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

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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[5], 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

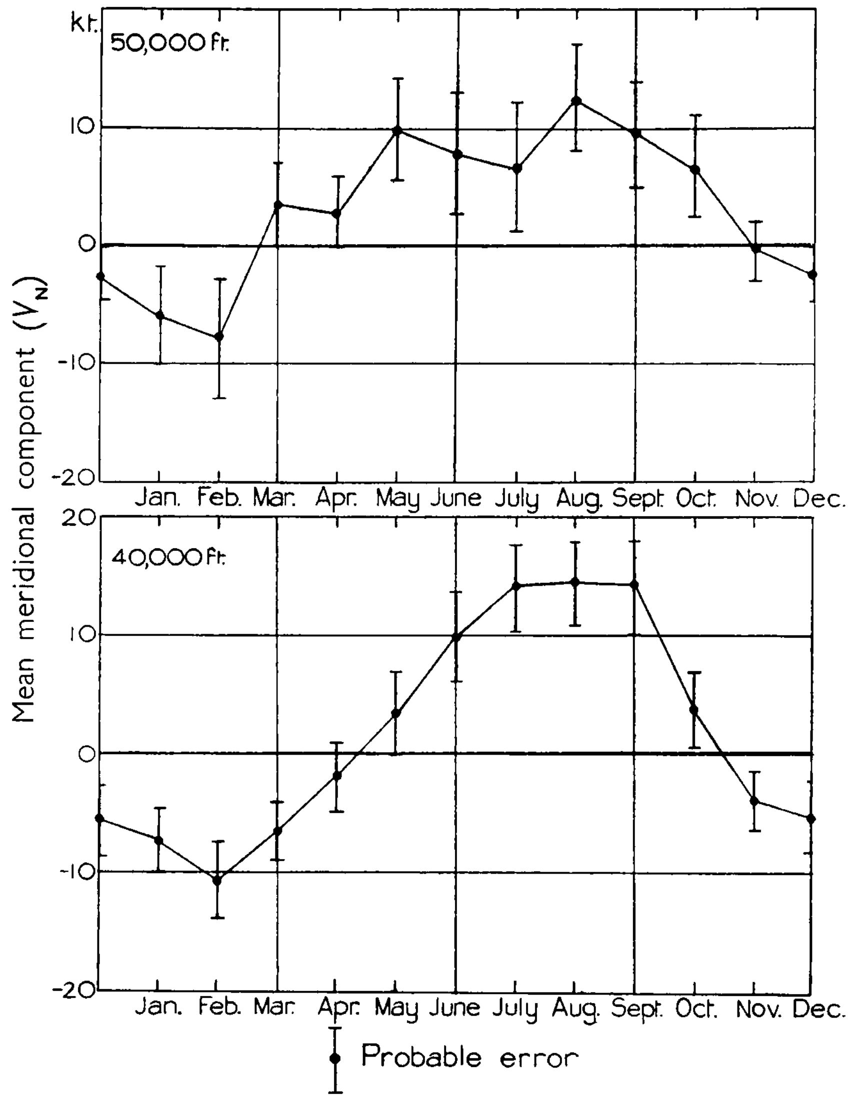

FIG. 1—MEAN MERIDIONAL WIND COMPONENT AT SINGAPORE

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 40,000 ft.	Upper limit likely to be exceeded on 5 per cent. of occasions at 50,000 ft.	Frequency of departures from mean exceeding 19 kt. and 39 kt. at 40,000 ft. >19 kt.	40,000 ft. >39 kt.	50,000 ft. >19 kt.	50,000 ft. >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., V_N as −1·2 kt., 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 $1 \cdot 52 \times 10^{-7}$. 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 $V_R = 41 \cdot 7$ 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

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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.

REFERENCES

1. HAY, R. F. M.; Wind at high levels over Singapore 1950–52. *Met. Res. Pap., London*, No. 770 1952.
2. Singapore, Malayan Meteorological Service. *Pilot balloon and radar wind data.*
3. BROOKS, C. E. P. and CARRUTHERS, N.; Handbook of statistical methods in meteorology. London, 1953.
4. London, Meteorological Office. Meteorological Office Discussion. *Met. Mag., London*, **82,** 1953, p. 120.
5. GEARY, R. C.; The ratio of the mean deviation to the standard deviation as a test of normality. *Biometrika, Cambridge*, **27,** 1935, p. 310.
6. DURST, C. S.; Variation of wind with time and distance. *Geophys. Mem., London*, **12,** No. 93, 1954.
7. VAN BEMMELEN, W.; Der intertropische Teil der allgemeinen Zirkulation nach Beobachtungen in Batavia. *Met. Z., Braunschweig*, **41,** 1924, p. 133.
8. PALMER, C. E.; The general circulation between 200 mb. and 10 mb. over the equatorial Pacific. *Weather, London*, **9,** 1954, p. 341.
9. AUSTIN, E. E. and DEWAR, D.; Upper winds over the Mediterranean and Middle East. *Met. Res. Pap., London*, No. 811, 1953.
10. MAUCHLY, J. W.; A significance-test for ellipticity in the harmonic dial. *Terr. Magn. atmos. Elect., Washtington D.C.*, **45,** 1940, p. 145.
11. BROOKS, C. E. P., DURST, C. S. and CARRUTHERS, N.; Upper winds over the world. Part I. The frequency distribution of winds at a point in the free air. *Quart. J. R. met. Soc., London*, **72,** 1946, p. 55.
12. BROOKS, C. E. P., DURST, C. S., CARRUTHERS, N., DEWAR, D. and SAWYER, J. S.; Upper winds over the world. *Geophys. Mem., London*, **10,** No. 85, 1950.

