I.O. 581

THE METEOROLOGICAL MAGAZINE

1954 Volume 83

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M.O. 581 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 83, No. 979, JANUARY 1954

HUMIDITIES IN THE LEE OF HILL MASSES

By L. P. SMITH, B.A.

During the course of an investigation into the incidence of potato blight, the Agricultural Branch of the Meteorological Office has examined the number of hours a day when the relative humidity was 90 per cent. or more in the middle and late summer. As a result, interesting facts have emerged regarding the values reported from stations which are situated near large hill masses. In particular, readings from Speke, Finningley and Shawbury appear to indicate the existence of a different humidity régime as compared with other stations of similar height and exposure in neighbouring areas, namely Squires Gate, Church Fenton and Ringway respectively.

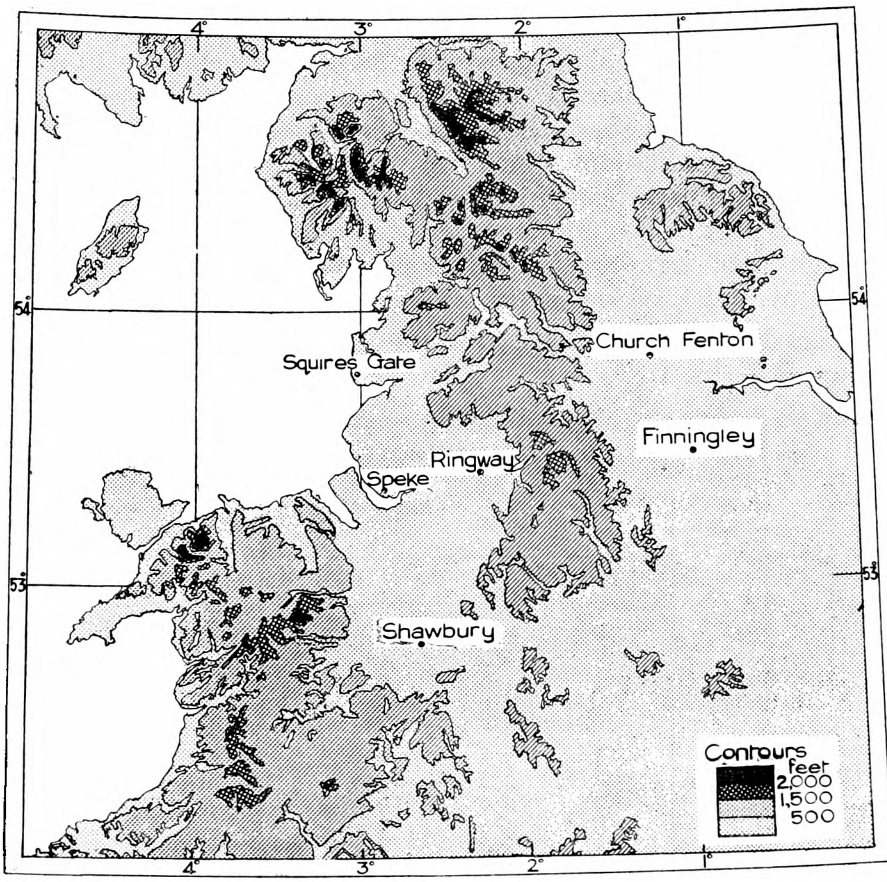
The values for 1950 and 1951, for the months June to September, are summarized in Table I.

TABLE I—AVERAGE NUMBER OF HOURS PER DAY WITH HUMIDITY 90 PER CENT. OR ABOVE, 1950–51

	General wind direction	Speke	Squires Gate	Finningley	Church Fenton	Shawbury	Ringway
				hours per day			
June ...	SW.	2·7	7·5	1·9	6·0	2·5	5·4
	NW.	2·9	2·5	1·3	5·7	1·8	6·7
	NE.	3·2	4·4	4·0	8·3	3·0	3·0
	SE.	3·3	4·5	3·1	8·9	3·3	3·1
	All directions	2·9	5·6	2·3	6·8	2·6	4·9
July ...	SW.	2·3	5·1	2·8	6·5	3·5	6·4
	NW.	3·8	3·7	4·4	7·0	3·7	8·9
	NE.	0·0	0·0	2·0	6·5	0·0	1·5
	SE.	3·8	4·2	3·2	8·5	6·0	4·0
	All directions	2·7	4·6	3·1	6·8	3·7	6·5
August ...	SW.	4·8	6·9	5·8	11·8	6·3	8·0
	NW.	5·3	3·1	4·9	9·5	5·5	9·7
	NE.	10·5	12·0	16·0	19·0	13·5	10·0
	SE.	9·5	12·5	11·0	17·0	9·7	9·7
	All directions	5·4	6·7	6·3	11·9	6·6	8·5
September	SW.	5·5	8·8	5·5	9·3	7·2	9·1
	NW.	1·4	3·1	1·8	5·6	3·9	6·5
	NE.	5·0	8·0	12·7	14·0	11·7	10·7
	SE.	3·4	5·2	9·2	10·4	6·4	1·2
	All directions	4·5	7·0	5·5	8·9	6·8	8·0
June to September	SW.	3·9	6·9	4·2	8·7	5·1	7·4
	NW.	3·3	3·1	3·1	6·9	3·7	8·0
	NE.	4·0	5·5	6·9	10·4	5·6	5·2
	SE.	4·5	6·1	5·8	10·5	5·8	4·1
	All directions	3·9	6·0	4·3	8·6	4·9	7·0

Examining the comparison between Speke and Squires Gate in detail, it is clear that Squires Gate has far longer periods of high humidity than Speke in south-westerly winds (over 75 per cent. more). In north-westerly winds off the Irish Sea, as might be expected, there is little difference. There is a difference, however, in winds with an easterly component; Speke is again less liable to high humidities, and this difference is not easily explainable. The large difference in south-westerly weather could be due to Speke's proximity to the mountains in north Wales.

A similar effect is seen in the comparison between Finningley and Church Fenton during winds with a westerly component. The magnitude of the difference is even greater, for Church Fenton experienced more than double



the number of hours of high humidity registered at Finningley. Furthermore, this relative dryness at Finningley persists even during south-easterly or north-easterly winds. This may be due in part to the difference in distance from the sea, but such an explanation is not completely satisfactory.

During north-westerly winds, Shawbury had less than half the "humid" hours measured at Ringway, a proportion which rises to two-thirds with south-westerly winds. There is little difference in north-easterly weather, but with the south-easterlies Ringway obtains more shelter from the Pennines and is appreciably drier than Shawbury.

In all areas the differences seem to diminish as the summer progresses.

Considering the lower afternoon humidities and comparing the average 1500 G.M.T. relative humidities as reported in the *Monthly Weather Report*, the results shown in Table II are obtained.

TABLE II—AVERAGE RELATIVE HUMIDITY AT 1500 G.M.T., 1950–51

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	June to Sept.	Year
						per cent.								
Speke... ...	82·5	73·0	68·0	60·5	60·0	59·5	62·5	69·0	70·0	71·0	77·0	79·5	65·3	69·4
Squires Gate...	88·0	81·0	78·5	68·5	67·5	67·5	71·0	74·5	76·0	76·5	82·0	82·5	72·3	76·1
Difference ...	5·5	8·0	10·5	8·0	7·5	8·0	8·5	5·5	6·0	5·5	5·0	3·0	7·0	6·7
Finningley ...	80·5	73·5	65·0	55·0	65·5	55·0	59·5	64·0	67·0	69·0	78·5	80·5	61·4	67·7
Church Fenton	84·0	76·0	71·0	65·5	71·0	63·5	66·0	73·5	71·0	74·0	83·5	85·5	68·5	73·7
Difference ...	3·5	2·5	6·0	10·5	5·5	8·5	6·5	9·5	4·0	5·0	5·0	5·0	7·1	6·0
Shawbury ...	78·5	74·0	68·0	58·5	60·5	56·5	58·0	66·0	69·5	70·5	79·0	82·5	62·5	68·5
Ringway ...	83·0	78·0	70·0	62·5	61·0	57·5	66·5	70·0	72·5	73·0	81·5	85·5	66·6	71·7
Difference ...	4·5	4·0	2·0	4·0	0·5	1·0	8·5	4·0	3·0	2·5	2·5	3·0	4·1	3·2

The differences here are consistent and at their maximum in late spring and early summer, except in the case of Shawbury and Ringway. A spell of easterly weather in May and June 1951 caused lower humidities for a time at Ringway and so reduced the normal difference.

Relative humidity is a difficult parameter with which to work because of its dependence on temperature. Table III gives the average vapour pressures, taking these as the mean of the four average values at 0300, 0900, 1500 and 2100 G.M.T. reported in the *Monthly Weather Report.*

TABLE III—AVERAGE VAPOUR PRESSURE, 1950–51

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	June to Sept.	Year
						millibars								
Speke... ...	7·21	6·99	7·47	7·43	9·40	12·21	13·66	13·57	12·67	10·15	8·75	6·95	13·03	9·71
Squires Gate...	7·37	7·33	7·76	7·89	9·76	12·74	14·14	14·01	13·00	10·43	9·06	7·10	13·47	10·05
Difference ...	0·16	0·34	0·29	0·46	0·36	0·53	0·48	0·44	0·33	0·28	0·31	0·15	0·44	0·34
Finningley ...	6·90	6·81	7·16	7·09	9·49	11·95	13·55	13·41	12·30	9·76	8·51	6·53	12·80	9·45
Church Fenton	7·04	6·93	7·44	7·80	10·15	12·94	14·27	14·51	12·74	10·21	8·84	6·77	13·61	9·97
Difference ...	0·14	0·12	0·28	0·71	0·66	0·99	0·72	1·10	0·44	0·45	0·33	0·24	0·81	0·52
Shawbury ...	6·94	6·97	7·44	7·24	9·33	11·97	13·51	13·30	12·57	9·90	8·60	6·89	12·84	9·55
Ringway ...	7·14	7·09	7·49	7·44	9·34	12·06	13·71	13·46	12·54	10·10	8·75	6·83	12·94	9·66
Difference ...	0·20	0·12	0·05	0·20	0·01	0·09	0·20	0·16	−0·03	0·20	0·15	−0·06	0·10	0·11

There was thus a considerable difference in vapour pressure averages between Finningley and Church Fenton during this period, although these stations (only 25 miles apart) are at almost identical heights above sea level and have immediate surroundings of a very similar character. The difference is smaller in the case of Speke and Squires Gate, but in both cases the maximum is observed in early summer. Between Shawbury and Ringway there is little to choose, probably partly because of the "reversal" effect noticed earlier. The alteration in the relative humidity is thus not entirely a temperature effect.

Relative humidity, despite its limitations, is a factor which enters constantly into agricultural research problems, such as questions of fungus disease and storage conditions. Differences of the order of those examined above are thus of considerable significance, and in confirmation of these differences it has been noticed that potato blight does not seem to occur early in a season in areas to the west of Finningley and Shawbury towards the hill masses.

ERRATUM

AUGUST 1953, PAGE 247, line 13; *for* "Sunrise was at 0743 in London on March 3." *read* "Sunrise was at 0643 in London on March 3."

WHIRLWIND AT SOUTHEND-ON-SEA, AUGUST 10, 1953

By E. N. LAWRENCE, B.Sc.

This note is a description of the whirlwind at Southend-on-Sea, Essex, August 10, 1953 and of similar incidents, together with a brief analysis of the prevailing meteorological conditions.

Reports.—The following are a selection of the observations reported:—

The Times, August 11, 1953 stated that

A whirlwind alarmed hundreds of people on the beach and esplanade at Westcliff, Essex this afternoon. A slight breeze blowing off the cliffs suddenly became a gale, involving a stretch of about 100 yd. The wind blew holiday-makers off the esplanade, and deck chairs and clothing were blown into the air.... Many people were blown to the ground, and a 60-ft. high waterspout arose near the shore. The whole incident lasted about 6 sec., and then the sea became smooth again. About a dozen people needed first-aid attention for cuts and bruises. When the wind subsided, bathers swam out and retrieved floating deck chairs and clothing. No other parts of the beach were involved and there was no damage to boats. An observer stated, "I was on one side of the esplanade and felt nothing of the whirlwind. I just saw the effect of it on the other side and it was very uncanny".

The Pier Master and Foreshore Manager said

The whirlwind was of very short duration, probably a period of about a minute or so and the velocity was near hurricane force. A small waterspout occurred. The anemometer on the roof of the Pier Office [see Fig. 1] was not affected in any way. Throughout the period 0900 to 2100 G.M.T. on the 10th, only light variable airs were experienced in this Borough, excepting during the above "whirl" itself.

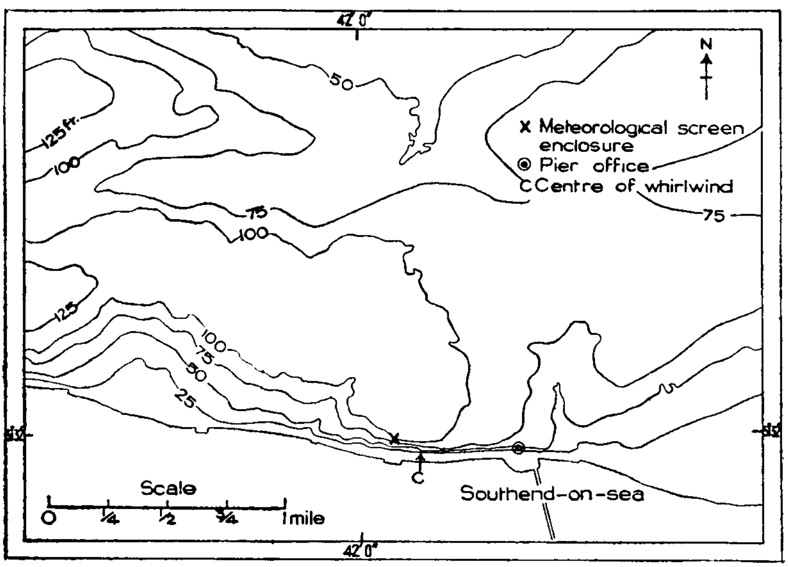


FIG. 1—CONTOURS AROUND SOUTHEND-ON-SEA

Miscellaneous observations collected by the writer stated that the main force of the disturbance was experienced just south-west of the Esplanade Hotel (Fig. 1) at 1450 G.M.T. (about 1500 according to another report) on a cemented stone beach, less than 20 yd. wide, with a slope length of about 20 ft. and inclined at about 25°, facing approximately south. The sea was covering the sand and pebbles and was just lapping the stone slope. High tide occurred at 1303. Just across the road, a little outside and to the east of this 20 yd. stretch of front, at the Esplanade Hotel, nothing was felt.

Other newspaper reports refer to a "large black cloud of dust" and "a bang" or "loud bang" when the whirlwind hit the sea. A further report mentions that "two motorists were caught in the whirl and whipped across the roadway" at the base of the cliffs.

Synoptic and upper air data.—At 1500 on August 10, 1953, an anticyclone extended from the Azores to the south of the British Isles (Fig. 2). A cold front, moving south-east, extended from Scandinavia to the southern North Sea area where pressure was fairly uniform. The wind gradient over Essex was light north-north-westerly. The whole of south-east England had fine weather with little or no cloud and light winds. The upper air data for Crawley, Sussex, (Fig. 3) showed that between 0300 and 1500, some cooling had occurred below about 700 mb. but that up to about 975 mb., surface heating had produced an almost dry adiabatic lapse rate. Upper winds are shown in Table I.

TABLE I—UPPER WINDS AT CRAWLEY, SUSSEX, AUGUST 10, 1953

Height	0300 G.M.T.		1500 G.M.T.		Height	0300 G.M.T.		1500 G.M.T.	
mb.	°	kt.	°	kt.	mb.	°	kt.	°	kt.
300	237	62	261	47	650	225	30	266	21
350	236	59	257	33	700	224	26	257	17
400	238	48	253	33	750	223	13	259	16
450	235	45	261	32	800	215	17	267	10
500	237	40	261	25	850	217	12	305	6
550	239	35	261	29	900	250	8	333	9
600	232	28	271	28	950	277	7	330	4
					Surface	270	2	310	5

Local data.—The local contours, the location of the centre of the whirlwind, C, and adjacent meteorological sites are shown in Fig. 1. Information extracted from the records at Southend-on-Sea meteorological station (position 51°32′N.,

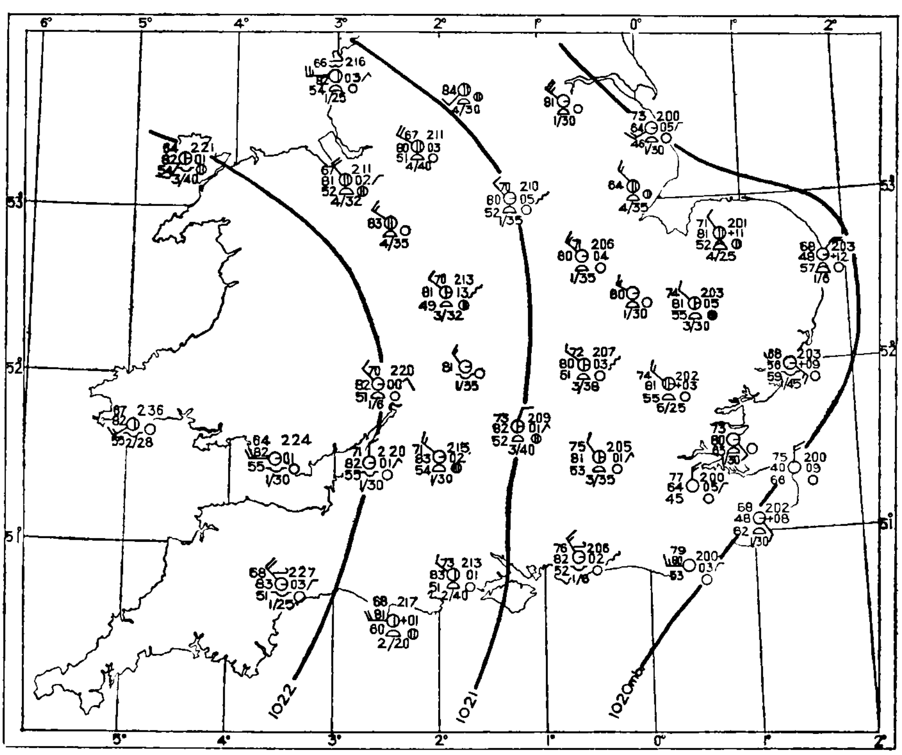


FIG. 2—SYNOPTIC CHART, AUGUST 10, 1953, 1500 G.M.T.

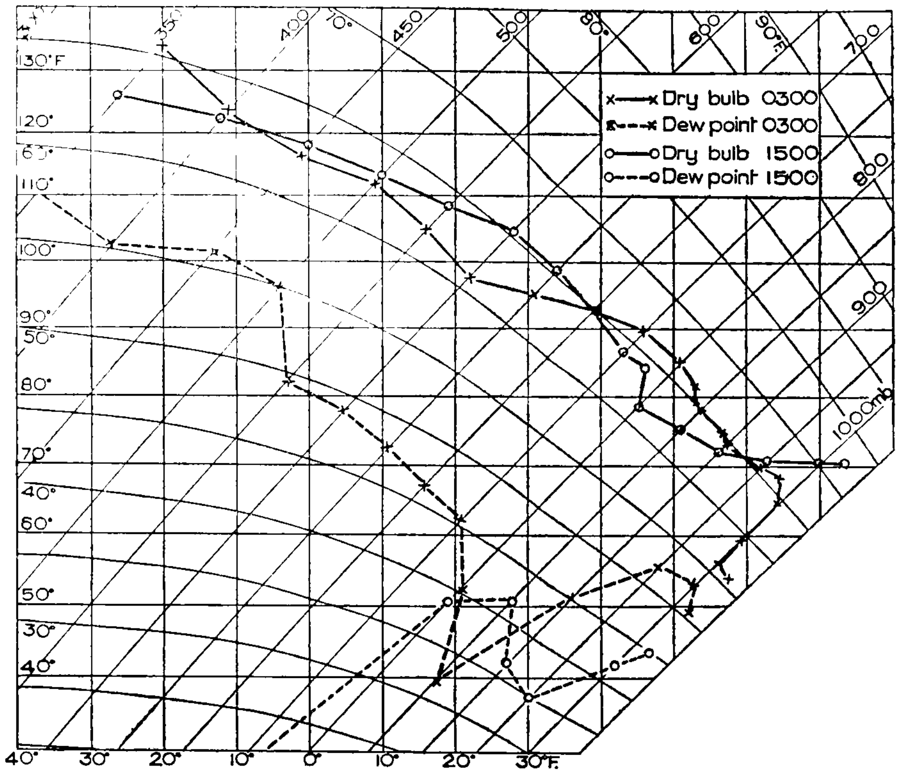


FIG. 3—UPPER AIR SOUNDINGS, CRAWLEY, AUGUST 10, 1953

0°42′E., height 90 ft. above M.S.L., height of wind vane 135 ft. above M.S.L.) is given in Table II.

The general weather after sunrise was fine (< 2 oktas cloud), but became partly cloudy (3 oktas cloud) during late afternoon. The total duration of sunshine was 12·2 hr. and the state of ground dry.

TABLE II—WEATHER DATA FOR SOUTHEND-ON-SEA, AUGUST 10, 1953

Time	Temperature					Relative humidity	Wind		Visibility	Rainfall
	Dry bulb	Wet bulb	Max.	Min.	Grass min.		Direction	Beaufort force		
G.M.T.	*degrees Fahrenheit*					%			miles	mm.
0900	66·8	61·8	75	60	57	74	N.	4	$6\frac{1}{4}$–$12\frac{1}{2}$	nil
1800	76·1	63·9	81	..	..	48	E.	2	$12\frac{1}{2}$–$18\frac{3}{4}$	nil

The autographic record from a barograph at the Pier Office is shown in Fig. 4. Throughout the late morning and afternoon of August 10, 1953, the trace was unusually disturbed. At 1450 (at the time of the whirlwind) the trace

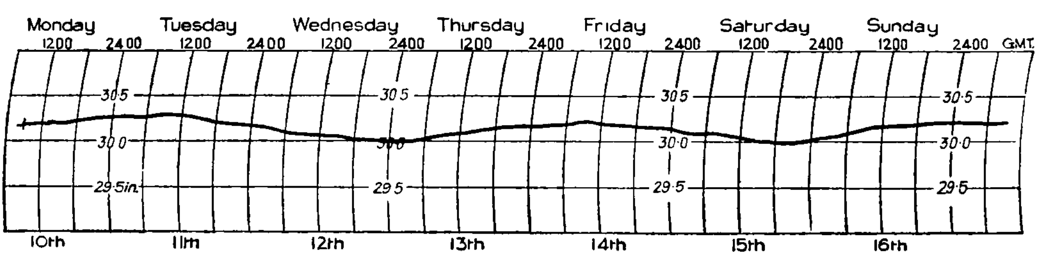


FIG. 4—BAROGRAM, SOUTHEND-ON-SEA, AUGUST 10–16, 1953

shows a slight fluctuation, though a larger fluctuation occurred (in the vicinity of the Pier Office) between noon and 1300. The only other part of the week's record which is comparable for unsteadiness, was on the evening of Saturday, August 15, when an occlusion passed over the area.

The *Galloper* lightship east of the Thames Estuary (51°44′N., 1°58′E.) reported a sea temperature of 62°F.

Discussion and conclusions.—In allocating the causes of the whirlwind, it is necessary to consider a number of prevailing factors, each of which has to some degree an influence on local air convection and on the production of a very unstable or superadiabatic lapse rate in the surface air layer.

The conditions of cloud, haze and humidity were all conducive to high insolation. Cloud was present only in small amounts, visibility was good or very good, and the air mass was not a very moist one and reached Southend after a considerable land track. High ground temperatures were further encouraged by the little or no wind over the area before the whirl, and as the time of occurrence of the disturbance was 2–3 hr. after noon, ground temperatures would be close to their diurnal maximum value. The time of the year, also, was particularly favourable for high temperature. It appears that the light gradient was sufficient to nullify the sea-breeze and its cooling effects. It has been suggested that air instability and convergence may have been increased by the coincidence of the passage of a weak cold front. An examination of the upper air data and general surface conditions (Figs. 2 and 3 and Table I) indicates that this was not an important factor, if indeed it existed at all, though a cold front was manifest further east.

The spatial rarity of the phenomenon suggests that these conditions, though essential, are probably not sufficient in themselves for the development which occurred, and that further contributory causes would be found in the microclimatic features of the area. The local topographical details are striking. Regarding aspect, the coast faces a little to the west of south, a favourable direction for high insolation and shelter from the northerly winds which persisted early in the day. The slope of the coastal strip is about 20° over stretches of 200 ft., but for substantial parts of this length the slope is of the order of 40°. The sun's altitude at this time of the year is 54° at noon, 52° at 1300, 47° at 1400 and about 40° at 1450; and the corresponding values of the sun's azimuth were 180°, 156°, 135° and 115° respectively. Hence for 1–2 hr. before the disturbance the sun's radiation was almost at right angles to large sections of the coastal slope, thus affording nearly maximum insolation per unit surface area. This was especially so at the centre of the whirl, where the slope was distinctly steeper than areas to both east and west and where the slight convexity of the length of slope and coastline enabled the sun to face a section of the ground surface over a longer period than if the coastline were absolutely straight with but a single aspect. The fact that the slope was "isolated" and that the coastline and slope were slightly convex may have caused a "concentration" of convergence. For a coastal station, daily maximum temperatures at Southend are above average and often show high records. This is presumably due to the fact that at Southend the coastline is not straight or exposed but in the form of an estuary, with the consequent restriction of sea-breeze cooling effects, and there is a large variation in the extent of the uncovered surface of mud, sand, etc.—at low tide on sunny days the sea front is effectively about 1 mile inland.

Having considered the local orographic conditions and the general orientation of land and sea, it now remains to examine the type of soil, ground cover and the state of ground, with reference to both present and past weather. The only rain recorded since the beginning of the month, apart from traces, was 0·06 in. on the 5th. Over 12 hr. of sunshine was recorded on August 9 and nearly 10 hr. on August 8. The steeply sloping loam-soil "cliffs" favour good water drainage, and the resulting very dry top soil was conducive to high surface temperatures. The cliffs are well covered with trees, but where gaps exist the grass was patchy and worn. The beach is stone, the esplanade concrete, etc., with a light-painted building at the bottom of the cliffs reflecting heat on to the roadway.

It has been mentioned that the sea-breeze was not very evident on August 10 before the whirlwind, presumably because of the opposing northerly gradient, and that the absence of this breeze was a major factor in the production of high surface temperatures (Southend meteorological station recorded a screen temperature maximum of 81°F.). However, the sea-breeze tendency would have increased during the earlier part of the day especially with the incoming tide and it is possible that some drift of sea air (forced upward by the slope) was the trigger action or part of it. The effect of an influx of cool sea air over hot ground would be to set up a superadiabatic lapse rate near the surface and encourage further influx of cold sea air. A wind from the sea was certainly reported by several observers at the onset of the disturbance. The general contour pattern (slope, direction and isolation) and the slight convexity of the coastline would all favour an influx of a wedge of cool moist air and the resulting centre of convergence at this point of the coast.

At about the same time of the day and year in 1951, on a hot day with "not a breeze", a similar phenomenon was reported along this part of the coastline. An observer, just east of the 1953 whirl-centre felt the wind "blowing up as for a storm", the sky appeared to darken and then a "windstorm" which seemed to come from the west lifted all light materials, knocked over heavier articles such as iron chairs and bent cliff trees well down towards the east. The storm appeared to move off towards the east, the sky lightened and debris was cleared. In a few minutes the storm which had moved to just east of the pier was observed to return down the esplanade, this time clearly visible as a dusty whirlwind. Articles were once more disturbed and trees bowed strongly to the west. The whirl disappeared to the west and finished up as a waterspout of short duration, not far to the west of the observer.

The same observer recalls several similar phenomena in this area during the last 30 yr. or so, and again in 1946, at about the same time of the year, a similar but larger disturbance in the Bristol area.

Regarding the track of the 1953 whirlwind at Southend, the disturbance moved into the sea, probably under the influence of the northerly wind gradient. The reported loud bang on reaching the sea was probably due to the sudden water movement. In common with other similar disturbances it disappeared quickly after reaching the sea, where surface temperatures were insufficient to maintain the high lapse rate in the surface air layer.

An interesting and enlightening observation of a whirlwind (about 1931, probably in June or July, at about 0930 and near high tide) was reported to have occurred about 100 yd. to the east of the centre of the 1953 whirl. On this occasion, the whirl sucked up newspapers and other articles (including a rather heavy pram cushion). The disturbance appeared to come from the direction of the land and it moved out to sea. The weather both before and afterwards was fine, but around the time of the whirl the sky became clouded over and the disturbance was followed by a short but heavy rainstorm.

From a consideration of whirlwind phenomena generally, it would appear that the most important contributory factors in the development of the Southend whirlwind of August 10, 1953 were:—

(i) little or no cloud and light gradient wind direction from a northerly point

(ii) the steep, south-facing slope of a not very exposed coast with large tidal variation in uncovered surface area

(iii) the time of day (afternoon) and season (summer) and the coincidence of high tide.

NIGHT COOLING UNDER CLEAR SKIES, EXETER AIRPORT

By W. E. SAUNDERS, B.Sc.

Summary.—Methods used in the preparation of night-cooling curves in respect of Northolt[1] have now been applied to Exeter. The results show only minor differences from those obtained for Northolt.

Evening temperature discontinuity.—Only hourly temperature readings were available as compared with half-hourly observations for Northolt, so that it was sometimes difficult to decide upon the time and temperature of the evening discontinuity in the rate of fall of temperature. However, an examination of all clear evenings during 1950 gave 52 occasions on which there was a discontinuity in the early evening and at the same time no indication of advective change of air mass. The times of the discontinuities are plotted in Fig. 1 according to the time of the year. Analysing these cases by the method used at Northolt the following relations were found to give the temperature of the discontinuity in terms of the afternoon observations:—

With no inversion (25 cases, standard deviation 1·4°F.),

$$T = \tfrac{1}{2}(T_{max} + T_d) - 1{\cdot}6°F.$$

With inversion (27 cases, standard deviation 1·1°F.),

$$T = \tfrac{1}{2}(T_{max} + T_d) - 4{\cdot}0°F.$$

where T is the screen-level temperature at the time of the discontinuity, T_{max} is the maximum dry-bulb temperature (taken here as the highest of the hourly temperatures) and T_d is the dew point at the time of T_{max}. An occasion was regarded as an inversion case or not according as there was, or was not, an inversion with base at, or below, 850 mb. in the afternoon ascent.

The regression equation for occasions of inversion is identical with that obtained for Northolt, whereas in the non-inversion cases the constant is one degree greater at Exeter. The standard deviations show that the scatter was rather greater at Exeter. The periods were not analysed separately, but it appeared the scatter was greater in summer than winter, and may be due to sea-breeze effects.

The times of discontinuity were in good accord with the curve obtained for Northolt, and the diagram is given in Fig. 1. No further evidence could be obtained regarding the transitional dates between summer and winter conditions, and in the remainder of this work these have been taken as March 31 and October 1. In 1953 the transition occurred somewhere between October 17 and 23, following a spell of dry weather.

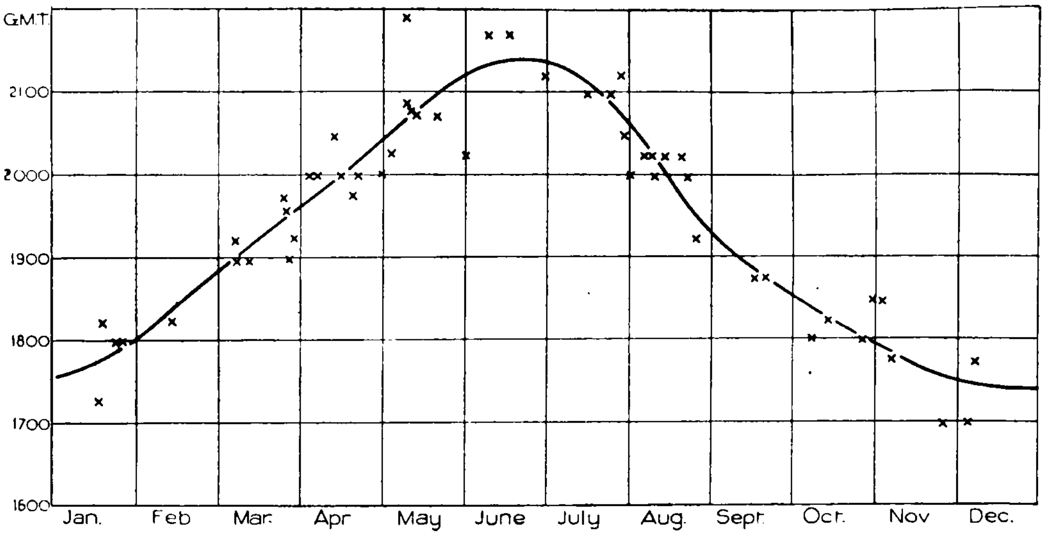
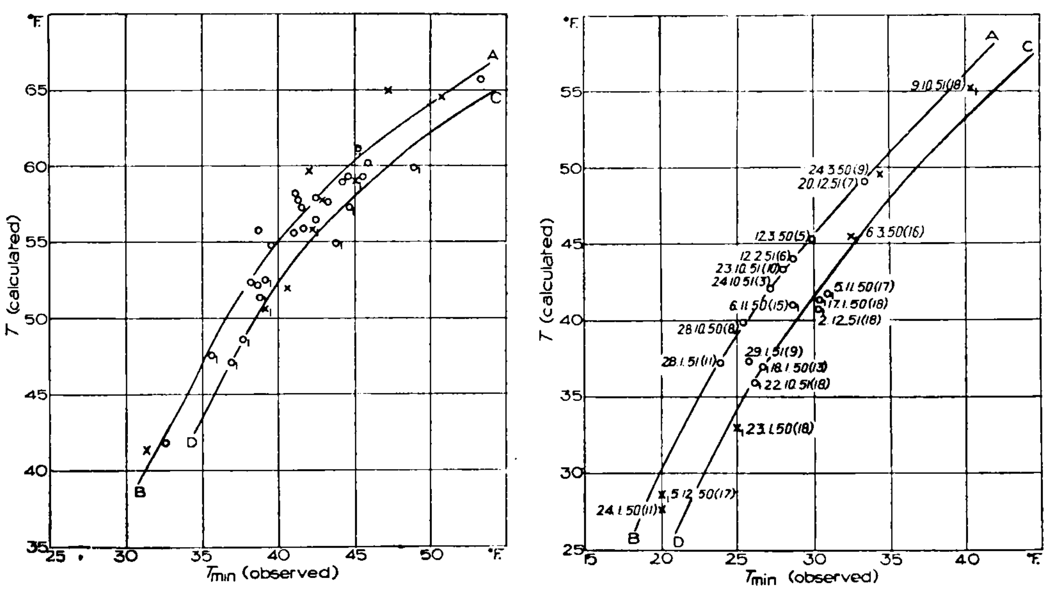


FIG. 1—VARIATION OF TIME OF EVENING TEMPERATURE DISCONTINUITY, EXETER, 1950

Subsequent cooling.—As for Northolt[1], a clear night was taken as one in which the mean cloud amount, excluding cirrus, did not exceed one okta. All clear nights during 1950 and 1951 were examined; 88 per cent. of occasions were used in preparing Fig. 2. On the remaining nights some advective change of temperature appeared to have taken place.



Summer　　　　Winter

FIG. 2—RELATION BETWEEN INITIAL AND FINAL TEMPERATURES OF THE PERIOD OF SUBSEQUENT COOLING FOR OCCASIONS OF CALM (MEAN GRADIENT WIND 0–12 KT.) AND LIGHT WIND (MEAN GRADIENT WIND 13–18 KT.)

