th and there were drifts up to 3 ft. deep on nearby hills. East Kent and east Sussex were very badly affected. Seven in. of snow fell at Hastings, Sussex, (149 ft.) and 13 in. at nearby Sedlescombe (170 ft.), and at Dover Military School, Kent, (402 ft.) level snow was 9–12 in. deep from the 18th to the 27th. Snow was deep and widespread in the extreme east of Kent during these 10 days especially around the 21st with drifts 6–12 ft. deep in many places. Fig. 3 shows the general pressure distribution over the British Isles at 1200 G.M.T. on the 21st, and also shows how at 0900 G.M.T. on that day the deepest snow was in the eastern part of the country and was particularly deep in parts of Kent and Sussex. Practically the whole of Great Britain had some snow cover.

March 1956.—Apart from a changeable first week with generally westerly winds, the weather during March was mainly dry and sunny and dominated by winds from the south and south-east. The movement of an upper cold pool north-westwards from the Balkans to the region of the British Isles was associated with the influx of colder air from the continent on the 14th to the 17th. Snow and sleet fell fairly widely in Scotland during this period and also during the first week. Snow cover was usually thin, but on the 17th snow lay 5½ in. deep at Glenshee, Aberdeenshire, (1,100 ft.), 2–3 in. at Braemar, Aberdeenshire, (1,113 ft.) and 1 in. in the Dundee area. Snow was fairly widespread in northern England and north Wales around the 16th, and there were some scattered snow showers in these areas around the 4th, but little snow in the south.

April 1956.—An anticyclone was centred over or near to the British Isles for most of this dry, sunny but cold month. Light northerly winds predominated. In north and east Scotland snow fell on most days from the 2nd to the 18th and around the 26th. It lay to a depth of 2½ in. at Glenmore Lodge, Inverness-shire, (1,071 ft.) and at Achnagoichan, Inverness-shire, (1,000 ft.) around the 15th. In England and Wales snow occurred mainly around the 17th and 27th, but in general the snow-line was between 2,000 and 3,000 ft. and little snow lay at the level of the observing stations.

May 1956.—Pressure was high over the British Isles for most of this very dry and sunny month, though depressions passing to the north-west frequently affected extreme north-western districts. In Scotland snow fell on 11 days; it was most widespread on the 18th when a few snow showers were also experienced over some of the higher ground of northern England and the Midlands. The snow-line was mainly above 3,000 ft. except in the extreme north of Scotland.

Duration of snow cover on British mountains.—The mean number of days of snow cover at 2,500 ft. on four mountain groups used as indices was 97 compared with an average of 83 for the past nine seasons. The stations used were Glenbrittle (Cuillin Hills 3,300 ft.*), Meggernie Castle (mountains round Glen Lyon 3,400 ft.*), Capel Curig (Snowdonia 3,500 ft.*) and Tairbull (Brecon Beacons 2,800 ft.*). Diagrams showing the distribution of snow cover relative to height for 11 stations are given in Fig. 4.

Harris, in the Outer Hebrides, was snow covered on October 13–21 and 24–30, but was free from snow during the whole of November. It was covered on December 7–13, 17–21 and 26–30, on January 5–31 (except the 29th) and on February 13–25. Snow cover was also observed 2 days in March, 5 days in April and 1 day in May.

The Cuillins of Skye were covered on October 14–19 and 25–29 and were free from snow during November. They were covered almost continuously from December 7 to March 13 except January 2–4 and February 7–8. Reports were incomplete during April but the peaks were snow covered for 7 days in May. Snow was observed to be down to sea level on 6 days during December, 4 days during January and 1 day in February.

The peaks around Glen Lyon were snow covered during the second half of October (except the 23rd and 24th), were free from snow during November and were almost continuously covered from December 8 to April 20, the snow extending below 1,000 ft. during much of January and February. Snow cover was observed on 1 day in May.

The Paps of Jura were covered on 6 days during December, on January 6–14, 17–18 and 21–25 and on February 15–27.

The Cairngorms were covered continuously from October 13 to May 25 except for November 5–7 and 25–30, 4 days in December, 1 day in January

* These values are mean heights of the mountain groups.

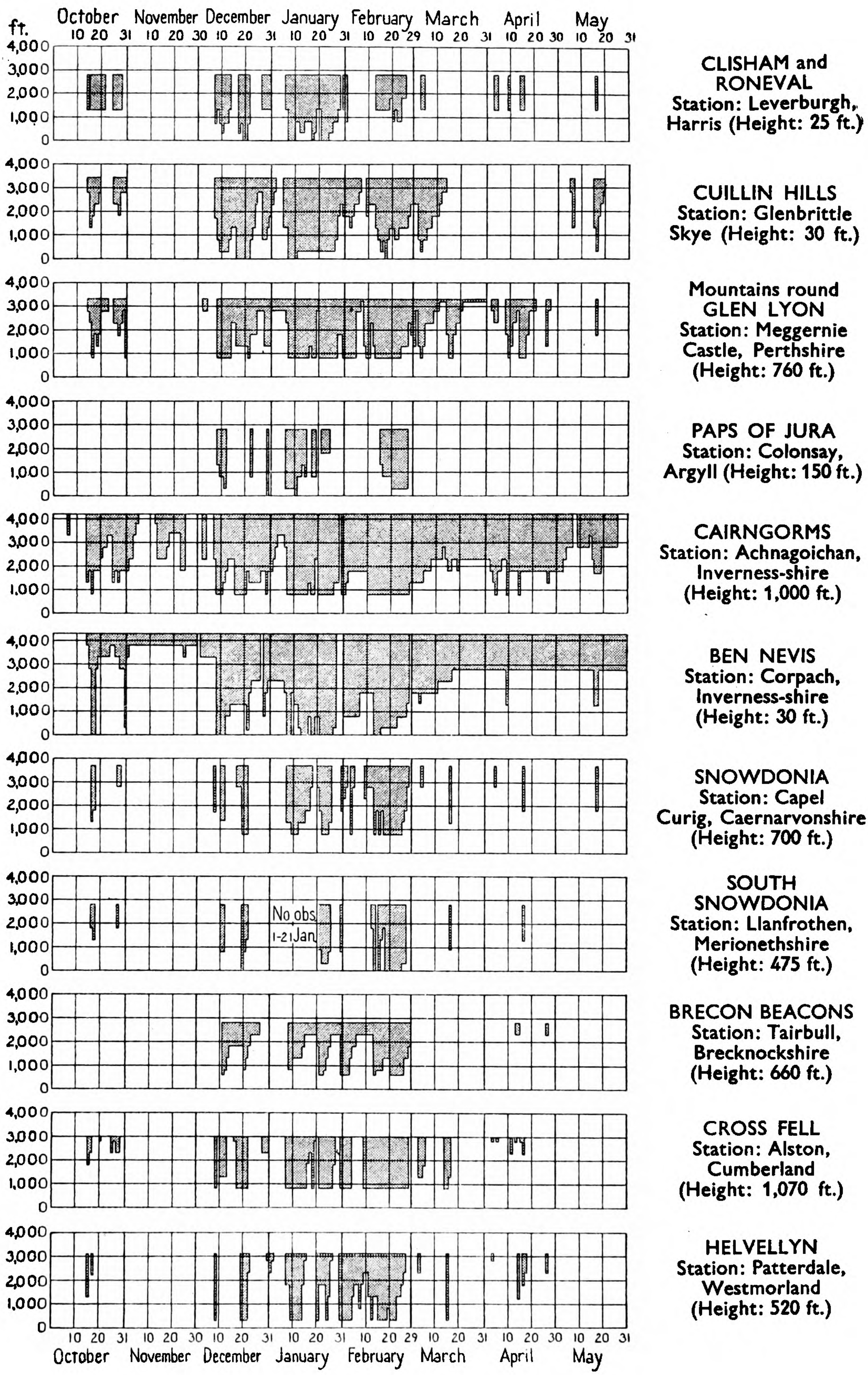

FIG. 4—DISTRIBUTION OF SNOW COVER IN RELATION TO HEIGHT

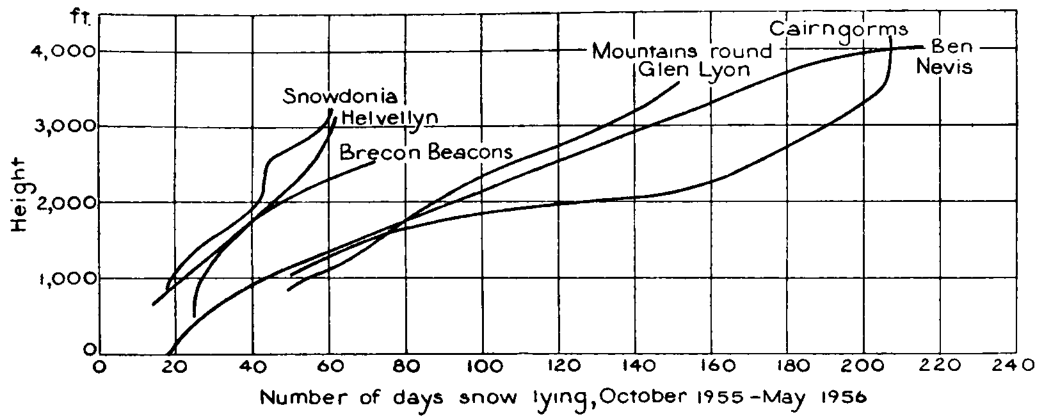

FIG. 5—SEASONAL DURATION OF SNOW COVER

and 2 days in May. Snow extended below 2,500 ft. from December 7–May 4 except for 5 days during the first week of January.

The summit of Ben Nevis was observed to be covered from October 13 until the end of the season except for November 30, December 27, January 28–30 and February 28. Snow extended below 3,000 ft. from December 8 until the end of the season except on the dates mentioned above when the summit was clear. Snow extended down to 1,000 ft. during the last three weeks of January and the first week and last two weeks of February except for the last three days.

The peaks near Capel Curig had snow cover above 3,000 ft. on 4 days during October, 8 days during December and from January 7 to February 27 except for January 8–9, 26–29 and February 2 and 5–8. Snow cover was also observed 2 days during March, 2 days during April and 1 day in May. Snow was reported down to sea level on most days during the third and fourth weeks of February.

The Brecon Beacons were snow covered at 2,500 ft. on December 12–26, January 8–February 28, and 3 days in April. Snow extended down to station level (660 ft.) on 1 day in December, 4 days during January and 10 days during February.

Cross Fell was snow-capped for 7 days in October, 13 days in December, from January 7 to February 27 (except February 4–8), on 6 days during both March and April and 1 day in May. Snow was observed down to station level (1,070 ft.) for much of the time from the second week of January until the end of February.

Helvellyn was snow covered for 2 days during October, 7 days during December, on January 7–15, 20–26 and January 30–February 26, and also 2 days during March and 4 days during April. Snow extended down to 2,000 ft. for most of this time, and down to station level (520 ft.) on 3 days during December, 9 days during January, 8 days during February and 1 dav in March.

Curves showing the total seasonal duration at six stations are drawn in Fig. 5; 200 days snow cover was exceeded on Ben Nevis at 3,300 ft. and on the Cairngorms at 4,000 ft., 100 days cover was exceeded on the mountains about Glen Lyon above 2,300 ft. and 50 days on the Brecon Beacons, Helvellyn and Snowdonia at 2,000 ft., 2,300 ft. and 2,800 ft. respectively.

AVERAGE PRESSURE AND TEMPERATURE OF THE TROPOPAUSE

By J. G. MOORE, B.Sc.

Introduction.—A study of the tropopause from the climatic point of view was undertaken as part of a larger investigation into the average distribution of upper air temperature over the world, the results of which have been approved for publication as a Geophysical Memoir[1]. In the course of the study charts were drawn of average pressure and temperature of the tropopause for the mid-season months. These were reproduced in a paper presented to the Meteorological Research Committee[2] of which the present note is a summary.