PATTERN OF RAINFALL

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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

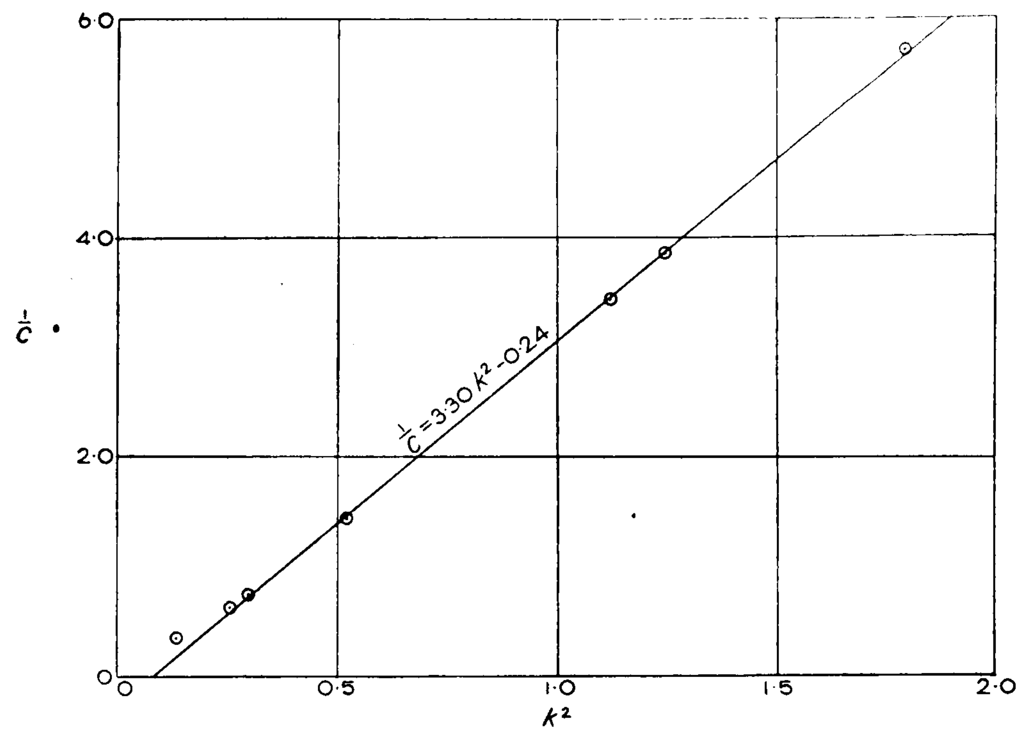

FIG. 1—RELATION BETWEEN $1/C$ AND k^2

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

$$\frac{1}{C} = 3 \cdot 30k^2 - 0 \cdot 24 \qquad \dots\dots (2)$$

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 $k > 0 \cdot 5$, formula (2) provides an excellent fit. Using formula (2), for $k > 0 \cdot 5$ formula (1) may be rewritten as

$$\frac{R}{N_r} = \frac{10^{k\sqrt{r}}}{3 \cdot 30k^2 - 0 \cdot 24}. \qquad \dots\dots (3)$$

Formula (3) may be used to determine k, and therefore the rainfall pattern for any suitable station (i.e. such that $k > 0 \cdot 5$) 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

$$y = \log\left(\frac{3 \cdot 3R}{N_r}\right) \qquad \dots\dots (4)$$

$$\text{and } y = k\sqrt{r} - \log(k^2 - 0 \cdot 073) \qquad \dots\dots (5)$$

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 $k^2 = 0 \cdot 073$, with a minimum at

$$k = k_m = \frac{1}{\mu\sqrt{r}}\left\{1 + \sqrt{(1 + 0 \cdot 073\mu^2 r)}\right\},$$

where $\mu = \log_e 10 = 2 \cdot 303$. 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,

$$k_m < 0 \cdot 6,$$

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 $0 \cdot 02$, 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

REFERENCES

1. THOMSON, A. B.; One aspect of the pattern of rainfall. *Met. Mag., London*, **83**, 1954, p. 293.
2. BROOKS, C. E. P. and CARRUTHERS, N.; Handbook of statistical methods in meteorology. London, 1953.