Cases which were non-inversion for the calculation of T are marked o if the mean gradient wind was 0–12 kt. and o_1 if it was 13–18 kt. Cases which were inversion are similarly marked x and x_1. AB is the curve drawn to fit cases o and x, and CD to fit cases o_1 and x_1

A correction to allow for the reduced length of night in midsummer has been subtracted from T_{min} for all occasions between May 5 and August 10.

Gradient wind speeds are included in brackets in the winter curves.

Fig. 2 gives the curves expressing T_{min}, the final temperature of the period of subsequent cooling, as a function of T (calculated), the initial temperature, for summer and winter respectively. Distinction is made between occasions of calm and light wind. The division into inversion and non-inversion cases adopted in dealing with the discontinuity was carried forward into this analysis, an occasion being marked x or o according as it was inversion on non-inversion in the calculation of T.

The midsummer correction given in Fig. 5 of the Northolt analysis[1], which is not reproduced here, is believed to be of general application in view of its close agreement with theory, i.e. with Brunt's equation[2]. A correction from that diagram has been subtracted from the observed T_{min} before plotting on Fig. 2, for each occasion between May 5 and August 10.

Fig. 3 gives the relation between the mean gradient wind speed, taken generally from the Larkhill and Camborne reports and the number of degrees subsequent cooling, for the occasions of stronger winds.

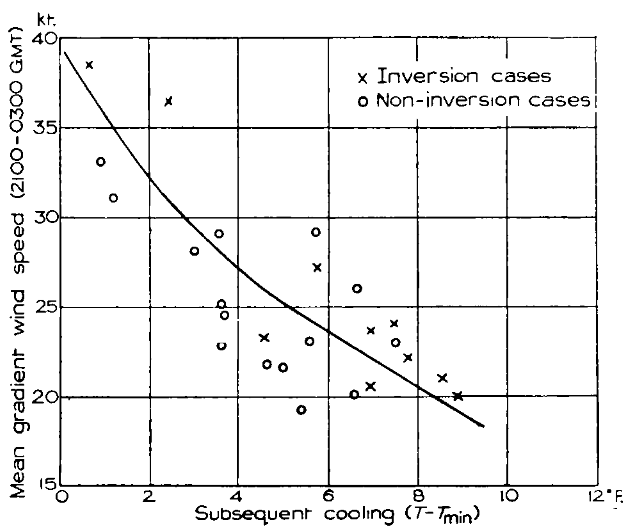


FIG. 3—RELATION BETWEEN THE MEAN GRADIENT WIND SPEED AND THE SUBSEQUENT COOLING FOR OCCASIONS OF STRONGER WIND

Mean gradient wind speed ⩾ 19 kt.

The scatter of individual cases from the mean curves of Figs. 2 and 3 gives standard deviations of 1·3°F. for summer and 0·9°F. for winter for Fig. 2 and 1·6°F. for Fig. 3. This suggests that the accuracy to be obtained from the winter curve is at least equal to that of the corresponding Northolt curve, while the Exeter curves for summer, and for strong winds, are rather less accurate. This is probably due to the proximity of the coast and estuary.

REFERENCES

1. SAUNDERS, W. E.; Some further aspects of night cooling under clear skies. *Quart. J.R. met. Soc., London,* **78,** 1952, p. 603.
2. BRUNT, D.; Physical and dynamical meteorology. Cambridge, 2nd edn, 1939, p. 138.

WIND-DIRECTION RECORDER

By THE TROPICAL TESTING ESTABLISHMENT, PORT HARCOURT

Introduction.—In 1948 it was found desirable to obtain regular records of wind direction, first at Port Harcourt, Nigeria with the immediate object of siting certain residential buildings, and afterwards on Lighthouse Beach, Lagos in connexion with trials on the corrosion of metals, where airborne salt was the controlling factor in corrosion. A device, designed and made in the workshops of the Tropical Testing Establishment, has now been working satisfactorily for over three years, and as it is the simplest and most convenient design with which we are acquainted, it seems to be worth bringing to the notice of any establishment which may have similar problems. The instrument has the additional advantage of being light and portable.

The main point in the design of a wind-direction recorder is how to transfer points on a circular locus to a convenient chart. The simplest device, in principle, is to have the recorder drum rotating with the wind, and the pen moving along the time scale parallel to the axis of the drum. Such an instrument was designed by Baxendell a long time ago. It makes, however, a rather

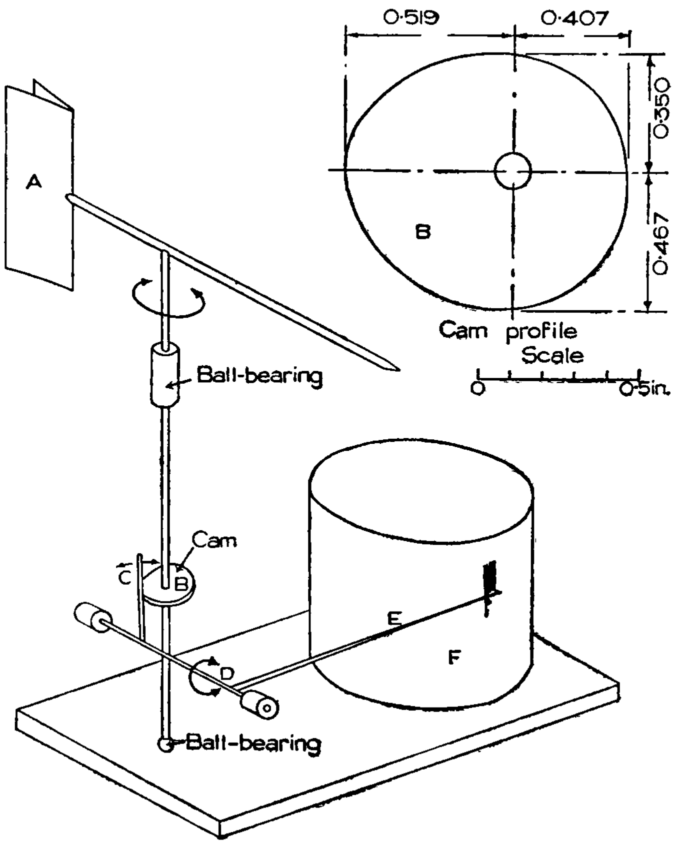


FIG. 1—WIND-DIRECTION RECORDER

inconvenient chart and the mechanism of the time movements involves difficulties. The current accepted method is that of Dines, in which the recording drum rotates with time, as with most recording instruments, and the trace is drawn by two pens, actuated by two separate cams which bring one pen in contact with the paper as the other comes off, the S. line being in the middle of the scale, and the N. at each extreme. This instrument is very satisfactory in its working, but the controlling cams and the balanced pens call for very skilled workmanship, and might be difficult and expensive to make in an ordinary workshop as an isolated job.

In the Munro-Rooker instrument a single pen engages a helix attached to the vane and the ends of the helix are joined by a straight groove occupying about 10° of the compass travel. The pen thus returns via this groove. The design is such as to keep this return to a minimum and also to avoid the pen stopping in the groove. The pen is made to go quickly to one or other end of the helix.

The design described in this report, like the Munro-Rooker, has a single pen, but is actuated not by a helical groove but by a cam. This gives the required linear traverse of the chart scale over a compass range of 270°, and a similarly linear but more rapid traverse in the opposite direction for the remaining 90°. This return is greater than in the case of the Munro-Rooker, but the instrument can be orientated to avoid frequent return traces. A cam action is simpler to produce and less likely to give trouble in a corrosive atmosphere than the helical type.

The instrument.—The instrument illustrated in the photograph (facing p. 16) was essentially an experimental model, being improvised from various readily available components. The plate vane shown in the photograph was later modified to a splayed vane as shown in Fig. 1.

The construction of the instrument is shown in the diagrammatic drawing (Fig. 1). The vertical shaft carrying the wind vane A is mounted in a tube and bears on a $\frac{5}{32}$ in. diameter ball at its base and is held by a ball race at the top. The shaft carries a cam B which bears against a lever C, the movement of which rotates the spindle D on which is mounted the pen arm E. The pen thus draws an arc on the chart of the drum which rotates once a day and round a vertical spindle. Fig. 1 also gives an enlarged view of the cam with its dimensions. These are such that as the cam rotates, the pen is raised progressively one third across the width of the chart, and when passing from the highest to the lowest point of the cam, it retraces the full width of the chart. The left-hand photograph in the centre of this Magazine shows the cam and lever system in detail.

It is convenient to orientate the instrument so that the prevailing wind comes near the middle of the 270° range. For use at Lagos for instance where the wind is mainly W. to S., the instrument is so placed that as the wind vane traverses from E. to N. via S. and W. the pen describes an arc from top to bottom of the chart (3 in. vertical distance) and as the vane swings on from N. to E. via NE., the pen returns from bottom to top of chart. This swing back is of minor importance as far as wind direction at Lagos is concerned, so in effect the chart is a record of oscillations within the segment E. to N. via S. and W. The chart can therefore be divided into three horizontal strips, the top one of which is E. to S., the middle one, S. to W. and the bottom one, W. to N.

The right-hand photograph in the centre of this Magazine shows two typical charts which illustrate the characteristic veering of the wind at Lagos most of which is between SE. and W. In chart A, the wind has oscillated between N. and W. from 0800 to 1200, i.e. within the segment of the slower traverse and so occupies the bottom third of the chart. In chart B, over the same time of day it has oscillated mainly between N. and E., so the graph covers the full width of the chart. In both charts after 1700, inspection shows that though there is plenty of veering N. to E., most of it is on the lesser scale N. to W.

When first set up difficulty was experienced with the high amplitude of the vane in a veering wind. Attempts were made to damp this by an oil bath at the base of the vane spindle. This did not reduce the amplitude sufficiently so the vane itself was modified to a splayed vane as shown in Fig. 1. This was found to reduce the oscillations considerably.

Fig. 2 has been prepared to show the type of trace obtained when the wind is veering 45° with the cam set for a prevailing SW. wind. The extreme left-hand block represents a 45° veer N. to NW. on the larger segment or N. to NNE. (approximately) on the smaller segment. The second block is a 45° veer through NE., that is on the smaller segment. The third block may be on either segment, SE. to E. or E. to ENE. (approximately). The next five blocks are 45° veers on the larger segment with means at the compass points indicated beneath them. The final block is a 45° veer N. to NE. on the smaller segment.

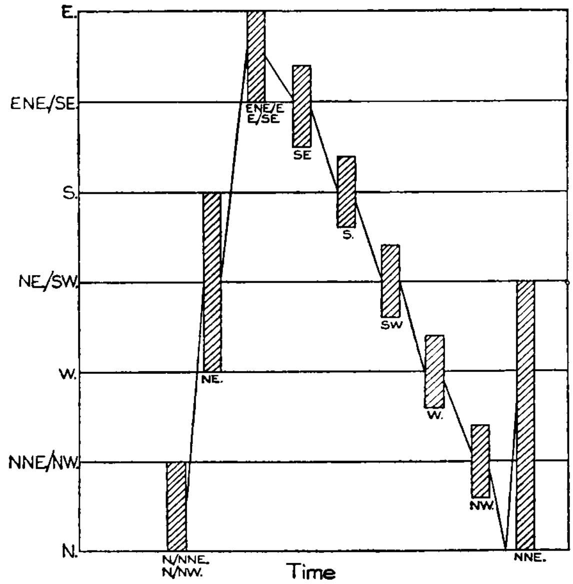


FIG. 2—TYPE OF TRACE OBTAINED FROM WIND-DIRECTION RECORDER

Wind recorder set for prevailing SW. wind. Chart shows veerings of 45° about the compass points indicated.

Summary.—A wind-direction recorder has been described which traces the wind changes over a time linear chart. For simplicity is is designed with a simple cam to cover the whole range of the compass, which accordingly has to be divided into two segments for one of which the pen reverses its movement over the chart. This cam was arranged for sectors of 270° and 90°, and the instrument can be set up so that the prevailing wind is within the 270° sector thus avoiding confusion with reverse traces on the chart. It is shown however that the charts can be analysed without difficulty even when traces from both sectors are present.

The instrument is simple in construction, easily portable and provides linear daily records from which the mean wind direction and the range of veer can readily be determined.

Acknowledgement.—The construction of the wind-direction recorder and much of its design was the work of Mr. J. H. Harrison. Thanks are due to the Chief Scientist, Ministry of Supply, for permission to publish this paper.

BOOKS RECEIVED

Jaarboek, B. Aardmagnetisme 1948. Koninklijk Nederlandsch Meteorologisch Instituut. No. 98. 13½ in × 9½ in., pp. iv + 28. Staatsdrukkerij-en Uitgeverijbedrijf, 's-Gravenhage, 1951. Price: *fl.* 3.00.

METEOROLOGICAL OFFICE DISCUSSION

Atmospheric ozone and its relation to meteorological conditions

The discussion on Monday, October 19, 1953 held at the Royal Society of Arts, was opened by Mr. D. H. McIntosh, who based his statement on the following paper:—

LANGLO, K.; On the amount of ozone and its relation to meteorological conditions. *Geofys. Publ., Oslo,* **18,** No. 6, 1952.

Mr. McIntosh began with a summary of the main facts concerning atmospheric ozone and a short description of the routine method of its measurement. Ozone is both formed and destroyed by the action of ultra-violet radiation, the spectral region from 1,760–1,925 Å being considered responsible for its formation, while absorption in the Hartley bands from about 2,000–3,000 Å reconverts ozone to oxygen. This latter absorption is so intense that available radiation in this wave-band is largely removed at the extreme top of the ozone layer, the consequences being that the temperature maximum due to the absorption occurs near the upper border of the ozone at about 50 Km. while most of the ozone in the atmosphere is relatively protected from the destruction process. The maximum ozone concentration expressed in centimetre thickness per kilometre of air is at about 25 Km. Its amount, varying between about 0·15 and 0·45 cm. thickness at normal temperature and pressure, is only about one thousandth that of carbon dioxide.

The routine method of ozone measurement consists in isolating two wave-lengths in the spectral region of partial ozone absorption (3,000–3,300Å), allowing them to fall in rapid succession on a photomultiplier connected to a galvanometer, and reducing, by means of a calibrated optical wedge, the intensity of the longer, less absorbed wave till the galvanometer records no output. The amount of ozone is given by the position of the wedge and the solar zenith angle at the time of observation.

The theory underlying the method is illustrated by the equations:—

$$\log I = \log I_0 - (\alpha x\mu + \beta m + \delta m)$$
$$\log I' = \log I_0' - (\alpha' x\mu + \beta' m + \delta' m).$$

By subtraction,

$$x = \frac{\log I_0/I_0' - \log I/I' - (\beta - \beta')m - (\delta - \delta')m}{(\alpha - \alpha')\mu}$$

Here the intensities of the selected wave-lengths as received at the ground, I, I', are related to their intensities outside the atmosphere, I_0, I_0', and the depletion by three separate processes on passage of the radiation through the atmosphere:—

(i) absorption by ozone, x being ozone amount, α, α' ozone absorption coefficients, μ relative path length of radiation through ozone layer;

(ii) molecular scattering, β, β' being molecular scattering coefficients, m relative path length through whole atmosphere;

(iii) larger particle scattering in lower troposphere, δ, δ' being appropriate scattering coefficients.

The fundamental ratio I_0/I_0', included as a constant of the instrument, is determined from series of observations of I/I' at various solar zenith angles and extrapolation for $\mu = m = 0$ (i.e. for conditions outside the atmosphere). The basic measurements are those made against direct sunlight, but observations are also made against the zenith sky, either clear or cloudy, using previously determined empirical relations with the direct sunlight observations.

Langlo, in his discussion of the various types of ozone variation, used data from about 10 northern hemisphere stations, some of which had not previously been discussed. A comparison over ten years of the year-to-year changes of mean annual ozone amount at Tromsø and Dombaas in Norway and Arosa in Switzerland, showed those changes to be very large (up to about 15 per cent.) and also markedly parallel at the three stations. Langlo remarked that the same sense of change was shown in individual cases at Shanghai and Delhi, and referred to the changes as being world-wide. The geographical extent of these long-period ozone variations appeared to the opener to be a basic ozone problem which could not yet be settled by available data. The possibility that the secular ozone variation is caused by a solar cyclic variation of the generating radiation had not been supported by investigation; Langlo considered it to be associated with year-to-year variations of the general circulation.

The main features of Langlo's picture of the latitudinal variation of mean annual amount in the northern hemisphere were the relative constancy of amount from 70° to 45°, the rapid fall from 45° to 25°, and the fairly constant amount from 25° southwards. His results suggested a latitudinal ozone gradient not much more than half that obtained by Prof. Dobson in his original survey. A monthly analysis of the latitudinal gradient showed the mean annual result to be highly composite, the north-to-south gradient being large in spring and very small in late summer and autumn. The results for 10 stations fitted a smooth variation curve well apart from an anomalously high value at Shanghai in every month. Langlo considered that, since the Shanghai results were means of 11 yr. observations, they could hardly be ignored. His explanation of the anomaly was the contrasting geographical situation of Shanghai as compared with the other stations (on the east as compared with the west side of a continent), presumably implying a contrasting climatic type.

The curves of annual variation of ozone amount shown for Tromsø, Dombaas, Shanghai and Delhi agreed in general with earlier results—a spring maximum and autumn minimum, with amplitude of variation decreasing to zero towards the equator. However, very low winter values measured at the Norwegian stations shifted the minimum there from autumn to winter. Langlo emphasized that the very low light intensities measured during the Norwegian winter involved a large casual error even in the period means; there was, however, evidence of systematically low midwinter values at high latitudes—a feature that has been termed the ozone "gap" or "hole".

Investigating the part played by horizontal advection in longer-period ozone variations, Langlo found that the ozone amounts in the early months of 1949 were below average, while the winds in the ozone incline region (15 to 18 Km.) had zonal components far above average strength. From this fact Langlo deduced—rather rashly, in the opinion of the opener—that strong zonal winds in high latitudes in winter prevent normal ozone formation. Langlo's explanation of the normal retreat from the spring ozone maximum was also in terms of the stratospheric winds, which, changing from being predominantly zonal in winter to being more frequently meridional in summer, then allow the more

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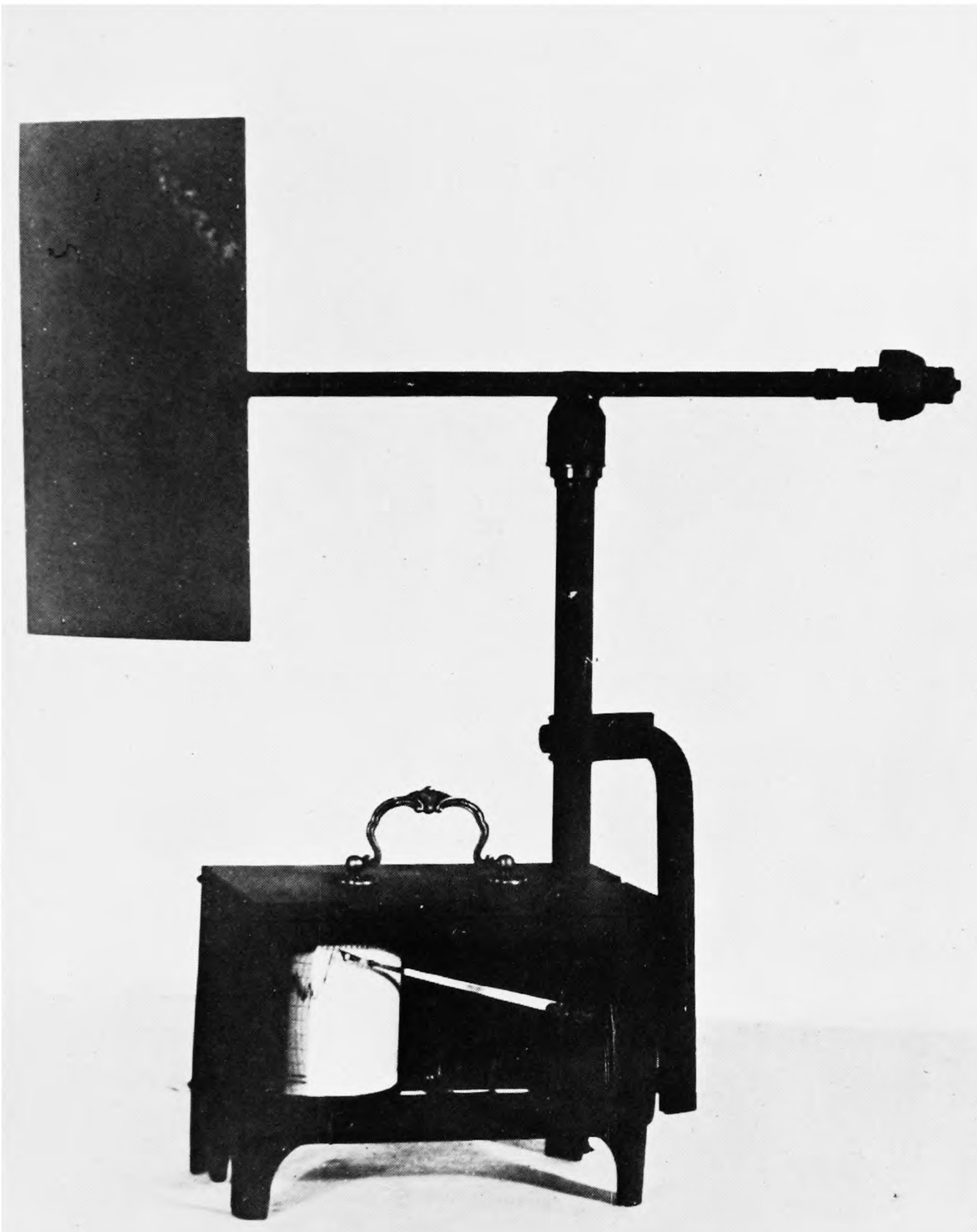
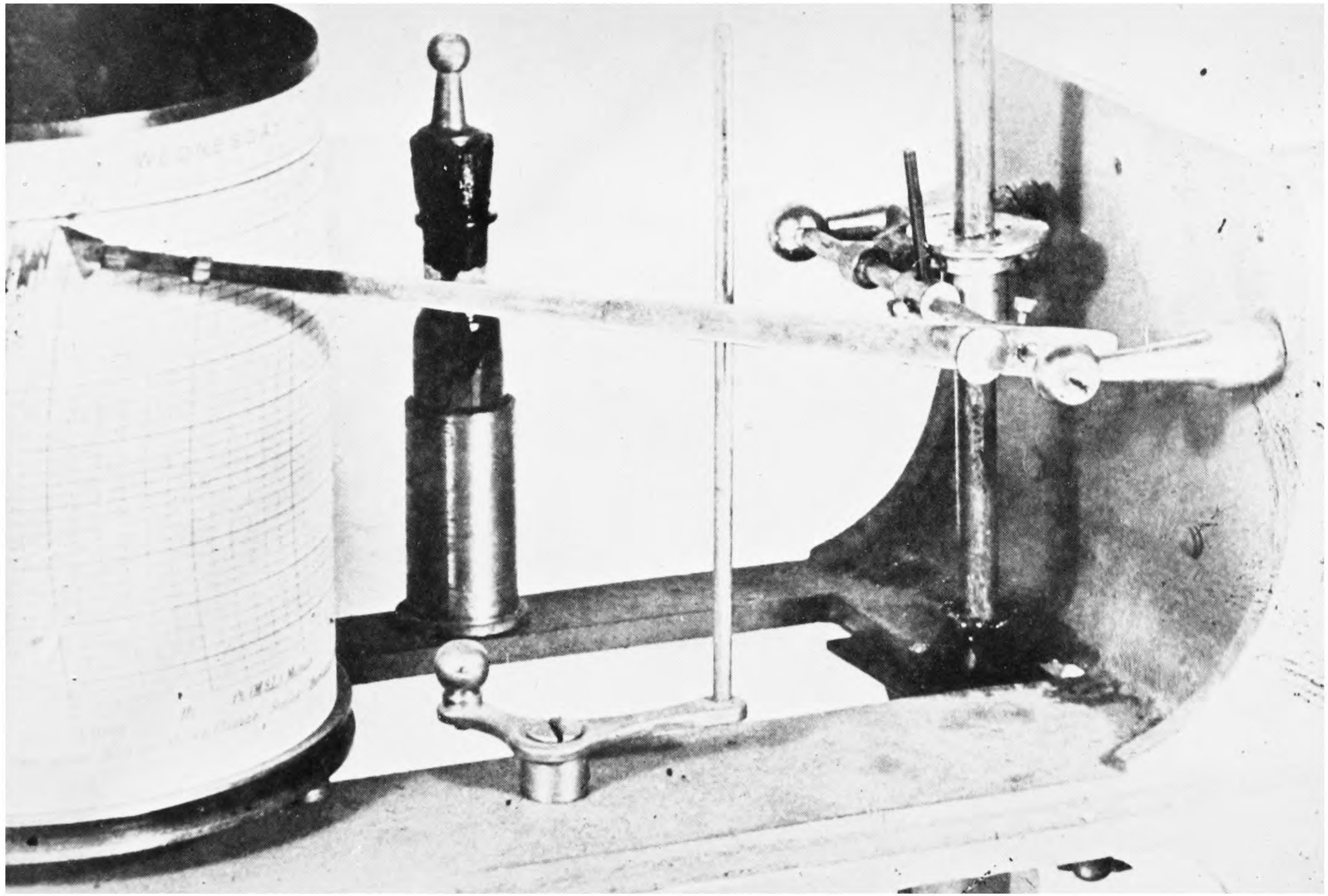
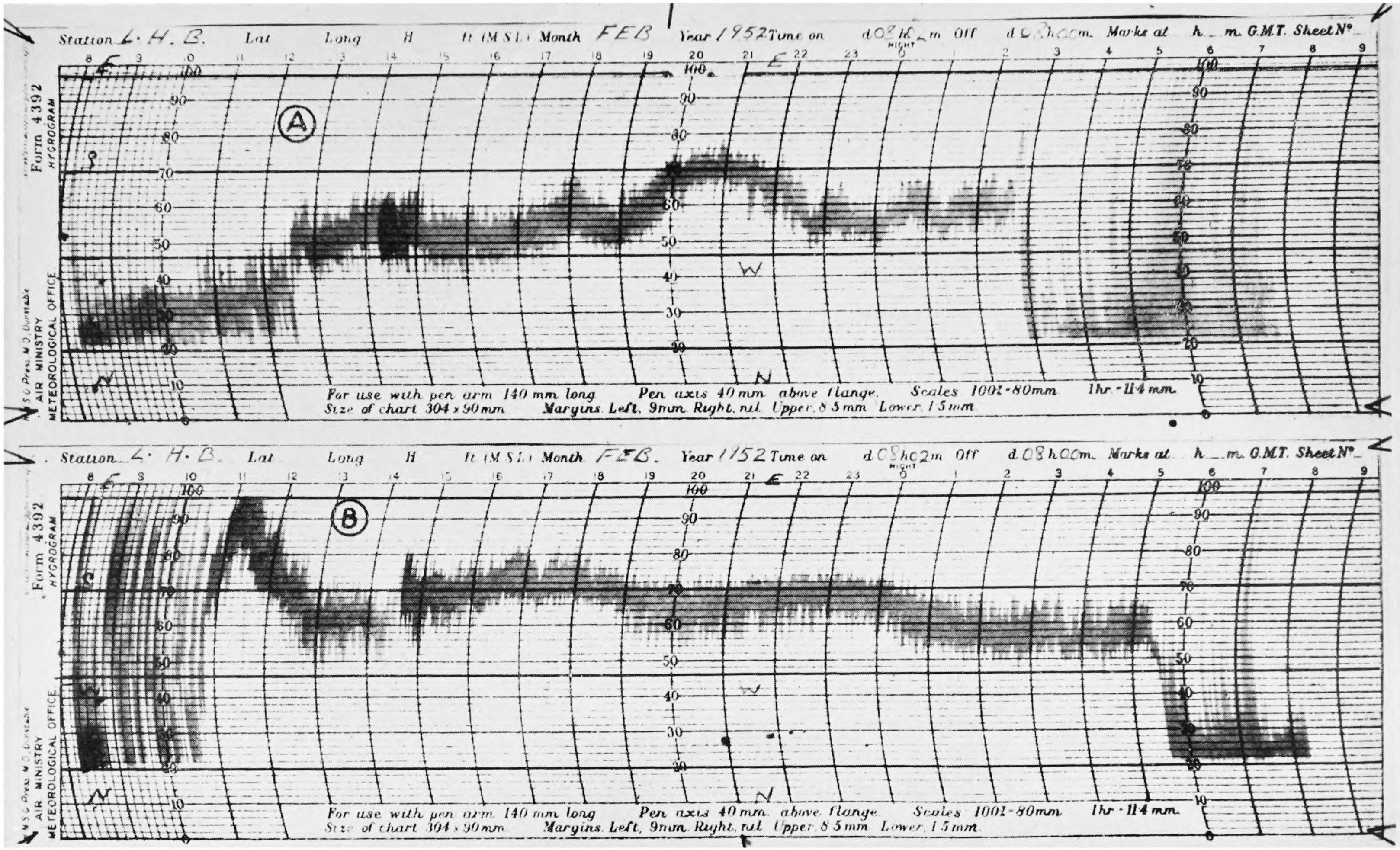


WIND-DIRECTION RECORDER

(see p. 11)



WIND-DIRECTION RECORDER, SHOWING CAM AND LEVER SYSTEM
(see p. 11)



TWO TYPICAL CHARTS OBTAINED FROM THE WIND-DIRECTION RECORDER

(see p. 11)

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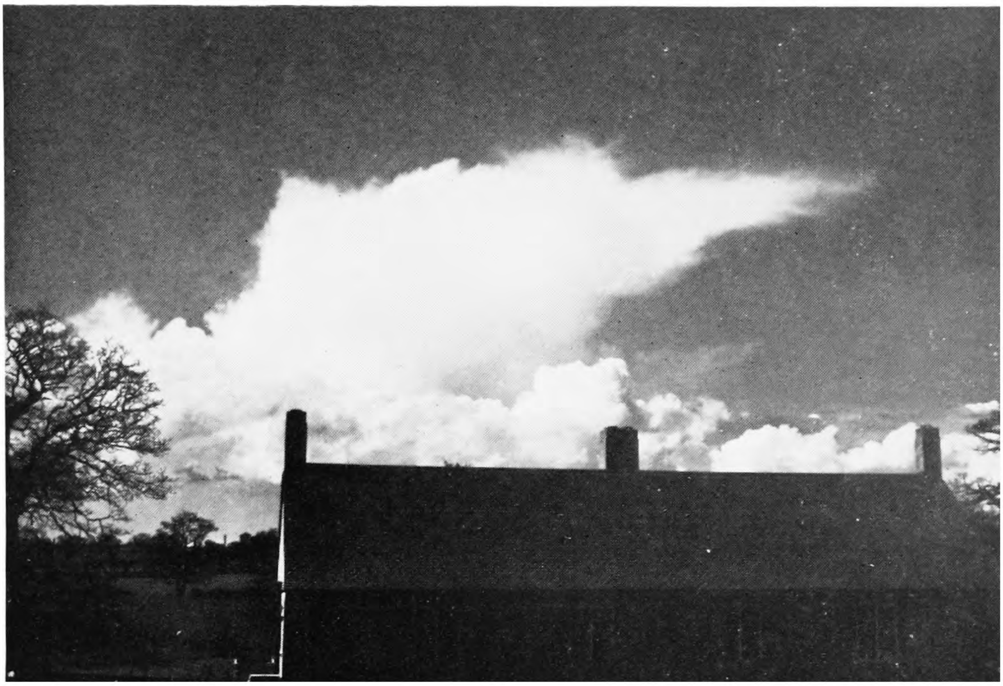

Reproduced by courtesy of E. J. Wilkinson

CUMULONIMBUS NEAR WOLVERHAMPTON, ABOUT 12.30 P.M., MAY 2, 1953
looking west

FAWLEY FLAME FROM CALSHOT CASTLE, AUGUST 22, 1952
(see p. 25)

frequent invasion of air of low ozone content from lower latitudes. Mr. McIntosh considered this argument unconvincing, and not, in fact, supported by Langlo's results for the year 1949. In this year the spring-to-summer wind change showed very markedly an interruption of a steady zonal component, but the corresponding ozone amounts showed an increase, relative to normal.

Referring to day-to-day ozone variations, Langlo showed first that even in spring the average zonal gradient is quite as large as the meridional gradient, and must play a bigger part in determining day-to-day ozone changes because of predominantly zonal stratospheric winds. Favouring a suggestion by Palmén that the ozone changes are most closely related to the upper contour patterns, and in particular to the passage of marked tropopause troughs, he illustrated the relation by means of a scatter diagram and by a number of synoptic examples. He concluded from the latter that the factor which affects ozone amounts is not the air-mass change as such, but the tropopause-height change which frequently but not invariably, accompanies a frontal passage.

From a study of the results of ozone measurements made on days on which the rare mother-of-pearl clouds were visible in Norway during a period of 11 yr., Langlo tentatively concluded that the ozone amount tends to be below normal on such days.

The important question of the vertical distribution of ozone was discussed with reference to the original suggestion by Wulf and Deming, that only a small part of the total ozone in the atmosphere—that near the top of the layer—is in a state of photochemical equilibrium, most of it being carried downwards to regions where it is protected against decomposition by ultra-violet radiation. This suggestion was based on theoretical calculations of the vertical distribution of ozone and of the rate of restoration, at various heights, of a state of photochemical equilibrium, assuming this to have been disturbed by some process. Langlo showed that this suggestion was supported by actual measurements made of the vertical distribution of ozone for various total amounts; increases in total ozone were concentrated in the "protected" region below the level of normal maximum.

Langlo finally discussed the various types of ozone variation in terms of the combined effects of vertical movement and horizontal advection in the ozone incline region. The annual variation was explained by an excess of downward movement in the lower stratosphere at high latitudes from October to March, and a predominance of advection of air from lower latitudes from April to September. The latitudinal variation was explained on the basis that, averaged over the year, the effect at middle and high latitudes of an excess of downward movement outweighs the effect of advection from lower latitudes. The year-to-year changes were considered to be caused by variations of large-scale weather types. Finally, Langlo disagreed with Reed's suggestion, which has won wide acceptance, that vertical movement cannot account for more than one third of the observed maximum 24-hr. ozone changes.

Dr. Stagg said that it was clear that atmospheric ozone, small though it was in amount, was of great meteorological significance. Before calling for general discussion, he invited Prof. Dobson to express his views.

Prof. Dobson stated that while he was in general agreement with Langlo's findings, he disagreed with them in some important respects. First, he considered the winter minimum at high latitudes to be very doubtful. Langlo's estimate of the error involved in the Tromsø and Oslo winter measurements, large though it is, is incorrect since, for observations on the zenith sky, a knowledge of the vertical distribution of ozone is necessary for the correct interpretation of the measurements made at very low solar zenith angles; recent moonlight observations do not support the reality of the winter ozone "gap". Secondly, he was very doubtful of the validity of the Shanghai results, on which Langlo has laid much emphasis. The Shanghai measurements were made with a very early instrument, and no adequate check has been kept on its constancy; it appeared very likely that the Shanghai readings were systematically too high. Prof. Dobson showed various slides illustrating the nature of the ozone–weather relationship. They included a comparison of day-to-day ozone variations at various stations in north-west Europe, and a representation of the ozone variations, both smoothed and unsmoothed, in relation to upper air parameters. Langlo has related the ozone variations to the tropopause height; the measurements made over western Europe during the last 10 yr. or so indicated that they are more closely related to the contours at 300 mb. or higher, and are probably to be explained largely in terms of vertical movement. Prof. Dobson finally described the method, devised by Sir Charles Normand, of correcting observations for the presence of haze, and discussed its applicability to observations made on occasions of a cloudy zenith sky.