In this paper charts of the world (Figs. 1 and 2) are reproduced showing the average pressure of the tropopause in January and July, a distinction being made between polar and tropical tropopauses. Charts are also reproduced (Figs. 3 and 4) showing for the same months, on circumpolar projection, the average pressure and temperature of the polar tropopause for the north polar region. An attempt has been made to delineate the region in which both polar and tropical tropopauses are found. The variation through the year of the monthly averages of pressure and temperature at the tropopause is also briefly discussed.

Definitions.—The tropopause marks the boundary between the troposphere in which the temperature falls more or less regularly with increasing height and the stratosphere where temperature rises or changes little with height.

Although the height of the tropopause, for the most part, increases from pole to equator, the tropopause itself is not, as was once thought, a continuous surface but comprises two clearly defined surfaces. These two surfaces, the high tropopause of equatorial regions and the lower tropopause of middle and high latitudes, extend poleward and equatorward respectively to overlap in the subtropics and form a region of two tropopauses. These are referred to as the tropical and polar tropopauses respectively. Even on average temperature-height curves for the subtropics two tropopauses are often shown quite clearly and, this being the case, it was thought necessary to distinguish between them when drawing the charts.

It was not possible to apply the same tropopause definition to all the available data. Many of the data were taken from publications of other meteorological services or received in manuscript with the mean values already evaluated. In such cases the tropopause definition used was generally unknown.

When the tropopause pressures and temperatures were extracted from individual daily ascents, the following definitions were used.

(i) The first tropopause is defined as the lowest level at which the lapse rate decreases to 2°C./Km. or less for at least 1 Km. above.

(ii) If in any higher layer the lapse rate exceeds 2°C./Km. for at least 1 Km., then a second tropopause above the first is defined by the same ruling as under (i).

A comparison between the results obtained from the above definitions and from those recommended by the World Meteorological Organization for trial in 1954 showed that they differed significantly only at the tropical tropopause. Upon evaluating average monthly values these discrepancies largely disappeared.

Data used.—The data used were mainly radio-sonde observations made between the years 1940 and 1952 with observations for earlier years at a few stations. The number of years available at the different stations varied considerably and no attempt has been made to adopt a uniform period.

Charts.—The values of the average pressure of the tropopause in January and July are set out on Mercator charts of the world extending from 75°N. to 55°S. (Figs. 1 and 2). The values of the average pressure and temperature of the tropopause in the same months are shown on charts on circumpolar projection of the northern hemisphere between the pole and 55°N. (Figs. 3 and 4). Isopleths are drawn for intervals of 20 mb. of pressure for the polar tropopause and 10 mb. for the tropical tropopause. Isopleths of temperature for the polar tropopause are drawn at intervals of 4°C. Temperatures are given in degrees Absolute.

In regions where few data for the polar tropopause were available certain general principles were borne in mind: first, that unless there was strong evidence to the contrary, the isopleths should not diverge much from the mean wind flow of the middle troposphere, i.e. from the pressure contour lines, and secondly, that in temperate latitudes there is high positive correlation between the height of the tropopause and the temperature of the troposphere[3], and that pressure at the tropopause is therefore likely to be low over regions where the troposphere is relatively warm.

In equatorial regions, if data were insufficient, the isopleths were drawn largely by analogy with the temperature at 100 mb.

Over the greater part of the northern hemisphere the isopleths have been drawn with reasonable confidence in so far as their main features are concerned, except perhaps over the U.S.S.R. where the data available were very scanty. In the tropics although data were not numerous the values at different stations showed good agreement, and errors are therefore not likely to be large. Over the southern hemisphere, except in the region of Australasia, information was available for very few stations and little reliance can be placed on the lines.

Since the charts do not show values of average tropopause temperature for the whole world, the following table gives some indication of its distribution at latitudes south of 55°N. In these regions the distributions of average polar and tropical tropopause temperatures are mainly latitudinal.

Latitude	Average temperature of polar tropopause		Average temperature of tropical tropopause	
	January	July	January	July
	degrees Absolute			
40°N.	215	217	214	210
20°N.	...	...	194	199
0°	...	...	189	197

Region with two tropopauses.—In the subtropical regions of both hemispheres, roughly between latitudes 30° and 45°, two tropopauses are frequently indicated on the curves of ascent, but on some occasions there

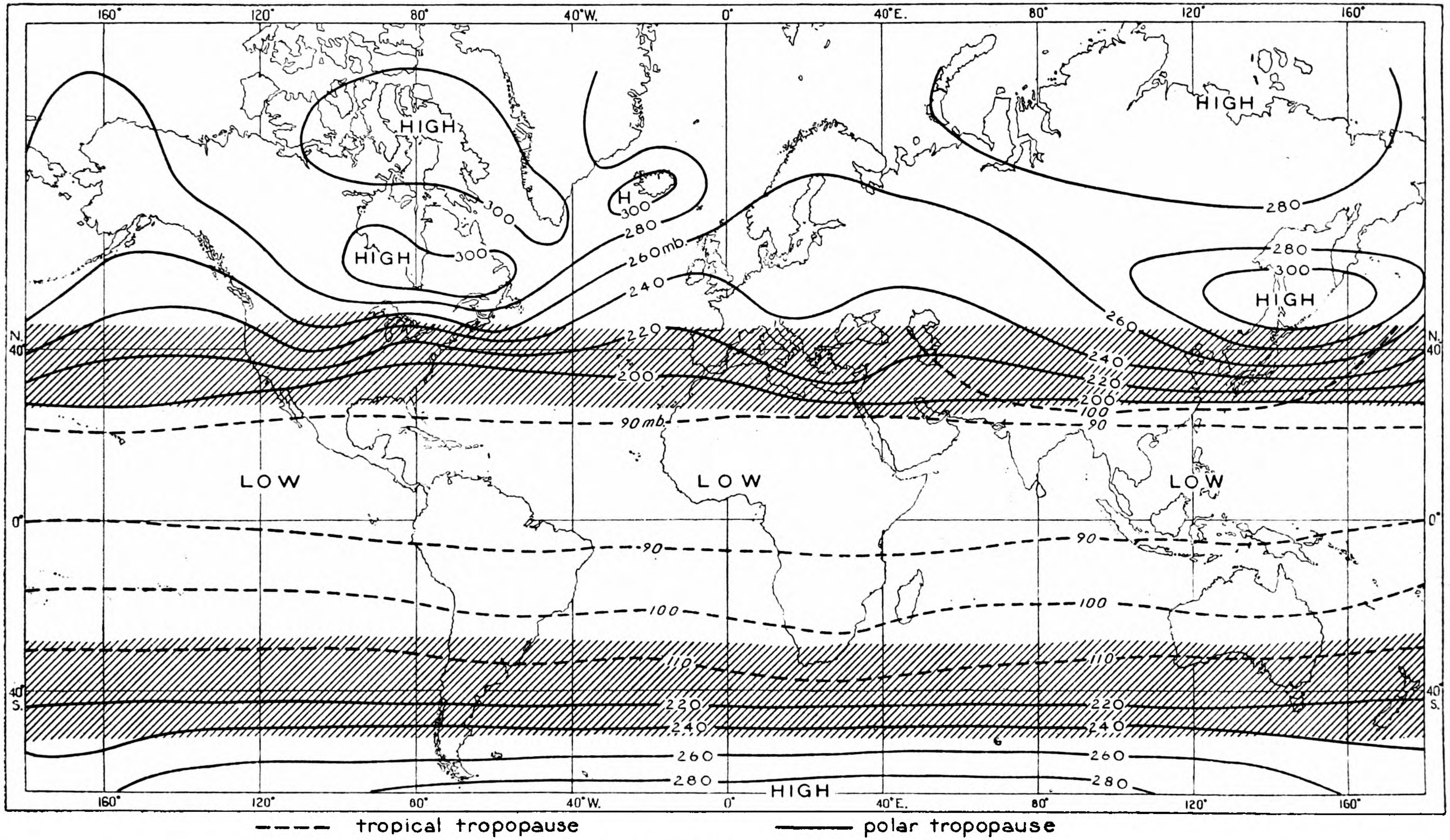

FIG. 1—AVERAGE PRESSURE OF THE TROPOPAUSE IN JANUARY

Areas in which frequencies of occurrence of both tropopauses are greater than 10 per cent. are shaded

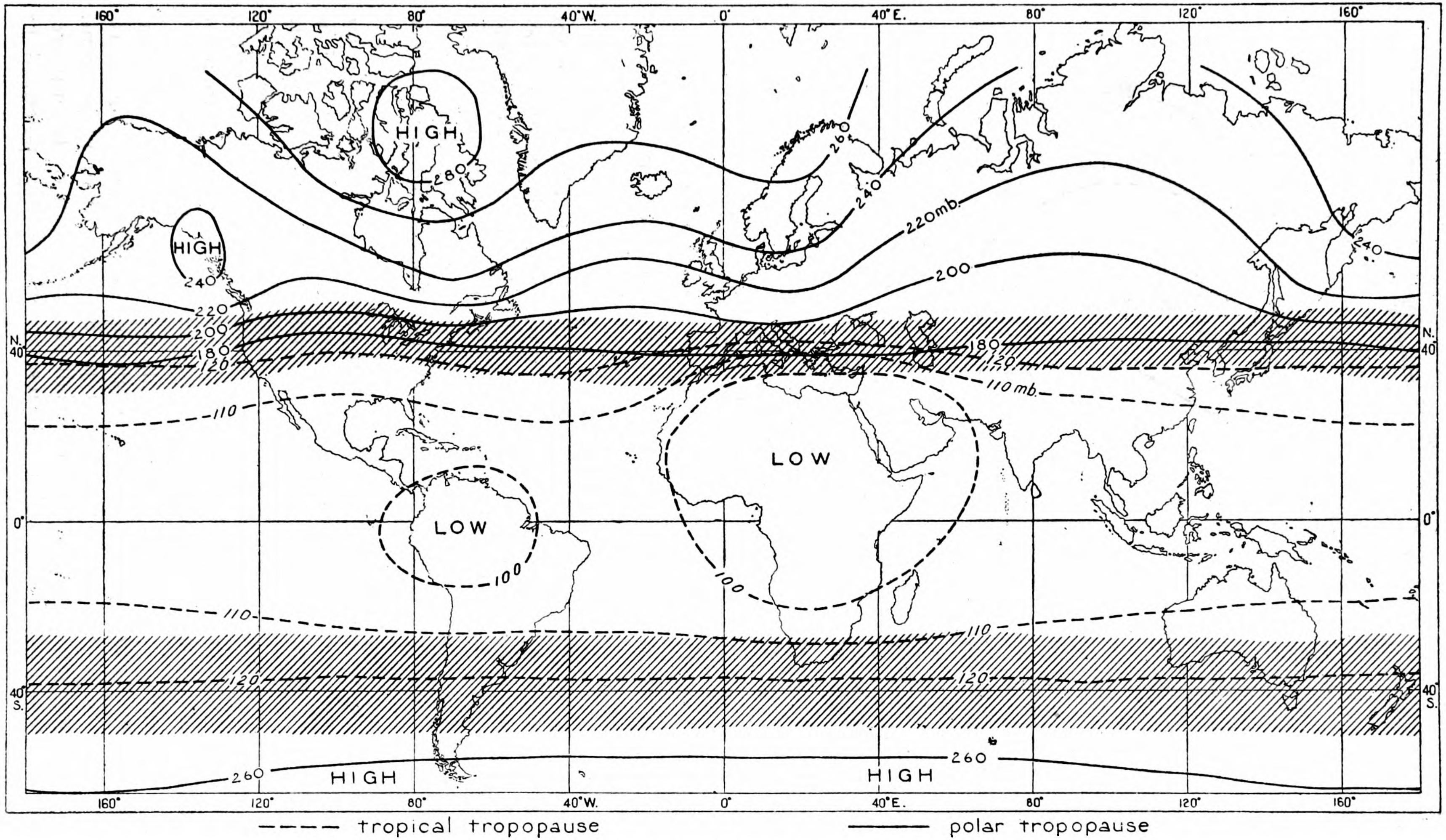

FIG. 2—AVERAGE PRESSURE OF THE TROPOPAUSE IN JULY

Areas in which frequencies of occurrence of both tropopauses are greater than 10 per cent. are shaded