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.

REFERENCES

1. BRUNT, SIR DAVID; Where to live—a meteorological problem. *Proc. roy. Instn. G.B., London*, **34**, 1947, p. 57.
2. BROOKS, C. E. P.; The English climate. London, 1954.
3. HAWKINS, E.; Medical climatology of England and Wales, London, 1923.
4. GUMBEL, E. J.; Statistical theory of extreme values and some practical applications. *Appl. Math. Ser. U.S. Bur. Stand., Washington D.C.* No. 33, 1954.
5. THOM, H. C. S.; The rational relationship between heating, degree days and temperature. *Mon. Weath. Rev., Washington D.C.*, **82**, 1954, p.1.
6. THOM, H. C. S.; Normal degree days below any base. *Mon. Weath. Rev., Washington D.C.*, **82**, 1954, p. 111.
7. LAWRENCE, E. N.; Estimation of weekly frost risk using weekly minimum temperatures. *Met. Mag., London*, **81**, 1952, p. 137.
8. LAWRENCE, E. N.; Estimation of the probabilities of given extreme minimum temperatures. *Met. Mag., London*, **84**, 1955, p. 1.
9. JENKINSON, A. F.; The frequency distribution of the annual maximum (or minimum) values of meteorological elements. *Quart. J. R. met. Soc., London*, **81**, 1955, p. 158.

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,

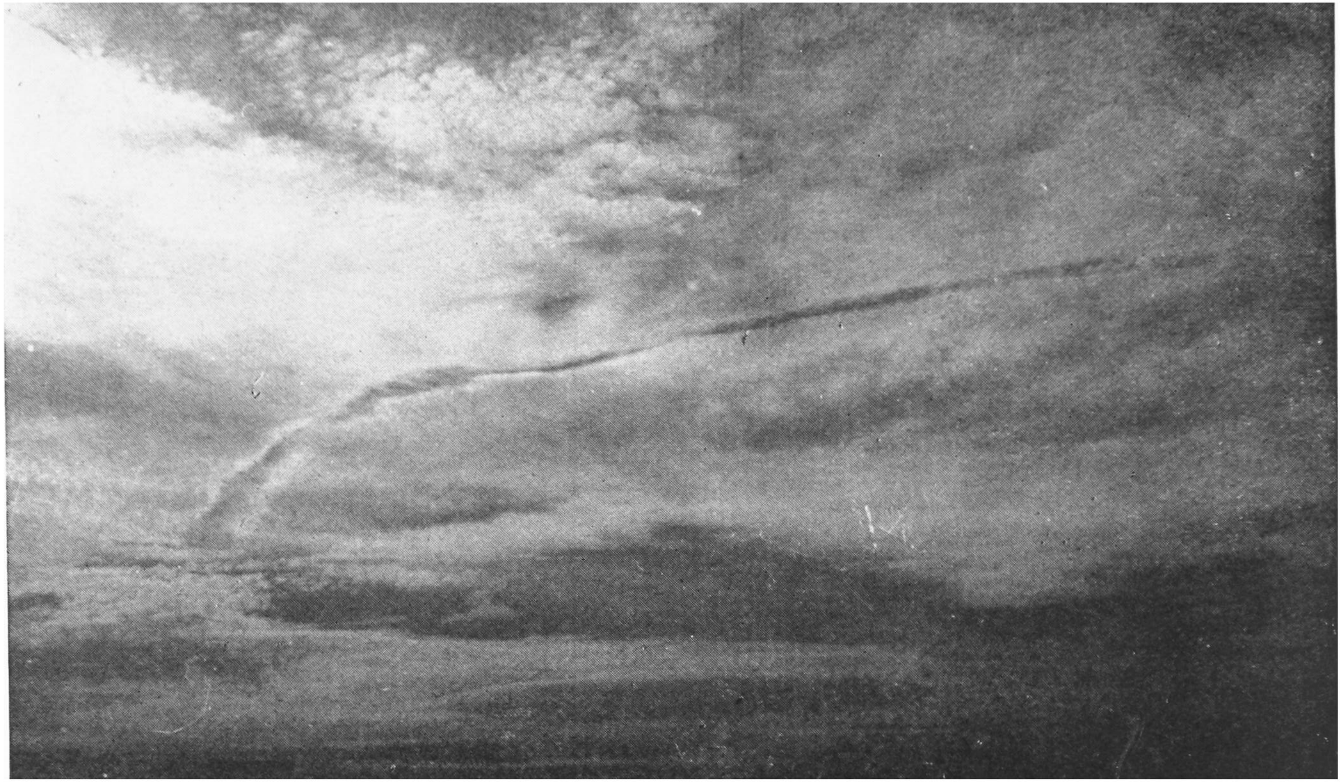
Capt. H. D. Horwood, R.N.R., of the New Zealand Shipping Company, who has been a voluntary observer since 1923,

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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