In reply to a question by Mr. McIntosh whether, in view of the very recent discovery that ozone amounts in India are systematically higher by night than by day, it is fair to deny the existence of the winter ozone "gap" in high latitudes on the basis of moonlight observations, Prof. Dobson stated that comparisons have shown that it is very doubtful if there is any systematic difference between day and night ozone amounts in higher latitudes. Asked further whether he thought that the sudden change in ozone content shown by Prof. Ramanathan about sunrise and sunset was real, Prof. Dobson said that while he thought that the greater amount of ozone found at night in India was real, yet the method which had been used was bound to show any real change between night and day as a sudden jump at sunrise and sunset, and this jump was therefore not necessarily real.

Prof. Dobson agreed with Dr. Stagg that a small diurnal variation of ozone amount, resulting from a differential effect between the radiations forming and destroying the ozone, is quite possible, but is, presumably, swamped by the much larger "synoptic" variations of the lower protected ozone.

Dr. Brewer pointed out, in relation to the ozone "gap", that measurements on the moon's spectrum made from R.C.A.F. aircraft flying near the north pole have indicated winter ozone amounts there as great as over Ottawa. He also regarded the absence of a marked discontinuity of ozone content across the tropopause, recently observed by a chemical method, as a clear indication that the vertical movement of the tropopause is not, physically, directly connected with the ozone variations.

Mr. Gold, stressing the important effects of horizontal convergence associated with vertical movement in effecting ozone variations, asked how far simultaneous changes of temperature supported the presence of vertical movement. Mr. McIntosh replied that the amount of vertical movement, computed on the assumption of adiabatic temperature changes, led to estimates of ozone changes much smaller than those actually observed, even in cases where it appeared that the effects of latitudinal ozone advection could be eliminated; this problem in atmospheric ozone was not yet satisfactorily settled. Referring to longitudinal variations of ozone, Mr. Gold thought it possible that, owing to the distribution of land and water in the northern hemisphere, the meridional flow even in the stratosphere, averaged over the whole year, might not be the same in all latitudes, and wondered if there is any indication of an excess north-to-south stratospheric flow to the east of Siberia or to the east of Canada. He considered also that for an adequate discussion of the horizontal advection of ozone, an examination of the trajectories of the air at the ozone level is necessary; the direction of upper air isobars or contours at the time of the ozone measurement does not reliably show whether the air had its recent source in higher or lower latitudes. Finally Mr. Gold stressed the desirability of obtaining more ozone measurements from the equatorial regions and southern hemisphere for a better knowledge of the ozone distribution over the globe and for an answer to the question whether changes occur simultaneously in both hemispheres and in the tropics.

Mr. Bannon said that a detailed consideration of the upper air circulation over Shanghai throughout the year could not explain the anomalously high ozone values observed there in every month. He thought also that the variation of ozone amount may be the explanation of the fact that the correlation at Lerwick between temperature in the lower stratosphere and tropopause height is much lower in spring than in summer and autumn.

Dr. Harrison pointed out that, if there is a diurnal variation in the amount of ozone, this will affect the value of log I_0, obtained by extrapolation to $\sec Z = 0$, (Z being the sun's zenith angle), and that since different wave-lengths will be affected differently, the value of log I_0 — log I_0' will be wrong and therefore the absolute value of ozone will be wrong. Prof. Dobson replied that this was recognized. Dr. Harrison also asked whether Langlo meant to suggest that there was a real connexion between mother-of-pearl clouds and ozone, and whether any apparent connexion could not be explained through the general meteorological situation and the state of the sky (mother-of-pearl clouds would not be seen if there were ordinary clouds). Mr. McIntosh replied that Langlo's tentative suggestion was that the two phenomena have direct causes in common; however an explanation of the kind suggested by Dr. Harrison appeared very possible.

Mr. Sawyer said that rough estimates which had been made of the vertical movement of the air at levels up to 100 mb. indicated that, on occasion, the air moved vertically by 1 Km. in 24 hr., but as such motion is not sustained over much longer periods it is doubtful if it is adequate to explain ozone variations. Mr. Sawyer also remarked that air at the 100-mb. level sometimes moved from Greenland to north Africa in 36 hr., and it would be unwise to base a theory of seasonal changes of ozone amount on the assumption that in winter the air in the arctic circle was not exposed to solar radiation. Although there are occasions when the high-level circulation is approximately zonal, it does not continue so throughout the winter.

Mr. Davis considered the vertical motion by which ozone is carried down from the ozone layer to be so slow as to invalidate an assumption of purely adiabatic temperature changes. Detailed consideration of ozone amounts, taking into account horizontal advection effects, should yield useful information on the vertical motion occurring in the lower stratosphere where differences in total ozone content are concentrated.

Dr. Sutcliffe also stressed the importance of horizontal divergence or convergence in causing ozone changes. Variations in tropopause pressure could be regarded as a measure of variations of the mass of air in the stratosphere, and so, to some degree, of variations of ozone amount. Dr. Sutcliffe considered the variations in tropopause pressure to be quite large enough to account for the observed ozone variations. Such tropopause variations are, however, only partly (perhaps one half) due to vertical motions, the contribution by horizontal advection also being important. The same was probably true of ozone in spring. In autumn when there was little longitudinal ozone gradient, the small-scale variations must be almost entirely due to dynamical processes. Dr. Sutcliffe added that there was at present no indication that ozone observations would help directly in forecasting in regions where upper air observations were available. They could be useful in regions without upper air data, and are of potential value in studies of the general circulation and long-range forecasting.

Mr. Veryard asked whether there was any suggestion that the unusual ozone values found in north-west Europe in early 1941 were due to an unusual amount of ultra-violet radiation. Mr. McIntosh replied that Langlo's explanation was based entirely on the type of weather prevalent during the period.

Mr. Murgatroyd said that flights by the Meteorological Research Flight to measure ozone by a chemical method up to about 12 Km. showed that there was, on the average, only about 8 per cent. of total ozone below this level; while most of the measurements of the vertical distribution, made by other methods, showed that the major increase in ozone concentration occurred some 5 Km. higher than this. On the other hand, many of the ozone–weather relationships used the 300-mb. contours, at about 10 Km. Since the major ozone changes would be expected to occur at levels of 17 Km. at least, it would be surprising if charts for levels lower than 100 mb. could be closely linked with the ozone changes. Mr. Murgatroyd also asked whether high ozone content was associated with high or low temperature at the top of the ozone layer. In reply Mr. McIntosh said that radiation considerations implied that high stratospheric temperatures accompanied high ozone content.

Dr. Stagg in conclusion, said that the discussion had shown that there were many unsolved problems which left much room for hypothesis. It seemed to him very desirable to have more frequent measurements made of the vertical ozone distribution to allow of a clearer assessment of the meteorological processes involved in the ozone variations.

METEOROLOGICAL RESEARCH COMMITTEE

The 16th meeting of the Instruments Sub-Committee of the Meteorological Research Committee was held on July 21, 1953.

At this meeting Dr. D. G. James presented a report by himself and Mr. R. J. Murgatroyd[1] on the development of some hot-wire anemometers for use on aircraft, and Mr. R. J. Murgatroyd[2] gave an analysis of the speed correction coefficient for aircraft thermometers as determined by the Meteorological Research Flight during 1951. Mr. M. J. Blackwell[3] described an improved form of a Robitzsch-type actinometer. The Committee also considered methods of determining the height of pressure levels on the basis of radio-sonde and radar observations.

The 26th meeting of the Physical Sub-Committee of the Meteorological Research Committee was held on October 1, 1953.

The Committee discussed a paper by Mr. R. F. Jones[4] dealing with five flights by an aircraft, fitted with a recording accelerometer, through a thunderstorm belt. The spatial distribution of vertical currents experienced is related to the picture of the cloud structure observed by a ground-based radar. The structure of convective clouds was also the subject of a paper by Mr. Day and Mr. Murgatroyd[5]. This paper dealt with observations, including nature and size of cloud particles, made by the Meteorological Research Flight in and near convective clouds. Clear-air turbulence was the subject of three reports. The first, by Dr. James[6], described instrumental methods of measuring such turbulence. The other two, by Mr. D. C. E. Jones[7,8], dealt with the relation of clear air turbulence to weather systems, especially jet streams. The last report, by Mr. Lawrence[9], considered by the Committee discussed the effects of a large wind-break on the speed and direction of the wind on the leeward side.

ABSTRACTS

1. MURGATROYD, R. J. and JAMES, D. G.; Hot-wire anemometers for use on aircraft. *Met. Res. Pap., London*, No. 804, S.C. I/78, 1953.

Requirements of a hot-wire anemometer to measure gustiness on an aircraft are set out, and the design of a temperature compensated platinum wire instrument is illustrated. A directional type to measure vertical gusts in flight is also shown. Flight procedure, calibration and mounting are described and specimen records shown. The simple instrument records gust speeds down to 2 ft./sec. and frequencies up to 50 c./sec.

2. MURGATROYD, R. J.; A report on the determinations of the speed correction coefficients of aircraft thermometers made by the Meteorological Research Flight in 1951. *Met. Res. Pap., London*, No. 822, S.C. I/79, 1953.

Correction to indicated dry-bulb temperature is $\alpha\ (V/100)^2$, $V =$ true air speed in knots. Values of α with 3 flat-plate (with and without trip wires) and 2 conical-head thermometers are given. No systematic increase of α was found between 5,000 and 21,000 ft. for flat plates but conical heads gave a slight increase. Trip wires decrease α (1·55 to 1·15). In Pt. II the technique of determining α for aircraft thermometers is described. In a calibrated research aircraft an accuracy of 0·5°F. should be attained, but in a fast uncalibrated aircraft error may be up to 5°F. Some comments by D. D. Clark are appended.

3. BLACKWELL, M. J.; On the development of an improved Robitzsch-type actinometer. *Met. Res. Pap., London*, No. 791, S.C. I/75, 1953.

Six recorders of Fuess-Robitzch type built in London were tested; defects found included marked variation of sensitivity with solar elevation. Modifications were introduced at Kew to remove defects and the Mk II recorder was completed in May 1951. After further tests an improved Mk III was completed in 1952. A photo is shown, performance and routine calibrations are described.

4. JONES, R. F.; Five flights through a thunderstorm belt. *Met. Res. Pap., London*, No. 820, S.C. III/156, 1953.

Accelerometer, altimeter and temperature records during flights through cumulonimbus clouds are presented in curves and discussed. Up- and down-currents of 20 ft./sec. or more occurred near together in the cloud; in one case an upward speed of 30 ft./sec. changed to a downward speed of 23 ft./sec. in 750 yd. Outside the cloud down-currents may exceed 10 ft./sec. but not up-currents. Results are correlated with 10-cm. radar; biggest gusts all occurred within the echoing part of the cloud.

5. DAY, G. J. and MURGATROYD, R. J.; The cumulus cloud investigations made by the Meteorological Research Flight during the period August 4–15, 1952. *Met. Res. Pap., London*, No. 826, S.C. III/158, 1953.

Eight flights in selected cumulus, cumulonimbus or stratocumulus clouds are described. Results, including temperature, frost point, icing rate, turbulence, droplet spectrum, ice crystals and vertical motion, are presented in detail and discussed. Points are: detailed cloud forecasting; entrainment (important near base of a large cumulus, decreasing at higher levels); cloud structure and composition; vertical motions and turbulence; water content and icing; field below cloud base.

6. JAMES, D. G.; An account of one of the methods employed in the investigation of clear-air turbulence. *Met. Res. Pap., London*, No. 792, S.C. III/148, 1953.

Trial aircraft observations with ultra-rapid instruments were made on May 22, 1952 in clear air at 9,000–11,000 ft. to measure mean temperature and wind and small-scale fluctuations, and frost point. Paths of smoke puffs from the aircraft were traced by camera obscura on the ground. The method of analysing the observations is set out. The apparatus proved suitable for measuring turbulence parameters in the free atmosphere.

7. JONES, D. C. E.; Investigation of high-altitude clear-air turbulence near jet streams: special flights by R.A.F. and R.A.E. aircraft. *Met. Res. Pap., London*, No. 827, S.C. III/159, 1953.

8. JONES, D. C. E.; Weather systems associated with some occasions of severe turbulence in clear air at high altitudes; a further analysis. *Met. Res. Pap., London*, No. 828, S.C. III/160, 1953.

Reports of turbulence at 15,000–40,000 ft. in flights over British Isles are summarized. Moderate or severe turbulence occurred mainly on low-pressure side of jet axis and to a less extent above the axis on high-pressure side. A few jet streams were not turbulent. Severe turbulence generally occurred with a vector difference $>$ 35 kt. between 300 and 500 mb. and a horizontal shear on low-pressure side at level of axis $> 0\cdot2$ hr.$^{-1}$ The second paper summarizes 147 reports of clear-air turbulence at 15,000–48,000 ft. Results: 71 per cent. associated with jet stream (three-quarters on low-pressure side), 20 per cent. with upper troughs, upper lows or strong winds, 9 per cent. not associated with any special feature.

9. LAWRENCE, E. N.; The effects of a wind-break on the speed and direction of wind. *Met. Res. Pap., London*, No. 797, S.C. III/149, 1953.

Observations at Manby, Lincolnshire, with lattice and slat wind-breaks 50 ft. high, 1,600 ft. long and 10 ft. wide are described. Winds were measured with cup anemometers on telescopic ladders, no-lift balloons and smoke candles, with surface winds of 9–30 m.p.h. at various angles of incidence, in unstable and neutral or stable temperature lapse. Results are presented in numerous horizontal and vertical sections showing contours of ratio of observed wind at any point to the estimated undisturbed wind at the corresponding height. Eddying conditions are discussed and conclusions summarized.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

Averages of bright sunshine for Great Britain and Northern Ireland for the period 1921–1950

This publication contains two tables, the first giving average monthly and annual totals of the duration of bright sunshine, in hours, together with the daily mean values for the period 1921–50 for 159 stations. Of this number, 33 are Scottish stations, 110 English and 14 Welsh, while the Isle of Man and Northern Ireland each contribute 1 record. The second table gives similar information for an additional 28 stations, but in this table the values are the direct arithmetic means for shorter periods, in no case less than 17 years.

These data are all obtained from the standard Campbell-Stokes recorder. The presence of obstacles obstructing the registration of bright sunshine for any appreciable length of time is indicated where necessary, but no correction factor has been introduced into the evaluations. The earlier periods used for published averages were also of 30 years, namely 1901–30 and 1906–35. The introductory text includes a comparative table for 7 selected stations for the 3 overlapping 30-yr. periods 1901–30, 1906–35 and 1921–50. For the year, the amount of sunshine received during the 30 years 1921–50 was a little less than over the earlier periods. June and December were generally sunnier than in the earlier periods, September and November were generally less sunny, but the differences are small.

Averages of temperature for Great Britain and Northern Ireland for the period 1921–1950

This publication gives monthly and annual values of the mean maximum, mean minimum and mean temperature for the period 1921–50 at 206 stations (46 in Scotland, 1 in the Isle of Man, 143 in England, 14 in Wales and 2 in Northern Ireland). In addition similar values are included for 15 stations for shorter periods. The earlier periods used for published averages were also of 30 yr., namely 1901–30 and 1906–35. A comparative table for 7 selected stations, given in the introductory text, brings out the differences in the averages for the periods 1901–30, 1906–35 and 1921–50. The overall pattern is that for the year the most recent period has been slightly warmer than the earlier periods resulting from the appreciably warmer summers and the slightly colder winters.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on October 21, Sir Charles Normand, Vice-President, in the chair, the following papers were read:—

*Batchelor, G. K.—The conditions for dynamical similarity of motions of a frictionless perfect-gas atmosphere**

Dr. Batchelor's paper is a mathematical one showing that as the Reynolds number is conserved in dynamically similar types of flow of a viscous fluid so the Richardson number is conserved in dynamically similar types of flow of a turbulent gas in approximately adiabatic equilibrium in which the scale of the motion and viscosity are small. The discussion, in which Prof. Sheppard, Dr. Robinson, Mr. Gold and Mr. Deacon joined, dealt mainly with the difficulty of defining and measuring the Richardson number in the atmosphere.

Berson, F. A.—A quantitative analysis of the evolution of large-scale flow with regard to the effect of eddy motion†

Dr. Berson's paper was described by Mr. J. S. Sawyer. It deals with the relation between the transport of vorticity in the mean flow averaged over five days to the transport of vorticity by the small-scale "eddies" constituting departures from the mean flow. It is shown that for a period in June 1949 the "eddy" transport of vorticity was opposite to the transport in the mean flow so that the "eddies" maintained the mean flow. Dr. Sutcliffe pointed out that this maintenance of a large-scale circulation by the small-scale eddies was in accordance with theoretical expectations.

Thompson, P. D.—On the theory of large-scale disturbances in a two-dimensional baroclinic equivalent of the atmosphere‡

P. D. Thompson's paper was described by Mr. F. H. Bushby. With numerical forecasting in mind Thompson derives two-dimensional equations of motion for a single layer in which the flow is equivalent to the flow of a baroclinic atmosphere in which the direction of the vertical wind shear is independent of the height. A numerical method of solving these equations is outlined. Mr. Bushby gave finally an example of forecasting cyclonic development at the 500-mb. level by Thompson's method, which agreed reasonably with the observed facts except the actual development was less intense than the predicted one. It was pointed out by Dr. Forsdyke in the course of the discussion that mathematical methods of forecasting neglected friction and damping processes, and so tended to predict exaggerated development.

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* *Quart. J. R. met. Soc., London,* **79**, 1953, p. 224. ‡ *Quart. J. R. met. Soc., London,* **79**, 1953, p. 51.
† *Quart. J. R. met. Soc., London,* **79**, 1953, p. 210.

Before the papers were read, Mr. G. E. R. Deacon of the Meteorological Department of the Commonwealth Scientific and Industrial Research Organization, Australia, described the work of the Department. He explained that this organization was equivalent to the British Department of Scientific and Industrial Research, and its meteorological department carried out research and development independently of the Australian Weather Bureau though in close collaboration with it. Work was in progress on turbulence in the lower atmosphere, for which a differential analyser machine had been built to enable flux values to be calculated rapidly; on frost protection for orchards, which was important even in Queensland; on evaporation in connexion with the development of the arid parts of Australia; and on large-scale heat and momentum transfer in the general circulation of the atmosphere.

At the meeting of the Society held on November 18, 1953, the President, Dr. O. G. Sutton, in the Chair, the following papers were read:—

*Hurst, G. W.—The profile of a jet stream observed 18 January 1952**

Hurst, G. W.—The profile of a jet stream observed 1 September 1952†

The technique employed in deriving wind speed from photographs taken vertically at 12-sec. intervals during flights at 300 mb. across the axis of a jet stream was described. In the first case there was a well marked northerly jet stream over the western half of the British Isles and photography of ground detail was successful during the flight between Greenwich and the Gower Peninsula. Means of the winds derived from ground drift taken over 5-print intervals, proved most reasonable and gave very close agreement both with winds obtained from Gee-fixes and with the reported winds. The flight of September 1, 1952, was made approximately south to north across the axis of the jet stream so that the structure of the 300-mb. wind on both the warm and cold side could be examined. Again close agreement was found with the Gee-winds and the resulting profile showed the sheer of wind to be more uniform and less intense on the warm edge than on the cold. The wind profiles exhibited some irregularities, but when Mr. Hurst took into account the possible sources of error in deriving winds he deduced that the winds obtained were consistent with a smooth curve.

In the course of the discussion Dr. Sutcliffe emphasized that this was the first technique to provide a detailed cross-section of a jet stream. Mr. Hurst mentioned that further flights were to be made and F.O. Slaymaker, the navigator, suggested that an even newer technique of photographing the dials of a Decca navigating instrument would give positions unaffected by oscillations of the aircraft.

Johnson, D. H.—A further study of the upper westerlies; the structure of the wind field in the eastern North Atlantic and western Europe in January 1950‡

This paper contained the results of an analysis of 62 vertical cross-section charts for mid-latitude wind fields for January 1950. They confirmed the conclusions based on a previous analysis for September 1950§ regarding the broad

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* *Quart. J. R. met. Soc., London*, **78**, 1952, p. 613.
† *Quart. J. R. met. Soc., London*, **79**, 1953, p. 407.
‡ *Quart. J. R. met. Soc., London*, **79**, 1953, p. 402.
§ *Quart. J. R. met. Soc., London.* **78**, 1952, p. 186.

structure of the upper westerlies, i.e. the existence of wind maxima of the jet-stream type with similar features in cross-section, and that the level of maximum wind tended to increase with decreasing latitude. No consistent relationship between jet streams and surface fronts was found. Profiles of mean velocity components at the levels of the centres of different types of jet streams showed broadly similar characteristics as regards form and distribution of shear. The mean January cross-section from Greenland to the Mediterranean resembled the mean winter cross-section both indicating a mean south-westerly jet stream as a normal seasonal feature.

Mr. Bonacina mentioned the jet stream about 30°N., pointed out that this was along the Himalayas and asked if there was any correlation between the departure of the jet stream from the Mount Everest region and the arrival there of the monsoon winds. Sir Charles Normand said that in some years there was an interval between these events and then there was a chance of reaching the summit, but in most years there was almost no interval. Mr. Sawyer said it was important that the structure of jet streams should continue to be determined, and it had been found that some of the jet streams initially described were not typical ones.

*Murray, R. and Daniels, S. M.—Transverse flow at entrance and exit to jet streams**

The components of wind perpendicular to the jet axis had been calculated and mean profiles drawn. These showed that at the entrance to a jet stream there is a cross-stream component towards the left (looking downstream) and at the exit a cross-stream component to the right. In both cases the components increase to a maximum at the level of the jet centre and they have been attributed to ageostrophic flow. The mean profiles were supported by statistical data. It was suggested that the transverse components would be consistent with the existence of circulations associated with the temperature distributions at the entrance and exit of a jet stream. From a further analysis of a sample of wind observations over the British Isles it was found that the mean pressure of the entrance region of the jet axis is about 27 mb. less (2,000 ft. higher) than that of the exit, but the evidence was inconclusive and no definite interpretation was made.

Dr. Stagg said this was one of the first papers in which lateral motion of air accelerating along its track was shown, and asked if the ideas of Murray and Daniels on the lateral and vertical movements could be used to explain the existence of free-air turbulence. Dr. Sutcliffe believed the whole structure revealed in the paper was in accordance with general theoretical principles, and Mr. Ludlam thought it agreed well with the cirrus structure of an advancing frontal system.

LETTERS TO THE EDITOR

"Fawley flame"

On the night of July 5–6, 1953, whilst making the observation at 0100 G.M.T., the duty observer noticed a reddish glow in the sky to the west-north-west. Upon further investigation this glow proved to be the reflection of the "Fawley flame" on cirrus cloud. Fawley flame, the local name applied to the exhaust flame given off from the Esso Oil Refinery, is approximately 2·2 miles on a bearing of 290° from Calshot Castle from which the observation was being made. It was estimated that the elevation of the reflection was 65°, thus giving an approximate height of 25,000 ft.

* *Quart. J. R. met. Soc., London.* **79**, 1953, p. 236.

The weather at the time was fair; cirrus and cirrostratus 6 oktas, visibility 10 miles and surface wind 250° 7 kt. At the next hour, i.e. 0200 G.M.T., when altocumulus had spread from the west and increased to 5 oktas at 15,000 ft. (estimated) the reflection was not observed.

The reflection faded and brightened with the movement of the flame and appeared as a narrow pencil of reddish pink light and was so pronounced at times that it gave the impression that the flame was being reflected from a mirror. It is estimated by the laboratory officials at the refinery that the average intensity of the flame that night was ½ million candle power, although at times it may have reached as much as 3 million candle power.

The lower photograph facing p. 17, showing the flame, was taken from Calshot Castle during the afternoon of August 22, 1952, a bright sunny day, and the flame can be seen as an intense white light against a bright background.

G. F. HILLMAN

Calshot, July 20, 1953

Unusual temperatures recorded in fog

The unusual temperature conditions in the few feet nearest the ground mentioned by Mr. Gold* as occurring in London early in March were by no means confined to the south-east of England. I have long been interested in the differences between screen minimum-thermometer and grass minimum-thermometer readings, and had come to regard the occurrence of higher grass minima as being confined to rare occasions of calm, mild, rainy conditions, particularly in summer. However, at Wrexham each of the first five days of March 1953 gave grass minima higher than the screen minima, the most notable being March 2, screen 26·4°F., grass 28·4°, and March 5, screen 26·4°, grass 28·8°. It was foggy on all these occasions with beautiful displays of rime, persisting generally until nearly midday, down to about 2 or 3 ft. from the ground, and soft ground and dewy grass. Dr. Robinson's explanation, involving supercooling, must clearly be invoked to account for the dew in view of the grass minimum temperatures quoted above.

The whole affair is difficult to explain. The soil was on the dry side, decreasing the specific heat and conductivity, thereby favouring low rather than high surface temperatures. The explanation offered by Mr. A. C. Best cannot apply to Wrexham as the grass minimum each night was below freezing point; and again, the observations of people coming down from the mountains show that at sunrise on each of these foggy days the depth of fog was about 500 ft.

For some time at Wrexham we have had a minimum thermometer exposed in the open air just outside the screen, at the same height as the minimum inside. It is hoped to discuss the results at a future date, but I can say now that on a normal radiation night the minimum temperature outside is nearly 3° below the screen minimum temperature, at any time of the year. But on these foggy nights it was within 0·1° of it, and on March 2 it was actually 0·2° above it. The reason for the lower readings outside is, of course, the radiation lost by the thermometer, so that on the nights in question it would seem that no radiation was being lost at that height. And here I think that the depth of the fog helped in preventing a greater loss by radiation.

* GOLD, E.; Unusual temperatures recorded in fog. *Met. Mag., London*, **82**, 1953, p. 246.

On only one of the nights considered did the fog become deep enough to extend to the station at Bwlchgwyn, almost exactly 1,000 ft. higher than Wrexham. On that day, the 3rd, the minimum temperature at Bwlchgwyn was well below that at Wrexham, as at the top of the fog heat must have been radiated in the normal manner.

In the surface layers of the air at Wrexham it was extremely damp, and I am sure that the copious deposition of dew and the release of latent heat must have had something to do with the abnormal surface temperatures.

S. E. ASHMORE

11 Percy Road, Wrexham, September 22, 1953

REVIEWS

The east coast floods, January 31–February 1, 1953. By J. A. Steers. *Geogr. J., London,* **119,** 1953, p. 280.

Prof. Steers gives in his paper the best overall account of the floods yet published. The meteorological events are described but meteorologists will be mainly interested in Prof. Steers's clear account of the tidal currents and the surge. The details of the way in which the water undermined the defences are given and illustrated with magnificent photographs. Finally, we learn that as East Anglia is sinking at the rate of 1 ft. in 150–300 yr. floods a few centuries hence may be even more difficult to combat.

G. A. BULL

The filling and drying of Lake Eyre. By C. Warren Bonython and B. Mason. *Geogr. J., London,* **119,** 1953, p. 321.

Unusually heavy rains over Queensland and northern Australia in the winter of 1949 caused flooding of the usually dry rivers in the Lake Eyre basin, and by the end of the winter the lake was half full. Much of the water in the lake survived the following summer, and the wet winter of 1950 caused the lake to fill completely by September. The following winters had relatively little rain and by the beginning of 1953 the lake was once more dry. The evaporation of the lake gave great scope for research, and the results of that work are described in detail in this paper. Records of the meteorological elements were kept and the evaporation to be expected on the basis of Ferguson's and Penman's formulae were compared with the evaporation deduced from the fall in the depth of the lake during 1951. All three values fall within the range of 80 to 95 in. a year.

G. A. BULL

OBITUARY

Lewis F. Richardson.—We regret to report the death of Dr. L. F. Richardson at his home at Kilmun, Argyllshire on September 30, 1953. Dr. Richardson, possessing one of the most able, original and versatile minds ever devoted to meteorology, will always be remembered for his pioneer work on the forecasting of the pressure distribution by transforming the equations of motion into finite-difference equations.

Dr. Richardson was born at Newcastle in 1881, and educated at the Durham College of Science, Newcastle and at King's College, Cambridge. He graduated with first-class honours in the Natural Science Tripos in 1903. Between 1903 and 1913 he worked first as an assistant at the National Physical Laboratory and later at an electric lamp factory.

On September 1, 1913, on the recommendation of the Gassiot Committee of the Royal Society, he was appointed Superintendent of Eskdalemuir Observatory. Before taking up his duties he visited the other British and three continental magnetic observatories with a dip circle and magnetometer to determine the differences in magnetic standards. Richardson had already published in 1910 an important paper on the solution of the differential equations of physical problems by finite differences[1], and after joining the staff of the Meteorological Office he applied these methods to the basic equations of meteorological dynamics and thermodynamics. A first draft of his work on weather prediction by numerical process was written by 1916 and communicated by Sir Napier Shaw to the Royal Society.

He remained at Eskdalemuir until 1916 when he joined the Friends' Ambulance Unit in France and served with it until the end of the war. Among the papers he left at Eskdalemuir is a file of useful hints and precepts on observatory matters characteristically entitled "The experience of each for the benefit of all". During this period he revised the work on numerical forecasting and has recorded that it was once lost and rediscovered months later under a heap of coal.

On returning to the Meteorological Office in 1919 he was posted to Benson Observatory under W. H. Dines, in charge, to quote from the *Annual Report of the Meteorological Committee*, "of experiments in the computation of the sequence of weather by numerical processes". At Benson he also worked on the application of photometric methods to the study of cloud structure, and on atmospheric turbulence, and wrote the well known paper[2] in the *Proceedings of the Royal Society* on the supply of energy from and to atmospheric eddies in which his well known criterion "for just no turbulence" was first given.

In 1920, when the Meteorological Office came under the Air Ministry, he, as a Quaker, resigned on conscientious grounds, and joined the staff of Westminster Training College as head of the Physics Department. In 1922 his *magnum opus* "Weather prediction by numerical process"[3] was published by the Cambridge University Press. A scheme for numerical forecasting was described in this book, and an example worked out on special computing forms[4]. Owing to the lack of sufficiently rapid methods of computation and insufficient upper air information no test of the method in day-to-day use could be made. The book had a wider scope than its title suggests, covering the whole field of atmospheric physics.

During the next ten years Richardson continued his researches into turbulence, and introduced the idea of diffusion as shown by the separation with time of initially neighbouring objects—the distance-neighbour graph[5], on the application of tidal theory to the atmosphere, on the convergence of upper winds, and on the albedo of the earth's surface. He published work done at Benson on methods of measuring wind and temperature in the lower layers by shooting small spheres vertically upwards and measuring the departure of the point of return to earth from the firing point. Apparatus devised by Richardson for measuring the vertical distribution of temperature over the sea was used by him and other distinguished meteorologists in the course of a voyage across the Atlantic in 1924 to attend the meeting of the British Association at Toronto. He was elected a Fellow of the Royal Society in 1926.

In 1929 he was appointed Principal of Paisley Technical College, and held that post until he retired in 1940. After 1930, Dr. Richardson's interests lay more in psychology and in original work on the psychological causes of war than in meteorology. He took the degrees of D.Sc. (London) in physics in 1926 and of B.Sc. (London) in psychology in 1929. However, in 1948, stimulated by the observations made by H. Stommel on the drifting apart of objects floating on the sea surface, he resumed his work on the separation by turbulence of neighbouring particles and published two papers of which the last, "Transforms for the eddy-diffusion of clusters"[6], appeared in the *Proceedings of the Royal Society* in 1952. He was a Fellow of the Royal Meteorological Society from 1919 and a Secretary from 1921 to 1924.

Mr. P. N. Skelton who served under Dr. Richardson at Eskdalemuir comments on the good influence he had on his young assistants on the one hand by his refusal to take anything, such as the scale value of a theodolite graticule, for granted and on the other by the encouragement he gave them in their studies and hobbies.

BIBLIOGRAPHY

1. On the approximate arithmetical solution by finite differences of physical problems involving differential equations with an application to the stresses in a masonry dam. *Phil. Trans., London*, A, **210**, 1910, p. 307.
2. The supply of energy from and to atmospheric eddies. *Proc. roy. Soc., London*, A, **97**, 1920, p. 354.
3. Weather prediction by numerical process. Cambridge, 1922.
4. Forms whereon to write the numerical calculations described in weather prediction by numerical process. Cambridge, 1922.
5. Atmospheric diffusion shown on a distance-neighbour graph. *Proc. roy. Soc., London*, A, **110**, 1926, p. 709.
6. Transforms for the eddy-diffusion of clusters. *Proc. roy. Soc., London*, A, **214**, 1952, p. 1.
7. The deferred approach to the limit. Pt. I. Single lattice. *Phil. Trans., London*, A, **226**, 1927, p. 299.
8. How to solve differential equations approximately by arithmetic. *Math. Gaz., London*, **25**, 1925, p. 415.
9. Measurement of water in clouds. *Proc. roy. Soc., London*, A, **96**, 1919, p. 19.
10. Atmospheric stirring measured by precipitation. *Proc. roy. Soc., London.*, A, **96**, 1919, p. 9.
11. Some measurements of atmospheric turbulence. *Phil. Trans., London*, A, **221**, 1920, p. 1.
12. Lizard balloons for signalling the ratio of pressure to temperature. *Prof. Notes met. Off., London*, **2**, No. 18, 1921, p. 73.
13. Cracker balloons for signalling temperature. *Prof. Notes met. Off., London*, **2**, No. 19, 1921, p. 95.
14. Wind above the night-calm at Benson at 7 a.m. *Quart. J. R. met. Soc., London*, **49**, 1923, p. 34.
15. Theory of the measurement of wind by shooting spheres upward. *Phil. Trans., London*, A, **223**, 1923, p. 345.
16. How to observe the wind by shooting spheres upward. *Prof. Notes met. Off., London*, **3**, No. 34, 1924.
17. Attempts to measure air temperature by shooting spheres upward. *Quart. J. R. met. Soc., London*, **50**, 1924, p. 19.
18. The aerodynamic resistance of spheres, shot upward to measure the wind. *Proc. phys. Soc., London*, **36**, 1924, p. 67.
19. Turbulence and vertical temperature difference near trees. *Phil. Mag., London*, **49**, 1925, p. 81.
20. The brown corona and the diameter of particles. *Quart. J. R. met. Soc., London*, **51**, 1925, p. 1.
21. Photometric observations on clouds and clear skies. *Quart. J. R. met. Soc., London*, **51**, 1925, p. 7.
22. Meteorological studies in connection with the Toronto meeting of the British Association. *Quart. J. R. met. Soc., London*, **53**, 1927, p. 295.
23. Report on photometers for a survey of the reflectivity of the earth's surface. Union Géodésique et Géophysique Internationale: Section de Météorologie. Troisième Assemblée Générale. Cambridge, 1928, p. 1.
24. A search for the law of atmospheric diffusion. *Beitr. Phys. frei. Atmos., Leipzig*, **15**, 1929, p. 24.
25. Reflectivity of woodland, fields and suburbs between London and St. Albans. *Quart. J .R. met. Soc., London*, **56**, 1930, p. 31.

26. RICHARDSON, L. F., WAGNER, A. and DIETZIUS, R.; An observation test of the geostrophic approximation in the stratosphere. *Quart. J. R. met. Soc., London,* **48,** 1922, p. 328.
27. RICHARDSON, L. F. and PROCTOR, D.; Diffusion over distances ranging from 3 Km. to 86 Km. *Mem. R. met. Soc., London,* **1,** 1926, p. 1.
28. RICHARDSON, L. F. and MUNDAY, R. E.; The single-layer problem in the atmosphere and the height-integral of pressure. *Mem. R. met. Soc., London,* **1,** 1926, p. 17.
29. RICHARDSON, L. F., PROCTOR, D. and SMITH, R. C.; The variance of upper wind and the accumulation of mass. *Mem. R. met. Soc., London,* **1,** 1926, p. 59.
30. RICHARDSON, L. F. and GAUNT, J. A.; Diffusion regarded as a compensation for smoothing. *Mem. R. met. Soc., London,* **3,** 1930, p. 191.
31. RICHARDSON, L. F. and STOMMEL, H.; Note on eddy diffusion in the sea. *J. Met., Lancaster Pa,* **5,** 1948, p. 238.