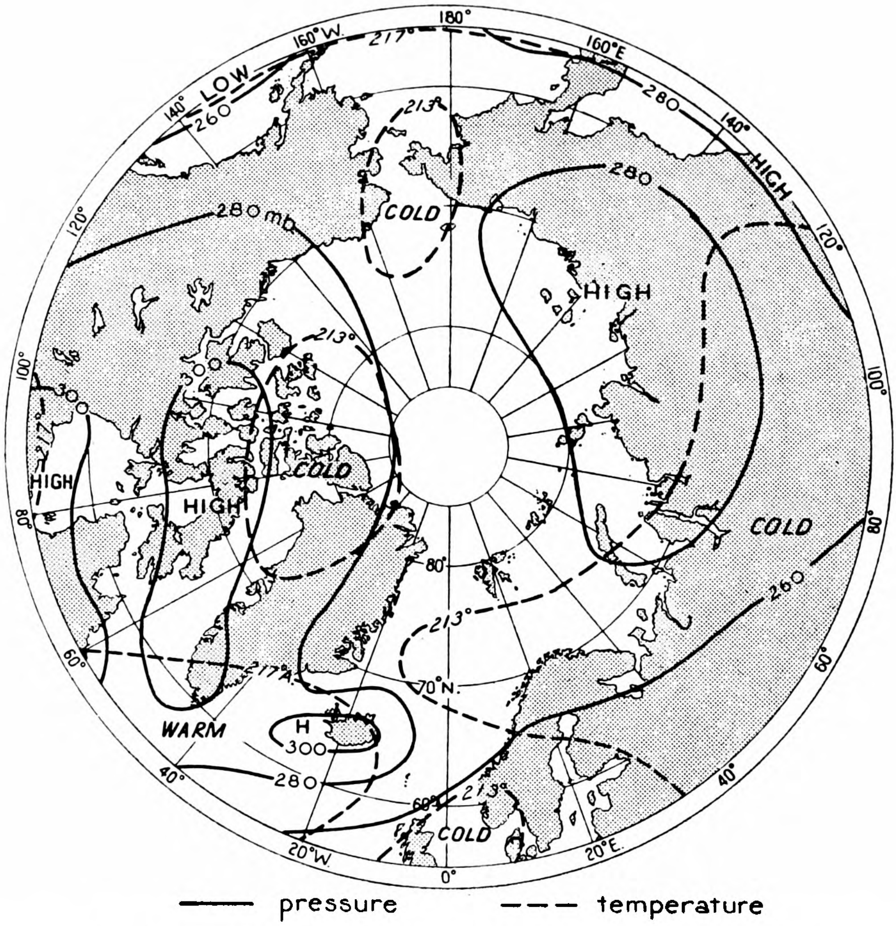

FIG. 3—AVERAGE PRESSURE AND TEMPERATURE OF THE POLAR TROPOPAUSE IN JANUARY

may be a polar tropopause only and on others a tropical one only. An attempt was therefore made to determine the frequencies with which the different types occurred. In order that the results should not be biased by the loss of records at great heights the data used were as far as possible restricted to those which reached 80 mb., unless below that level an upper tropopause had already been reached or its presence had been indicated by the existence of a tropospheric lapse rate above the lower tropopause.

The results show that, in any month, with increasing latitude the polar tropopause occurs more and more frequently until at a certain latitude it is always present, whereas the tropical tropopause occurs less and less frequently until finally it does not occur at all; similarly as the latitude decreases the tropical tropopause becomes more frequent until equatorward of a certain latitude it is always present whereas the polar tropopause becomes less frequent and finally ceases to appear at all.

In order to give an idea of the approximate poleward limit of the tropical tropopause and equatorward limit of the polar tropopause, areas on the charts are hatched where the frequency of both types is greater than 10 per cent. These limits are largely conjectural especially in the southern hemisphere. The data show that the tropical tropopause extends further poleward in

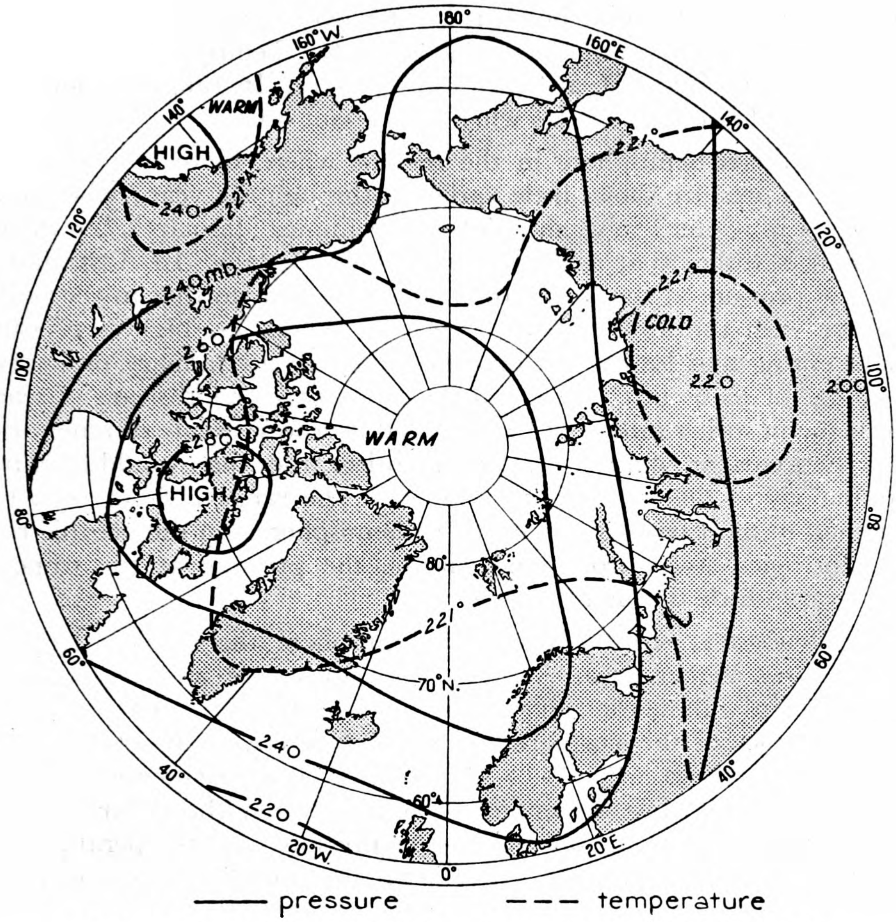

FIG. 4—AVERAGE PRESSURE AND TEMPERATURE OF THE POLAR TROPOPAUSE IN JULY

summer than in winter, reaching furthest north in July in the northern hemisphere and furthest south in January in the southern. The polar tropopause extends further towards the equator in winter than in summer but it reaches its lowest latitude in April in the northern hemisphere and in October in the southern.

At most stations in the zone of two tropopauses the polar tropopause is most frequent in spring and least frequent in summer, *e.g.* at Benina where it occurs on 78 per cent. of occasions in April but vanishes entirely in July. The tropical tropopause is most frequent in summer and least frequent in winter, *e.g.* at Gibraltar 80 per cent. in July compared with 45 per cent. in April.

In the transition regions from two tropopauses to a single tropopause the isopleths of pressure of the less frequent tropopause should be treated with reserve because of the relatively few occasions on which this tropopause exists.

Variation through the year.—Averages for all 12 months of the year have been computed for a few stations where the necessary data were avilable but, for the most part, the variation through the years has to be judged from data for the mid-season months only.

Polar tropopause.—In the northern hemisphere, in general, the pressure at the tropopause is highest in April and lowest in July. In most parts the difference is of the order of 40–60 mb., but it is greater over the large land masses and probably reaches 80–100 mb. over the U.S.S.R. Temperature is highest in July when pressure is lowest, and lowest in January. Its range is about 4–6°C. except over the large land masses where it is about 9°C.

In the southern hemisphere in the regions where there is a single polar tropopause its pressure shows little variation through the year. The temperature is lowest in winter (July) and highest in summer (January), but the range of variation is difficult to assess owing to lack of data. In Australasia the variation of pressure at the polar tropopause is similar to that in the northern hemisphere with the appropriate reversal of season, *i.e.* highest pressure in winter or spring and lowest in summer (frequently in January or February) with a range of 40–60 mb. Temperature on the other hand seems to reach its highest value in spring (around October) and its lowest in late summer or early autumn (February or March), *i.e.* three months earlier than would be expected on the analogy of the northern hemisphere. The range is 8° or 9°C. rather greater than in most parts of the northern hemisphere. In the oceanic regions of the subtropics, away from land masses, the pressure at the tropopause probably varies little through the year.

Tropical tropopause.—In the northern hemisphere the tropical tropopause generally shows higher mean values of both pressure and temperature in summer than in winter, the range being 15–20 mb. and 4–6°C. respectively. In the subtropics of the northern hemisphere, however, at such stations as Malta and Habbaniya where two tropopauses occur frequently for a large part of the year, during the summer months, when the polar tropopause ceases to exist or becomes infrequent, the pressure and temperature of the tropical tropopause depart from this pattern, and both fall instead of rising.

For those regions of the southern hemisphere where the tropical tropopause occurs frequently throughout the year, the few data available indicate that the annual variation of the pressure at the tropopause is less pronounced than in the northern hemisphere. With a range of 10–15 mb. the monthly mean tropopause pressure reaches its highest value in winter or spring and lowest in summer or autumn. Temperature shows a range of 6–8°C. with highest values in spring and lowest in summer or autumn.

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AVERAGE HEIGHT OF THE STANDARD ISOBARIC SURFACES OVER THE NORTH POLAR REGIONS IN JANUARY

By H. HEASTIE, M.Sc.

Introduction.—*Geophysical Memoirs* No. 85 "Upper winds over the world"[1] includes seasonal charts of the average heights of the isobaric surfaces 700, 500, 300, 200 and 130 mb. These charts were necessarily based on data for earlier years when the network of upper air stations was, in most parts of the world, extremely sparse. All available data were used irrespective of period, but the approach had still to be largely statistical. It was realized at the

Ilford F.P.3. 1/50th sec., f5.6, orange filter. *Reproduced by courtesy of D. O. Booth*

STORM CLOUD IN THE INDIAN OCEAN

This photograph was taken on July 24, 1955 between 6.00 and 6.30 p.m. from H.M.S. *Asturias* almost midway between Singapore and Colombo. This was the beginning of the storm cloud building up from the west during a monsoon period, and the storm which lasted almost 48 hr., although not terribly severe, brought torrential rain for several hours at a stretch during this period. The swell was quite considerable as we had to alter course to counteract the list and the roll, and the waves rose quite frequently to a height of 40 ft. and crashed over the bows to reach the bridge. The previous day, before the storm, had been unusually calm.