METEOROLOGICAL OFFICE NEWS

For the flight of Her Majesty The Queen and H.R.H. The Duke of Edinburgh from England to Bermuda, via Gander (Newfoundland) on the night of November 23–24, 1953, ocean weather ships on stations I and J provided special navigational aids to the aircraft. H.M. ships and H.M. Canadian ships were deployed across the North Atlantic and aircraft of the R.A.F. and R.C.A.F. also played their parts.

Her Majesty The Queen has been graciously pleased to cause the following message to be sent to the Masters of O.W.S. *Weather Recorder* (station J) and *Weather Explorer* (station I): "Please convey my thanks to these ships and authorities concerned for the admirable manner in which they have carried out their duties in connection with my flight from England— Elizabeth R."

ERRATUM

December 1953, Photographs in the centre of the Magazine; interchange the captions "RADAR-SONDE PRESSURE-, HUMIDITY- AND TEMPERATURE-SENSITIVE UNITS" and "RADAR-SONDE WIND-DIRECTION RECORDER INCORPORATING THE WIND COMPUTER".

WEATHER OF NOVEMBER 1953

Mean pressure was below normal in the north Atlantic, north of latitude 55°N., including Iceland where it was as much as 13 mb. below normal. Mean pressure was above normal over the whole of Europe; it reached a maximum value of 1029 mb. in south-east Europe, where it was 11 mb. above normal. Mean pressure was also above normal, 1–3 mb. generally in the east and south of the United States.

As a result of the marked pressure gradient for south-westerly winds, temperature was above normal over northern Europe, as much as 10°F. in places in the north of Scandinavia; temperature was 2–3°F. below normal in south-east Europe and 4–5°F. below normal in the central and eastern Mediterranean. Mean temperature was also above normal over much of the United States and Canada.

In the British Isles the weather was unusually mild, with rainfall well below average in south and east England, the Midlands and east Scotland, but considerably above average in west Scotland, north-west England and parts of Wales. Although rainfall was so much below average in south-east England, relative humidity was rather high (at Kew Observatory in the afternoon the relative humidity was 2 to 3 per cent. above average). The duration of bright sunshine was generally well below average, though some places registered rather more than average.

A changeable westerly type of weather prevailed until the 9th, with depressions passing near our north-west coasts giving frequent rain or showers, with local thunderstorms on the 1st, 2nd, 7th and 9th; there were, however, long sunny periods on some days. Rainfall was considerable on the 1st, 3rd and 8th and in the north-west on the 6th (3·05 in. at Fort William and 2·72 in. at Glenshero, Inverness-shire on the 6th). Wind reached gale force at a number of places on the 1st and 2nd and locally in the north on the 4th, 6th and 7th. In the south-east the only heavy rainfall of the month occurred on the 1st, and, following the heavy rain on October 31, it caused some flooding in southern counties. Between the 2nd and the 10th wedges of high pressure following the troughs of low pressure were accompanied by occasional ground frost and slight local air frost, but during the rest of the month there was hardly any air frost in England and Wales and remarkably little ground frost. A dry spell began in the south on the 10th with a belt of high pressure to southward of the British Isles. In the north and west it was still changeable with heavy rain at times (3·25 in. at Watendlath Farm, Cumberland on the 11th, 3·61 in. at Llechwedd Quarries, Blaenau Festiniog, Merionethshire on the 13th and 2·20 in. at Oakley Slate Quarries and 2·00 in. at Rothesay, Bute on the 14th). By the 17th the ridge had spread north over England, and most of the south and Midlands had persistent fog on that day and to a less extent on the 18th and again on the 20th. By the 20th almost the whole country was under the influence of the wedge, and rain was confined to the extreme north of Scotland on the 20th and practically no rain fell anywhere on the 21st. Subsequently a trough of low pressure spreading slowly east brought rain to Ireland on the night of the 22nd and to all districts during the following days, the rain reaching south-east England by the 24th, ending the dry spell there. An unsettled south-westerly type of weather persisted until the 28th; frontal troughs associated with a deep depression near Iceland gave widespread heavy rain to western districts on the 26th to the 27th (3·50 in. at Watendlath Farm, 3·44 in. at Ambleside and 2·00 in. near Trecastle, Brecknockshire in the 24 hr. up to 0900 on the 27th). On the 28th an elongated ridge of high pressure built up over the southern districts of the British Isles, while depressions moved east across Iceland bringing further rain and strong winds, reaching gale force locally, to Scotland.

During the long mild spell there were few noteworthy maximum temperatures, though 60°F. was registered locally on a number of days and 61°F. at Hawarden Bridge and Wrexham on the 15th, Aber on the 23rd, Gillingham, Kent, on the 28th and Bromley on the 29th. Minimum temperatures were unusually high on the whole: at Oxford the lowest minimum, 35°F., was the highest for November in a record going back to 1881.

The general character of the weather is shown by the following table.

	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 ...	61	25	+3·3	81	−5	84
Scotland	63	25	+3·3	138	+1	79
Northern Ireland ...	58	31	+2·5	96	−2	85

RAINFALL OF NOVEMBER 1953

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	0·83	35	*Glam.*	Cardiff, Penylan ...	3·83	95
Kent	Dover	2·18	69	*Pemb.*	Tenby, The Priory ...	4·41	101
,,	Edenbridge, Falconhurst	1·51	43	*Radnor*	Tyrmynydd	5·51	83
Sussex	Compton, Compton Ho.	1·97	52	*Mont.*	Lake Vyrnwy	8·14	142
,,	Worthing, Beach Ho. Pk.	1·90	59	*Mer.*	Blaenau Festiniog ...	16·12	151
Hants.	Ventnor Cemetery ...	2·25	69	,,	Aberdovey	5·53	122
,,	Southampton, East Pk.	1·33	42	*Carn.*	Llandudno	2·83	98
,,	South Farnborough ...	1·72	65	*Angl.*	Llanerchymedd ...	5·65	134
Herts.	Royston, Therfield Rec.	1·34	58	*I. Man*	Douglas, Borough Cem.	5·91	125
Bucks.	Slough, Upton... ...	1·58	71	*Wigtown*	Newton Stewart ...	6·51	131
Oxford	Oxford, Radcliffe ...	1·55	67	*Dumf.*	Dumfries, Crichton R.I.	6·90	187
N'hants.	Wellingboro' Swanspool	1·50	70	,,	Eskdalemuir Obsy. ...	8·73	151
Essex	Shoeburyness	1·13	53	*Roxb.*	Crailing	2·14	90
,,	Dovercourt	0·90	42	*Peebles*	Stobo Castle	4·41	133
Suffolk	Lowestoft Sec. School...	0·96	41	*Berwick*	Marchmont House ...	2·32	77
,,	Bury St. Ed., Westley H.	1·30	57	*E. Loth.*	North Berwick Res. ...	2·23	100
Norfolk	Sandringham Ho. Gdns.	1·81	73	*Midl'n.*	Edinburgh, Blackf'd. H.	3·06	137
Wilts.	Aldbourne	1·59	54	*Lanark*	Hamilton W. W., T'nhill	6·85	192
Dorset	Creech Grange... ...	2·69	65	*Ayr*	Colmonell, Knockdolian	6·04	121
,,	Beaminster, East St. ...	1·81	46	,,	Glen Afton, Ayr San. ...	7·54	137
Devon	Teignmouth, Den Gdns.	1·86	58	*Renfrew*	Greenock, Prospect Hill	11·23	185
,,	Ilfracombe	3·71	94	*Bute*	Rothesay, Ardencraig...	8·28	163
,,	Okehampton	3·19	60	*Argyll*	Morven (Drimnin) ...	11·39	168
Cornwall	Bude, School House ...	2·56	72	,,	Poltalloch	12·28	218
,,	Penzance, Morrab Gdns.	2·22	48	,,	Inveraray Castle ...	17·24	204
,,	St. Austell	3·03	62	,,	Islay, Eallabus... ...	8·61	160
,,	Scilly, Tresco Abbey ...	2·33	68	,,	Tiree	7·97	165
Somerset	Taunton	1·78	61	*Kinross*	Loch Leven Sluice ...	4·86	135
Glos.	Cirencester	1·98	66	*Fife*	Leuchars Airfield ...	2·39	104
Salop	Church Stretton ...	2·29	74	*Perth*	Loch Dhu	13·46	155
,,	Shrewsbury, Monksmore	1·85	82	,,	Crieff, Strathearn Hyd.	5·20	120
Worcs.	Malvern, Free Library...	1·36	54	,,	Pitlochry, Fincastle ...	3·48	94
Warwick	Birmingham, Edgbaston	1·37	58	*Angus*	Montrose, Sunnyside ...	2·51	95
Leics.	Thornton Reservoir ...	1·32	58	*Aberd.*	Braemar	3·01	78
Lincs.	Boston, Skirbeck ...	1·61	81	,,	Dyce, Craibstone ...	2·53	78
,,	Skegness, Marine Gdns.	1·17	54	,,	New Deer School House	1·93	57
Notts.	Mansfield, Carr Bank...	..	..	*Moray*	Gordon Castle	1·82	63
Derby	Buxton, Terrace Slopes	3·28	70	*Nairn*	Nairn, Achareidh ...	2·27	101
Ches.	Bidston Observatory ...	2·89	116	*Inverness*	Loch Ness, Garthbeg ...	..	..
,,	Manchester, Ringway...	2·73	105	,,	Glenquoich	24·60	203
Lancs.	Stonyhurst College ...	5·87	130	,,	Fort William, Teviot ...	15·83	193
,,	Squires Gate	3·89	118	,,	Skye, Broadford ...	15·91	185
Yorks.	Wakefield, Clarence Pk.	2·02	95	,,	Skye, Duntuilm ...	9·94	166
,,	Hull, Pearson Park ...	1·72	79	*R. & C.*	Tain (Mayfield) ...	2·35	79
,,	Felixkirk, Mt. St. John...	2·42	99	,,	Inverbroom, Glackour...	10·38	167
,,	York Museum	1·98	95	,,	Achnashellach	15·01	174
,,	Scarborough	1·94	79	*Suth.*	Lochinver, Bank Ho. ...	9·75	193
,,	Middlesbrough... ...	1·31	62	*Caith.*	Wick Airfield	2·47	79
,,	Baldersdale, Hury Res.	3·52	97	*Shetland*	Lerwick Observatory ...	6·79	159
Norl'd.	Newcastle, Leazes Pk....	0·79	34	*Ferm.*	Crom Castle	3·52	101
,,	Bellingham, High Green	3·50	102	*Armagh*	Armagh Observatory ...	2·64	93
,,	Lilburn Tower Gdns. ...	1·97	59	*Down*	Seaforde	3·41	90
Cumb.	Geltsdale	4·48	137	*Antrim*	Aldergrove Airfield ...	3·06	94
,,	Keswick, High Hill ...	10·05	178	,,	Ballymena, Harryville...	3·20	79
,,	Ravenglass, The Grove	8·28	185	*L'derry*	Garvagh, Moneydig ...	3·31	84
Mon.	A'gavenny, Plâs Derwen	2·38	57	,,	Londonderry, Creggan	4·63	113
Glam.	Ystalyfera, Wern House	7·87	120	*Tyrone*	Omagh, Edenfel ...	4·40	116

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

Wt-34. K16.

M.O. 581 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 83, No. 980, FEBRUARY 1954

NOTES ON SOUTHERN-HEMISPHERE CIRCULATION

By S. T. A. MIRRLEES, M.A.

Summary.—Data of some of the pre-war expeditions to the South American sector of Antarctica are examined for a possible relation between circulation types and the surface zonal westerly index[1]. Some comparison is made with results of northern-hemisphere investigations and points for future investigations are suggested.

Introduction.—Antarctic exploration has been described as a "spasmodic affair proceeding by great efforts separated by intervals of inertness and inattention . . . the results were seldom fully recorded and published."[2]

Meteorological, and in particular climatological, exploration of Graham Land is now in a better way since the Falkland Islands Dependencies Survey[3] was set up, and, what is more important, has maintained continuously for several years a number of observation posts in latitudes 63–68°S.

When it was announced that the data of the Falkland Islands Dependencies Survey were being prepared for publication it occurred to the writer to examine data of some earlier expeditions to see if any line of investigation might be suggested for work on the more complete data of the Survey.

Data and method of working.—In the appropriate "source books"[4,5] data of mean monthly barometric pressure were available for 1903, 1904 and 1909, at various fixed stations (see Fig. 1). For 1915 there was a "drift station" (Shackleton's expedition) and considerable extrapolation was necessary to "reduce" the data to a fixed position in northern Graham Land. This process of course begs the question of the mean pressure distribution, but is perhaps no more outrageous than some of the extrapolation often involved in work on antarctic climatology. Data of the South American stations shown on the map were also extracted, and a series of charts of monthly pressure anomaly was prepared. Charts for 1935–37 were available from previous work[6].

Preliminary examination of the whole series of charts suggested a type classification on the following lines:—

(i) Since the maps of normal pressure distribution show that the westerlies prevail throughout the year on the west coast of South America only about as far north as 43°S., the term high- or low-index month is used to denote a month in which the gradient of mean monthly pressure

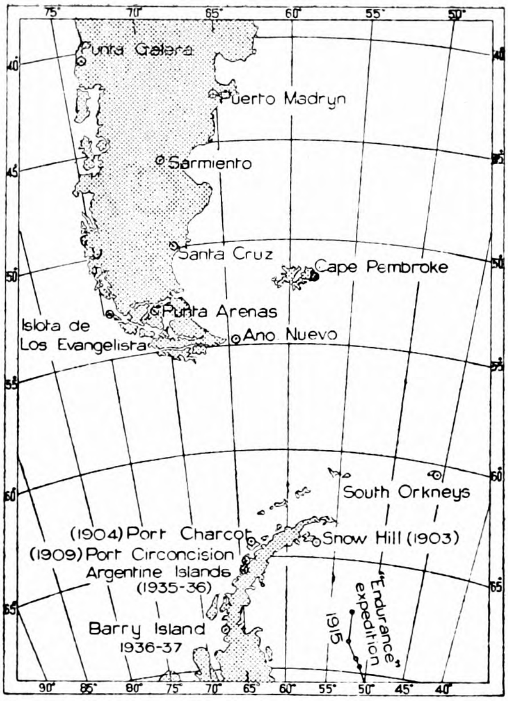


FIG. 1—POSITION OF STATIONS

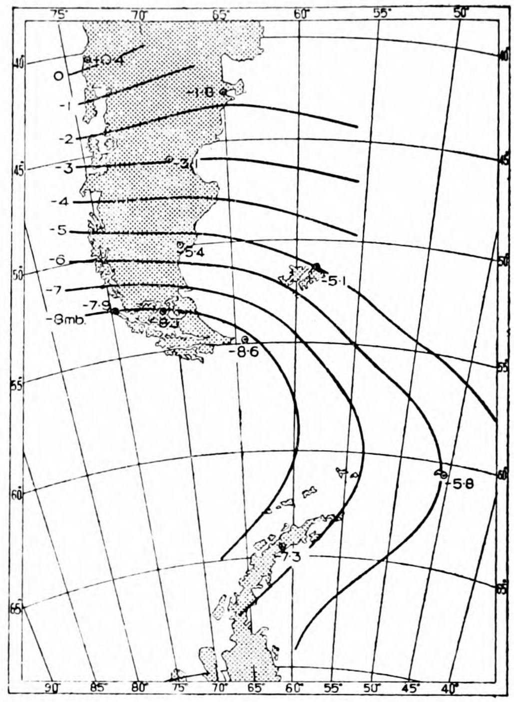


FIG. 2—COMPOSITE CHART OF THE FIVE HIGHEST INDEX W MONTHS

Average isanomalies of March 1903, March 1904, August 1909, March 1935 and December 1936.

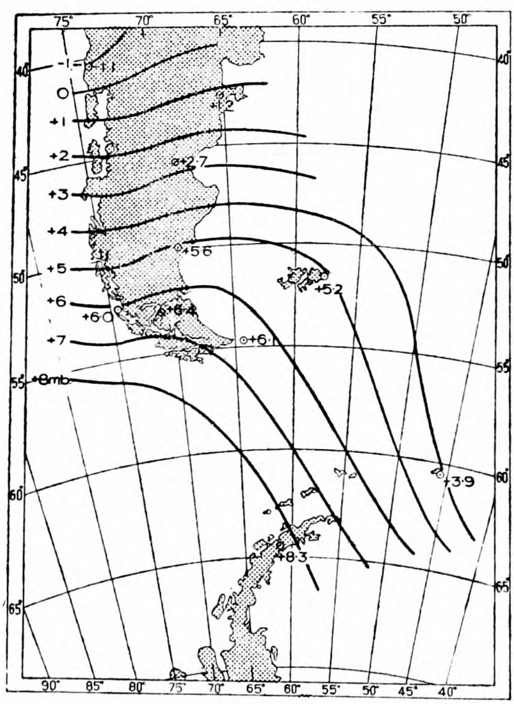


FIG. 3—COMPOSITE CHART OF THE FIVE LOWEST INDEX B MONTHS

Average isanomalies of May, November and December 1904, October 1935 and August 1936.

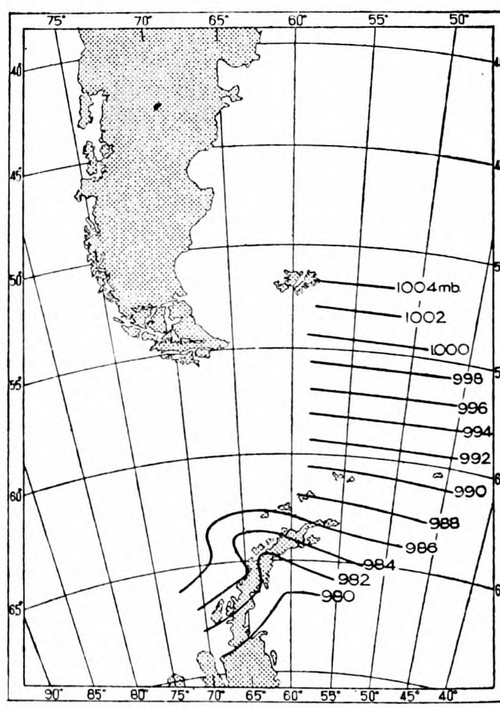


FIG. 4—MEAN MONTHLY SEA LEVEL PRESSURE, OCTOBER 1948

Part of the CLIMAT broadcast.

at mean sea level, Punta Galera – Los Evangelistas, was above or below normal for the time of year.

(ii) Subdivisions were made according as the mean monthly sea-level pressure at certain key stations was above (+) or below (−) normal.

TABLE I—CLASSIFICATION OF TYPES OF MONTHLY PRESSURE ANOMALY

	Type of monthly pressure anomaly at Falkland Islands	South Orkneys	Type indicator
High index ...	−	−	W
		+	X
	+	−	Y
		+	Z
Low index ...	+	−	A
		+	B
	−	−	C
		+	No example

This scheme of types seems adequate for a preliminary investigation, being objective and easily applied. When more complete data are available it would be possible to make a detailed air-mass investigation on dynamical–climatological lines.

Results of the type classification.—The results of the classification process are shown in Tables II, III and IV. Of the 70 months included, there are 41 with high index and 29 with low index. This result suggests that

TABLE II—DISTRIBUTION OF TYPES

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1903	...	...	W	Y	Z	W	Y	Y	Z	Z	Z	Y
1904	A	A	W	B	B	Z	A	X	X	X	B	B
1905	Z	...	...	...	...	...	...	...	...	...	...	...
1909	A	C	B	W	W	W	X	W	B	B	A	...
1915	A	C	B	W	X	W	X	X	Z	Z	Z	C
1935	...	...	W	A	W	X	C	A	C	B	W	W
1936	X	A	C	B	C	W	Z	B	W	W	A	W
1937	B	X	...	...	...	...	...	...	...	...	...	...

TABLE III—SEASONAL DISTRIBUTION OF TYPES

	High-index months W	X	Y	Z	Low-index months A	B	C
	Number of occasions						
Spring	3	2	0	6	2	4	1
Summer	2	2	1	1	5	2	3
Autumn	7	1	1	1	1	5	2
Winter	5	5	2	2	2	1	1

TABLE IV—RELATION OF TYPES TO PRESSURE DIFFERENCE BETWEEN SOUTH ORKNEYS AND GRAHAM LAND

Pressure difference South Orkneys – Graham Land	Type of classification High-index months W	X	Y	Z	Low-index months A	B	C
	Number of occurrences						
+	13	10	4	10	5	9	4
0	1	...	...	...	...	...	...
−	3	...	...	...	5	3	3

expeditions were in the field mainly in high-index years, or the adopted "normals" may be doubtful, and is a point for future investigation along with the following:—

(i) The seasonal trend is for high-index types in winter and spring, low-index types in summer and autumn.

(ii) Type W (Fig. 2) shows the closest association with season (7 in autumn, 2 in summer).

(iii) Of low-index types, B (Fig. 3) shows a slight predominance over A on the whole year.

In the previous work[6] some indication was found of a tendency for months when pressure over Graham Land was higher than over South Orkneys to be associated with low zonal index. Now, using data of 70 instead of 24 months, a different régime appears (see Table IV). This may be some indication of secular change, and is a point for future investigation.

Comparison with northern-hemisphere investigations.—

(i) Namias[7] finds a suggestion that during the colder parts of the year low-index periods are more persistent than high—according to Table III if periods of one month are considered, the chances are 14 to 4 against a winter month being a low-index month. A point for future investigation is whether there is a 30-day rhythm in pressure, over the area considered, which in certain years may be "in step" with the calendar.

(ii) Brier[8,9] has found a tendency for mean monthly sea-level pressure patterns resembling summer–autumn pressure patterns towards the end of that period (1899–1939) and winter–spring pressure patterns towards the earlier part of the period. Table II shows something of the same kind—of 23 months in 1903–05 there were 16 of high index and 7 of low index whereas in 1935–37 the proportion was 12 to 12.

(iii) Namias[10] has found some indication that low- or high-index patterns are more consistent within the same year than from year to year, e.g. a low-index feature is apt to repeat in the same fashion in the same season. Table II has some indication of this (sequence A, C, B) but without emphasis on "the same season".

Conclusion.—It seems that charts of monthly pressure anomaly afford a means of using the data of early expeditions to Graham Land in conjunction with the data of the Falkland Islands Dependencies Survey for study of circulation patterns and investigation of secular change in these.

CLIMAT broadcasts.—As part of the scheme of the World Meteorological Organization for exchange of data, each meteorological authority makes radio broadcasts of mean surface values of meteorological elements (including pressure) for a selection of stations "as soon as possible after the end of the month and not later than the 5th".

As an instance of the advance in climatological exploration since the first expedition wintered in Graham Land some fifty years ago, it may be noted that the climatologist may (in favourable conditions of radio propagation), by listening on the short-wave band of his domestic radio, have the data for drawing the map of pressure distribution over Graham Land (Fig. 4) "not later than the 5th".

[Dr. J. Pepper comments, with reference to Mr. Mirrlees's suggestion on secular change, that his studies of the region show that the mean monthly pressure in the Graham Land region undergoes very large variation, and he is doubtful if even 10 years' observations suffice for the examination of secular change.—Ed., *M.M.*]

REFERENCES

1. FORSDYKE, A. G.; Zonal and other indices. *Met. Mag., London,* **80,** 1951, p. 156.
2. London, Admiralty, Hydrographic Department. Antarctic pilot. London, 2nd edn, 1948.
3. ROBIN, G. DE Q.; Notes on synoptic weather analysis on the fringe of Antarctica. *Met. Mag., London,* **78,** 1949, p. 216.
4. CLAYTON, H. H.; World weather records. *Smithson. misc. Coll., Washington,* **79,** 1927.
5. KÖPPEN, W. and GEIGER, R.; Handbuch der Klimatologie. Band IV, Teil U. Klimakunde der Antarktis, by W. Meinardus. Berlin, 1938.
6. MIRRLEES, S. T. A.; Notes on southern hemisphere circulation. *Met. Mag., London,* **78,** 1949, p. 315.
7. NAMIAS, J.; The annual course of month to month persistence in climatic anomalies. *Bull. Amer. met. Soc., Lancaster Pa,* **32,** 1951, p. 397.
8. BRIER, G. W.; 40-year trends in northern hemisphere surface pressure. *Bull. Amer. met. Soc., Lancaster Pa,* **28,** 1947, p. 237.
9. BRIER, G. W.; Forty-year sea level pressure and sunspots. *Tellus, Stockholm,* **4,** 1952, p. 262.
10. NAMIAS, J.; Extended forecasting by mean circulation methods. Washington, 1947.

ACCURACY OF 100-MB. CONTOUR HEIGHTS

By D. H. JOHNSON, M.Sc.

Summary.—Comparison between observed winds and slopes of the 100-mb. pressure surface indicate that the standard error in the measurement of 100-mb. contour height, using radio-sonde data for British land stations, is of the order of 145 ft.

Introduction.—Reports of 100-mb. winds show flow patterns at the 100-mb. level to be smoother than those of the troposphere. If, however, the contours of the 100-mb. surface are drawn to agree strictly with the measurements of contour height, patterns are obtained which are far more irregular and have a much greater variability in space and time than the observed flow. The dominant terms in the expression for the ageostrophic wind depend on the local and spatial accelerations. Since these are small at 100 mb. the ageostrophic winds will also be small. So, knowing the observed winds to be reasonably accurate[1], the large apparent geostrophic departure must be accounted for in terms of contour-height errors. A method of estimating the standard error in measurements of 100-mb. contour height is described below.

Expression for the standard error.—An estimate of the standard error of the contour-height measurements can be obtained simply by comparing the measured contour gradients with the observed winds, due consideration being given to errors, other than those of the contour heights themselves, which may affect the comparison. The problem may be formulated as follows. The value ascribed to the 100-mb. contour height above a given station is obtained from radio-sonde observations of temperature and pressure by integration of the hydrostatic equation. This value is known to contain not only the usual errors of measurement and computation but also errors caused by the fact that the basic observations are not made simultaneously at all levels; they are made over finite intervals of time during which the balloon travels some distance away from the point to which they are taken to refer. The object of the present test is to get an estimate of the total error in the values obtained and not to discriminate between the various component parts.

Observations are required from two adjacent upper air stations at points A and B. Let

V = true wind component perpendicular to AB.
U = measured wind component perpendicular to AB.
ε = error in measured component perpendicular to AB.
J = geostrophic wind component perpendicular to AB.
V' = ageostrophic wind component perpendicular to AB.
x = distance measured along AB.
d = distance between A and B.
h = true height of 100-mb. surface.
H = measured height of 100-mb. surface.
θ = error in measured height of 100-mb. surface.

g and l have their usual significance. Suffixes A, B denote values of the variables at points A, B.

Then
$$V = V' + J$$
where
$$J = \frac{g}{l}\left(\frac{\partial h}{\partial x}\right)_{100}$$

Taking mean values over the distance AB for a particular occasion
$$\bar{V} - \bar{V}' = \bar{J}$$
$$= \frac{g}{ld}(h_B - h_A)$$
so
$$(H_B - H_A) + (\theta_B - \theta_A) = \frac{ld}{g}(\bar{V} - \bar{V}'). \qquad \text{.....} (1)$$

Now let η be the difference between the true wind component at any point along AB and the wind component obtained by linear interpolation between the true winds at A and B,

so that
$$\bar{V} = \tfrac{1}{2}(V_A + V_B) + \bar{\eta}$$
$$= \tfrac{1}{2}(U_A + U_B) + \tfrac{1}{2}(\varepsilon_A + \varepsilon_B) + \bar{\eta}$$
and from equation (1)
$$(H_B - H_A) - \frac{ld}{2g}(U_A + U_B) = (\theta_A - \theta_B) + \frac{ld}{g}[\tfrac{1}{2}(\varepsilon_A + \varepsilon_B) + \bar{\eta} - \bar{V}'].$$

Now taking the mean-square values of both sides of the equation over a large number, N, of occasions and assuming θ, ε, η and V' to be independent,
$$\frac{1}{N}\Sigma\left[(H_B - H_A) - \frac{ld}{2g}(U_A + U_B)\right]^2 = \frac{2}{N}\Sigma\,\theta^2 + \frac{l^2d^2}{Ng^2}\left(\frac{1}{2}\Sigma\varepsilon^2 + \Sigma\bar{\eta}^2 + \Sigma\bar{V}'^2\right)$$
and the standard error in the measured height
$$\left[\frac{1}{N}\Sigma\theta^2\right]^{\frac{1}{2}} = \frac{1}{2^{\frac{1}{2}}}\left\{\frac{1}{N}\Sigma\left[(H_B - H_A) - \frac{ld}{2g}(U_A + U_B)\right]^2 - \frac{l^2d^2}{Ng^2}\left[\frac{1}{2}\Sigma\varepsilon^2 + \Sigma\bar{\eta}^2 + \Sigma\bar{V}'^2\right]\right\}^{\frac{1}{2}}.$$

Evaluation of the errors.—The first term in the expression for $[(1/N)\Sigma\theta^2]^{\frac{1}{2}}$ has been calculated using 356 pairs of observations for the first nine months of 1952 made by 6 pairs of British radio-sonde stations. The root-mean-square of

$$\left[(H_B - H_A) - \frac{ld}{2g}(U_A + U_B)\right]$$

was 207 ft., implying an upper limit to $[(1/N)\Sigma\theta^2]^{\frac{1}{2}}$ of 145 ft.

It is reasonable to assume that $(1/N)\Sigma\bar{\eta}^2$ is not greater than $(1/N)\Sigma\eta_m{}^2$ where η_m is the error of interpolation at the mid point of AB. Now an estimate, (7 kt.)^2, of $(3/2N)\Sigma\varepsilon^2 + (1/N)\Sigma\eta_m{}^2$ has previously been obtained[1] by comparing an interpolation between winds observed at Aldergrove and Downham Market with the wind observed at Liverpool. This estimate applied to a winter sample of winds and the distance Aldergrove—Downham Market exceeds the distance between any of the pairs of stations used in the present test. So we may safely take the value of the terms $(1/2N)\Sigma\varepsilon^2 + (1/N)\Sigma\bar{\eta}^2$ as being less than (7 kt.)^2; $(1/N)\overline{V'^2}$ will be of the same order as $(1/N)\Sigma(V'_A)^2$ or $(1/N)\Sigma(V'_B)^2$. Representative values of the observed time and space variations of 100-mb. wind over the British Isles are 11 kt./12 hr. and 12 kt./300 miles in winter and less in summer. Since the total geostrophic departure $\mathbf{V}'$ is related to the flow accelerations by the equation

$$l\mathbf{V}' = \mathbf{k} \times \left(\frac{d\mathbf{V}}{dt}\right)_h + 2V_z\,\omega_h$$

where $d/dt = \partial/\partial t + \mathbf{V}.\nabla$, $\mathbf{k}$ is unit vector in the vertical, ω represents the angular velocity of the earth and h, z denote components in the horizontal and vertical respectively, it may be deduced that the ageostrophic wind is unlikely to average more than 3 or 4 kt. Also (5 kt.)^2 is probably a generous allowance for the mean square of the ageostrophic wind components at A or B and so for $(1/N)\Sigma\overline{V'^2}$.

The factor ld/g combined with that required to convert knots to feet per second varies between different pairs of stations from 4 to 5 sec. From these considerations we can estimate that the term $(l^2d^2/Ng^2)[\frac{1}{2}\Sigma\varepsilon^2 + \Sigma\bar{\eta}^2 + \Sigma\overline{V'^2}]$ will be less than 1,850 ft.^{2} So $[(1/N)\Sigma\theta^2]^{\frac{1}{2}}$ will be greater than

$$2^{-\frac{1}{2}}[(207)^2 - 1850]^{\frac{1}{2}} = 142 \text{ ft.}$$

Strictly, the values of U employed in these calculations should refer to points vertically above A and B at 100 mb., but the average spatial variation of U can reasonably be expected to be so small over the 10 to 30 miles the balloon is usually carried away from its station as to have a negligible effect on these results.

It is of interest to compare the 100-mb. standard error with those given by Murray[2] for lower levels, which are contained in Table I.

TABLE I—STANDARD ERRORS IN HEIGHTS OF ISOBARIC SURFACES COMPUTED FROM RADIO-SONDE OBSERVATIONS FOR BRITISH LAND STATIONS

Pressure level (mb.)	700	500	300	200	100
Approximate height (ft.) ...	10,000	18,000	30,000	38,000	53,000
Standard error (ft.)	20	30	70	100	145

REFERENCES

1. JOHNSON, D. H.; Accuracy of 100-mb. winds. *Met. Mag., London*, **82**, 1953, p. 44.
2. MURRAY, R.; On the accuracy of contour charts in forecasting upper winds. *Prof. Notes met. Off., London*, **7**, No. 110 (in the press).

MOBILE DEPRESSION WITH AN UNUSUAL THERMAL STRUCTURE

By C. A. S. LOWNDES

Experience in the use of 1000–500-mb. thickness patterns has led to the recognition of certain types of association between such patterns and particular features and phases of development on surface charts. For example, cyclogenesis is usually accompanied by a distortion of the thickness pattern, with a developing cold trough to the rear and a warm ridge ahead of the surface depression. Later, when the occlusion process is well advanced, the cold trough sometimes overtakes the surface low, which is then usually slow moving and in the process of filling. Thermal gradients in these circumstances are often weak and a cold pool may become associated with the surface low.

A system which formed near Greenland on October 4, 1952, started as a normal depression but subsequently developed a well marked cold trough in phase with the centre. In this case, however, the low did not become stationary or begin to fill up, but after a period of erratic motion continued its south-eastward movement without much change of pressure at the centre (Fig. 1).

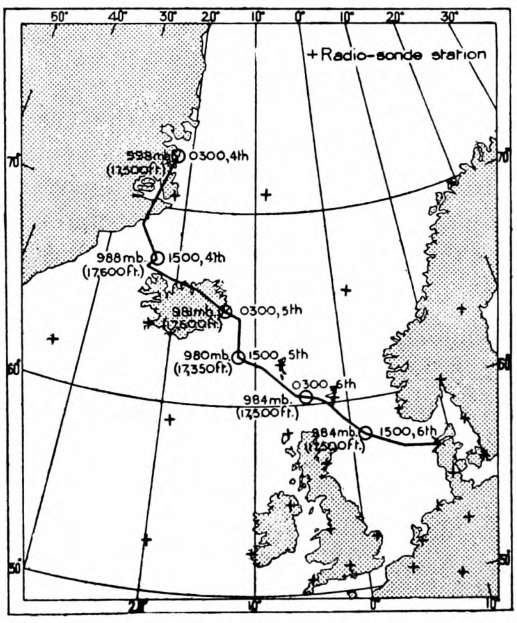


FIG. 1—TRACK OF DEPRESSION

The central M.S.L. pressure and the associated 1000–500-mb. thickness are shown at 12-hr intervals.