D. O. BOOTH

Photograph reproduced by courtesy of K. E. Woodley

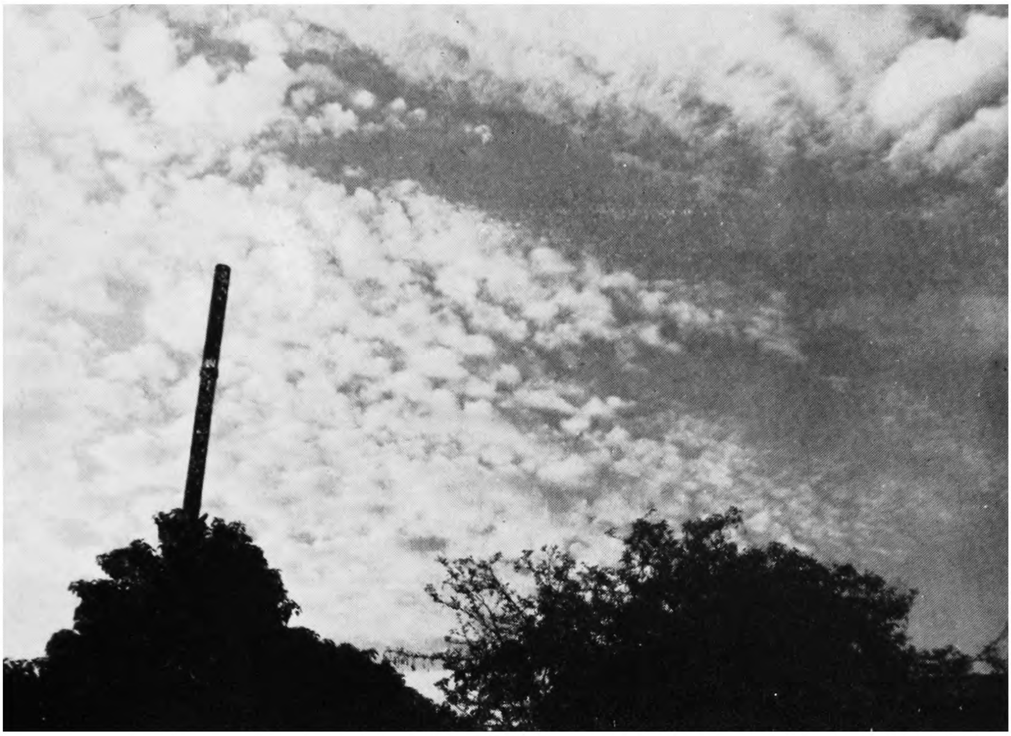
1800 G.M.T.

Photograph reproduced by courtesy of K. E. Woodley

1802 G.M.T.

CIRRIFORM CLOUD AT RICHMOND, JULY 8, 1956

These photographs were taken looking west-north-west
(see p. 374)



Photograph reproduced by courtesy of K. E. Woodley

1806 G.M.T.

Photograph reproduced by courtesy of K. E. Woodley

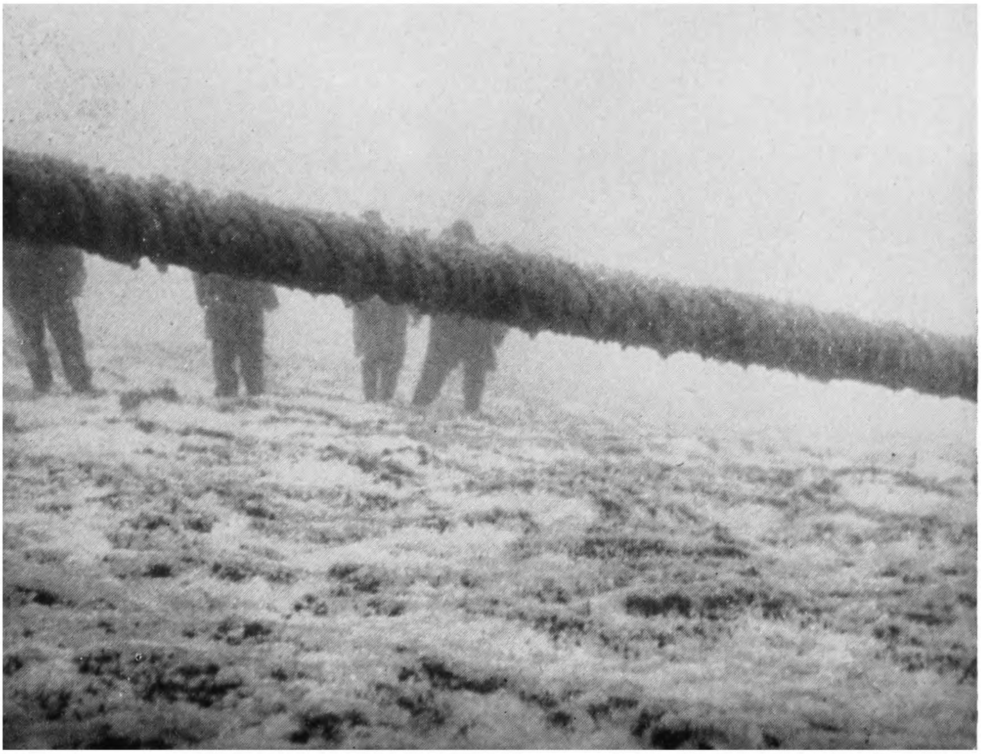
1807 G.M.T.

ALTOCUMULOUS CLOUD AT RICHMOND, JULY 8, 1956

These photographs were taken looking north-west

(see p. 374)

To face p. 369]



Reproduced by courtesy of the North of Scotland Hydro-Electricity Board

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ICING ON AN ELECTRIC POWER LINE IN THE GRAMPIANS

The photographs are of icing on the bottom conductor over Lecht and were taken at 1500 G.M.T., March 21, 1956

(see p. 376)

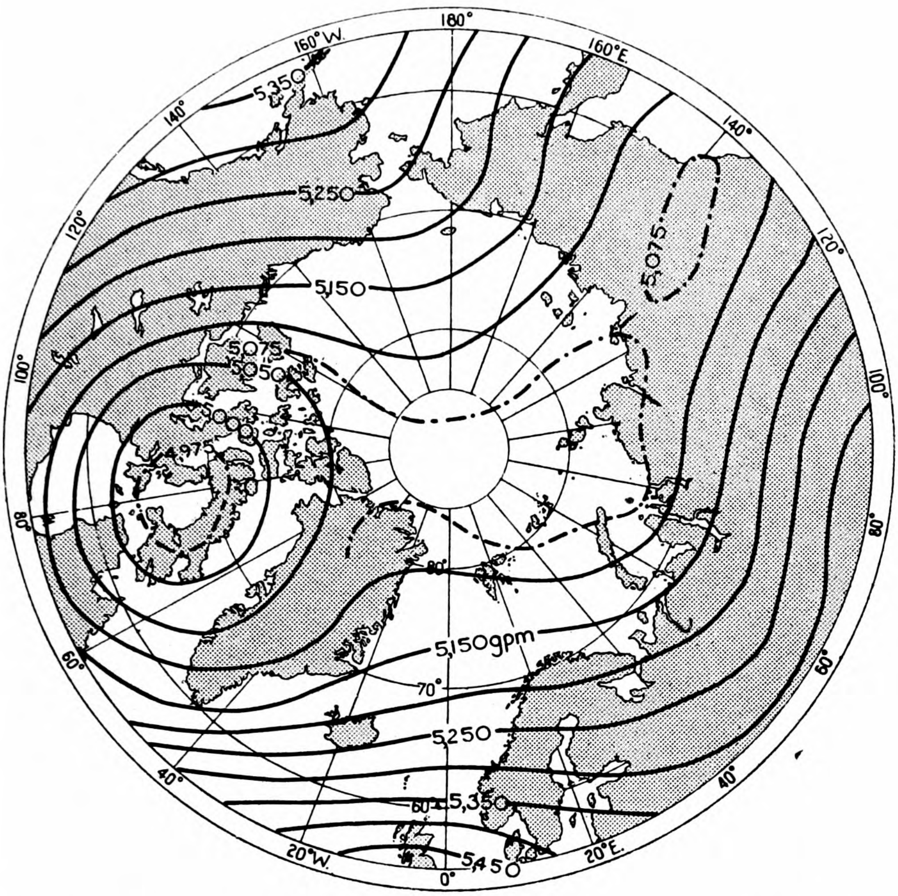

FIG. 1—AVERAGE 500-MB. CONTOUR HEIGHTS, JANUARY 1949–53

time of publication that these charts would need revision and, by about 1953, the increasing number of upper air data available made such a revision feasible.

The charts in *Geophysical Memoirs* No. 85 are on a Mercator projection and do not extend beyond 75°N. Therefore, in view of the increasing importance of the polar regions for aviation, it was decided to start the revision by constructing circumpolar charts for the standard isobaric surfaces. The charts of the original Memoir apply to the four seasons, each of three months. However, changes within a season can be very marked and, to obviate the difficulty of maintaining equal weighting all over the chart for each month of the season, the charts were to be drawn for the mid-season months—January, April, July and October. This procedure also enables the full seasonal changes to be shown more clearly. Further, attention was to be confined to a fixed period rather than to one varied to include earlier years in particular areas. The five-year period 1949–53 was chosen, mainly because January 1949 marked the beginning of both regular CLIMAT-TEMP data and publication by the meteorological service in western Germany[2] of monthly mean 500-mb. contour charts for a large part of the northern hemisphere. Finally it was decided to extend the range to 100 mb. and to include a chart for 150 mb.

This paper presents some of the circumpolar average contour charts for January and a brief discussion of their preparation. Details of the method are given elsewhere[3].

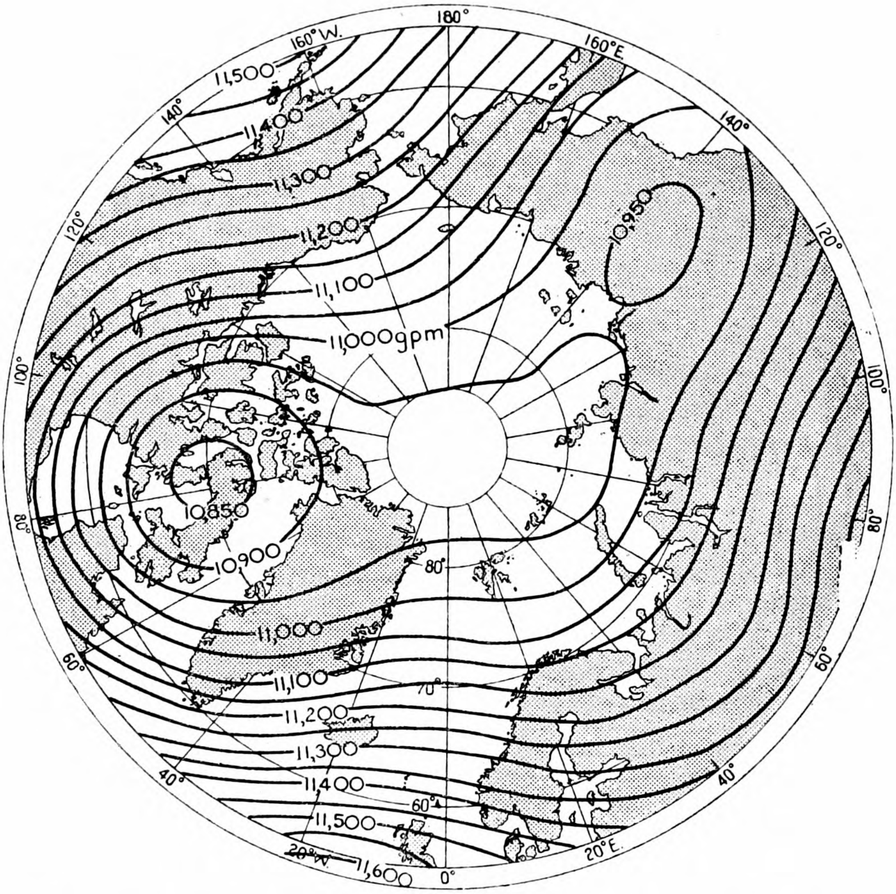

FIG. 2—AVERAGE 200-MB. CONTOUR HEIGHTS, JANUARY 1949–53

Data.—A CLIMAT-TEMP report provides monthly mean values of the contour height and temperature of the standard isobaric surfaces up to 200 mb. and the CLIMAT-TEMP reporting stations give a reasonable network of data except over the U.S.S.R. and eastern Europe. Over this area (and particularly Siberia) the German monthly mean contour charts were used to supplement the very sparse Russian data. These German charts were used since reference to the corresponding daily charts suggested that more data from the U.S.S.R. were available in Germany than in Great Britain.

The main sources of data used in the preparation of the charts were the CLIMAT TEMP reports and the data tabulations from United States Weather Bureau *Daily series synoptic weather maps*. These were supplemented by data on micro-film supplied by the Statens Meteorologisk-Hydrografiska Anstalt, Stockholm and Det Norske Meteorologiska Institutt, Oslo and by manuscript data supplied by the United States Weather Bureau and the Canadian Meteorological Service. The *Daily series synoptic weather maps* for January 1953 were not available, so for this month data were extracted from the synoptic charts of the Central Forecasting Office, Dunstable, and all Russian data received there were examined.

Method of constructing the charts.—Very few stations were available with equal reliability for all five years, particularly above 200 mb., and it proved necessary to construct a separate set of charts for each year in order to

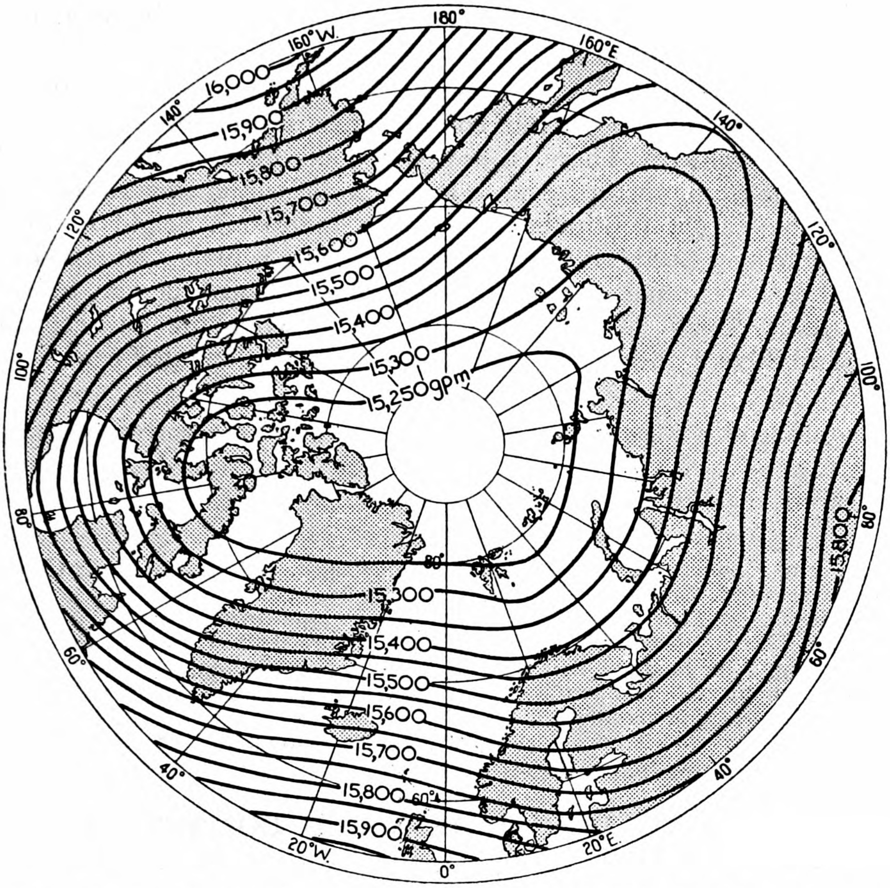

FIG. 3—AVERAGE 100-MB. CONTOUR HEIGHTS, JANUARY 1949–53

make the best use of the available data. The data from Siberia were particularly sparse and the 500-mb. contour charts were drawn first so that assistance in drawing this area could be obtained from the monthly mean 500-mb. contour charts published in the monthly supplement to the *Täglicher Wetterbericht*. The charts for the other levels were then constructed by drawing the thickness charts for the various layers 700–500 mb., 500–300 mb. etc.

Over the U.S.S.R. no useful data were available above 300 mb. and the average thickness charts were extended over this area by constructing a chart of average 300-mb. temperature and using temperature lapse rates derived from charts of average temperature of standard isobaric surfaces[4]. For the layer containing the tropopause a "correction for tropopause" was evaluated by using charts of average temperature and pressure at the tropopause[4].

Charts.—Three only of the charts are illustrated here. The 500-mb. contour chart (Fig. 1) represents the flow pattern in the troposphere. Three main troughs are indicated at about 55°E., 135°E. and 80°W. The two low centres, one to the north of Hudson Bay and the second, a composite low over northern Siberia, correspond very closely to the two centres of low tropopause on the tropopause pressure charts[4]. The pattern of flow at 700 mb., 300 mb. and 200 mb. (Fig. 2) is very similar to that at 500 mb. while the strength of flow increases with height. The contour height difference (*c.*100 m.) between the two low centres remains practically constant, and, indeed, is a reflection of the difference in average surface pressure (*c*.12 mb.)[5] between northern Canada and northern Siberia.

The 200-mb. contour chart represents the flow in the lower stratosphere and is very similar to the 300-mb. contour chart representing the flow at the top of the troposphere. There is, however, some increase in the strength of flow, owing to the temperature lapse in the arctic winter stratosphere. Above 200 mb. temperature continues to fall with increasing height in the arctic regions, while over northern Siberia the tropopause is higher and stratospheric temperatures lower than over northern Canada. Consequently, at 100 mb. (Fig. 3) the westerly flow increases in general while the low centres over Canada and Siberia at 200 mb. are replaced by one elongated centre over the pole.

The contour charts for all six levels together with the corresponding thickness charts are shown in "Average height of the standard isobaric surfaces over the area from the North Pole to 55°N. in January"[3].

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2. Bad Kissingen, Deutsche Wetterdienst. *Die Grosswetterlagen Mitteleuropas.*
3. HEASTIE, H.; Average height of the standard isobaric surfaces over the area from the North Pole to 55°N. in January. *Met. Res. Pap., London*, No. 918, 1955.
4. GOLDIE, N., MOORE, J. G. and AUSTIN, E. E.; Upper air temperature over the world. *Geophys. Mem., London* (in preparation).
5. BROOKS, C. E. P.; Studies on the mean atmospheric circulation. *Bull. Amer. Met. Soc., Worcester Mass.*, **18**, 1937, p. 313.

METEOROLOGICAL RESEARCH COMMITTEE

At the 35th meeting of the Synoptic and Dynamical Sub-Committee, held on May 31, 1956 the paper by Mr. R. F. M. Hay[1] on variations of air and sea temperature in short periods of time at the ocean weather stations I and J in 1948–52, including factual information and deductions therefrom, gave rise to discussion on the constituents of the energy exchange at the sea surface. The Sub-Committee hoped that this pioneer study would be the starting point for other investigations in the same field. Mr. D. H. Johnson[2] described experiments made in the Meteorological Office on the objective analysis of 500-mb. pressure contour charts with the aim of greatly reducing the time required in preparing such charts (by conventional methods) prior to their use in production of forecast charts by the numerical-prediction (electronic computer) technique. The method tried consisted in finding, by least squares, a quadratic or cubic surface, which gave the best fit to observed contour heights and winds at a group of upper air stations, and results obtained were held fully to justify further work on these lines. The third of a series of reports on the harmonic representation of the annual temperature variation was presented by Mr. J. M. Craddock[3]. The report gives, for 160 stations in the British Isles, the temperature normals in the form of the parameters in a two-term harmonic. During discussion on the distribution of the amplitude and phase over the area the author said that he hoped to deal later with the physical causes of prominent features of the annual variation in temperature. Mr. J. K. Bannon[4] described his attempt to reduce the irregular variations in the mean monthly pressures at the tropopause (and corresponding temperatures at a number of levels) at Lerwick and Larkhill 1942–53, on the basis of the values of mean-sea-level pressures for the longer period 1900–39. In the discussion, a suggestion was made that the annual variation of upper air data, for a relatively short period of years, might be represented satisfactorily by a two-term harmonic. In the discussion on Mr. H. Heastie's paper[5] which is a sequel to *Met. Res. Pap.* No. 918 dealing with the average height of isobaric surfaces in January, the comment was made that it is rather surprising that at high levels there should be symmetry of thickness patterns about the pole but asymmetry in the pressure contour-height pattern.

At the 22nd meeting of the Instruments Sub-Committee, held on June 19, 1956 the development of a vertical gustiness recorder described by Mr. J. I. P. Jones[6] and simultaneous records recently obtained at three heights were noted with very great interest. The technique will yield valuable data for the study of atmospheric turbulence up to heights of a few thousand feet. Discussion on the characteristics and performance of particular lithium chloride dew-point hygrometers as used in the London area[7] and by the British North Greenland Expedition[8] led to suggestions on the possibility of using other hygroscopic substances in order to extend the humidity range of these instruments at temperatures well below −20°C., and on the desirability of increasing the thermal load. There is need for further investigation on the determination of humidity at very low temperatures. Mr. M. J. Blackwell[9] reported the improvements which have been achieved in the new version of the daylight illumination recorder and in its calibration and maintenance. It is proposed to install the new form of recorder at Kew Observatory, Victory House (London), Eskdalemuir and Lerwick. Consideration was given to various aspects of the problem of measurement of the surface wind, *e.g.*, correction of measured wind speed to standard height above the ground and for the effects of site exposure, and the horizontal interpolation of wind from satisfactory measurements obtained at places a considerable distance apart. Reference was made to requirements for specialized information on air flow near the surface in relation to building, farming and forestry activities. The possibility of undertaking field experiments for further investigation of these problems is to be examined.

ABSTRACTS

1. HAY, R. F. M.; Some aspects of variations of air and sea surface temperature in short periods at ocean weather stations I and J of significance to the synoptic climatologist. *Met. Res. Pap., London*, No. 949, S.C. II/201, 1956.

The abstract of this paper will be published later.

2. JOHNSON, D. H.; Objective analysis. *Met. Res. Pap., London*, No. 965, S.C. II/207, 1956.

Time would be saved by machine calculation of a contour height as a quadratic function of geographical co-ordinates, obtained by fitting a least-squares solution to observed heights and winds suitably weighted. This paper describes preliminary computations using a six-station network over the British Isles and a five-station network, mainly of weather ships. A cubic surface was also tried. Further work is described by F. H. Bushby in *Met. Res. Pap.*, No. 986, 1956.

3. CRADDOCK, J. M.; The harmonic representation of the annual temperature variation in different parts of the British Isles. *Met. Res. Pap., London*, No. 970, S.C. II/208, 1956.

In continuation of *Met. Res. Pap.* No. 915 the mean annual temperature 1921–50 and the phase and amplitude of the first and second harmonics, calculated from the monthly means, are given and plotted for 160 stations in the British Isles. The phase of the second harmonic is shown by the number of days its maximum falls after that of the first.

4. BANNON, J. K.; Long-period averages for the upper air. *Met. Res. Pap., London*, No. 978, S.C. II/209, 1956.

Average monthly tropopause pressures and temperatures and temperatures at 100, 150, 200, 300, 500 and 700 mb. at Larkhill and Lerwick are given for 1942–53. Estimated values for 1900–39 are calculated from regression equations on surface pressures, resulting in a smoother annual variation. The values are also shown graphically, including extremes of pressure and standard deviations at the tropopause.

5. HEASTIE, H.; Average height of the standard isobaric surfaces over the area from the North Pole to 55°N. in July. *Met. Res. Pap., London,* No, 981, S.C. II/210, 1956.