Initial development of the depression.—By 0300 G.M.T. on October 4, 1952 a trough of low surface pressure off the east coast of Greenland had developed a closed centre at about 72°N. The new centre (pressure 998 mb.) was situated in a moderate thermal gradient near the "top" of a diffluent ridge in the 1000–500-mb. thickness pattern (Fig. 2). The corresponding patterns for the partial thicknesses of the layers 500–300 mb., 700–500 mb. and 1000–700 mb. were similar, the ridge being more sharply defined in the lower layers (Fig. 2). The depression deepened rapidly and moved (rather at variance with thermal steering) on a southerly track to the north-west of

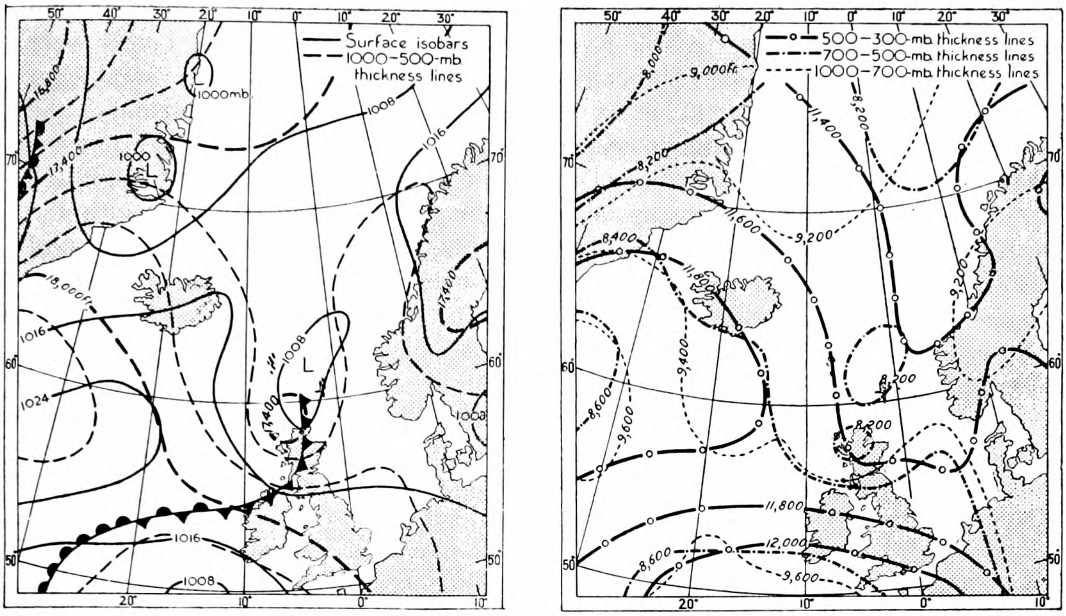


FIG. 2—SYNOPTIC CHART, OCTOBER 4, 0300 G.M.T.

Iceland by 1500, the central pressure falling to 988 mb. During the morning, a cold occlusion moved south-east over Greenland, became slow moving near the east coast, and then moved steadily south across the Denmark Strait, becoming associated with the developing low. The low deepened to 983 mb. by 1800, and continued east-south-east across Iceland without much further intensification and was situated near the east coast of Iceland by 0300 on the 5th. Warm frontogenesis was then occurring between Iceland and Scotland, ahead of the cold occlusion. The associated 1000–500-mb. thickness pattern showed a well developed cold trough to the rear and a warm ridge ahead of the low (Fig. 3).

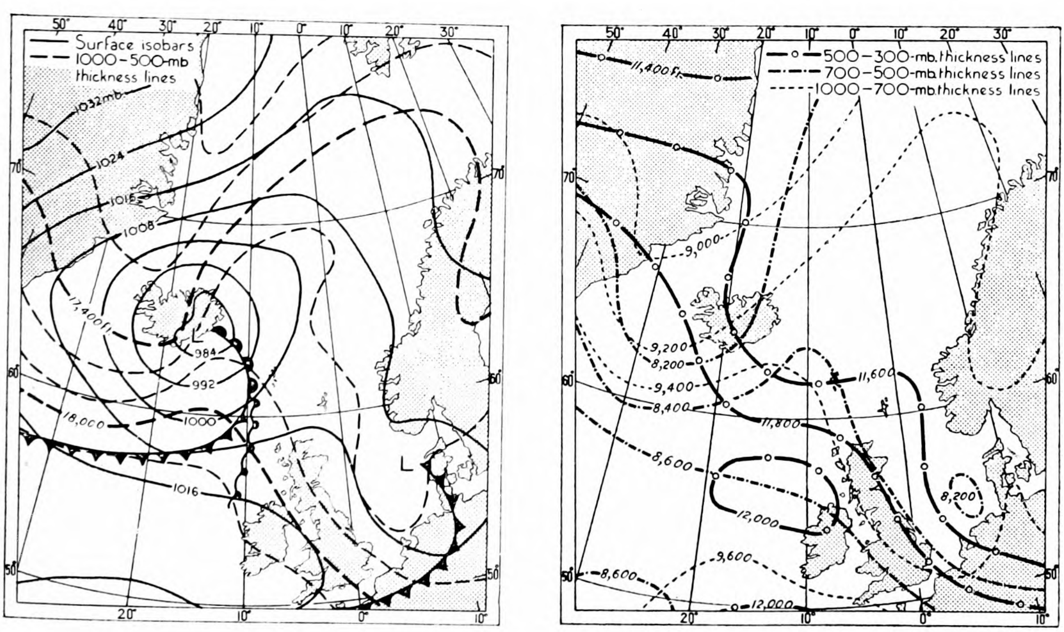


FIG. 3—SYNOPTIC CHART, OCTOBER 5, 0300 G.M.T.

Relative positions of upper air troughs and low pressure at the surface.—The patterns for the 1000–700-mb. and 700–500-mb. layers were very similar, the warm ridge and cold trough in the higher layer being somewhat ahead of that in the lower layer, as is normally found. On the other hand, the 500–300-mb. thickness pattern was rather abnormal; the entire wave pattern at this level was so far in advance of the lower patterns that the cold trough was almost in phase with the warm ridges of the two lower layers and with the surface depression itself (Fig. 3). It is interesting to note that the orientation of the 500–300-mb. thickness pattern at 0300 was much more in keeping with the south-south-east movement of the low during the next 12 hr. The thermal wind below 500 mb. over the depression centre at this time was south-westerly in direction.

By 1500, an equally remarkable transformation had occurred in the 1000–500-mb. pattern, the cold trough of which had apparently moved rapidly south-east so as to overtake the surface low (as had the trough in the 500–300-mb. layer previously) whilst the warm ridge had moved still further ahead and had weakened. This phase-change was largely effected in the 700–500-mb. layer as will be seen from the isopleths (Fig. 4). The normal structure, with the cold trough to the rear and the warm ridge ahead of the surface centre, was still in evidence in the 1000–700-mb. layer.

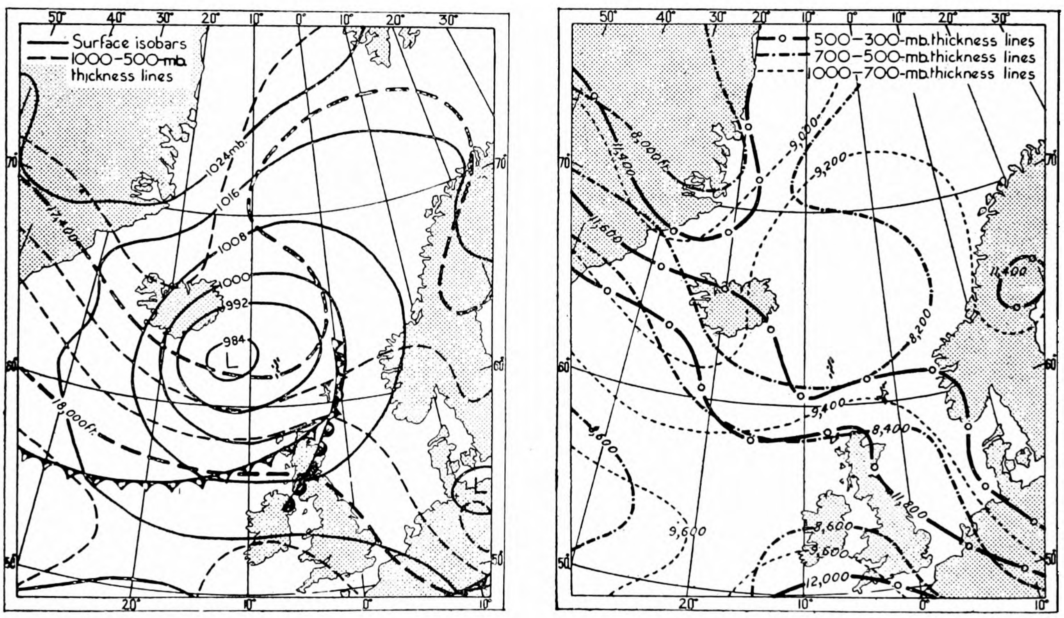


FIG. 4—SYNOPTIC CHART, OCTOBER 5, 1500 G.M.T.

Movement of depression after overtaking of surface depression by upper trough.—During the period 0300 to 1500 on October 5, the greatest 1000–500-mb. thickness change occurred at the depression centre, as the main cold trough in this layer moved into phase with the surface low (Fig. 4). Simultaneously, the centre of the low became detached from the occlusion. Thermal steering would have taken the low north-east, yet it moved almost south-south-east into its own cold trough. The movement of the depression was rather erratic over this period, with symptoms of splitting into two early on, which suggests that the anomalous movement with respect to the 1000–500-mb. pattern may have been due to a re-development further south in the cold air.

The cooling around and ahead of the centre during this period is particularly interesting, because it occurred at a time when the low was of constant depth and when it was moving obliquely across the thickness lines to the warmer side and also south-south-east over a warmer under-surface. Whatever the causes and the nature of the abnormal movement of the low, this remarkable cooling must have been a result of dynamical temperature changes (the lifting of a stable layer) or of ageostrophic cold air advection. It is possible that some cold air was advected (geostrophically) round the southern flank of the low which was then transferred south into it, as previously noted, but this could not have accounted for the magnitude or the extent of the cooling which occurred. This is brought out in Fig. 5 which shows the position of the 1000–500-mb. thickness line for 17,400 ft. at the beginning and end of the period in question, and also where it would have been if it had been advected by the component of the surface geostrophic wind normal to it.*

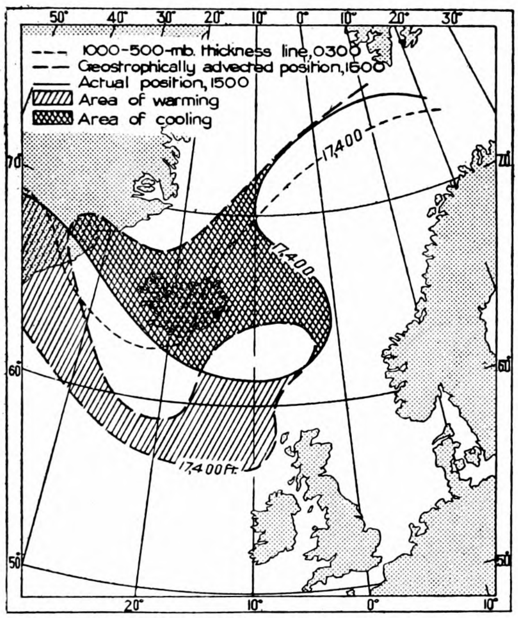


FIG. 5—AREAS OF MAXIMUM NON-ADVECTIONAL WARMING AND COOLING

The shaded segments give an indication of the areas of maximum non-advectional warming and cooling. Warming from below as the cold air moved southwards over the relatively warm sea surface was probably an important agency in the former. Some computations based on the Sutcliffe formula† gave a reasonably good correspondence between the area of maximum vertical ascent required by this theory and the area of maximum cooling. Ageostrophic advection of cold air towards the centre is, however, the essence of the occlusion process and was undoubtedly a contributory factor in the present instance.

Subsequent history.—By 0300 on the 6th, the centre had moved south-east to a position north of Scotland having filled a little and was situated at the "tip" of the trough in the 1000–500-mb. thickness pattern whilst the warm ridge was

* This was done by progressive extrapolation using synoptic charts of the surface isobars at 3-hr. intervals.

† SUTCLIFFE, R. C.; A contribution to the problem of development. *Quart. J. R. met. Soc., London,* **73**, 1947, p. 370.

rapidly developing to the west in spite of the opposing cold air advection (Fig. 6). The partial thickness patterns showed that a cold pool had developed above the surface depression in the 500–300-mb. layer. The trough in the 700–500-mb. pattern was apparently beginning to lag behind the surface centre again at this stage, but later moved forward to become associated with it again. By 1500 the upper cold pool was also apparent in the 700–500-mb. layer whilst that in the layer above had split into two. The thermal gradient in the lowest layer (1000–700 mb.) remained weak throughout.

From this stage, the centre accelerated on an east-south-east track to north Denmark and then slowed down. Before the depression filled, a more normal thermal structure developed in the 1000–500-mb. thickness pattern, namely a cold trough to the rear and a warm ridge ahead. This change was also apparent in the 1000–700-mb. layer, but in the two upper layers the cold pools persisted in association with the centre of surface pressure. The thermal gradients at all levels were weak throughout this period.

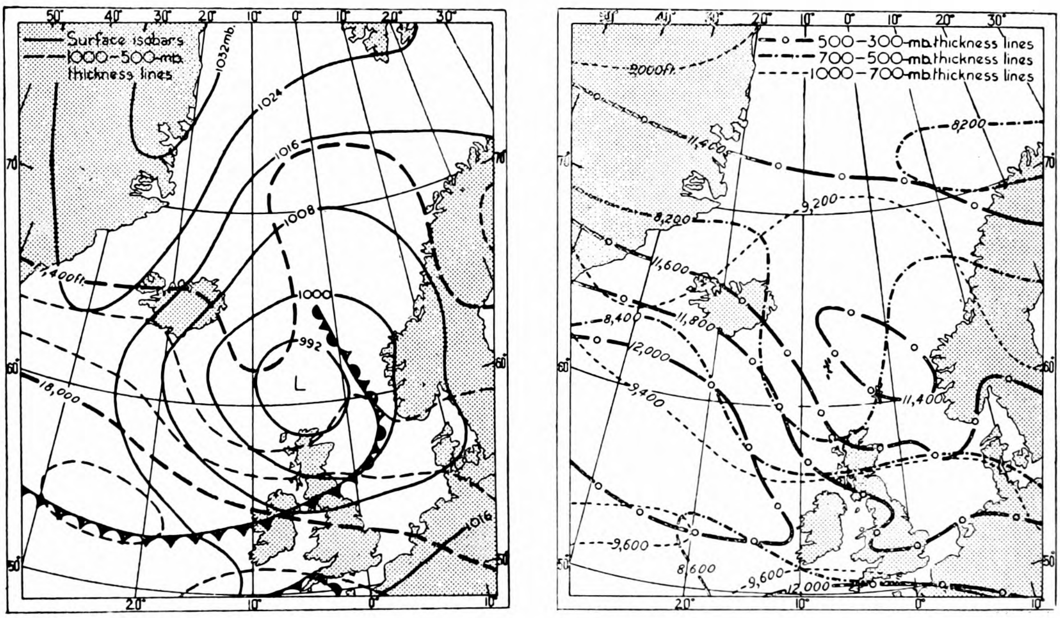


FIG. 6—SYNOPTIC CHART, OCTOBER 6, 0300 G.M.T.

Concluding remarks.—This case-study illustrates how complex the thermal structure of extratropical cyclones can be, and, in particular, points to the possible importance of the 500–300-mb. thickness pattern on some occasions in forecasting. Moreover, the fact that such complex structures and evolutions occur and are possibly significant with respect to surface developments, suggests that no simple cyclone model can provide the basis for a method of forecasting or of deriving numerical solutions of the equations of motion, which will succeed in all cases.

NEW CLIMATOLOGICAL AVERAGES FOR GREAT BRITAIN

By J. GLASSPOOLE, Ph.D.

Station averages are used as a standard for reference, so that the weather of any month or year may be classified in relation to these averages. In the course of time the average over a definite number of years may change. Moreover some of the stations for which averages have been computed cease to report, while new stations may be started. It is therefore useful for a more up-to-date period to be brought into use as the standard for comparison. When this is done it is important to define the differences in the averages for the two periods.

In the *Monthly Weather Report*, 1953, averages of temperature and sunshine for the period 1921–50 were introduced, replacing those for 1906–35. These new averages have now been published[1,2]. Pressure averages at 9h. for 1921–50 are available for inclusion in the *Monthly Weather Report*, 1954, while rainfall averages for 1916–50 will replace those for 1881–1915 when the necessary computations have been carried out.

Temperature.—Serial monthly values of mean temperature at sea level over England and Wales and over Scotland were published by Glasspoole and Hogg[3] covering the period 1901–40, and these values have been continued in the form of departures in the *Monthly Weather Report.* Using these values it is possible to give a comparison of the averages for 1921–50 with those for 1906–35 as set out in Table I.

TABLE I—MEAN TEMPERATURE AT SEA LEVEL

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
							degrees Fahrenheit						
							ENGLAND AND WALES						
1921–50	40·4	40·6	43·6	47·5	52·8	58·2	61·6	61·3	57·6	51·4	45·0	41·6	50·1
1906–35	40·5	40·6	42·9	46·6	53·2	57·7	61·1	60·9	57·0	50·9	44·1	41·5	49·7
							SCOTLAND						
1921–50	39·1	39·5	41·8	44·9	49·7	54·7	58·1	57·4	53·7	48·4	42·8	40·4	47·5
1906–35	39·4	39·6	41·0	44·2	49·6	54·2	57·8	57·1	53·1	48·0	42·2	39·9	47·1

On the basis of this table the period 1921–50 was warmer than 1906–35 by 0·4°F. over England and Wales and over Scotland. The increase in the temperature was most marked in the spring months March and April, and there was a slightly greater increase in the autumn than in the summer. The mean monthly differences, 1921–50 minus 1906–35, for the various seasons are set out in Table II. The seasonal changes are therefore similar over England and Wales and over Scotland.

TABLE II—MEAN MONTHLY DIFFERENCE OF TEMPERATURE, 1921–50 MINUS 1906–35

	Spring Mar.–May	Summer June–Aug.	Autumn Sept.–Nov.	Winter Dec.–Feb.
		degrees Fahrenheit		
England and Wales ...	+0·4	+0·5	+0·7	0·0
Scotland	+0·5	+0·4	+0·5	+0·0

For most stations annual averages for 1921–50 were greater than those for 1906–35 by 0·2–0·6°F. The values were rather less than 0·4°F. in the western half of Scotland, over the English Lake District and from north Wales and the Wash across the Midlands to the south coast between Weymouth and Dover. The difference was therefore rather more than 0·4°F. in the east of Scotland, over much of England north of Derbyshire, over south Wales and much of Devon and Somerset, as well as in parts of East Anglia. The main feature, however, is the uniformity of the difference over the country.

Sunshine.—Serial monthly values of sunshine were published by Hancock covering the period 1909 to 1948[4,5], and in order to enable a comparison to be made Mr. Hancock kindly continued the values back to 1906. These serial values are based on the maps published in the *Monthly Weather Report*, and the general distribution shown on these maps may have changed somewhat as more information became available. Moreover, homogeneous sunshine records are relatively few because of changes caused by diminution in the efficiency of the sphere and by changing exposure, as trees grow etc. General values for England and Wales and Scotland, in the form of departures, have been published in the *Monthly Weather Report* deduced from the means of representative stations in each district. These values are in close accord with those prepared by Mr. Hancock, and they have been used from 1934 onwards, because this series is likely to be continued in the future. A comparison for the two periods is given in Table III.

TABLE III—AVERAGES OF SUNSHINE

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	hours a day												
	ENGLAND AND WALES												
1921–50	1·51	2·31	3·76	5·02	6·09	6·70	5·82	5·47	4·40	3·18	1·89	1·34	3·96
1906–35	1·55	2·39	3·70	4·99	6·03	6·54	5·92	5·38	4·69	3·17	2·01	1·27	3·98
	SCOTLAND												
1921–50	1·18	2·16	3·27	4·59	5·68	5·80	4·54	4·36	3·60	2·54	1·58	0·93	3·35
1906–35	1·14	2·12	3·34	4·67	5·36	5·83	4·83	4·18	3·78	2·58	1·65	0·92	3·36

On the basis of Table III the period 1921–50 was about as sunny as 1906–35 for the year as a whole and during the winter. It was rather sunnier in the spring but less sunny in the autumn, while in the summer it was sunnier over England and Wales but less sunny over Scotland. The mean daily differences 1921–50 minus 1906–35 for the various seasons are set out in Table IV.

TABLE IV—CHANGE IN SEASONAL AVERAGES OF SUNSHINE, 1921–50 MINUS 1906–35

	Spring Mar.–May	Summer June–Aug.	Autumn Sept.–Nov.	Winter Dec.–Feb.
	hours a day			
England and Wales ...	+0·05	+0·05	−0·13	−0·02
Scotland	+0·06	−0·05	−0·10	+0·03

The seasonal difference in the averages for the two periods in the autumn over England and Wales amounts to the loss, as judged by 1906–35 standards, of about one autumn's sunshine in the 30 yr., 1921–50.

Pressure.—Estimates of the monthly changes of pressure at 9h. in the two periods 1901–30 and 1921–50 were obtained from the mean values for 10 well distributed places over Scotland and 20 over England, Wales and the Isle of Man. Station values were taken where available but occasionally values were estimated from the average monthly maps in order to obtain a better distribution. The estimated values for the two periods are set out in Table V.

TABLE V—AVERAGES OF PRESSURE* AT 9H.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	millibars												
	ENGLAND AND WALES												
1921–50	13·7	15·1	15·5	13·7	15·3	16·5	14·6	14·6	15·7	14·1	12·3	14·0	14·6
1901–30	15·2	13·9	12·5	13·3	15·4	16·6	15·6	14·2	16·8	13·3	13·0	11·2	14·3
	SCOTLAND												
1921–50	8·0	11·2	12·8	11·6	14·4	13·9	11·6	11·6	12·0	10·0	8·5	8·9	11·2
1901–30	8·6	8·9	9·2	11·3	14·0	14·7	13·2	10·8	13·7	9·9	8·8	5·9	10·7

* The first two figures are omitted in this table, e.g. 1013·7 is printed as 13·7.

On the basis of Table V the outstanding monthly changes are the higher pressure during 1921–50 in March and December and the lower pressure in January, July and September. The mean monthly differences for the seasons are given in Table VI.

TABLE VI—CHANGE IN SEASONAL AVERAGES OF PRESSURE, 1921–50 MINUS 1901–30

	Spring Mar.–May	Summer June–Aug.	Autumn Sept.–Nov.	Winter Dec.–Feb.
	millibars			
England and Wales ...	+1·1	−0·2	−0·3	+0·8
Scotland	+1·5	−0·5	−0·6	+1·6

The seasonal pressure changes in the two periods were small but the higher pressures during 1921–50 were due mainly to the higher pressures of the winter and spring, which more than balanced the rather lower pressures in the summer and autumn.

From Table V it can be inferred that the mean annual pressure at 9h. for 1921–50 was greater than that for 1901–30 by 0·3 mb. over England and Wales and by 0·5 mb. over Scotland. The difference was only 0·2 mb. from south Wales to the south coast between Land's End and the Isle of Wight, but the values increased to the east coast of England and to the northern half of Scotland, where they exceeded 0·5 mb.

From the monthly maps the pressure gradient between Cape Wrath and Dungeness was estimated for the two periods, and the seasonal changes are set out in Table VII, the plus sign indicating that the pressure gradient for 1921–50 was greater than that for 1901–30.

TABLE VII—SEASONAL CHANGE IN PRESSURE GRADIENT BETWEEN CAPE WRATH AND DUNGENESS, 1921–50 MINUS 1901–30

	Spring Mar.–May	Summer June–Aug.	Autumn Sept.–Nov.	Winter Dec.–Feb.
	millibars			
Change in pressure gradient	−0·01	+1·05	+1·33	−0·28

The two seasonal tables above suggest that in the summer and autumn the pressure gradient was greater in 1921–50 than in 1901–30, while there was a small decrease of pressure over the country; in the winter and spring the gradient was less but the pressure was greater.

Rainfall.—Serial values of monthly and annual rainfall over England and Wales, and over Scotland, were published in *British Rainfall*[6], and these series have been continued in the annual volumes. Using these values a comparison is given in Table VIII of the averages for the two periods 1881–1915 and 1916–50.

TABLE VIII—AVERAGES OF RAINFALL

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
	inches												
	ENGLAND AND WALES												
1916–50	3·83	2·74	2·31	2·38	2·49	2·18	3·10	3·26	3·04	3·70	3·90	3·63	36·56
1881–1915	2·99	2·57	2·67	2·12	2·30	2·44	2·87	3·35	2·54	3·97	3·49	3·92	35·23
	SCOTLAND												
1916–50	5·90	4·00	3·27	3·21	3·14	3·12	4·11	4·41	4·86	5·77	5·32	5·32	52·43
1881–1915	4·90	4·18	4·05	2·99	3·01	2·83	3·78	4·51	4·00	4·90	5·29	5·88	50·32

Table VIII suggests that the mean rainfall was greater during 1916–50 than 1881–1915 by 1·33 in./yr. over England and Wales, and by 2·11 in./yr. over Scotland. This means that the 35 yr. 1916–50 gave as much rain as occurred in 1881–1915 plus that of more than an extra year of the 1881–1915 standard over England and Wales and also over Scotland. The greater rainfall during 1916–50, over that for 1881–1915, was contributed mainly by January, September and November over England and Wales, and by January, September and October over Scotland. There was rather less during 1916–50 in a number of months—March, June, August, October and December over England and Wales and February, March, August and December over Scotland.

The seasonal differences are set out in Table IX. The increase in the rainfall 1916–50 compared with 1881–1915 is mainly attributable therefore to the increase in the autumn and winter.

TABLE IX—SEASONAL DIFFERENCES OF RAINFALL, 1916–50 MINUS 1881–1915

	Spring Mar.–May	Summer June–Aug.	Autumn Sept.–Nov.	Winter Dec.–Feb.
			inches	
England and Wales ...	+0·09	−0·12	+0·64	+0·72
Scotland	−0·43	+0·52	+1·76	+0·26

Parts of the country experienced less rain in 1916–50 than in 1881–1915, i.e. parts of the east of Great Britain, the Midlands and the extreme south-west of England—from the Moray Firth to Aberdeen, around Berwickshire, from Flamborough Head to Great Yarmouth and around Huntingdon and Cambridge, from Hereford to Oxford and over much of Cornwall. Over by far the greater part of the country 1916–50 was wetter, and the excess was more than 5 per cent. over a broad strip along the west coast from Stornoway to Swansea, as well as along the south coast from Torquay to Dungeness. The excess reached 10 per cent. in parts of south Wales, north Wales and in the Oban to Glasgow area.

REFERENCES

1. London, Meteorological Office. Averages of temperature over Great Britain and Northern Ireland for the period 1921–1950. London, 1953.
2. London, Meteorological Office. Averages of sunshine over Great Britain and Northern Ireland for the period 1921–1950. London, 1953.
3. GLASSPOOLE, J. and HOGG, W. H.; Serial monthly values of mean temperature over the British Isles, 1881–1940 and annual values, 1866–1940. *Quart. J. R. met. Soc., London,* **68,** 1942, p. 45.
4. HANCOCK, D. S.; General sunshine values England and Wales, Scotland, Ireland and the British Isles for the period 1909–1933. *Quart. J. R. met. Soc., London,* **61,** 1935, p. 45.
5. HANCOCK, D. S.; An analysis of sunshine values in the British Isles for the period 1909–1948. *Quart. J. R. met. Soc., London,* 77, 1942, p. 127.
6. GLASSPOOLE, J.; General monthly rainfall over the British Isles, 1881–1924. *Brit. Rainf. 1924, London,* 1925, p. 256.

SEVERE TURBULENCE AT HIGH LEVELS OVER NEW SOUTH WALES

By U. RADOK

On August 22, 1951, a Canberra jet aircraft flying from Laverton (near Melbourne) to Sydney at a constant pressure altitude of 30,000 ft. (300 mb.) encountered a 30-mile stretch of severe turbulence in clear air over Tumut, New South Wales. Details of the incident were given by the pilot, Wg-Cmdr D. R. Cuming, at the end of a letter reproduced in the *Meteorological Magazine*[1]. Immediately before entering the turbulence it was noticed that the airspeed

[To face p. 48

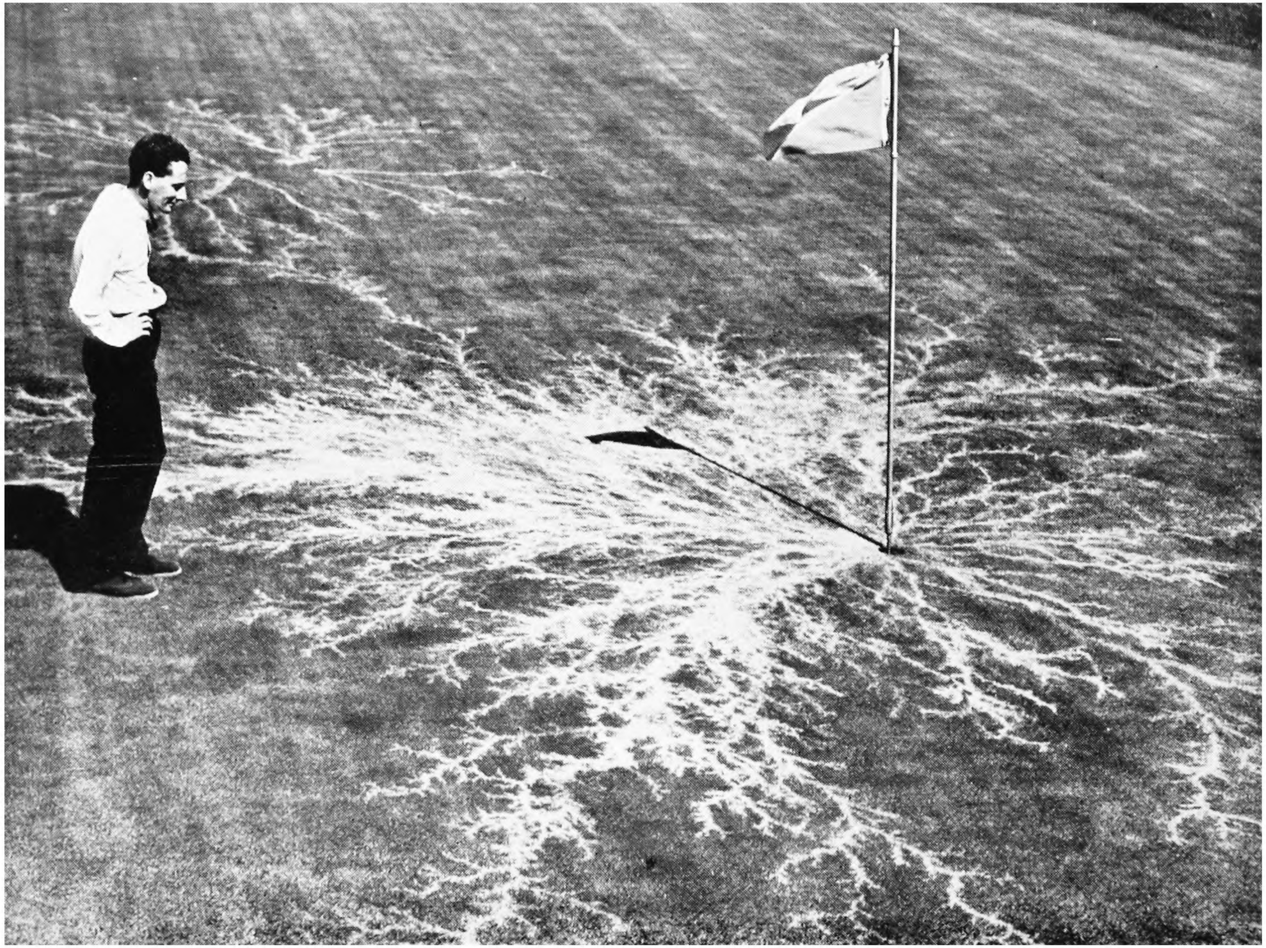
ALTOCUMULUS FROM 27,000 FT. AT 1502, SEPTEMBER 11, 1944
This sheep's back pattern of clouds was observed just north of Münster.

LENTICULAR ALTOCUMULUS CLOUDS SEEN AT

Reproduced by courtesy of Flt-Lt Webb

BALLYKELLY, NORTHERN IRELAND, NOVEMBER 29, 1953

To face p. 49]



(c) N.G.S. Courtesy National Geographic Magazine

MARKS LEFT BY LIGHTNING FLASH, CHEVY CHASE CLUB, NEAR WASHINGTON D.C.

dropped while maintaining a constant pressure altitude. This apparent loss of power, which ended with the turbulence, was too pronounced to have arisen from a rise in air temperature, and Wg-Cmdr Cuming therefore attributed it to a tailwind component increasing gradually in a field of horizontal wind shear.

Figs. 1, 2 and 3 provide the meteorological background for the incident. At that time the Australian upper air network was too sparse to reveal, as a rule, finer details.* However, on this occasion the pressure distribution happened to be symmetrical with respect to the eastern Australian radio-sonde stations (see Fig. 1). Thus all upper air observations in the region despite their differences in longitude could legitimately be combined in a single meridional cross-section along 145°E. The temperature curves in Fig. 2 show this very clearly; they suggest, incidentally, that the middle-latitude tropopause continued as an inversion to at least the latitude of Charleville or even Garbutt (where it appeared at the 550-mb. level).

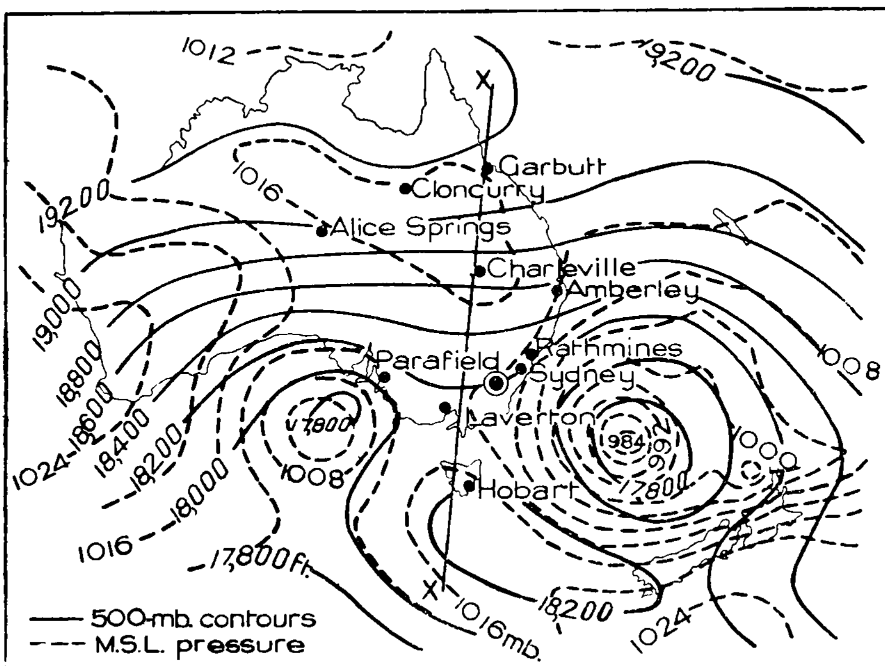


FIG. 1—SYNOPTIC CHART, AUGUST 22, 1951
◉ turbulence

The speed isopleths in the cross-section (Fig. 3) were constructed from the winds at 500 mb. and the isentropic slopes, using the method suggested for zonal sections by Matthewman[2] and modified for meridional ones by Radok and Grant[3]. A check on the geostrophic speeds is provided by the radar-wind observations from Sydney, also shown in the cross-section. The discrepancy of 30 m.p.h. in the maximum speeds seems reasonable, considering the anticyclonic curvature in the longitude of the section and the steeper gradients in the longitude of Sydney. The region of interest, marked by a dot in a circle, thus appears to have been located on the low-pressure side of the entrance to the eastern branch of the jet stream.

* Since then the number of high-level wind observations has been greatly increased, and the routine analysis now extends to the 100-mb. level.

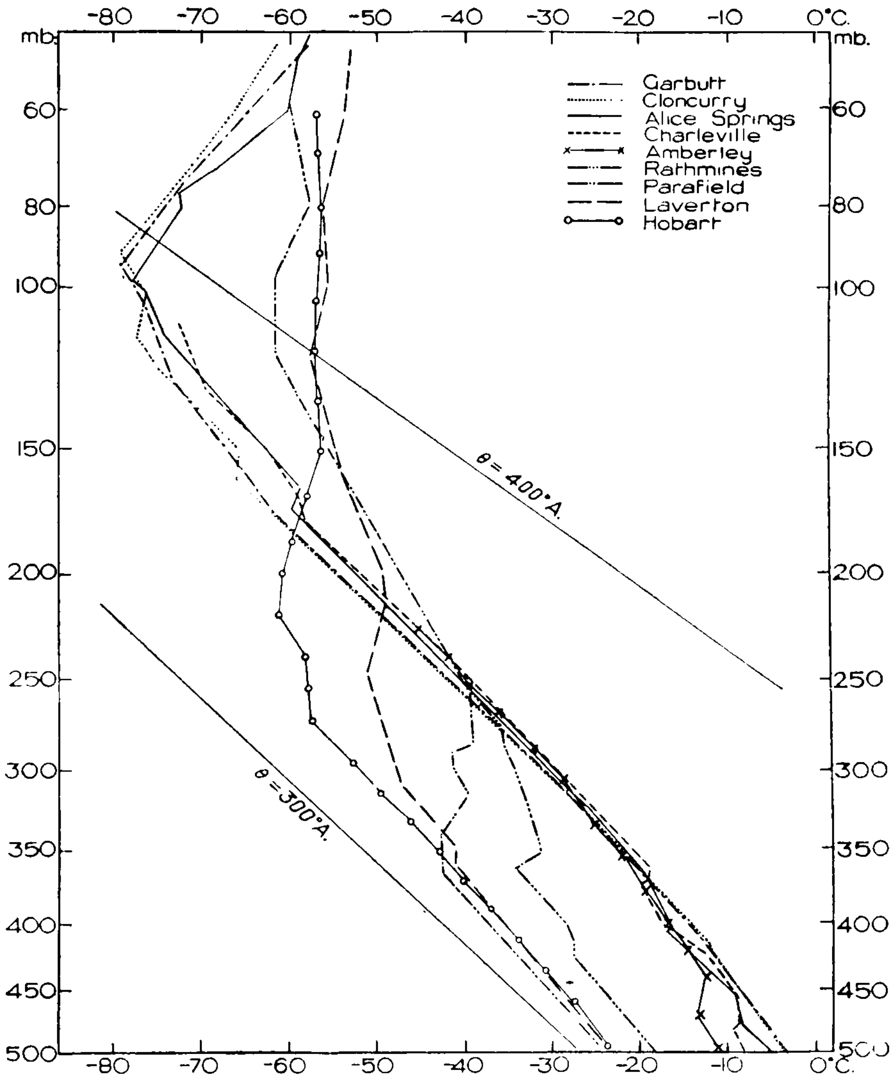


FIG. 2—UPPER AIR SOUNDINGS, AUGUST 22, 1951

Now the low-pressure side of jet streams is well known to be especially prone to turbulence (Bannon[4]), and this fact might be taken as a satisfactory explanation of the incident in question. However, it is hard to evade some curiosity as to why the turbulence was especially severe on this occasion, and moreover restricted entirely to such a narrow area.

It is more than likely that the answer to these questions has been lost irretrievably in the smoothing required for the construction of the cross-section; on the other hand there exists the possibility that the clue to the problem might be found in the surface topography. The map, Fig. 4, shows that at the time the aircraft was flying past the south-west corner of a gap in the Australian Alps, not far from where the ground descends by more than 4,000 ft. to below the 1,000-ft. level. With the stable stratification of the surface layers and the large vertical wind shear suggested by the cross-section the flow further south must have been deformed by the mountains up to considerable heights. The occurrence of severe turbulence in the region of transition to the less affected flow through the mountain gap then becomes intelligible.

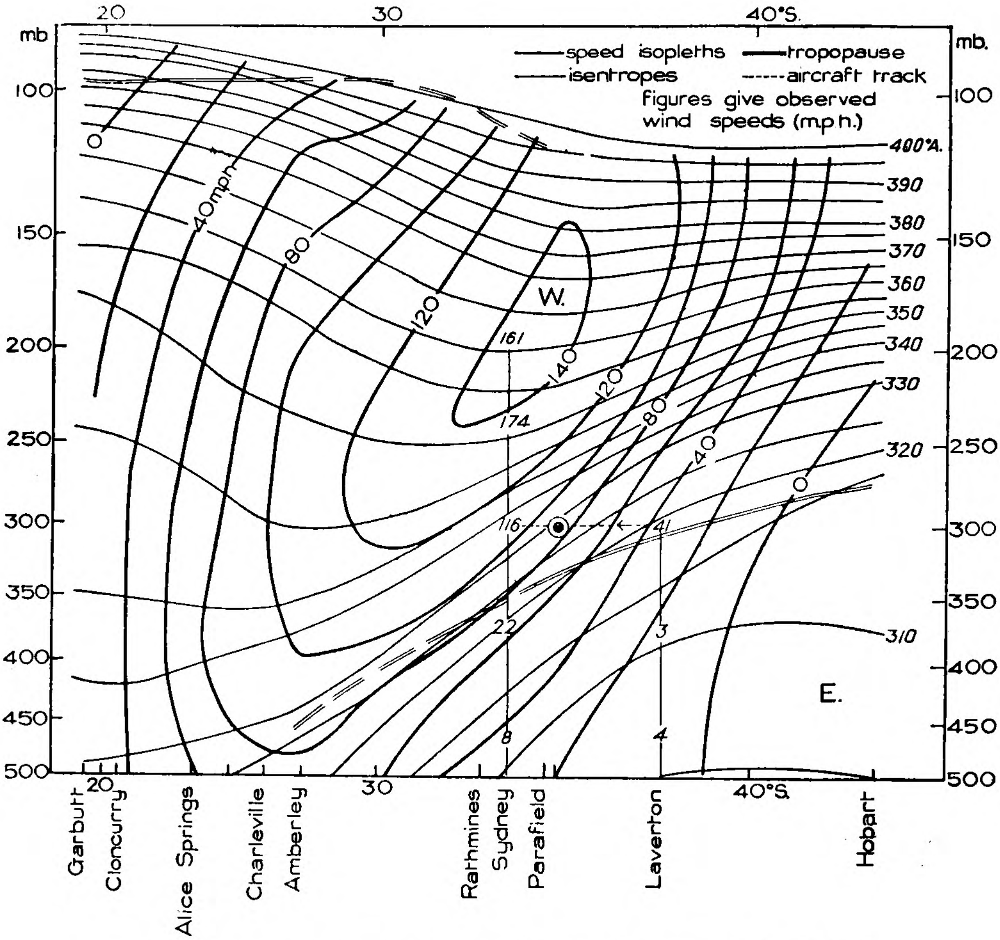


FIG. 3—VERTICAL CROSS-SECTION ALONG LINE XX OF FIG. I

◉ turbulence

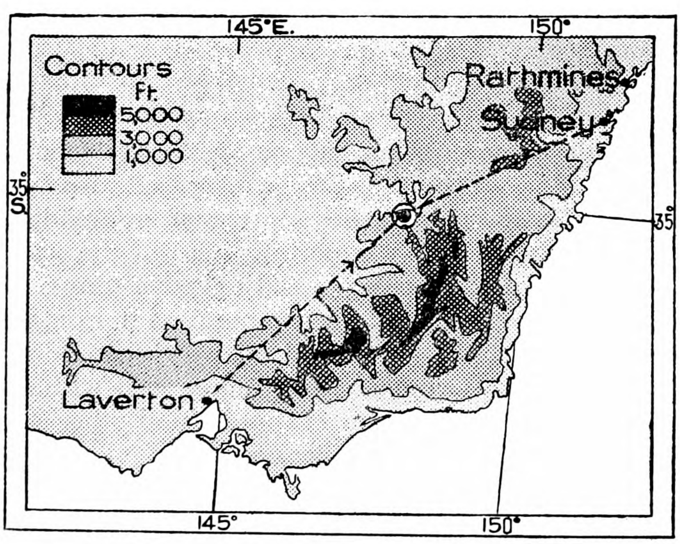


FIG. 4—SOUTH-EAST AUSTRALIA

- - - - - aircraft track

◉ turbulence

The same transition would also account for the tailwind component suspected as cause of the apparent loss of power in the turbulent region. This is otherwise hard to understand since recent work on the flow near jet-stream entrances[5] has confirmed its transversal component directed towards the low-pressure side of the jet, which had already been expected on theoretical grounds.[6]

Acknowledgements.—The writer is indebted to Wg-Cmdr D. R. Cuming for information concerning the incident and suggestions for its interpretation, and to the Director, Meteorological Branch, for the radio-sonde data.

REFERENCES

1. BATTY, R. P.; Meteorological observations on a flight by a Canberra jet aircraft from England to Australia. *Met. Mag., London,* **81,** 1952, p. 218.
2. MATTHEWMAN, A. G.; Variation of geostrophic wind with potential temperature in the horizontal and in the vertical, with application to vertical cross-section diagrams. *Met. Mag., London,* **79,** 1950, p. 97.
3. RADOK, U. and GRANT, A. M.; A note on cross-section technique. *Weath. Dev. Res. Bull., Melbourne,* **17,** 1951, p. 39.
4. BANNON, J. K.; Meteorological aspects of turbulence affecting aircraft at high altitudes. *Prof. Notes met. Off., London,* **7,** No. 104, 1951.
5. MURRAY, R. and DANIELS, S. M.; Transverse flow at entrance and exit to jet streams. *Quart. J.R. met. Soc., London,* **79,** 1953, p. 236.
6. RYD, V. H.; Meteorological problems. II. The energy of winds. *Medd. danske met. Inst., Copenhagen,* No. 7, 1927.

METEOROLOGICAL OFFICE DISCUSSION

Lake evaporation

The discussion was held on Monday, November 16, 1953 at the Royal Society of Arts.

In his introductory remarks, the Director said that he was pleased to attend his first Discussion since assuming the Directorship, although he had in the past attended many of these Discussions. It was to the benefit of all in a service which is spread far and wide that we should gather together to discuss recent research, for scientists do not readily twinkle in isolation and gleam most strongly in the irradiation of their fellow scientists.

Mr. E. Knighting opened the discussion with a summary of the following report:—

Washington, Department of Interior. Water-loss investigations: Vol. I—Lake Hefner studies technical report. *Circ. U.S. geol. Surv., Washington,* 1952.

At Lake Hefner the water budget can be satisfactorily balanced, because the measurement of inflow and outflow can be measured with fair accuracy; the evaporation can thus be determined with a precision not readily obtainable at most reservoirs. Evaporation is an important item in the water budget and not the small difference of large positive and negative terms, so that it could be used as a control to sieve out the evaporation formulae (based upon turbulence theory and the heat energy budget) which can be used with confidence elsewhere. Using the formulae which agree well with the evaporation as determined by the water budget, the evaporation at other stored-water sites can be computed from meteorological measurements.

Lake Hefner is an almost circular lake lying in flat country about 1,200 ft. above sea level and is about 4 square miles in surface area. Four meteorological stations were set up, three on the periphery of the lake and the fourth on a barge at the centre of the lake. Observations of wind speed, temperature and humidity were made at all four stations at heights of 2, 4, 8 and 16 m. above water-surface level; in addition, at the barge, the incoming solar radiation was measured by an Eppley pyrheliometer, the total incoming radiation by a Gier and Dunkle flat-plate radiometer and the reflected solar radiation by two Eppley pyrheliometers pointing downwards towards the lake. Observations of water-surface temperature were also made and measurements of the water temperature with depth at various parts of the lake; rain-gauges were set up around the periphery of the lake and at the barge station.

Many evaporation formulae based upon the theory of turbulent flow were tested, using the meteorological observations to determine the parameters in these equations. Of these formulae only those of Sverdrup (1937) and Sutton (1949) were found to agree well with experiment; these two predicted the daily evaporation within about 10 per cent. of the mean, whereas the other equations over-estimated the evaporation by a factor of 2 or more. It was also found that variations in lapse rate had little effect upon the daily evaporation and that the flow was always "rough".

An empirical equation was constructed to give the evaporation using the wind speed and vapour pressure at a nearby airport some 13 miles to the south, and the saturated vapour pressure at the lake-surface temperature; the accuracy of this formula was less than that of the two theoretical formulae, but a formula of this type is most valuable because the only non-routine measurement needed is the lake-surface temperature.

The heat-balance method consists of measuring the heat going into or out of the lake with the exception of that used for evaporation and that flowing from the water surface to the air. It had been intended to determine the atmospheric radiation by subtracting the solar radiation as measured by the pyrheliometer from the total incoming radiation as measured by the flat-plate radiometer, but this difference, which should have been sensibly constant, showed a great variation in the day-time, and so the night values obtained from the radiometer were taken as applying to the day-time also. The instruments must be regarded as suspect. The ratio of the heat flowing from water to air to that used in evaporation, known as Bowen's ratio, showed very marked daily fluctuations, but when averaged over a period of days its behaviour became more coherent, suggesting that the evaporation as determined by the energy budget would be more accurate over a period of days than over a single day. The daily evaporation calculated by the energy budget showed a very wide scatter when compared with the evaporation calculated by the water budget; the standard error of estimate decreased as the period for which the evaporation was calculated was increased, and the accuracy obtained by the energy budget for a period of one week was about the same as that obtained by using Sutton's equation for a period of one day.

So far the actual observations recorded at Lake Hefner have not been published, and the report is not specific as to the methods of calculation used in determining the evaporation from the various equations. The barge records are the most important and the most difficult to observe, and possibly more than one barge is desirable. The energy-budget method used at Lake Hefner could not be used elsewhere since it requires just the same water measurements as does the water-budget method, and in addition other complex instrumentation. While some of the radiative items in the budget may be estimated from synoptic observations, such estimations must seriously vitiate the accuracy of the computed evaporation.

Dr. Penman said that the report must be treated with reserve until the actual data were published. There were several inconsistencies, instanced by two tables of monthly evaporation which did not agree, which must be reconciled before an opinion could be offered. The water-budget results cannot be checked at this stage and will have to be accepted. The evaporation equation given by Sverdrup in 1946 is much more acceptable physically than that given in 1937, yet it over-estimated the evaporation by a factor of 2. Previously the Thornthwaite-Holzman formula had been known to give better results than the Sverdrup 1937 formula using the same wind profile. Since nearly all these formulae depended upon the measurement of vapour pressure at two heights, the choice of these heights may be quite important. The technique for measuring water-surface temperature is not adequate since the surface is probably cooler than at $\frac{1}{4}$ in. below the surface; measurements at Rothamsted had shown differences of 0·7° to 1·0°C. Attention should be drawn to the incorrect curvature of the plot of evaporation against vapour-pressure difference for Sutton's equation as given in the report. With regard to the energy-budget measurements, the solar-radiation measurements seem to be rather high, and an error must be introduced by the swaying of the barge which prevented the pyrheliometer from pointing vertically. Using his own formula, he found values of evaporation which were 10 per cent. too high.

Mr. Ryder pointed out that though the measurements were not sufficiently accurate to test the Thornthwaite-Holzman formula, the figure given in the report did show that there was a fairly clear-cut division between evaporation under stable and unstable conditions, evaporation being over-estimated under stable conditions.

Dr. Sutton said that we must be grateful to the Americans for undertaking a programme of experiments which was beyond the scale available in this country; the actual observations would be very valuable indeed. The report had, however, failed to distinguish between evaporation from a semi-infinite area and an infinite area, and these were two very different things. His formula applies to a semi-infinite area in which there is a distinct leading edge to the area from which evaporation takes place; although it has been applied to a circular area it is not strictly applicable because there must be diffusion sideways as well as in the direction of the mean wind. The results were rather surprising and it would be best to await the publication of the experimental values.

Mr. Bleasdale said that he had carried out a test of Dr. Penman's method of computation of evaporation for the average monthly values as given in diagrammatic form in the report. It was surprising to find that there was little correlation with the evaporation as determined by the water budget, but very good agreement with that determined by the evaporation pans at Lake Hefner. He suggested that the water budget might have been in error owing to the rainfall or the flow in and out being in error. The test of the formulae derived from turbulence theory was confined to days upon which these errors were small, but the errors upon the other days might have been quite large.

Mr. Gold asked if any idea of the variation of the various meteorological elements across the lake could be given. The wind had been measured at four heights, but only the measurements at two heights seemed to have been used. What use was made of the other measurements? He asked also if any comparison had been made with Jeffreys's formula for evaporation from a limited area.

Dr. Glasspoole said that in the report there was no statement as to the forecast value of the annual evaporation over the Lake Hefner area, although he was quite sure that before the work of constructing the dam was authorized some estimate would have been made, based on past experience. Estimates of evaporation were made for every reservoir constructed in England. It would have been of value to know how far the original estimates of annual evaporation were confirmed. The other losses from such areas, due to geological factors, are often even more difficult to forecast, and yet clearly some guess must have been made before it was judged worth-while to build this reservoir. From the report these losses were expected to be negligible, and this was confirmed by the work carried out for this report. This is an important point because what is needed, from a practical aspect, is a more precise estimate of the annual evaporation than is available at present, and in such a form as to be applicable to other areas with precision. Even 1 in. of water over the total area of reservoirs in this country represents a great deal of water—the run-off of the Thames above Teddington is less than 10 in. a year. The final recommendations of the Lake Hefner report were for further study of evaporation from water surfaces. If a similar study could be carried out in this country, then the comparison, with the different climatological conditions here, would cover a range of evaporation from about 50 in. a year at Lake Hefner to 20 in. a year in the south of England. The recommendations also include the collection of water-temperature data in lakes and reservoirs and of wind data at the sites of existing and proposed reservoirs. It should be realized that in this country very little information is apparently available under these two headings. This report seems to be only a first step in solving our hydrological problems, since it deals only with evaporation from a water surface. Most reservoirs have a much larger collecting land area, and there is the further problem of the amount of water stored in the ground, with a variation over a period of years of the same order as the annual evaporation. In addition we want to know how the evaporation varies with different types of ground cover, how it varies over the country, how it varies from wet to dry years, and how the ground storage varies from year to year and during the year. This seems a most valuable report, comparing theory with practical problems of water supply, and he (Dr. Glasspoole) hoped that similar practical investigations might be carried out in this country.

Dr. Robinson remarked that the Gier and Dunkle flat-plate radiometer which was installed at Kew gave an answer within about 5 per cent. when used very carefully. The same is true of most pyrheliometers and such errors were reflected in much larger percentage errors in evaporation. While it was true that very accurate measurements of wind, temperature and radiation terms had been made, they were over periods of 20 min. or so, and no-one had yet tried to achieve such accuracy over a continuous period of a year.

Mr. Knighting answered various points which arose in the course of the discussion, and Dr. Sutton closed by remarking that this report was difficult reading for the non-specialist, which accounted for the relatively few speakers.

Dr. Pasquill in a review of the Lake Hefner Report, written for the *Meteorological Magazine* before the decision to hold this discussion was taken, draws attention to the following points which were not brought out in the course of the discussion:—

(i) The absence of any experimental indication of a transition between "smooth" and "rough" flow at some particular speed. At Lake Hefner the flow is apparently always aerodynamically rough with the roughness parameter varying systematically from 0·58 to 1·15 cm. for wind speeds varying from 1 to 15 m./sec. at a height of 8 m. There has previously been some conflicting evidence about such a transition over the sea.

(ii) Confusion has been added to the complex issue of the influence of stability in the form of the wind profile between 2 and 8 m. On the one hand the results are claimed to show no appreciable stability influence on the form of the wind profile; on the other hand the results apparently lead to a wide range of Deacon's parameter β* with a systematic relation between β and stability consistent with observations over grassland. Publication of the wind-profile results in full will, no doubt, stimulate further critical discussion of their interpretation.

(iii) It is important to remember that the absolute rate of evaporation from a finite area is not necessarily a unique test of the theory. A more penetrating test is provided by the developing distribution of vapour above the evaporating surface, and in future work it would be a great pity not to take the opportunity of making a comprehensive investigation of this feature in company with the other elaborate measurements.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Royal Meteorological Society held on December 16, 1953, the President, Dr. O. G. Sutton, in the Chair, a discussion was held in collaboration with the Royal Astronomical Society on the subject of stellar scintillation.

Dr. H. E. Butler and Dr. M. A. Ellison, both of the Royal Observatory, Edinburgh, described detailed observations of scintillation made visually and instrumentally with photo-electric cells. The image of the star varies in colour and total brightness, moves about in an irregular way, changes in area, and the pattern of illumination over the image is neither constant nor uniform. The instrumental observations showed that the periodicity of the fluctuations in brightness increased with altitude of the star but the amplitude decreased. There was little doubt that scintillation was produced by the passage of the light through the earth's atmosphere. On the general connexion of twinkling with weather it was well known to astronomers that the steadiest images were obtained on rather hazy nights and that very clear nights often gave poor "seeing". Experiments with rotating prisms and with parallel slits in the eyepiece of the telescope showed that on many occasions the scintillation consisted of a steadily travelling regular series of peaks of illumination as though it was produced by a regular pattern of small eddies travelling with the wind.

Dr. E. C. Megaw of the Royal Naval Scientific Service discussed the general physics of the fluctuations in the refractive index of the air which were presumably responsible for scintillation. Temperature fluctuations were the more important for light, but the same phenomenon occurred on radio wave-lengths and for them humidity fluctuations were more important. Pressure fluctuations associated with small changes in speed were unimportant.

Dr. J. van Isacker of the Royal Meteorological Institute of Belgium described his mathematical investigations into the relation between atmospheric turbulence and scintillation.

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*DEACON, E. L.; Vertical diffusion in the lowest layers of the atmosphere. *Quart. J. R. met. Soc., London,* 75, 1949, p. 89.

The discussion dealt very largely with the regularly moving patterns of disturbance often observed which appeared to indicate that the turbulence responsible for them was confined to a shallow layer of the atmosphere. Dr. Ellison and Dr. Butler mentioned that on occasion more than one set of steadily travelling patterns could be seen. Mr. Grant described the Meteorological Research Flight observations of temperature anomalies in the free air, which on the smallest observable scale amounted to about 0·5°F. in a distance of 50 ft. This distance, however, was too great for the eddies causing twinkling which, according to the astronomers, have dimensions of the order of inches.

LETTERS TO THE EDITOR

An unusually clear example of lenticular clouds

On Sunday evening, November 29, for about two hours before sunset, the sky over Northern Ireland was covered by 3–4 oktas of lenticular altocumulus. These clouds had marked irisation. To the delicate colouring of the cloud were added the effects of the setting sun which coloured the clouds from the underneath in shades ranging from purple and a fiery red to yellow. The whole colouring was against the pale blue.

Many people saw and commented on the cloud forms and colours, and the photographs in the centre of this Magazine were taken by Flt-Lt Webb, the Station Adjutant at Ballykelly.

F. M. BANCROFT

Ballykelly, December 1953

[Northern Ireland lay in a weak warm sector with a weak cold front lying, at 1800 G.M.T., from Stornoway to a point 100 miles west of Blacksod and thence south-westwards. This front moved eastwards reaching Aldergrove by midnight.

The 0200 G.M.T. Aldergrove temperature sounding showed subsided air above 700 mb., but by 1400 G.M.T. the air above 700 mb. was considerably moister, while the lower layers had dried out a little. The upper winds in the medium levels were 240–270°, about 40 kt.—J. ROSS.]

Optical phenomena observed at Seletar, Singapore on August 19, 1953

At 0700 local time on August 19, 1953 at Seletar, Singapore, S.A.C. Allen noticed that the sun, which had risen to an altitude of 8° azimuth 70° from magnetic north, had developed a pillar above and below it, that below being shorter in length than that above. Also a very small arc of the 22° halo was evident directly above the sun, and it appeared to spread out on its upper side to form the shape of a fan. The cloud at the time was high cirrus and cirrostratus which was tinged reddish brown by the sun.

About 1½ hr. later on the same morning, when the sun had risen to an altitude of 28°, azimuth 72°, more complicated phenomena began to form. By 0845 these had become most pronounced and complete, and after this time gradually disappeared as the cirrus and cirrostratus dispersed, and the sun's altitude increased.

The phenomena shown by Fig. 1 were visible at 0845 but gradually disappeared as the sun rose in the sky and as the cirrus and cirrostratus dispersed; by 0915 none was visible.

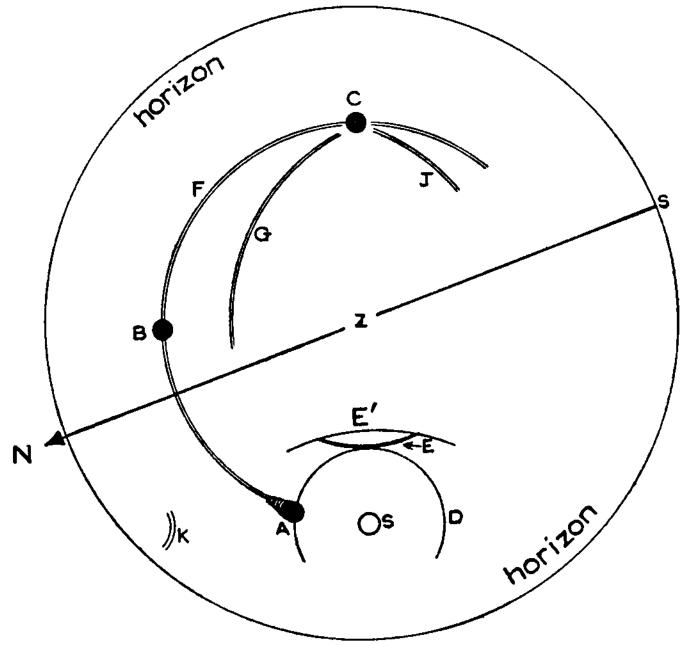

FIG. I—OPTICAL PHENOMENA AT SELETAR, SINGAPORE, 0845 LOCAL TIME, AUGUST 19, 1953

D A faint and incomplete 22° halo.

E, E′ Arcs of upper contact, the lower one, E, being broader and shorter than the higher, E′. Both contained faintly the colours of the spectrum, red being nearest the sun in both. The lower arc appeared to coincide with the highest point of the 22° halo, and its outer ends to curve gradually into the higher arc. The angular distance, as observed from the ground, between the two arcs was 7°.

F The parhelic circle, which was very distinct and white, was only visible between 50° and 230° (through north) due to the absence of cloud in the other sector.

A A 22° mock sun, at the intersection of the 22° halo and the parhelic circle. It contained very faintly the spectrum colours, red being nearest the sun. The corresponding mock sun on the opposite side of the sun was not visible.

B A 90° mock sun on the parhelic circle, which was not visibly coloured.

C The anthelion or counter sun, which was extremely faint and was also on the parhelic circle, being diametrically opposite the sun.

G An oblique arc through the anthelion, on the western side of the zenith, and visible only as far as 350°.

J The corresponding oblique arc to G, though extremely faint and much shorter.

K A short arc, rainbow coloured, at an elevation of 5°, azimuth 32°. Red in this arc was again nearest the sun.

The cirrus and cirrostratus, of which there was estimated to be just over half coverage, was at a height estimated to be 28,000 ft. The surface wind was calm and the visibility 5–10 miles. All these latter phenomena were observed by S.A.C. Allen and myself.

J. M. BAYLISS

Singapore, September 18, 1953

[It is unusual for such a complex display to be seen in the tropics and some of the phenomena are individually rare. The Parry arc (E′), anthelic arcs (G and J) and the infralateral arc to the 46° halo (K) are rare. The observers have confirmed that the angle to the 90° mock sun (B) on the parhelic circle was measured in azimuth round the circle.—Ed., *M.M.*]

NOTES AND NEWS

High wet-bulb temperatures, Aden, June 1953

June is considered by the inhabitants of Aden to be the most unpleasant month of the year and meteorological records support this opinion. The weather in June 1953 was described by residents of Aden as the most uncomfortable they have experienced for at least 20 yr. It is interesting therefore to compare the records for June 1953 with observations for the same period in previous years.

Table I gives a comparison of the average June temperature and humidity for the 5-yr. period 1948–52 with those of June 1953.

TABLE I—TEMPERATURE AND HUMIDITY, ADEN

	Temperature						Relative humidity
	Mean daily				Extreme		
	Dry bulb	Wet bulb	Max.	Min.	Max.	Min.	Mean daily
	degrees Fahrenheit						%
June 1948–52	90·0	80·6	97·4	83·7	103	79	67
June 1953 ...	90·9	81·8	98·7	85·3	105	82	67

This table does not suggest that June 1953 was much more unpleasant than the average conditions over the past 5 yr. The mean daily wet-bulb temperature was, however, 1·2°F. above the average, which, although small, is quite significant.

The reason why June 1953 was so uncomfortable is that the wet-bulb temperature remained high for longer periods than usual and the relative humidity was also high. Table II shows this more clearly. This table gives the average number of hours in June 1948–52 and the number of hours in June 1953 when the wet-bulb temperature reached or exceeded stated values.

TABLE II—NUMBER OF HOURS WHEN THE WET-BULB TEMPERATURE REACHED OR EXCEEDED CERTAIN VALUES, ADEN

	Wet-bulb temperature						
	82°F.	83°F.	84°F.	85°F.	86°F.	87°F.	88°F.
	number of hours						
June 1948–52 ...	246	138	52	15	2	0·2	...
June 1953 ...	387	249	146	55	10	1	...

Daily maximum wet-bulb temperatures have been recorded at Aden since 1947. Table III shows the average number of days in June 1948–52 and also the number of days in June 1953 when the maximum wet-bulb temperature reached or exceeded stated values.

TABLE III—NUMBER OF DAYS WHEN THE MAXIMUM WET-BULB TEMPERATURE REACHED OR EXCEEDED CERTAIN VALUES, ADEN

	Wet-bulb temperature						
	82°F.	83°F.	84°F.	85°F.	86°F.	87°F.	88°F.
	number of days						
June 1948–52 ...	29	27	22	13	4	1	0·2
June 1953 ...	30	30	25	17	7	2	2

Table III does not show that the conditions were much worse in June 1953 than on the average, but even in a June when the mean daily wet-bulb temperature is below normal the maximum wet-bulb temperature may reach high values. It is common for the wet-bulb temperature, like the dry-bulb temperature, to vary by 2–3°F. in a matter of minutes. The extreme maximum dry-bulb temperature for June 1953 of 105°F. occurred on the 12th, but the highest temperature recorded at any reporting hour on that day was 102°F. The extreme maximum wet-bulb temperature of 88°F. also occurred on the 12th and the highest reading of the wet-bulb at any reporting hour on that day was 86·5°F.

All the temperatures quoted above were recorded in a Stevenson screen. There is, however, little difference between conditions indoors or outdoors at Aden during the hot season, as doors and windows are not as a rule shut during the day. Human comfort during the hot season depends almost entirely on the wet-bulb temperature and wind speed. Conditions are invariably most uncomfortable when the wet-bulb temperature reaches or exceeds 84°. It will be noted from Table II that the number of hours in June 1953 when the wet bulb reached or exceeded 84°F. was 146. It is also of interest to note that the mean relative humidity during these 146 hr. was as high as 73 per cent. which is 6 per cent. above the mean daily relative humidity for June 1953.

C. C. NEWMAN

REVIEWS

Deep-sea research. **1,** No. 1, 10 in. × 6¾ in., pp. 64, *Illus.*, Pergamon Press Ltd, London, 1953. Price: £4 10*s.*, p.a.

Deep-sea research has become much more widely studied since the second world war, particularly by meteorologists in view of the information on past climates which Professor Petterssen, Mr. Ovey and others have shown to be obtainable from the cores of the sediments of the deep oceans. The Brussels meeting of the International Union of Geodesy and Geophysics set up a new Commission specifically to cover deep-sea research with Dr. J. H. D. Wiseman of the British Museum (Natural History) as President and Mr. C. D. Ovey (Geography Department, Cambridge) as Secretary. The new Commission at its first meeting in September 1952 recommended the establishment of a journal.

Now with Professor L. Fage (Paris), Mr. C. D. Ovey and Dr. Mary Sears (Woods Hole, United States) as editors, the Pergamon Press, London have begun publication of a journal specifically devoted to deep-sea research. The first number shows the journal will deal with the structure, physics, and biology of the deep sea and the sea floor and their relations to other sciences.

The journal is to be published quarterly at a subscription price of £4 10s. 0d. a volume.

G. A. BULL

Der Blitz in der Bildenden Kunst. By A. Rieth. 10½ in. × 8 in., pp. 48+68, *Illus.*, Ernst Heimeran Verlag, München, 1953. Price: *DM.* 12.

As is well known to every historically minded student of thunderstorm and lightning phenomena the folklore inspired by the lightning discharge, the symbolism to which it has given rise, and the influence it has exerted on various religious cults have aroused—and continue to arouse—the interest of physicists and meteorologists whether these are professional men or amateurs. It is therefore not altogether surprising to learn that a traveller admiring a painting by del Sarto depicting the lightning miracle of St. Philip suddenly felt an impulse to collect "lightning pictures". The result of his search, which embraces not only various continental art collections but also many learned treatises on lightning, its symbolism and its manifestations, is a beautiful book, itself a work of art, which will not fail to receive an enthusiastic reception alike from meteorologists and art lovers.

The book is divided into a descriptive and an illustrative part comprising 67 art plates. Starting from ancient conceptions and representations, in various parts of the world, of a material thunderbolt which falls from heaven the author traces the pictorial symbolism representing the heavenly fire in the antique cultures of the Middle East, Greece, Rome, and later the Europe of the Middle Ages. He shows how these antique representations are revived in the Renaissance, and how it is left to the Italian masters of the early sixteenth century to introduce, possibly for the first time, a lightning stroke into a landscape, and to make full artistic use of the dark and light of an active thundercloud and its effect on human beings. Continuing this historical survey, the representation of the lightning stroke as a meteorological phenomenon and as a symbol is traced up to the present time with its surrealistic aberrations.

From the artist's world the author turns to modern science. He exemplifies the inherent beauty of lightning photographs and sketches their influence on present-day knowledge of the lightning discharge. Then, leaving the lightning discharge as such, an interesting chapter traces the historical development of beliefs in weather saints and the personal protection afforded by them, and this leads to an account of the history of the lightning conductor.

To the scientific mind the beauty of a lightning photograph may appear supreme. Yet, it is left to the artist to depict the feelings aroused in the human spectator by that awesome spectacle. To anyone interested in this wider aspect of one of the most spectacular meteorological phenomena this book cannot fail to give exquisite pleasure.

R. H. GOLDE

BOOK RECEIVED

A radio-sonde ascent through the Sierra Wave. By E. L. Corton, Jr. *Tech. Memor. U.S. Nav. Ordn. test Sta.* No. 225. 10¼ in. × 8 in., pp. v + 22. *Illus.*, London, 1953. Price: 10*s*. 6*d*.

HONOURS

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

C.B.

Dr. J. M. Stagg, O.B.E., Principal Deputy Director, Meteorological Office.

M.B.E.

Mr. D. F. Bowering, Senior Experimental Officer, Meteorological Office.

METEOROLOGICAL OFFICE NEWS

Academic successes.—To the lists published in the October number should be added:—

General Certificate of Education (Advanced).—R. E. Workman: physics, applied mathematics.

Athletics.—Messrs. M. K. Garrod, I. P. McDonald, W. P. Bird, J. Lomax, D. Limbert and G. F. Burton were members of the Air Ministry team which ran second in the Civil Service Cross-Country Team Championship at Wimbledon on Saturday, December 5. Mr. I. P. McDonald came second and Mr. M. K. Garrod third in the Air Ministry Cross-Country Championship held at Hayes on Saturday, November 28, over a five-mile course. Only three seconds covered the first three men home. The Meteorological Office had six men in the first seven men home and gained first and second places in the team race. Mr. G. F. Burton was placed second in the sealed handicap.