In continuation of M.R.P. 918, circumpolar charts for standard pressure levels are given for July 1949–53, for 700, 500, 300, 200, 150 and 100 mb. and intervening thicknesses. They show marked differences from January, especially an asymmetric mainly westerly flow over Eurasia, increasing with height, and extending across the pole to give easterly winds over northernmost Canada and Greenland.

6. JONES, J. I. P.; A vertical gustiness recorder for use with a captive balloon. *Met. Res. Pap., London,* No. 974, S.C. I/113, 1956.

This lightweight instrument consists of a balsa wood and tissue paper inclination vane which actuates a potentiometer, and a windmill-type anemometer, at either end of a suspended arm damped to prevent oscillation. Ground recording is electrical. Photographs, wiring diagrams and specimen records are shown.

7. MACDOWALL, J.; An electrical dewpoint hygrometer suitable for routine meteorological use. *Met. Res. Pap., London,* No. 977, S.C. I/114, 1956.

A hygrometer suitable for continuous recording of dew point (resembling that of J. H. Conover) is described and illustrated. It consists of a varnished brass tube covered with glass tape impregnated with lithium chloride and wound with two parallel silver wires. Operation and comparison with an Assmann psychrometer are described; accuracy is better than ± 3 per cent.

8. HAMILTON, R. A.; The measurement of humidity at Britannia Sø 1952–53. *Met. Res. Pap., London,* No. 983, S.C. I/115, 1956.

The hygrometers used by the British North Greenland Expedition at Britannia Sø (77°9'N. 23°36'W.) for measuring humidities at low temperatures were dry-bulb and wet-bulb, hair hygrometer and lithium chloride hygrometer. Comparisons between these are set out in a number of tables and standard errors given. Calibration of the lithium chloride hygrometer is plotted.

9. BLACKWELL, M. J. and POWELL, D. B. B.; On the development of an improved daylight illumination recorder. *Met. Res. Pap., London,* No. 988, S.C. I/116, 1956.

The faults of the present Mk. II instrument at Kew include a temperature coefficient, cosine-law response, spectral sensitivity and unequal illumination of diffusing plate. An improved Model Mk. III is described in which these are corrected. Comparisons between Mk. II and III are given.

LETTERS TO THE EDITOR

Unstable cloud layer

During the seven min. between 1800 and 1807 G.M.T. on Sunday, July 8, 1956, four photographs were taken at Richmond, Surrey, of a large cloud patch developing from a fine structure, almost cirriform in appearance, into alto-cumulus floccus. The first two photographs [in the centre of this magazine] were taken looking approximately west-north-west within a minute or so of each other and show the sheet increasing whilst still consisting of small cloudlets. The second pair of photographs show the same cloud sheet some five min. afterwards, the camera then having been swung round to approximately north-west. The whole of the cloud patch had by then turned into well broken floccus. This drifted away north-eastwards gradually dissipating, the sky becoming almost cloudless. No further photographs were possible.

The rate of progress of the cloud in its fine-structure state left doubts that the advance was genuine movement, especially when the comparatively slow movement away of the cloud when in its floccus state was taken into account. It is probable, therefore, that most of the apparent advance in the leading edge was due to rapid formation of the cloud.

K. E. WOODLEY

Harrow, July 18, 1956

[At 1800 G.M.T. on July 8 a depression was centred about 100 miles north-west of Ireland. There was a large warm sector, the warm front running eastwards across the north of Scotland to the Heligoland Bight and the cold front southwards to the Bay of Biscay. Pressure was almost uniform from central England to southern France. The air in the rear of the cold front was much colder than that in the warm sector at all levels. The cold front reached the London area at about 0600 G.M.T. the following day. Heavy thunderstorms occurred over south-east England during the night of July 8–9 and were particularly heavy in the early morning.—Ed., *M.M.*]

Speed of warm fronts

The *Meteorological Magazine* for August 1955 contains an important note by C. H. Hinkel and W. E. Saunders, who found that on the Atlantic warm fronts move at an average speed of five-sixths of the geostrophic value, compared with the two-thirds which has been accepted as normal both in the British Isles and North America. This difference is unexpectedly large, and must be important for forecasting, considering that the difference in position after 24 hr. must often exceed 100 miles. Now that the figures have been available for about a year, it would be interesting to know how they are interpreted. The authors mention frictional drag as the most probable explanation and this is the only obvious difference between a sea and a land surface. Nevertheless if this is a complete explanation there are points of difficulty. Frontal analysis has always aimed at independence of very shallow cold layers, even when upper air information was scanty. Most warm fronts over western and central Europe are drawn to fit the isobaric troughs. Are we to infer that the trough is commonly held back 100 miles or more by surface friction?

The combination of surface friction with other factors may be worth considering. Just ahead of a warm front there is a strong thermal wind parallel to it and under such conditions turbulence originating on the ground may influence the wind up to a greater height than normal. Another factor liable to influence the effective movement of a warm front is a strong forward shear a few thousand feet above it, due to a non-frontal thermal wind, combined with rapid surface heating of the shallow cold air just ahead of the front. On the whole this process is most effective over the sea, especially if the existence of precipitation or clouds determines the retention of a weakening front in some marginal cases.

On the whole it appears that friction comes into the problem and that quasi-geostrophic dynamical theory cannot explain the whole of the ageostrophic motion of fronts. This last point receives some support from Table III of the recently published *Geophysical Memoir* No. 98.

C. K. M. DOUGLAS

Set Fair, Beer, Devon, July 17, 1956

[With regard to the question raised in the first paragraph of Mr. Douglas's letter, the fronts were placed using the normal surface properties of warm fronts. This implies that account is taken of shallow cold layers. There seems no reason why the trough should not tend to get ahead of the surface front and presumably this is what sometimes occurs over land.

Of the two factors mentioned in the second paragraph, the second one seems largely to have been ruled out by the criteria of selection of the fronts used in the investigation, though it might be effective with weaker fronts which were excluded because they were not considered to be sufficiently marked.

We are inclined to the view that a combination of friction and turbulence would appear to be the most likely cause. We feel, however, that a very much more detailed study, than that undertaken, would be necessary for a definite conclusion to be reached.

Forecasting practice has provided many examples of the operation of the the "five-sixths rule" over the North Atlantic and we have no reason to doubt the genuineness of the result.—W. E. SAUNDERS and C. H. HINKEL.]

NOTES AND NEWS

Icing of overhead high-voltage electric power lines in the Grampians

During previous winters, electric power failures due to icing of lines had occurred on several occasions on two particular stretches of line in the Grampians. During the past winter a careful watch was kept on weather conditions in this area and a record of failures certainly or possibly due to icing maintained. There was one failure possibly due to icing and two certainly due to icing, all occurring within a three-day period although weather conditions made icing a decided risk on many occasions.

The sections of line considered were Fort Augustus to Laggan Bridge which goes through the high pass of Corrieyairick, rising to 2,507 ft. above sea level, and from Cock Bridge to Tomintoul through the high pass of the Lecht rising to a height of 2,170 ft. Both these high passes run roughly at right angles to most of the valleys in the area which run from south-west to north-east parallel to the Great Glen, so that even at such a height there is shelter which makes assessment of cloud base in the area extremely difficult.

During the period March 19 to March 21, 1956, when the failures were reported, the area was affected by a south-easterly air stream. East coast areas of Scotland had complete cover of stratocumulus with extensive low stratus underneath with base below 1,000 ft. Cloud base rose gradually to the west, due to drying out in passage over the mountains, and cloud was well broken in west coast areas. The main top of the cloud was of the order of 4,000—5,000 ft. and freezing level remained between 1,000 and 2,000 ft. until the 21st when it rose to nearly 5,000 ft. with a change of air mass preceded by a belt of mainly slight precipitation. Up to this time there had been only negligible amounts of precipitation, usually local light drizzle. The drizzle became moderate at Glenlivet (1,075 ft.) with cloud on or near the ground just before 1800 G.M.T. on the 20th and these conditions (confirmed at 2100 G.M.T.) probably persisted through the night, drizzle changing to rain between 0600 G.M.T. and 0900 G.M.T. on the 21st. The total fall in this spell of rain and drizzle was 2·6 mm. Temperatures at Glenlivet in the period up to 0900 G.M.T. on the 21st varied from 31° to 38°F. rising to 41°F. on the 21st. Winds were mainly E. to SE., rarely falling below 10 kt. and occasionally reaching 20 kt.

The failures were as follows:—

March 19.—At 0018 G.M.T. the Fort Augustus–Laggan Bridge line failed, presumably due to ice loading reducing working clearances, but the line was restored five minutes later and there was no permanent damage so that it is not certain that the interruption was due to ice.

March 20.—One of the lines over the Lecht failed at 1905 G.M.T. This was due to clashing and burning of the conductors probably caused by oscillation after shedding of ice load and excessive sag due to conductor slip at the suspension clamps on the Lecht summit. Radial thickness of the ice on bare conductor at 0930 G.M.T. on the 20th was 2½ in. and on one of the conductors which had been covered with a skin of poly-vinyl plastic about $\frac{1}{16}$ in. thick was 3 in. This line was out of action until the 23rd, having two broken conductors right on the Lecht summit.

March 21.—The second line over the Lecht (conductors carried on opposite side of pylons) failed at 0148 G.M.T. but was restored at 0241 G.M.T. so that at that time there were no conductors in contact with each other or with the earth. The fault may have been due to shedding of ice causing a conductor to oscillate and contact another conductor. The line failed again at 0737 G.M.T. and once more there were two broken conductors right on the Lecht summit. (See photographs facing p. 369)

The following is a careful description of the icing, provided by the Aberdeen area Manager:—

"The ice on spans 429–431 was almost truly radial and 6 in. in diameter and caused the bottom AF (Aberdeen/Fort Augustus) conductor to sag very low. The ice had a solid core, becoming porous and less dense at the surface, and was much darker in colour than the ice seen on any previous occasion. It is worth noting that the above deposits were formed in the presence of thick mist at freezing temperature and a light easterly wind. So far as I am aware, all previous ice deposits causing outages were formed in the presence of sleet in high winds. The resulting effects from these two causes of ice formation confirm that "fog" ice deposits are the heaviest. You will recollect that on February 16, 1955 when the conductors were loaded with elliptical ice formation 9 in. across by 7 in. down, deposited by wind-borne snow, the bottom conductor was roughtly 18 ft. above ground level.

At 2020 G.M.T. on March 20, we telephoned the proprietors of the Allargue Hotel, Corgarff, (south of the Lecht summit) for a weather report, and this was given as "freezing—thick mist—light easterly wind".

You will no doubt be aware that the severest ice deposits occurring in the past on the Lecht section have been on spans between towers 429 and 432, which lie approximately 2,170 ft. and 1,930 ft. respectively above sea level.

It is probably significant that the lowest cloud reported at Glenlivet (1,075 ft.) which is on the lee side of the Lecht was consistently 1,300–1,400 ft. (i.e. 2,400 ft. above sea level) throughout the 19th and on the 20th up to and including 1500 G.M.T. Between 1200 and 1500 G.M.T. the wind backed from SE. to E. and this was probably responsible for the low stratus creeping up the Don Valley to the Lecht summit and into Glenlivet between 1500 and 1800 G.M.T. It is possible that the Lecht summit was not in cloud on the 19th and early 20th; if so deposition of rime must have been remarkably fast and judging from the appearance must have been deposited from the surrounding cloud in quiet conditions, sheltered from wind, because of the circular cross-section.

Tentative conclusions to be drawn from the winter's records are that, because of shelter effects, the worst icing conditions, associated with icing in shower cloud, do not often affect the lines long enough to cause serious icing but that serious icing can occur in freezing cloud of the layer type when this penetrates into the high passes. The fact that temperatures were only just below freezing may be important in determining the relative rate of deposition in these circumstances.

The author is indebted to Mr. N. B. Macarthur, System Operation Engineer,

Pitlochry for much of the information on which the article is based and to the North of Scotland Hydro Electric Board for permission to publish this.