Retirement.—Miss D. G. Chambers retired from the Meteorological Office on January 9, 1954 after 40 years' service. Miss Chambers joined the secretarial staff of the Office in October 1913. From 1921 to 1938 she was the Director's (Sir George Simpson's) personal assistant, and in that capacity did much work for the British National Committee for the International Polar Year 1932–33 and in connexion with the International Meteorological Organization. Miss Chambers was Secretary of the Meteorological Committee from 1935 to 1946.

Miss Chambers was presented by her colleagues with a cheque which she intends to use for items of furniture. In expressing her thanks she recounted interesting and amusing recollections of her early days in the Office when comparatively few women were employed in Government service. It is more than usually fitting that Miss Chambers's retirement should be noted in "Meteorological Office News". She has compiled the items under this heading in the *Meteorological Magazine* since they first appeared in March 1950.

CORRIGENDUM

OCTOBER 1953, PAGE 318, *General Certificate of Education (Advanced level) for* "pure mathematics . . . . F. B. Webster" *read* "pure mathematics, physics, R. C. Friend, P. J. S. Greenaway; pure mathematics, physics, geography, F. B. Webster".

WEATHER OF DECEMBER 1953

Mean pressure was above normal over the whole of Europe except the Iberian peninsula; it was below normal over most of North America, the north-west Atlantic and the region between the Azores and Portugal. A mean pressure of 1032 mb. was reached over south-east Europe, which was as much as 13 mb. above normal. The lowest mean pressure, 985 mb., occurred off the coast of south-east Greenland; this pressure was 13 mb. below normal.

Mean temperature was above normal over most of Europe as a result of the mean pressure distribution favourable to S. or SW. winds; mean temperature was, however, below normal in the countries bordering the eastern Mediterranean. The greatest excess of temperature above normal was 14°F. in the north of Scandinavia. Mean temperature was also above normal in most parts of North America, the excess being generally 5°F.

In the British Isles the weather was unusually mild; it was dry except over much of central and east Scotland and dull on the whole in England and Ireland, but sunnier than usual in Scotland. The mildness was the more remarkable since it followed a very mild November. Until the 18th the dominant type of weather was a mild southerly; owing to the influence of a continental anticyclone, over a large area in the south-east there was little rain but a good deal of drizzle and fog but little sunshine. From the 19th onwards a changeable, mainly westerly type of weather prevailed finally becoming north-west to north.

Southerly winds from low latitudes resulted in exceptionally high temperatures on the 2nd, lasting over the 4th in southern England and East Anglia; 63°F. was reached at St. James's Park, London and at Thetford, Norfolk on the 4th. The exceptional character of the maxima on these days is illustrated by readings at stations with long records; at Falmouth, 59°F. on the 2nd was the highest temperature in December since before 1871, while the same reading at Kew Observatory on the 4th equalled that of December 4, 1931, which was the highest since before 1871. A rainy cold front moved slowly south-east over Scotland on the 2nd becoming almost stationary over the Irish Sea and the Scottish Border on the 3rd when a depression moved north-east along it from south-west of Ireland to the North Sea giving heavy rain in the west and north of the British Isles (1·99 in. at Ardgour House and 1·89 in. at Inveraray Castle Gardens, both in Argyllshire, on the 2nd and 2·22 in. at Kilkeel, County Down and 1·79 in. at Hamilton Water Works, Lanarkshire on the 3rd). There was flooding in parts of Scotland and Ireland. The cold front crossed England on the 4th but in the south-east it only gave drizzle. An anticyclone moved eastward over south Scotland on the 5th and intensified when it reached Poland next day; frost occurred in parts of Ireland and Scotland and valley fog in south Scotland. A dull, mild south-easterly to easterly type of weather followed which lasted with minor variations until the 9th; rainfall was slight from the 5th to the 7th but heavier in the north-west on the 8th and 9th. Subsequently pressure was high on the Continent and low to the west and north-west of the British Isles and mild southerly conditions prevailed; fronts associated with Atlantic depressions caused frequent rain in the west and north but amounts were very small in the south-east. On the 14th a trough moved right across the country and some rain fell in all districts. A new anticyclone developed over the eastern districts of Great Britain on the 15th and was soon absorbed into the anticyclone on the Continent. On the 16th–17th there was keen frost over much of Scotland, particularly the north-east; there was fog in many districts between the 15th and 18th, notably in London and the Midlands on the 15th and 18th. The formation of a small depression over the North Sea early on the 19th, together with a new anticyclone off west Ireland, ended the long southerly spell. Early on the 21st a ridge of high pressure gave frost in south-east England, with renewed fog which recurred on the 23rd. Meanwhile troughs to Atlantic depressions brought rain to the west and north on the 20th and 21st and to most of the country on the 22nd and 23rd, though falls were still small in the south-east. Subsequently a changeable south-west to west type of weather set in finally becoming north-west to north, with somewhat colder weather; rain or showers occurred at times but there were also long sunny periods on some days. In London there was remarkably little sunshine up to the 23rd but five of the seven days 24th to 29th were sunny, and it was one of the sunniest Christmas periods of the century.

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 ...	64	22	+4·6	36	−4	77
Scotland	59	16	+2·9	95	−1	128
Northern Ireland ...	56	23	+3·6	92	−1	74

RAINFALL OF DECEMBER 1953

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	0·63	26	*Glam.*	Cardiff, Penylan ...	1·73	35
Kent	Dover	1·45	47	*Pemb.*	Tenby	1·39	28
„	Edenbridge, Falconhurst	0·77	23	*Radnor*	Tyrmynydd	2·21	27
Sussex	Compton, Compton Ho.	1·12	27	*Mont.*	Lake Vyrnwy	2·08	29
„	Worthing, Beach Ho. Pk.	0·88	29	*Mer.*	Blaenau Festiniog ...	5·15	41
Hants.	Ventnor Park	0·99	29	„	Aberdovey	1·64	34
„	Southampton (East Pk.)	0·80	22	*Carn.*	Llandudno	1·22	42
„	South Farnborough ...	0·66	23	*Angl.*	Llanerchymedd ...	2·45	56
Herts.	Royston, Therfield Rec.	0·54	23	*I. Man*	Douglas, Borough Cem.	2·65	54
Bucks.	Slough, Upton... ...	0·55	22	*Wigtown*	Newton Stewart ...	4·80	89
Oxford	Oxford, Radcliffe ...	0·70	28	*Dumf.*	Dumfries, Crichton R.I.	2·65	62
N'hants.	Wellingboro' Swanspool	0·62	26	„	Eskdalemuir Obsy. ...	4·38	63
Essex	Shoeburyness	0·63	34	*Roxb.*	Crailing...	1·53	57
„	Dovercourt	0·80	37	*Peebles*	Stobo Castle	3·37	89
Suffolk	Lowestoft Sec. School...	0·88	38	*Berwick*	Marchmont House ...	2·45	87
„	Bury St. Ed., Westley H.	0·86	36	*E. Loth.*	North Berwick Res. ...	2·72	127
Norfolk	Sandringham Ho. Gdns.	1·17	46	*Midl'n.*	Edinburgh, Blackf'd. H.	3·26	139
Wilts.	Aldbourne	1·01	31	*Lanark*	Hamilton W. W., T'nhill	4·71	109
Dorset	Creech Grange... ...	1·03	23	*Ayr*	Colmonell, Knockdolian	4·31	77
„	Beaminster, East St. ...	0·89	19	„	Glen Afton, Ayr San. ...	5·46	85
Devon	Teignmouth, Den Gdns.	0·54	13	*Renfrew.*	Greenock, Prospect Hill	6·92	93
„	Ilfracombe	1·38	29	*Bute*	Rothesay, Ardencraig...	5·35	98
„	Okehampton	1·80	25	*Argyll*	Morven (Drimnin) ...	7·31	93
Cornwall	Bude, School House ...	1·32	30	„	Poltalloch	6·10	96
„	Penzance, Morrab Gdns.	1·11	20	„	Inveraray Castle ...	10·02	101
„	St. Austell	1·58	26	„	Islay, Eallabus... ...	5·59	94
„	Scilly, Tresco Abbey ...	1·87	40	„	Tiree	4·64	89
Somerset	Taunton	0·79	22	*Kinross*	Loch Leven Sluice ...	4·27	108
Glos.	Cirencester	0·98	29	*Fife*	Leuchars Airfield ...	2·80	113
Salop	Church Stretton ...	1·50	42	*Perth*	Loch Dhu	9·49	94
„	Shrewsbury, Monkmore	1·08	44	„	Crieff, Strathearn Hyd.	5·13	115
Worcs.	Malvern, Free Library...	1·37	49	„	Pitlochry, Fincastle ...	5·13	127
Warwick	Birmingham, Edgbaston	1·19	44	*Angus*	Montrose, Sunnyside ...	3·35	121
Leics.	Thornton Reservoir ...	0·97	36	*Aberd.*	Braemar	4·11	115
Lincs.	Boston, Skirbeck ...	0·83	39	„	Dyce, Craibstone ...	2·75	81
„	Skegness, Marine Gdns.	0·78	35	„	New Deer School House	2·66	78
Notts.	Mansfield, Carr Bank...	0·84	29	*Moray*	Gordon Castle	2·96	110
Derby	Buxton, Terrace Slopes	2·43	43	*Nairn*	Nairn, Achareidh ...	2·14	104
Ches.	Bidston Observatory ...	1·26	48	*Inverness*	Loch Ness, Garthbeg ...	5·25	114
„	Manchester, Ringway...	1·26	41	„	Glenquoich	10·39	71
Lancs.	Stonyhurst College ...	2·48	51	„	Fort William, Teviot ...	9·76	96
„	Squires Gate	1·56	50	„	Skye, Broadford ...	6·88	77
Yorks.	Wakefield, Clarence Pk.	1·14	47	„	Skye, Duntuilm ...	5·62	90
„	Hull, Pearson Park ...	1·10	46	*R. & C.*	Tain, Mayfield... ...	2·18	77
„	Felixkirk, Mt. St. John...	1·21	50	„	Inverbroom, Glackour...	5·11	70
„	York Museum	1·31	58	„	Achnashellach	8·18	86
„	Scarborough	1·06	45	*Suth.*	Lochinver, Bank Ho. ...	5·37	96
„	Middlesbrough... ...	0·86	44	*Caith.*	Wick Airfield	2·30	75
„	Baldersdale, Hury Res.	1·60	42	*Shetland*	Lerwick Observatory ...	5·03	105
Norl'd.	Newcastle, Leazes Pk....	0·79	34	*Ferm.*	Crom Castle	3·59	87
„	Bellingham, High Green	1·79	49	*Armagh*	Armagh Observatory ...	3·52	112
„	Lilburn Tower Gdns. ...	1·00	38	*Down*	Seaforde	3·34	81
Cumb.	Geltsdale	2·17	57	*Antrim*	Aldergrove Airfield ...	3·34	97
„	Keswick, High Hill ...	3·50	52	„	Ballymena, Harryville...	3·76	85
„	Ravenglass, The Grove	2·80	61	*L'derry*	Garvagh, Moneydig ...	3·85	96
Mon.	A'gavenny, Plâs Derwen	1·72	35	„	Londonderry, Creggan	3·69	84
Glam.	Ystalyfera, Wern House	1·94	23	*Tyrone*	Omagh, Edenfel ...	3·83	91

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

Wt-34. K16.

M.O. 581 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 83, No. 981, MARCH 1954

WEATHER FORECASTS ON TELEVISION

By THE DIRECTOR OF THE METEOROLOGICAL OFFICE

On January 11, the B.B.C. began the transmission of a new type of weather news item in the regular television programmes. Previously the forecasts had been read by an unseen announcer during the display of two "still" charts. As many readers of the *Meteorological Magazine* are aware, in the new programmes a member of the Office staff appears in the studio every night and spends five minutes discussing the weather situation, past, present and future, with the aid of simplified isobaric charts.

The new series has barely completed a month's run at the time of writing so that it is far too early to attempt any serious evaluation of the techniques adopted, but it is safe to say that, judged by the reaction of the press, the "live" presentation is generally looked upon as a big improvement on the old "static" programme. To a certain extent the present period is regarded by the Meteorological Office and the B.B.C. as experimental, and it was recognized that the forecasters chosen for this exacting work would need a little time to accustom themselves to their new duties. Actually, the three meteorologists who have initiated the new series—T. H. Clifton, G. Cowling, and P. McAllen—seem to have struck the right note from the start.

There is, of course, nothing essentially new in this use of television, and the weather talk has been accepted as an essential ingredient of television programmes in the United States and in Canada for some time. However, the British system differs from those in vogue across the Atlantic in several ways. In at least one widely distributed American programme the forecaster speaks from his office to the announcer in the studio who draws a simplified map according to the forecaster's instructions. In other programmes the forecasts are given by one selected "weather man". I believe that the present policy of bringing the forecasters to the studio and of using a team, instead of an individual, is the right choice for this country. The method of presentation, namely the "serial story" which starts by a brief recital of the successes and mishaps of yesterday's forecasts followed by a quick run-over of present weather as a lead-in to the prebaratic chart and the area forecasts, is one which will have to be judged by results over a long period. Before the programmes were put on the air, the B.B.C. and the Meteorological Office co-operated in a long series of experiments with various types of presentation, including animation, but there is no finality in the choice of the present method and suggestions for improvements would be welcomed.

I believe that the introduction of this direct "forecaster to public" service is an event of considerable significance for the Meteorological Office. The communication of the conclusions of the meteorologist to the user is at least as important as the preparation of the forecast, and in this connexion it must be realized that the general public needs special attention. I believe it is generally recognized by the specialist users that a forecast is a statement of probabilities, a warning that the physical conditions obtaining in the atmosphere at a given time may lead to certain eventualities, and the prudent professional user makes his plans accordingly. Meteorologists should try to get the same view adopted by the general public to a greater extent than at present. In the present state of our knowledge of atmospheric processes it is often not possible to go beyond admitting a risk of certain unpleasant forms of weather, such as thunderstorms, in certain areas, but the forecast is not necessarily valueless if these possibilities do not materialize. The meteorologist, in fact, should regard himself as much an adviser as a prophet. The direct broadcast, especially on television, allows this approach to be made more easily and more convincingly than does the written bulletin, which tends to give the impression of hedging if it contains too many expressions of uncertainty. It remains to be seen if the new venture will achieve success in promoting a better understanding of the work of the forecaster; that it will engender a more lively interest in meteorology can hardly be in doubt.

For these reasons, if no other, the advent of the television weather programme is to be welcomed, and the Meteorological Office is grateful to the British Broadcasting Corporation for the advice and assistance which have been given so freely in the preparation and maintenance of the new programme.

MEASURES OF SUCCESS IN FORECASTING

By A. F. CROSSLEY, M.A.

Information on the accuracy of forecasts is required in order to provide a measure of progress and to compare the merits of different techniques. While it is now amply recognized that in general 100 per cent. accuracy can never be achieved[1], there is nevertheless still room for progress in many directions and considerable effort is being expended to make advances wherever possible. It is thus important to be provided with a quantitative assessment of the progress achieved by any developments in techniques. Since in practice it is seldom that more than one technique is applied to precisely the same set of data, it is necessary to be able to compare the success of different techniques applied to different sets of data. Hence suitable indices of success need to be devised which will be, as far as possible, independent of the technique used and of the varying circumstances in which the forecasts are made. Further, it is desirable to minimize the effects of persistence in the elements being forecast, since repetitive cases can often be forecast without much aid from highly developed techniques, with the result that the presence of persistence tends to conceal any essential usefulness of those techniques. In other words, a correct forecast of a substantial change in conditions is usually reckoned as being more meritorious than a correct forecast when conditions remain steady.

Indices for forecasts of the "black or white" type will be considered first, and subsequently those for forecasts of scalar or vector elements.

Part I.—Forecasts of "black or white" type

Useful effort, and the condition for worth-while forecasting.—In an earlier paper[2] it was shown how the usefulness of forecasts of two mutually exclusive events is related to the accuracy of the forecasts. Such forecasts are said to be of the "black or white" type. If the proportion of whites in a given period is denoted by b, and the proportions of whites and of blacks correctly forecast are denoted by c, c' respectively, then the results may be shown symbolically by Table I.

TABLE I—FORECAST CONTINGENCY TABLE

	Forecast	Not forecast	Total
White	bc	$b(1-c)$	b
Black	$(1-b)c'$	$(1-b)(1-c')$	$1-b$
Total	$bc+(1-b)c'$	$b(1-c)+(1-b)(1-c')$	1

The useful effort, E, defined as the successful proportion of forecasts of white, is given by

$$E = \frac{bc}{bc + (1-b)(1-c')}, \qquad \dots\dots (1)$$

while a similar expression defines the useful effort in regard to forecasts of black. In this connexion, one desires to know whether, and to what extent, forecasting constitutes an improvement on a policy of merely waiting for suitable opportunities to come along. If forecasting is to be worth-while in this respect, it is necessary that the number of successful forecasts in a given period should exceed the number of occurrences of the event; that is, one requires E to exceed b. The value of E in relation to b may therefore be taken as a measure of the usefulness, but this leads to certain difficulties to which Mr. P. M. Shaw and Mr. F. E. Lumb have drawn attention. Thus the value of E become unity when $c' = 1$, whatever the value of c; and it becomes zero when $c = 0$, whatever the value of c'. Moreover, the possible range of both E and E/b varies with b, so that two or more values of either index are not readily comparable. An alternative condition for worth-while forecasting was given in the earlier paper, where it was seen that the condition $E > b$ leads, after reduction, to

$$I_1 = c + c' > 1 \qquad \dots\dots (2)$$

which shows that the sum of the two forecast accuracies must exceed unity for worth-while forecasting of whites. This condition is, however, symmetrical with regard to both c and c', so that the same inequality follows from consideration of the useful effort in regard to the black occasions. The value of $c + c'$, or some function of this expression, may therefore be considered as a more appropriate index of the usefulness of the forecasts. Various other indices may also be derived to express the same condition, and their respective merits will now be considered.

Types of index of usefulness.—When the results of a set of forecasts are summarized, the contingency table takes the form of Table II.

TABLE II—SUMMARY OF RESULTS OF FORECASTS

	Forecast	Not forecast	Total
White	A	B	$A+B$
Black	C	D	$C+D$
Total	$A+C$	$B+D$	$A+B+C+D$

From this, if E relates to the forecasts of whites,

$$E = \frac{A}{A + D},$$

$$b = \frac{A + B}{A + B + C + D},$$

$$c = \frac{A}{A + B},$$

$$c' = \frac{C}{C + D}.$$

The condition for worth-while forecasting, $E > b$, then becomes

$$\frac{A}{A + D} > \frac{A + B}{A + B + C + D}.$$

This leads to an index in the form

$$I_2 = \frac{A(A + B + C + D)}{(A + D)(A + B)} \qquad \ldots\ldots (3)$$

which also will exceed unity for worth-while forecasting. Although both are derived from the same inequality, the numerical value of I_2 is in general different from that of I_1. Either of the inequalities, expressions (2) and (3), when reduced to their simplest form in terms of A, B, C, and D, leads to

$$AC > BD$$

and this gives yet another possible index,

$$I_3 = \frac{AC}{BD} \qquad \ldots\ldots (4)$$

One may, in fact, derive an unlimited number of indices of this type, since from any inequality a new one may be formed by adding the same arbitrary quantity to both sides. The problem then is to choose the one most suitable for the purpose under consideration. The general characteristics of such indices will be appreciated from a discussion of the three given above.

Consider the range of variation of each of these indices. It may be shown that each of them increases whenever c or c' increases. The lower limits of the indices therefore occur when the forecast is wrong every time, $c = c' = 0$, or $A = C = 0$; the upper limits arise when the forecast is correct every time, $c = c' = 1$, or $B = D = 0$. The following are the ranges of variation:—

for I_1, $\quad 0 \leqslant c + c' \leqslant 2$

for I_2, $\quad 0 \leqslant \frac{A(A + B + C + D)}{(A + D)(A + B)} \leqslant 1 + \frac{C}{A}$

for I_3, $\quad 0 \leqslant \frac{AC}{BD} \leqslant \infty$.

Of these ranges, the first is constant, the second varies with the data, and the third is infinite. In terms of b, c and c',

$$I_2 = \frac{c}{bc + (1 - b)(1 - c')}, \qquad \ldots\ldots (5)$$

so that the value of the index depends on the frequency of occurrence of the element which is being forecast. Thus for two different periods, different values of the index may be obtained even though the accuracy of forecasting is the same in both cases. Moreover the symmetry between forecasts of blacks and whites is lost with this index, and the expressions (3) or (5) derived from the forecasts of whites are not identical with the corresponding expressions for the blacks. For these reasons, I_2 does not constitute a satisfactory index.

Such considerations suggest that the most suitable index should be a symmetrical function of c and c', and independent of b. This is true of I_1 and also of I_3, which can be expressed as

$$I_3 = \frac{cc'}{(1 - c)(1 - c')}.$$

Of the two, clearly I_1 is to be preferred on account of its simplicity, its linear form, and its finite range. Since, however, it is more convenient that the range should run from 0 to 1, the index will be adopted in the form

$$I = \tfrac{1}{2}(c + c'). \qquad \ldots\ldots (6)$$

It is then the mean of the two forecast accuracies; for worth-while forecasting of either whites or blacks, in the sense used here, its value must exceed one half, or 50 per cent. It will be termed the "usefulness". In terms of the elements of Table II, it may be expressed in the form

$$I = \tfrac{1}{2}\left(\frac{A}{A + B} + \frac{C}{C + D}\right). \qquad \ldots\ldots (7)$$

While this index therefore gives a suitable measure of the usefulness of the forecasts, the value is in part dependent on persistence. It is necessary to proceed a stage further in order to obtain a measure of the success of forecasting, which, for present purposes, may be defined as the degree of improvement beyond the point reached by persistence. This will be considered in the next section.

Elimination of the effects of persistence.—Next consider how estimates of success in forecasting are related to persistence or repetition of the element concerned. In the extreme case, if the element were known to be a constant, no skill would be required once that fact had been observed. In ordinary cases there is a repetitive tendency in the element which is reflected in a tendency to forecast a recurrence of the event. Often this does not require much skill and is more or less independent of the particular technique used; on the other hand, where a change is expected but the time of occurrence is uncertain, much care may be exercised before a forecast of no change is issued. Generally, however, persistence is a factor which operates towards accurate forecasting irrespectively of the techniques used. In assessing the value of a technique it is therefore desirable that the effects of persistence should be removed.

Suppose then that the value of the index I or $\frac{1}{2}(c + c')$ has been obtained for a particular set of black and white forecasts. Another index I_0 can similarly be computed for the same occasions on the assumption that the forecast every time is one of repetition of the existing conditions. Then the difference $I - I_0$ would give a measure of the success of the technique used, over and above that to be obtained by use of persistence. To be more precise, we need to consider the improvement in the value of I over that of I_0 in relation to the maximum possible improvement. Since the maximum of either index is unity, this leads to the following expression* for the measure of success of a forecasting technique,

$$J = \frac{I - I_0}{1 - I_0}. \qquad \ldots\ldots (8)$$

If I exceeds I_0, the value of J lies between 0 and 1. If I is less than I_0, then J is negative and may take any value; in this case the forecasting technique is worthless, since the elementary method of persistence gives better results.

The particular form in which forecasts of persistence are made will depend on the nature of the element being forecast. Forecasts of no change from current conditions will be appropriate in certain circumstances; if on the other hand there is a marked diurnal variation, a forecast of repetition after 24 hr. may be more appropriate. Again, if the element is largely influenced by advection, the persistence forecast might consist of the value of the element in a location displaced up wind by the time interval of the forecast.

It is seen then that the index J, expression (8), measures the success in forecasting beyond that which would be achieved by the application of persistence. Moreover, in virtue of the definitions of I and I_0, the forecast accuracies of both white and black occasions are treated on an equal footing, while any effects due to the frequency of occurrence of the element considered are eliminated. As regards one set of data alone, the value of the difference $I - I_0$ would be a sufficient indication, but in comparing different sets or different techniques the expression J should be used to evaluate the success.

Improvement of one technique over another.—A formula of the same type as (8) may be used as a measure of the improvement of one method of forecasting over another. If I, I' are the respective indices of usefulness, the improvement of the second method over the first, in relation to the maximum possible improvement, is given by

$$\frac{I' - I}{1 - I}. \qquad \ldots\ldots (9)$$

As this expression is independent of I_0, it is unnecessary to consider persistence—unless I itself corresponds with persistence forecasting, in which case the formula reduces to (8).

Applications to black and white forecasts.—*Forecasts of change of weather type* made in a series of 4-day forecast trials have been discussed previously[2]. The accuracy of forecasts of a change of type, c, was found to be 0·53, the accuracy of forecasts of no change, c', was 0·82, hence $I = 0{\cdot}675$. If one had forecast no change of type, i.e. persistence, on every occasion, the result would have been $c = 0$, $c' = 1$, $I_0 = 0{\cdot}5$. This again illustrates that I must exceed 0·5 for the results to be worth-while. In this case the success over persistence forecasting is given by $J = 0{\cdot}175/0{\cdot}5 = 0{\cdot}35$.

Formation of secondary depressions.—Another example which was also discussed previously[2] concerns the application of Sawyer's criterion for the formation of secondary depressions at points of occlusion. The values were $c = 0{\cdot}82$ for the formation, and $c' = 0{\cdot}86$ for the non-formation of a secondary. These give $I = 0{\cdot}84$. In this example, the question of persistence is irrelevant.

*This expression resembles one proposed by Meetham[3] in which an arbitrary marking system was used for assessing terms corresponding with I and I_0.

Forecasts of frost on conductor rails.—The results of certain forecasts of the temperature of conductor rails were supplied by Mr. F. E. Lumb, Meteorological Office, Preston, from which Table III has been prepared.

TABLE III—FORECASTS OF CONDUCTOR-RAIL TEMPERATURE

Temperature	Forecast	Not forecast	Total
$\leqslant$32°F.	33	8	41
>32°F.	112	13	125
Total	145	21	166

This gives $c = 0{\cdot}80$ for occurrence of frost, $c' = 0{\cdot}90$ for its non-occurrence, and $I = 0{\cdot}85$. No information is available in this case regarding persistence.

Forecasts of rain.—An analysis of forecasts of rain contained in broadcasts by the B.B.C. at 5.55 p.m. each day during a period of 12 months in 1946–47 is given by Gold[4]. The parts of the forecasts concerning rain in south-east England within the ensuing 24 hr. were checked by comparison with observations at Kew Observatory. The 267 unqualified forecasts of rain or no rain are summarized in Table IV.

TABLE IV—FORECASTS OF RAIN IN SOUTH-EAST ENGLAND

	Forecast	Not forecast	Total
Rain	167	21	188
No rain	59	20	79
Total	226	41	267

For the accuracy of forecasts of rain, $c = 0{\cdot}89$, and of no rain, $c' = 0{\cdot}75$, giving $I = 0{\cdot}82$, a high figure. Information is not given from which the corresponding value for persistence forecasting could be obtained, but the result would clearly be quite low.

Forecasting the fog point.—Corby and Saunders[5] give the results of a test of a method of predicting the temperature at which radiation fog forms. On potentially foggy occasions during the period August 1 to October 5, 1950, the fog point on the ensuing night was estimated from upper air soundings at 1500 G.M.T. by a method due to Saunders, and the results were compared with observations at a number of stations. The results were separated into two groups according to whether fog did or did not form. In the fog group, the forecast was considered successful if the predicted fog point did not exceed the actual fog point by more than 1°F.; in the other group, the forecast was considered successful if the predicted fog point was less than the night minimum temperature. Table V summarizes the findings.

TABLE V—FORECASTS OF THE FOG POINT

	Forecast	Not forecast	Total
Fog	44	11	55
No fog	78	15	93
Total	122	26	148

This example is concerned with forecasts of one type of event in two different sets of conditions, but at the time of the forecast it is not known which set applies. Since $c = 0{\cdot}80$, $c' = 0{\cdot}84$, the results show that the forecast accuracy is practically independent of the subsequent occurrence of fog. Interpreted as forecasts of fog, the usefulness is $I = 0{\cdot}82$, but this is an over-estimate, since in practice it is necessary also to forecast the night minimum temperature.

Forecasts of visibility at Northolt.—Although visibility is an element subject to continuous variation, the forecasts are conveniently considered under the head of black or white, since the position of an observation on the conventional visibility scale is usually of more importance than the precise visibility distance. Table VI contains results in regard to forecasts of the local visibility above and below certain limits; they were made four times daily between November 1951 and March 1952, the total number of forecasts being 556.

TABLE VI—FORECASTS OF VISIBILITY AT NORTHOLT

November 1951—March 1952

Visibility limit	Forecast period 1 hr. c	1 hr. c'	1 hr. I	4½ hr. c	4½ hr. c'	4½ hr. I	12 hr. c	12 hr. c'	12 hr. I
yd.				*per cent.*					
220	100	71	85	99	42	71	99	7	53
550	99	76	87	98	60	79	99	32	65
1,100	99	90	95	96	61	79	95	44	69
2,200	95	90	93	91	73	82	88	63	75
4,400	92	89	91	87	76	81	78	64	71
miles									
6¼	68	99	83	37	96	67	13	95	54

c and c' are the percentage accuracies of forecasts above and below the limits indicated, and $I = \frac{1}{2}(c + c')$ is the percentage usefulness.

Among the several points of interest to be inferred from this table, attention is drawn to the following:—

(i) The forecast accuracies c and c', as well as the index I, decrease as the period of the forecast increases. This is only to be expected.

(ii) The values of c decrease, and the values of c' increase, as the visibility limit increases. This too is to be expected.

(iii) For each forecast period, the value of I is greatest for moderate limits, and least for the extreme limits.

These show that the forecasting is most useful in regard to the moderate limits with a maximum usefulness at about 2,200 yd., and that it becomes less useful as the limits become more extreme. In particular, forecasts for 12 hr. ahead for the limits of 220 yd. and 6¼ miles are only just within the useful range, for which I must exceed 50 per cent. This is due almost entirely to the very low accuracy of forecasting visibility less than 220 yd. or greater than 6¼ miles, for a 12-hr. period.

The results which would have been obtained by persistence forecasting, i.e. by making the forecast visibility always the same as the actual visibility at the time of issue, are shown in Table VII.

Comparison of Tables VI and VII shows that:—

(i) For forecasts of visibility greater than a given limit, there is little difference between c and c_0 except at 6¼ miles, where persistence gives definitely better results.

(ii) For forecasts below a given limit, c' is little different from c_0' for 1 hr. ahead, but rather better at 4½ hr. and 12 hr. with the exception of 220 yd. at 12 hr., where persistence is the better.

TABLE VII—PERSISTENCE FORECASTS OF VISIBILITY AT NORTHOLT

November 1951—March 1951

Visibility limit	Forecast period 1 hr. c_0	1 hr. c_0'	1 hr. I_0	4½ hr. c_0	4½ hr. c_0'	4½ hr. I_0	12 hr. c_0	12 hr. c_0'	12 hr. I_0
yd.				per cent.					
220	100	71	85	98	33	65	98	29	63
550	99	86	93	97	48	73	97	24	61
1,100	98	89	93	97	63	80	95	40	67
2,200	96	85	91	91	55	73	89	47	68
4,400	90	89	89	80	73	77	70	55	63
miles									
6¼	85	97	91	52	91	71	30	84	57

For explanation see note to Table VI.

The usefulness as indicated by I or I_0 can be similarly compared, but for possible comparison with other data, the index of success, J, is computed, the values of which are shown in Table VIII.

TABLE VIII—INDEX OF SUCCESS OF VISIBILITY FORECASTING AT NORTHOLT

November 1951—March 1952

Visibility limit	Forecast period 1 hr.	4½ hr.	12 hr.
yd.		per cent.	
220	0	15	−29
550	−67	24	13
1,100	15	−5	6
2,200	21	33	23
4,400	9	21	23
miles			
6¼	−83	−18	−7

From this table it is seen that:—

(i) For the limit of 6¼ miles better results would have been obtained by forecasting existing conditions for each period.

(ii) For 220 yd., existing conditions would have given better results at 12 hr. ahead.

(iii) For forecasts for 1 hr. ahead, the actual results show an improvement over persistence only for the liniits 1,100 to 4,400 yd.

(iv) On the whole the forecasting was most successful in regard to the middle ranges 2,200 and 4,400 yd. and least successful for the extreme ranges.

Similar data for visibility forecasts are available for a number of other stations, the checking of which can be carried out in the same manner.

(To be continued)

REFERENCES

1. SUTCLIFFE, R. C.; Principles of synoptic weather forecasting. *Quart. J. R. met. Soc., London*, **78**, 1952, p. 291.
2. CROSSLEY, A. F.; Usefulness of forecasts. *Met. Mag., London*, **81**, 1952, p. 193.
3. MEETHAM, A.R.; Weather forecasting and the ordinary citizen. *Weather, London*, **2**, 1947, p. 44.
4. GOLD, E.; Weather forecasts. *Quart. J. R. met. Soc., London*, **73**, 1947, p. 151.
5. CORBY, G. A. and SAUNDERS, W. E.; Water-fog point—a further test. *Met. Mag., London*, **81**, 1952, p. 225.

ESTIMATION OF METEOROLOGICAL AVERAGES FOR OTHER MONTHS GIVEN AVERAGE VALUES FOR JANUARY, APRIL, JULY AND OCTOBER

By A. F. JENKINSON, B.A.

Introduction.—Annual and semi-annual harmonic terms can be fitted to the averages for January, April, July and October, thus giving a general expression from which averages for the remaining months may be computed. The formula may also be arranged to give monthly average values when only seasonal values, say December–February, March–May, June–August, September–November are given.

Annual variation.—In compiling data for a large number of stations to show the average annual variation of a meteorological element it is often customary to present averages for 4 mid-season months. The time required to work up data for all 12 months is usually prohibitive, especially for world maps, and data for January, April, July and October are considered sufficiently representative. Interpolation from values for these 4 months however may not be easy. Linear or graphical methods of interpolation are often quite inadequate or subjective.

Fortunately, the annual variation of most meteorological elements is usually adequately represented by two harmonics; and when annual and semi-annual terms are fitted to the averages for January, April, July and October, the values which can then be estimated for the other months are very close to the true values.

Harmonic Analysis.—For a two-term analysis $M_t = \overline{M} + a_1 \cos(30t)^\circ + b_1 \sin(30t)^\circ + a_2 \cos(60t)^\circ + b_2 \sin(60t)^\circ$ where M_t ($t = 0, 1, \ldots 11$) are the values taken by the element in mid January, mid February, . . . mid December, regarded as nearly the average values for January, February, . . . December, and $\overline{M}$ is the average annual value.

a_1, a_2, b_1 and b_2 can be computed by least-square procedure taking

$$\overline{M} = 0{\cdot}25(M_0 + M_3 + M_6 + M_9).$$

Then

$$\begin{aligned} M_t = {} & M_0[0{\cdot}25 + 0{\cdot}5\cos(30t)^\circ + 0{\cdot}25\cos(60t)] \\ & + M_3[0{\cdot}25 + 0{\cdot}5\sin(30t)^\circ - 0{\cdot}25\cos(60t)^\circ] \\ & + M_6[0{\cdot}25 - 0{\cdot}5\cos(30t)^\circ + 0{\cdot}25\cos(60t)^\circ] \\ & + M_9[0{\cdot}25 - 0{\cdot}5\sin(30t)^\circ - 0{\cdot}25\cos(60t)^\circ] \qquad \ldots\ldots(1) \end{aligned}$$

Table I gives the multiplying factors for computing values for each month and for each season in terms of the values for January, April, July and October.