P. E. PHILLIPS

REVIEWS

The generation of electricity by wind power. By E. W. Golding. Spon's electrical engineering series. $8\frac{3}{4}$ in. × $5\frac{3}{4}$ in., xviii + 318, *Illus*. E. and F. N. Spon Ltd., London, 1955. Price 50*s*.

Whether the generation of electricity by wind power would, or would not, be economic depends not only on the average wind over a long period, but also on how the wind fluctuates about the average. The dependence upon the wind fluctuations is three-fold: first, wind eddies which are small compared with the size of the windmill rotor may result in unbalance, and the rotor and control gear must be sufficiently robust to withstand the consequent stresses; second, since the output from a wind turbine varies as the cube of the wind speed (assuming constant efficiency) the total output in a fluctuating wind, $k\int v^3dt$, is affected by the size and nature of the fluctuations; third, the fluctuations in output which result from fluctuations in wind speed may carry an economic penalty.

The smaller eddies, those which lead to stresses in the rotor, are difficult to measure and their importance difficult to assess. Golding states that eddies smaller than 10 ft. across are not significant in this connexion. Arguing that in a 70 m.p.h. wind (the strongest in which a wind turbine is likely to have to operate) an eddy of this size would pass a fixed point in about 1/10 sec., Golding deduces that an anemometer with a response time of this order is required if these eddies are to be studied, and a special "gust anemometer" was developed by the Electrical Research Association for this purpose. Since changes in wind direction, and also deviations from the horizontal, may be as important as changes in speed, three types of anemometer were developed; for the measurement of (*a*) horizontal component of wind velocity without regard to direction; (*b*) velocity components in two directions at right angles; (*c*) vertical components. Meteorologists will be disappointed that, apart from reproducing one or two traces from the first of these types, no information is given about the results obtained. Meteorologists will also wonder whether Golding is altogether justified in ignoring, as he does, the time factor. An eddy which is 10 ft. across will take, as has been said, something like 1/10 sec. to pass the turbine blades. Is this long enough to do any damage? It is usually considered that for ordinary buildings mean winds over a period of about a minute are what matter. Could an eddy lasting only 1/10 sec. do any damage to the rotating blades of a wind turbine?

Rather larger eddies are of importance because they affect the output from the generator. Since $\int_0^T v^3.dt/T$ is always greater than $\left[\int_0^T v.dt/T\right]^3$, the total output in a fluctuating wind (assuming constant efficiency) is always greater than the output from the mean wind—and the greater the fluctuations, and the lower the mean wind, the greater this difference usually is. In assessing the total output from a proposed wind turbine these fluctuations should therefore be taken into account. Bearing in mind that the "time-constant" of an ordinary cup generator anemometer is about one sec., it seems likely that the output from a wind turbine would be noticeably affected only by eddies which last for several sec. Fluctuations of this size are easy enough to measure but there are two complications. First, it is not fluctuations of wind speed "at a point" that matter, but the fluctuations of the mean wind speed (or mean wind pressure?) over the area swept out by the turbine blades—a circle of up to 200 ft. in diameter. Second, the application of these measurements to the computation of the probable output from a wind turbine is complicated by the fact that wind direction is also varying. These variations of wind direction would have to be taken into account and estimates would have to be made about the speed of response of the control gear. These difficulties may explain why the author, who bases his estimates of output on hourly means, makes no quantitative assessment of the effect of these fluctuations. The nearest approach to such an assessment is when it is shown that the ratio

$$\frac{\int_0^T v^3.dt}{T} \Bigg/ \left(\frac{\int_0^T v.dt}{T}\right)^3$$

is very near unity at speeds greater than 45 m.p.h. These speeds are, however, well above the rated speed of any likely wind turbine and at such speeds fluctuations, provided that the speed does not fall below the rated speed, do not affect the output at all. The ratio may differ appreciably from unity at lower speeds and the output over a period of 1 hr. may differ significantly from that computed from the hourly mean wind.

Apart from their effect on the integrated output, and therefore on the economy, of a wind turbine, the fluctuations in output which result from wind fluctuations may be more directly embarrassing. Where generators are used to feed into a National Grid, as could be the case in this country, operating mainly as fuel savers, fluctuations over fairly long periods would not matter and fluctuations over shorter periods could be smoothed out by having a large number of generators connected to the network. But where the generator is not connected to a grid then fluctuations would usually mean that some sort of storage facility (either of electricity or of energy in some other form) would be required. Golding lists possible energy storage devices and estimates that the cost of power production may well be doubled if storage is needed.

Rather more than half of this book is devoted to the meteorological aspects of the generation of electricity by wind power. In addition to discussion of the importance of wind fluctuations there is some account of wind flow over hills and a description of wind surveys that have been carried out in various countries. The author is not a meteorologist and, inevitably, faults can be found in these sections. The definition of an isobar as "a line joining points having the same atmospheric pressure (at sea level and corrected for temperature and latitude)" shows confusion of thought, or of understanding, between reducing pressure to sea level on the one hand, and measuring atmospheric pressure using one particular pressure-measuring device, a mercury barometer, on the other. Again the statement "A hill may accelerate the wind over the summit, through compression of the lower layers of air by those above" does not really describe what happens. There are also a number of errors of fact. Beaded edges to the cups of anemometers, for example, were introduced for greater strength, not ". . . to improve the constancy of rate of revolution" (whatever that may mean). But these are small points. The author has collected together a vast and, for anyone interested in the subject of the generation of electricity by wind power, a valuable bibliography (whilst, oddly enough, omitting a paper by C. E. P. Brooks*, which was written specifically in connexion with the generation of electricity from the wind) and he has prepared a number of useful summaries and tables (again not entirely free from error).

The book is well produced, with few printing errors. A list of Tables would have been useful and the Index is noticeably incomplete.

R. FRITH

The structure of turbulent shear flow. By A. A. Townsend. $8\frac{1}{2}$ in. × $5\frac{1}{2}$ in., pp. xii + 154, *Illus.*, Cambridge University Press, 1956. Price 40*s*.

The present book is one of a series of monographs which began in 1953 with Dr. G. K. Batchelor's "The theory of homogeneous turbulence". As is evident from the title, the latter work excluded application to the atmosphere in general, though the possibility of the existence of an approximation to homogeneity in the turbulence in certain conditions away from the earth's surface is not to be ignored. However, for the most part atmospheric motion does involve shear of some form or other, and because of this Dr. Townsend's volume which is concerned with the physical properties of turbulent flow in the presence of shear, will draw considerable interest from meteorologists.

The growth of our understanding of turbulent motion is well known to be greatly dependent on experimental observation and, as Dr. Townsend explains in his preface, the ideas which he develops are essentially an outcome of experimental studies conducted over the past few years in the Cavendish Laboratory School. Indeed, one of the stated reasons for the book is the connected presentation of studies which have hitherto been described in various papers, and of an individual interpretation thereof, in an attempt to provide a "physically consistent description of turbulent shear flow".

After a general introduction and a chapter dealing with the equations of motion, Dr. Townsend first discusses certain simplified types of flow, especially isotropic homogeneous turbulence, with the expressed object of forming a general basis for the understanding of more complicated flows involving shear. In particular, he sets out the ideas of "self preservation" and "Reynolds number similarity", which are his terms for the existence of a universal character in the distribution of turbulent properties at various times in the flow and at various Reynolds numbers. These ideas are applied and developed in discussions of shear flow, at first on a very general basis, and then with reference to the special flows in wakes, jets, pipes and channels, and in boundary layers with and without pressure gradient.

It is of course not to be expected that a treatment of the present type will provide material for immediate discussion in relation to our atmospheric problems of turbulent mixing and transport, for the substance of the treatment is

* BROOKS, C. E. P.; Frequency of winds between given velocities. *Met. Mag., London*, **78**, 1949, p. 33.

that very feature which until recently has been so little explored in the atmosphere, namely the actual properties, as distinct from the effects, of turbulent motion. The real value to meteorology lies in the demonstration of the progress which has been made in building up a physical description of laboratory flow, by elaborate measurement of the intensities, stresses, scales and spectral distributions in the turbulent motion. Interest in studying these properties in atmospheric flow has grown rapidly in the last few years, and it is in this direction that we should ultimately profit from the impressive collection of data, and the penetrating discussion thereof, which are now presented in Dr. Townsend's book.

F. PASQUILL

Le temps et les travaux des champs. By A. Viaut and J. Sanson, 7½ in. × 5½ in., pp. 144., *Illus.*, Presses Universitaires de France, Paris, 1953. Price: 500 *fr.*

This book would appear to live up to its sub-title "Conseils aux agriculteurs" whilst also containing much of interest to the professional meteorologist.

Chapters 1 and 2 outline the methods of preparing short-range (12-48 hr.) and medium-range (5–6 day) forecasts with special emphasis on their relevance to agricultural operations on similar time scales. The "on-site" meteorological observation needed if the maximum value is to be gained from the general forecasts are described at some length in Chapter 3. Chapter 4 deals with sunshine and radiation indicating some connexions between the global radiation experienced by the vine and the quality of the subsequent wine. Temperature, frost, frost prevention and some relationships between plant growth and temperature, including damage by frost, form the subject of Chapter 5. Chapter 6, on precipitation and humidity, contains some useful information on the effectiveness of a given fall of rain taking into account infiltration into the soil and evaporation. We are also told that the main meteorological stations will supply by telephone information on the vertical structure of the atmosphere to anyone contemplating "cloud seeding" operations. The beneficial and deleterious effects of wind on plants are only briefly reviewed in Chapter 7, but Chapter 8, on the importance of the knowledge of climatology to agricultural scientists, is worth close study. Chapter 9 on the forecasting of crop yields from weather data sets out methods adopted by the French to solve a problem which has so far defeated the efforts of investigators in this country. The effects of weather and climate upon industries serving agriculture are briefly reviewed in Chapter 10 and the final chapter outlines the use of aircraft to aid food production.

Different sections may appeal to different readers, but no one can fail to note both the efforts which the French Meteorological Office takes to assemble their information in a form related as closely as possible to the many types of agricultural enterprise, and their attempts to frame a suitable organization for disseminating the information.

R. W. GLOYNE

HONOURS AND AWARDS

Mr. C. S. Durst, Senior Scientific Officer, formerly Assistant Director (Special Investigations), Meteorological Office, has been awarded the Bronze Medal of the Institute of Navigation for 1956 for his paper, "The accuracy of dead reckoning in the air", published in the April 1955 number of the Institute's Journal.

BOOK RECEIVED

A proposal for the Hawaii Institute of Geophysics. 8½ in. × 11 in., pp. 16, *Illus.* University of Hawaii, *s.a.*

ERRATA

SEPTEMBER 1956, PAGE 284, line 27; *for* "one part in 107 has a third." *read* "one part in 10^8 has a third."

NOVEMBER 1956, PAGE 345, Fig. 1; In the county of Middlesex *insert* "9·7".

METEOROLOGICAL OFFICE NEWS

A letter was received by Dr. J. Pepper, M.O.6, from the Flag Officer H.M. Yacht *Britannia*, stating he was instructed by H.R.H. the Duke of Edinburgh to say that His Royal Highness was glad to accept the copy of "Meteorology of the Falkland Islands and Dependencies, 1944–50", presented by the author.

Academic successes.—The following members of staff have been successful in examinations; we offer them our congratulations. General Certificate of Education (Advanced Level):

Senior Aircraftman K. C. Adamson and Senior Aircraftman M. F. Smith.

Swimming.—At the Air Ministry Swimming Gala held at Messrs. Bourne and Hollingsworth's Baths in Gower Street on October 11, Mr. A. R. Evling was second in the Backstroke Championship and third in the Free Style and Breaststroke Championships. Miss K. E. Payne was third in the Ladies' Championship and won the Ladies' Handicap.

Horticultural Show.—At the Air Ministry Horticultural Society's autumn show held in Whitehall Gardens on October 4, Miss H. G. Chivers and Messrs. B. G. Brame and H. A. Scotney gained prizes. Mr. Scotney was runner up for the Banksian Medal (the aggregate prize for the year) and also runner up for the aggregate for the autumn show.

WEATHER OF OCTOBER 1956

The main cyclonic activity in the Atlantic was of usual intensity but transferred well north and north-east of normal.

Lowest pressure for the month was about 1000 mb. between Iceland and Greenland and near Jan Mayen (maximum anomalies −7 mb.). Correspondingly, the main high-pressure belt was shifted north and appeared as two cells, one centre with mean pressure for the month 1024 mb. near 42°N. over New England and over the St. Lawrence valley, the other with similar pressure values over Biscay and extending its influence over Great Britain and continental Europe as far as 55°–60°N. and south-east to the Balkans. The greatest pressure anomaly was +11 mb. near south-west Ireland, attributable more to abnormality of position than intensity which was within the most usual figures.

There was an important col over the Atlantic near 40°W. between the American and European high-pressure cells, but pressure was above normal everywhere between 40° and 55°N.

Our search for anomalies up stream (in the sense of the upper westerlies) which might explain the shift of the main centres of action in the Atlantic region reveals that the north-western half of Canada and a strip south along the Rockies and American west coast to 40°N. was everywhere colder than normal (greatest anomalies −5°C. to −6°C, in and near the Yukon). The rest of North America (the greater part) was 0°C. to 3°C. warmer than normal. Deep depressions on the Pacific carried the lowest pressure well east close to the tip of British Columbia instead of the usual position over the Alaska peninsula. Thus cold air of the rear side of these depressions spread over all Alaska and was swept round over the Alaskan Gulf to the west coast of Canada and the United States. This appears to have established the North American cold trough in an unusually western position, steering cyclonic activity towards high latitudes on either side of Greenland.

Rainfall was deficient in the central regions dominated by the west European and east American anticyclones, but was above normal over most of Germany. There was excess rainfall over the western and central Rockies and Southern Alaska. Most of India also had much rain, great excesses occurring in the north-west.

The British Isles had showery and cold weather during the first week of the month as complex depressions north of Scotland moved eastward to Scandinavia, but weather during the second week was warmer and anticyclonic. During the latter half of the month a westerly air stream brought a return to less settled conditions; weather became much cooler on the 24th as winds veered to a northerly point.

On the 1st a developing warm-front wave moved slowly north-east from our south-west approaches across southern England giving substantial rainfall over a wide area. Flooding occurred at many places in and around London; London Airport recorded 2·16 in. of rain in 12 hr., nearly as much as the normal for the whole month. Wind veered to the north-west on the 3rd and weather became cold and showery for the next three or four days with scattered thunderstorms. The first snow of the season fell on some of the higher peaks of Scotland and northern England during this period. There was drizzle in many places on the 7th and some local thunderstorms on the 8th as warm air from the Atlantic spread over the country. Next day pressure began to rise over the British Isles and by the 10th a belt of high pressure extended from north of the Azores, across the Midlands, to Austria. Weather was generally dry until the 15th with night fog over England and Wales which persisted into the afternoon in many places; temperatures rose steadily, widely exceeding 60°F. and reached 70°F. at Kinloss (Morayshire) on the 15th. During the next two days a deep depression moving north-eastwards passed between Scotland and Iceland bringing to most places on the 16th their first substantial rainfall for over two weeks, and on the 17th a return to cooler weather with westerly gales in Scotland. Another depression, following a parallel but more southerly track, crossed Scotland during the night of the 19th–20th and brought a renewal of widespread rain over the British Isles which was heavy at times in the west and north. Weather was dry in England and Wales on the 21st and 22nd as an anticyclone from the Azores moved eastward into Germany, but on the 24th an influx of arctic air from the north brought showers to all areas, which were heavy at times with hail and thunder; temperatures were about 10°F. lower the next day. Showers and scattered thunderstorms continued for two or three days and there was slight frost at night. On the 27th winds backed temporarily to the south-west and showers became less frequent as a tongue of warmer Atlantic air crossed the country. A depression developed on the tip of this warm-sector tongue as it reached the North Sea giving severe gales along our eastern seaboard on the 29th with frequent showers over most of the country, which were of hail locally, and of snow over some high ground in the north. Gales moderated slowly the next day as pressure rose over Northern Scotland and the depression over the North Sea filled up. Pressure at Dyce, near Aberdeen, reached 1045·6 mb. on the 31st, 5 mb. higher than the previous October highest pressure in the British Isles which was recorded at Nottingham in 1877. The last two days of the month were mostly fine and cold.

Temperatures were about average for most of the month but dropped sharply during the last week. Sunshine was above average in most districts except in parts of east and south-east England and north and north-west Scotland. With 150 hr. during the month the North Riding of Yorkshire had nearly twice its normal amount of sunshine for the month. Rainfall was below average in nearly all areas except over north and north-west Scotland. It was less than half the average in counties bordering the south coast from Sussex to Devonshire, in South Wales, parts of the Midlands, Lincolnshire, the southern part of Yorkshire, parts of Northumberland and in the south-eastern coastal districts of Scotland. Most farm work has proceeded with little hindrance from the weather. Sunny days and frost-free nights without much heavy rain have enabled farmers to make good progress with their autumn cultivations including potato and sugar-beet lifting, cropping of broccoli and sprouts and planting out of spring *brassicae*.

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 ...	71	24	−1·0	57	−3	113
Scotland	70	21	0·0	90	−2	108
Northern Ireland ...	63	27	+0·1	91	−2	115

RAINFALL OF OCTOBER 1956

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·24	85	*Glam.*	Cardiff, Penylan ...	2·72	57
Kent	Dover	2·46	63	*Pemb.*	Tenby	1·14	23
,,	Edenbridge, Falconhurst	1·56	43	*Radnor*	Tyrmynydd	4·11	62
Sussex	Compton, Compton Ho.	1·88	41	*Mont.*	Lake Vyrnwy	3·84	66
,,	Worthing, Beach Ho. Pk.	1·23	34	*Mer.*	Blaenau Festiniog ...	9·52	94
Hants.	St. Catherine's L'thouse	1·31	35	,,	Aberdovey	2·78	58
,,	Southampton (East Pk.)	1·74	44	*Carn.*	Llandudno	1·24	37
,,	South Farnborough ...	2·17	68	*Angl.*	Llanerchymedd ...	3·24	72
Herts.	Harpenden, Rothamsted	1·74	55	*I. Man*	Douglas, Borough Cem.	3·57	79
Bucks.	Slough, Upton	2·50	89	*Wigtown*	Newton Stewart ...	3·08	68
Oxford	Oxford, Radcliffe ...	1·80	62	*Dumf.*	Dumfries, Crichton R.I.	2·99	76
N'hants.	Wellingboro' Swanspool	1·47	58	,,	Eskdalemuir Obsy. ...	5·14	95
Essex	Southend, W. W. ...	1·21	48	*Roxb.*	Crailing	1·34	47
Suffolk	Felixstowe	1·29	56	*Peebles*	Stobo Castle	2·73	79
,,	Lowestoft Sec. School ...	3·76	135	*Berwick*	Marchmont House ...	1·98	52
,,	Bury St. Ed., Westley H.	1·70	63	*E. Loth.*	North Berwick Gas Wks.	1·32	45
Norfolk	Sandringham Ho. Gdns.	1·50	49	*Midl'n.*	Edinburgh, Blackf'd. H.	1·54	56
Wilts.	Aldbourne	2·04	57	*Lanark*	Hamilton W. W., T'nhill	3·59	110
Dorset	Creech Grange... ...	2·20	43	*Ayr*	Prestwick	3·30	115
,,	Beaminster, East St. ...	2·35	53	,,	Glen Afton, Ayr San. ...	4·42	87
Devon	Teignmouth, Den Gdns.	1·69	44	*Renfrew*	Greenock, Prospect Hill	3·70	73
,,	Ilfracombe	2·33	51	*Bute*	Rothesay, Ardencraig ...	2·61	59
,,	Princetown	4·32	51	*Argyll*	Morven, Drimnin ...	6·39	107
,,	Werrington Park ...	2·65	51	,,	Poltalloch	3·35	68
Cornwall	Penzance	2·54	55	,,	Inveraray Castle ...	6·47	92
,,	St. Austell	2·84	54	,,	Islay, Eallabus	3·54	74
,,	Scilly, Tresco Abbey ...	1·84	48	,,	Tiree	4·03	88
Somerset	Taunton	1·47	46	*Kinross*	Loch Leven Sluice ...	2·03	59
Glos.	Cirencester	1·32	39	*Fife*	Leuchars Airfield ...	1·15	44
Salop	Church Stretton ...	2·01	55	*Perth*	Loch Dhu	5·89	82
,,	Shrewsbury, Monkmore	2·01	72	,,	Crieff, Strathearn Hyd.	2·83	72
Worcs.	Malvern, Free Library...	1·26	42	,,	Pitlochry, Fincastle ...	2·48	76
Warwick	Birmingham, Edgbaston	1·64	54	*Angus*	Montrose Hospital ...	1·87	68
Leics.	Thornton Reservoir ...	1·32	47	*Aberd.*	Braemar	2·51	67
Lincs.	Boston, Skirbeck ...	0·75	27	,,	Dyce, Craibstone ...	2·90	86
,,	Skegness, Marine Gdns.	1·15	42	,,	New Deer School House	3·31	87
Notts.	Mansfield, Carr Bank ...	1·01	33	*Moray*	Gordon Castle	2·42	77
Derby	Buxton, Terrace Slopes	3·13	64	*Nairn*	Nairn, Achareidh ...	2·73	119
Ches.	Bidston Observatory ...	1·76	54	*Inverness*	Loch Ness, Garthbeg ...	4·71	132
,,	Manchester, Ringway...	2·26	73	,,	Loch Hourn, Kinl'hourn	11·58	117
Lancs.	Stonyhurst College ...	3·60	80	,,	Fort William, Teviot ...	9·19	129
,,	Squires Gate	2·23	63	,,	Skye, Broadford ...	8·59	113
Yorks.	Wakefield, Clarence Pk.	1·09	38	,,	Skye, Duntulm ...	5·59	103
,,	Hull, Pearson Park ...	1·05	35	*R. & C.*	Tain, Mayfield... ...	3·53	128
,,	Felixkirk, Mt. St.John...	1·61	56	,,	Inverbroom, Glackour...	6·32	112
,,	York Museum	1·24	46	,,	Achnashellach	10·14	133
,,	Scarborough	1·54	49	*Suth.*	Lochinver, Bank Ho. ...	5·73	125
,,	Middlesbrough... ...	1·00	33	*Caith.*	Wick Airfield	2·73	92
,,	Baldersdale, Hury Res.	2·83	76	*Shetland*	Lerwick Observatory ...	4·89	123
Norl'd.	Newcastle, Leazes Pk....	1·86	60	*Ferm.*	Crom Castle	3·30	102
,,	Bellingham, High Green	1·91	49	*Armagh*	Armagh Observatory ...	1·85	68
,,	Lilburn Tower Gdns. ...	1·58	43	*Down*	Seaforde	2·44	69
Cumb.	Geltsdale	3·75	101	*Antrim*	Aldergrove Airfield ...	2·07	69
,,	Keswick, High Hill ...	4·50	80	,,	Ballymena, Harryville...	3·63	98
,,	Ravenglass, The Grove	3·99	92	*L'derry*	Garvagh, Moneydig ...	3·99	113
Mon.	A'gavenny, Plâs Derwen	1·84	40	,,	Londonderry, Creggan	3·81	104
Glam.	Ystalyfera, Wern House	3·03	44	*Tyrone*	Omagh, Edenfel ...	4·00	109

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