TABLE I—MULTIPLYING FACTORS TO COMPUTE MONTHLY AND SEASONAL VALUES FROM THE VALUES FOR JANUARY, APRIL, JULY AND OCTOBER

	Feb.	Mar.	May	June	Aug.	Sept.	Nov.	Dec.	Dec.–Feb.	Mar.–May	June–Aug.	Sept.–Nov.
Jan. ...	0·81	0·37	−0·12	−0·06	−0·06	−0·12	0·37	0·81	0·88	0·08	−0·04	0·08
Apr. ...	0·37	0·81	0·81	0·37	−0·12	−0·06	−0·06	−0·12	0·08	0·88	0·08	−0·04
July ...	−0·06	−0·12	0·37	0·81	0·81	0·37	−0·12	−0·06	−0·04	0·08	0·88	0·08
Oct. ...	−0·12	−0·06	−0·06	−0·12	0·37	0·81	0·81	0·37	0·08	−0·04	0·08	0·88

e.g. $M_{\text{Feb.}} = 0{\cdot}81\, M_{\text{Jan.}} + 0{\cdot}37\, M_{\text{Apr.}} - 0{\cdot}06\, M_{\text{July}} - 0{\cdot}12\, M_{\text{Oct.}}$

Given seasonal values for Dec.–Feb., Mar.–May, June–Aug. and Sept.–Nov., the values for January, April, July and October may be computed by using the lower part of Table I and hence those for all months from expression (1). Table II gives the multiplying factors.

TABLE II—MULTIPLYING FACTORS TO COMPUTE MONTHLY VALUES FROM SEASONAL VALUES

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Dec.–Feb. ...	1·18	0·92	0·34	−0·13	−0·22	−0·04	0·08	−0·04	−0·22	−0·13	0·34	0·92
Mar.–May ...	−0·13	0·34	0·92	1·18	0·92	0·34	−0·13	−0·22	−0·04	0·08	−0·04	−0·22
June–Aug. ...	0·08	0·04	−0·22	−0·13	0·34	0·92	1·18	0·92	0·34	−0·13	−0·22	−0·04
Sept.–Nov. ...	−0·13	−0·22	−0·04	0·08	−0·04	−0·22	−0·13	0·34	0·92	1·18	0·92	0·34

Comparison of estimated with actual values.—*Vapour pressure.*—Table I was used to estimate values of vapour pressure for other months given the values for January, April, July and October. The results are shown in Table III.

TABLE III—COMPARISON OF ESTIMATED VALUES OF VAPOUR PRESSURE WITH ACTUAL VALUES

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						millibars						
ATHENS, 1901–40												
Estimated value		8·1	8·9		12·5	14·5		16·4	15·9		12·3	10·0
Actual value	8·5	8·5	9·2	10·5	12·8	15·2	15·9	16·0	15·1	14·4	12·0	10·0
Difference		−0·4	−0·3		−0·3	−0·7		+0·4	+0·8		+0·3	0·0
NAPLES, 1866–1925												
Estimated value		7·8	9·4		14·3	17·5		19·2	17·4		11·9	9·5
Actual value	8·1	8·4	9·2	11·2	13·9	17·2	19·3	19·6	17·6	14·7	11·1	9·2
Difference		−0·6	+0·2		+0·4	+0·3		−0·4	−0·2		+0·8	+0·3
BEIRUT, 1933–52												
Estimated value		11·5	13·2		20·6	24·0		26·1	24·0		17·0	13·6
Actual value	11·7	11·9	13·5	16·3	20·0	23·3	26·1	26·5	24·3	20·7	16·8	13·2
Difference		−0·4	−0·3		+0·6	+0·7		−0·4	−0·3		+0·2	+0·4

Wind.—Table II was used to estimate monthly values for wind direction given seasonal values. An example is shown in Table IV.

TABLE IV—PERCENTAGE WIND FREQUENCIES AT RHODES, 1400 ZONE TIME, DURING THE PERIOD 1933–1940

Wind direction	Seasonal frequencies Dec.–Feb.	Mar.–May	June–Aug.	Sept.–Nov.	Monthly frequencies, November Estimated	Actual
		per cent.			*per cent.*	
N.	10	3	0·5	7	10	13
NE.	4	2	0·5	1	2	2
E.	5	5	0·3	2	3	2
SE.	22	16	2	14	19	20
S.	10	6	0·4	4	7	6
SW.	7	8	16	7	5	3
W.	11	32	66	41	26	22
NW.	23	22	13	19	21	23
Calm	8	6	1	5	7	9

Temperature.—Table I was used to give estimated values for average daily maximum temperature for other months given those for January, April, July and October. The results are shown in Table V.

TABLE V—COMPARISON OF AVERAGE DAILY MAXIMUM TEMPERATURE WITH ESTIMATED VALUES

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						degrees Centigrade						
NAPLES, 1901–25												
Estimated value		11·1	13·4		21·8	26·1		27·7	24·6		16·2	12·7
Actual value	11·0	12·0	14·1	17·2	21·8	25·3	28·2	28·3	25·2	20·4	15·5	12·2
Difference		−0·9	−0·7		0·0	+0·8		−0·6	−0·6		+0·7	+0·5
						degrees Fahrenheit						
KEW, 1871–1950												
Estimated value		44·7	48·8		62·2	68·5		69·4	64·6		50·2	45·1
Actual value	43·8	45·1	49·3	55·0	62·0	67·8	71·1	70·1	65·0	56·6	49·0	44·6
Difference		−0·4	−0·5		+0·2	+0·7		−0·7	−0·4		+1·2	+0·5

AN EXTENSIVE DOUBLE TROPOPAUSE

By D. H. JOHNSON, M.Sc.

J. Bjerknes and Palmén in a paper[1] which has become one of the classics of aerological analysis, commented on the multiple tropopause which occurred on a series of ascents made at short intervals from Uccle on February 15 and 16, 1935. The multiple tropopause was defined as a system of successive changes in lapse rate (double, triple etc.), occurring in the boundary region between troposphere and stratosphere. It was implied that such a system should be recognizable from one ascent to another in time or space, and it was suggested,

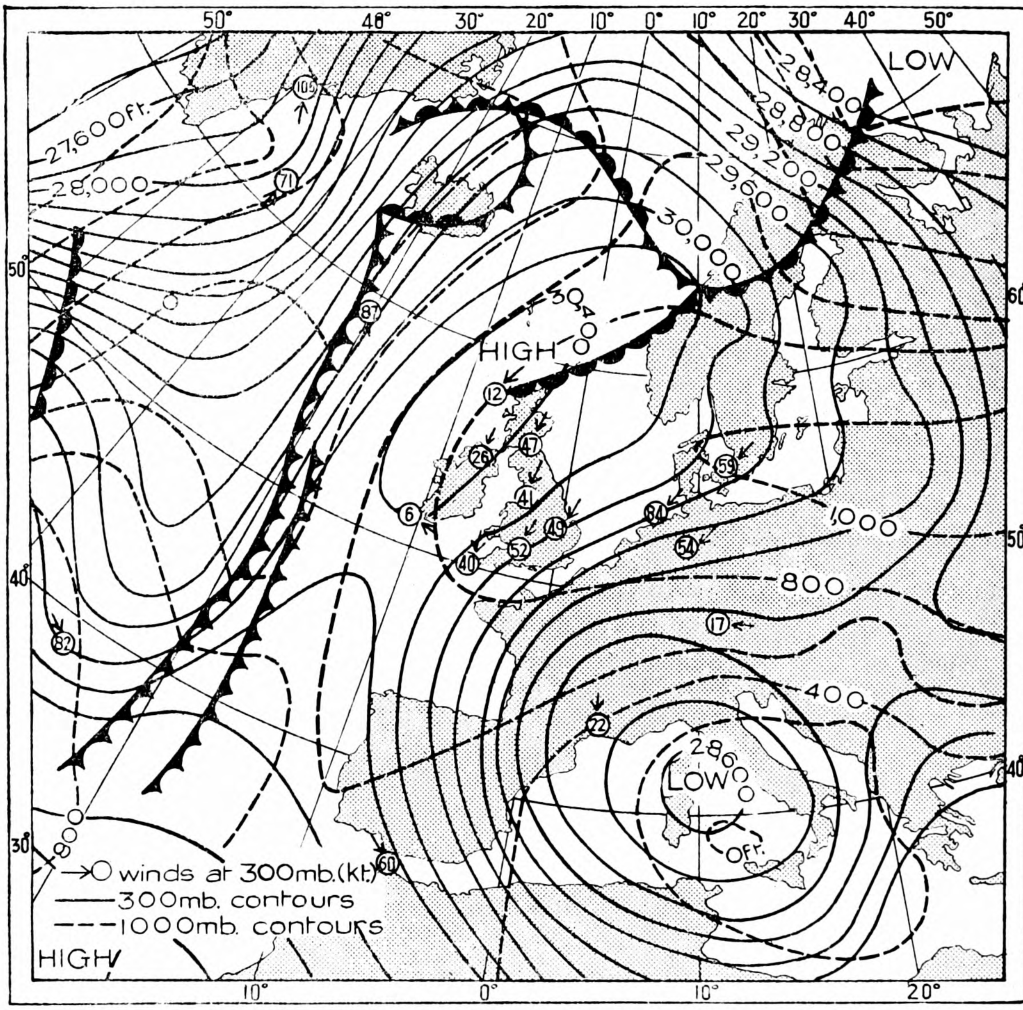

FIG. 1—CONTOURS OF THE 1000-MB. AND 300-MB. SURFACES AT 1500 G.M.T., JANUARY 19, 1950

as a working hypothesis, that the potential temperature is relatively constant over each tropopause layer, although the height of the layer varies. Although complexities in the structure of the tropopause are frequent, it is unusual for a multiple tropopause to be identifiable over a wide area, and the following account of a particularly extensive double tropopause may be of interest. It extended from Iceland to central Europe and from northern Norway to ocean weather station JULIET (54°N., 18°W.).

Fig. 1 shows the 1000-mb. and 300-mb. flows at 1500 G.M.T., January 19, 1950. The westerlies which had prevailed for the earlier part of the month were becoming blocked, with the establishment of a cold pool in the Mediterranean and an upper high to the north-west of the British Isles which developed towards Scandinavia. At the surface, the continental anticyclone, with a ridge extending across the British Isles, gave Europe a seasonable spell of winter easterlies.

The double tropopause appeared on many of the 1500 G.M.T. ascents made from stations in western Europe, Scandinavia and the north-east Atlantic on this occasion. Fig. 2 contains tephigrams of the upper parts of several of these ascents. A double tropopause can be found without difficulty on each of those illustrated with the possible exception of that from Larkhill where the upper tropopause is not very well defined. Examination of the original plots of frequency against time for signals received from the temperature elements of the British radio-sondes confirmed that each of the apparent tropopauses was a real singularity; they did not arise accidentally because temperatures were reported only at a discrete set of pressures in regions where the lapse rate might have been varying continuously with pressure over a fairly thick layer.

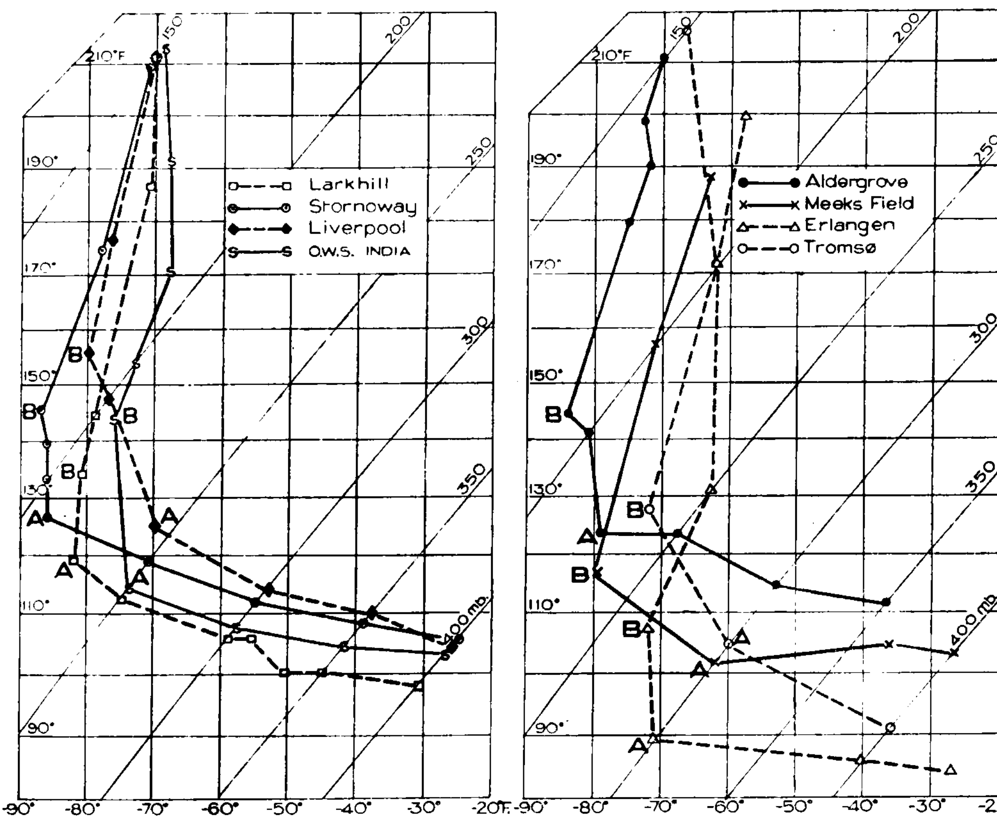

FIG. 2—TEPHIGRAMS OF THE UPPER PARTS OF ASCENTS MADE AT 1500 G.M.T., JANUARY 19, 1950

From the ascents in the left-hand tephigram in Fig. 2, it is not unreasonable to associate the lower of the singularities (marked A) as belonging to one tropopause surface and the upper singularities (marked B) as belonging to a second tropopause surface. The ascents shown in the right-hand tephigram, however, were made at stations which are much farther apart than those whose ascents appear in the left-hand one, and, while each ascent does contain two singular points, it is not clear from inspection of this tephigram that all the

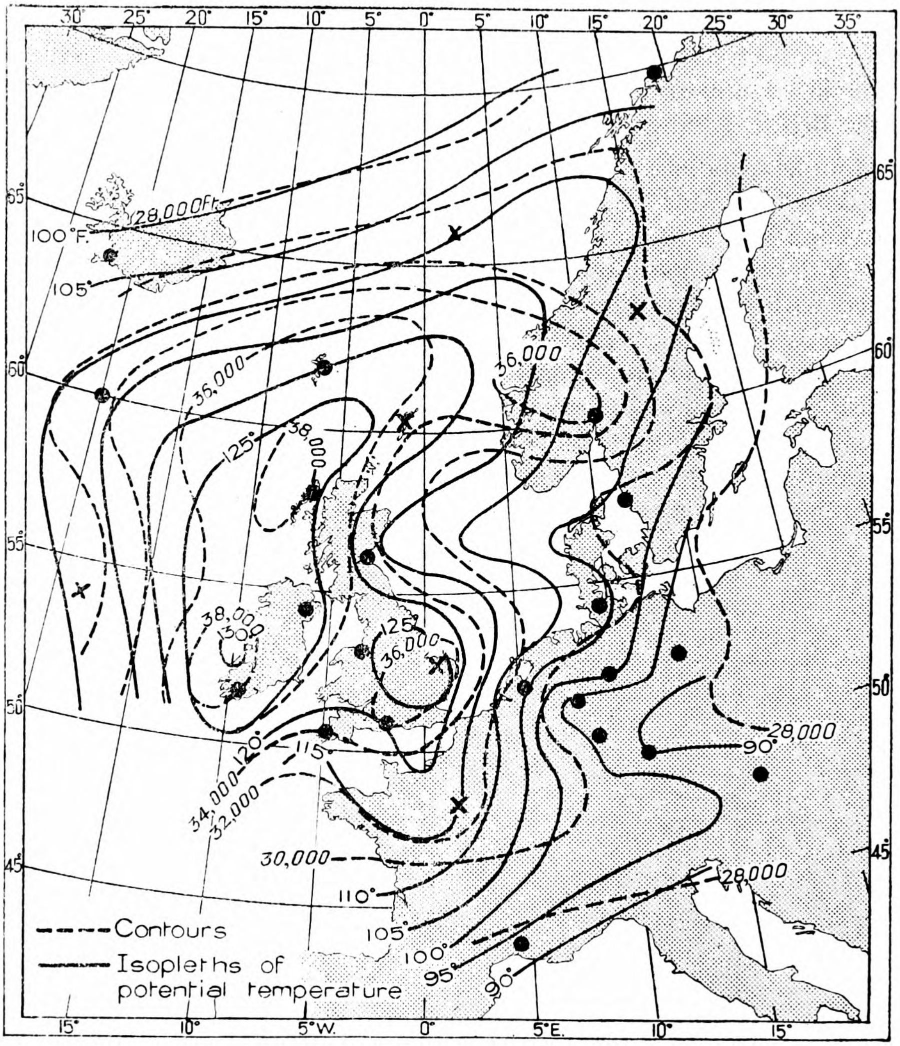

FIG. 3—ISOPLETHS OF POTENTIAL TEMPERATURE AND CONTOURS OF THE LOWER TROPOPAUSE

● Stations showing the double tropopause clearly.

X Stations where ascents failed to reach both tropopauses or with three possible tropopauses.

points A can reasonably be taken to be on one tropopause surface and all the points B to lie on a second distinct tropopause surface. Such an analysis, however, becomes more plausible if the space distributions of height, potential temperature and temperature at the two singularities are considered. This has been done in two ways.

First, isopleths were drawn of the heights and potential temperatures of each singularity. These are reproduced in Figs. 3 and 4 which show, in addition, the location of those stations whose ascents have been examined. Ascents from stations located by a dot showed the double change of lapse clearly and unambiguously. Of the ascents from stations marked as a cross, those from the ship at station METRO (66°N., 2°E.) and Östersund-Frösön (63°N., 14°E.) reached only the lower tropopause. The ascent from the weather ship station INDIA (53°N., 18°W.) did not reach tropopause levels at 1500 G.M.T., but a double change of lapse showed clearly at 0900 G.M.T. and 2100 G.M.T. Ascents

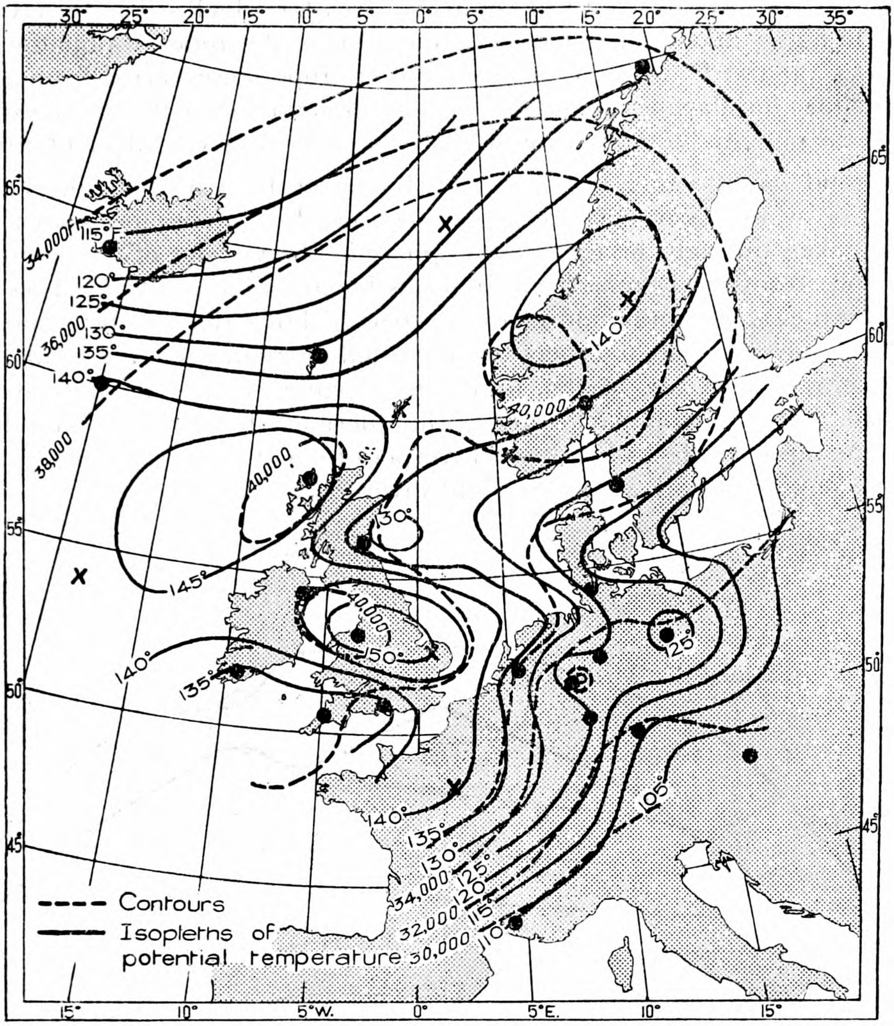

FIG. 4—ISOPLETHS OF POTENTIAL TEMPERATURE AND CONTOURS OF THE UPPER TROPOPAUSE

● Stations showing the double tropopause clearly.

X Stations where ascents failed to reach both tropopauses or with three possible tropopauses.

from Downham Market (53°N., 0°E.), Lerwick (60°N., 1°W.), Trappes (49°N., 2°E.) and Jever (54°N., 8°E.) all contained three points which might be considered as singularities. For each of these last ascents, two of the singularities were selected as being most likely to correspond to the widespread tropopauses, consideration being given to the general character of the ascent in relation to features of ascents from neighbouring stations.

Comparing Figs. 3 and 4 with Fig. 1 it is seen that the heights and potential temperatures at each tropopause were greatest in the central region of the upper anticyclone and decreased towards its periphery. The potential temperatures at each tropopause were reasonably uniform only over limited regions. For stations in the British Isles, for example, the potential temperatures reported at the upper tropopause varied from 154° to 133°F. and at the lower tropopause from 132° to 115°F. It is therefore just possible on this occasion to use potential temperature as a means of deciding to which layer a tropopause observed over the British Isles belonged. Over the wider area for which isopleths have been drawn in Figs. 3 and 4, the potential temperature at the upper tropopause varied from 154° to 103°F. whilst that at the lower tropopause varied from 132° to 90°F. Thus, for classification of tropopauses observed over this more extensive region, the potential temperature by itself does not provide a sufficient criterion.

A second way in which the space distribution of the two tropopauses may be studied is by means of a vertical cross-section. Fig. 5 contains such a cross-section taken through the upper atmosphere in the vicinity of the tropopause. It extends from the Denmark Strait across Iceland and the British Isles to the Mediterranean. Examination of the isotherms shows that in the troposphere below the lower tropopause there was the usual temperature lapse, whilst in the lower stratosphere above the upper tropopause, there was an inversion. Between the two tropopause sheets the thermal stratification varied from moderate lapse at Meeks Field and Liverpool to near isothermal at Stornoway and the ship at station INDIA and slight inversion at Larkhill.

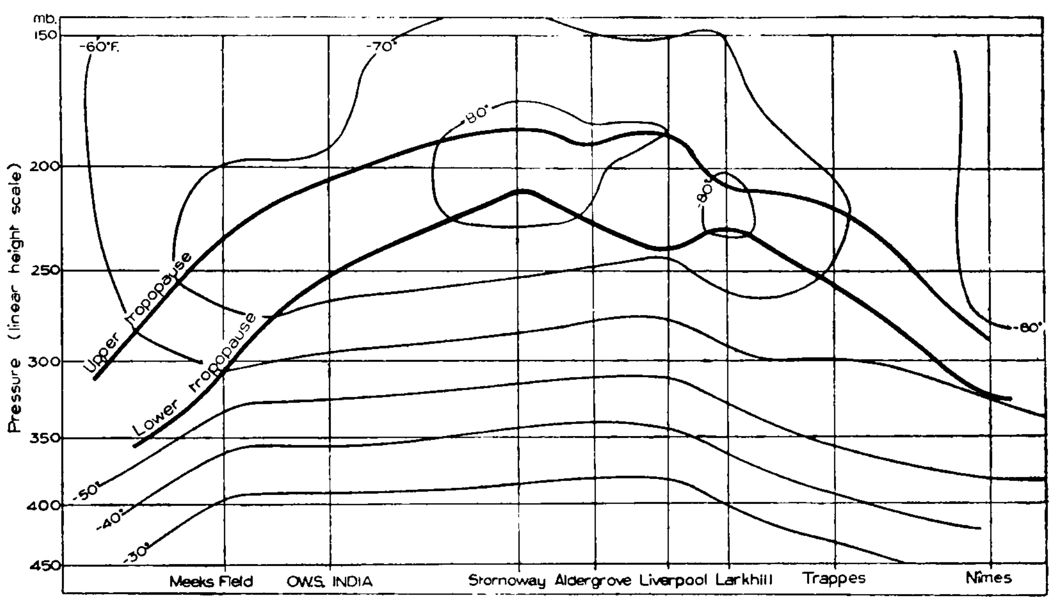

FIG. 5—CROSS-SECTION FROM THE DENMARK STRAITS TO THE MEDITERRANEAN THROUGH THE UPPER TROPOSPHERE AND LOWER STRATOSPHERE

It is interesting to apply to the ascents used in the construction of the cross-section a definition of the tropopause which does not recognize the existence of multiple singularities. Such a definition is given in the introduction to the *Daily Aerological Record*[2]. Three types of tropopause are defined, namely

Type I. The tropopause is indicated by a definite inversion.

Type II. There is no inversion, but a sharp discontinuity, the lapse rate above the discontinuity being 1°F./1,000 ft. or less.

Type III. There is neither an inversion nor a discontinuity, but the lapse rate falls gradually to a value less than 1°F./1,000 ft. The point where the lapse rate drops to the value is taken as the tropopause.

Using this definition we are obliged to take as the tropopause the lower singularities at Larkhill (Type I), Stornoway (Type II) and the ship at station INDIA (Type II), and the upper singularities at Meeks Field (Type I), Aldergrove

READING THE BAROMETER
Also to be seen are the Gold slide, an oil-damped barograph and a cloud card. The Gold slide is used for reducing the pressure as read to sea level and at the same time allowing for index error, latitude and temperature.

READING THE SCREEN THERMOMETERS
It will be seen that the screen is only temporarily secured in its present position, since it should always be hung on the windward side of the ship.

OBSERVATIONS ABOARD A "SELECTED" SHIP
(see p. 91)

[To face p. 80

OBSERVING THE WIND DIRECTION

The direction of movement of wave ripples or spume streaks is sighted over the gyro compass, thus obtaining the wind direction free from the necessity of any correction for ship's course and speed.

COPYING THE CODED MESSAGE ON TO THE SIGNAL PAD

OBSERVATIONS ABOARD
(see

READING THE SEA TEMPERATURE

The special bucket (Meteorological Office pattern, Mk III) is trailed through the water and the temperature of the resulting "catch" is measured as seen in the photograph.

TRANSMITTING THE MESSAGE

A "SELECTED" SHIP
p. 91)

To face p. 81]

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SCHOOL PARTIES VISITING THE O.W.S. *Weather Watcher* IN JUNE 1952 AND MAY 1953

The *Weather Watcher* has been adopted by the Eastbank Secondary School, Glasgow. The lower photograph shows Capt. Elston presenting a silver trophy to the Headmaster of the school.

(Type I) and Liverpool (Type I). A definition which is convenient for statistical purposes, is not necessarily satisfactory from the point of view of aerological analysis. The problem of revising the definition of the tropopause to meet this and other difficulties is under consideration.

REFERENCES

1. BJERKNES, J., and PALMÉN, E.; Investigations of selected European cyclones by means of serial ascents, Case 4: February 15–17, 1935. *Geofys. Publ., Oslo*, **12**, No. 2, 1937.
2. London, Meteorological Office. Introduction to the *Daily Aerological Record.* Published quarterly.

LENGTH OF A FROST-FREE PERIOD

By L. P. SMITH, B.A.

In agricultural meteorology, questions are sometimes asked with regard to the average length of the frost-free period in a given area. The difficulty about such requests is that minimum air temperatures (at screen height) are of limited validity unless taken on the actual site, and that the simple long-term average gives a very incomplete picture.

As an example, the dates of first and last screen frost (minimum 32°F. or below) were extracted for Rothamsted for the years 1921–50. The date of the last frost varied from March 23 to May 29 with April 29 as the average. Similarly the first autumn frost lay between October 11 and November 15, with the average at October 26. By subtraction, the length of the frost-free period in any year ranged from 148 to 230 days, average length 180 days.

At Rothamsted during this period, the variation in the date of last frost in spring was greater than the variation in the date of the first frost in autumn. It is not therefore surprising that the longest frost-free periods occurred in 1943 (230 days) and 1942 (221 days) when the dates of the last spring frost were abnormally early, namely on March 23 and March 29 respectively. Conversely, with a very late spring frost, such as May 29 in 1927, the frost-free period was the shortest in the 30 yr. (148 days). The next shortest was in 1941 (150 days) when the similar date was May 16.

An average by itself is thus of limited use and we need a simple way of expressing the variation about the average. On the evidence available, the shortest period in 30 yr. was 148 days, implying that the odds were 29–1 against a period of 148 days or less. The next shortest was 150, with odds 14–1 against for a period of this length or less. The longest but one was 221 days, with odds 0·034–1 against (or 29–1 on) a period of this length or less; this is perhaps better stated as odds of 29–1 against a period longer than 221 days.

If these odds are plotted against the length of period, a logarithmic curve is obtained (see Fig. 1), and the equation of the closest fit is

$$\text{length} = (178{\cdot}6 - 24{\cdot}2 \log C) \text{ days}$$

where C is the odds against unity of a frost-free period of the given length or less. From this it can immediately be seen that there is an even chance of at least 178·6 days, a 10–1 against chance of 154·4 days or less, and a 10–1 against chance of more than 202·8 days. Table I shows the observed and calculated values. It is perhaps unfair to compare these figures with those recorded in the nearby frost hollow at Rickmansworth, which were listed by E. L. Hawke[1]. Nevertheless, if we do so, some interesting points emerge. The comparable data are given in Table II.

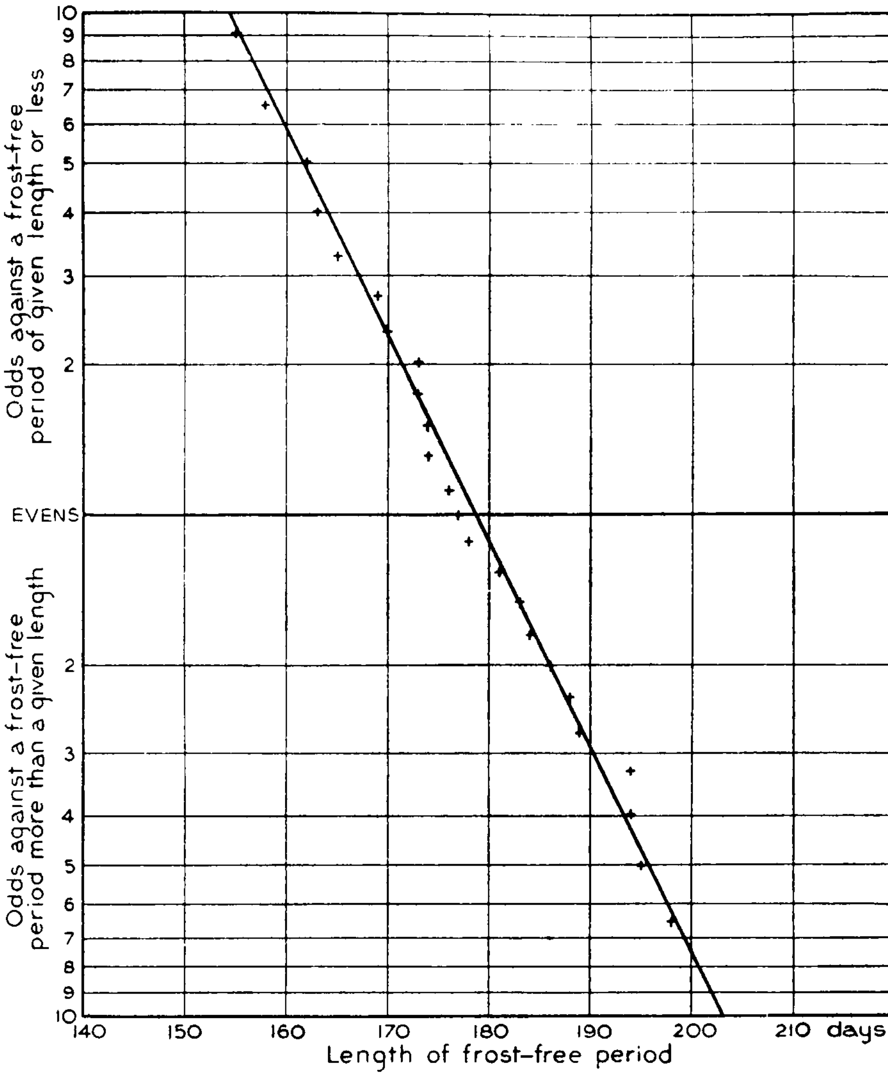

FIG. I

TABLE I—MAXIMUM LENGTH OF FROST-FREE PERIOD IN THE LEAST FAVOURABLE YEARS IN 10

	Observed	Calculated	Error
		days	
1 year in 10	155	155·5	0·5
2 years in 10...	163	164·0	1·0
3 years in 10...	170	169·7	0·3
4 years in 10...	174	174·3	0·3
5 years in 10...	177	178·6	1·6
6 years in 10...	183	182·9	0·1
7 years in 10...	188	187·5	0·5
8 years in 10...	194	193·2	0·8
9 years in 10...	200	201·7	1·7

Not only is the length of frost-free period much shorter at Rickmansworth, it is also more variable; the comparable length-odds equation is

$$\text{length} = (97\cdot3 - 31\cdot7 \log C) \text{ days.}$$

There is no correlation between the last two columns of figures in the above

TABLE II

	Date of last frost		Date of first frost		Length of frost-free period	
	Rothamsted	Rickmansworth	Rothamsted	Rickmansworth	Rothamsted	Rickmansworth
1930	Apr. 22	May 9	Oct. 27	Oct. 10	188	153
1931	Apr. 22	May 21	Oct. 22	Sept. 7	183	108
1932	May 8	June 10	Oct. 29	Sept. 26	174	107
1933	Apr. 23	May 27	Oct. 18	Oct. 13	178	138
1934	Apr. 10	May 25	Oct. 30	Aug. 26	202	92
1935	May 19	June 9	Oct. 21	Aug. 28	155	79
1936	Apr. 23	June 4	Oct. 29	Sept. 29	189	116
1937	Apr. 27	June 30	Oct. 18	Sept. 16	174	77
1938	May 8	June 11	Oct. 24	Aug. 21	169	70
1939	Apr. 28	July 2	Oct. 26	Sept. 28	181	87
1940	Apr. 18	May 21	Oct. 29	Aug. 24	194	94
1941	May 16	May 21	Oct. 13	Sept. 17	150	118
1942	Mar. 29	June 26	Nov. 5	Sept. 16	221	81
Mean	Apr. 29	June 5	Oct. 25	Sept. 15	181	101

table, as the coefficient is approximately zero. In 1942, when Rothamsted had one of its longest frost-free periods (221 days) Rickmansworth had one of its shortest (81 days). Indeed, it would have been surprising if any uniform pattern of relationship had been found between the two sets of figures.

It is suggested that the following conclusions must be drawn:—

(1) A meteorological average must be supported by some indication of the scale of variation about that average.

(2) A meteorological average is only valid for the site on which the observations were taken; any extrapolation must be done with extreme care, especially when dealing with parameters involving threshold values.

(3) The representation of frost statistics by isopleths on small-scale maps is of limited practical use.

REFERENCE

1. HAWKE, E. L.; Thermal characteristics of a Hertfordshire frost-hollow. *Quart. J. R. met. Soc., London*, **70**, 1944, p. 23.

METEOROLOGICAL OFFICE DISCUSSION

Frontal analysis in the higher troposphere and the lower stratosphere

The discussion on Monday, December 21, 1953, held at the Royal Society of Arts, was opened by Mr. C. L. Hawson who based his statement on the paper:—

BERGGREN, R.; On frontal analysis in the higher troposphere and the lower stratosphere. *Ark. Geofys., Stockholm*, **2**, 1953, p. 13.

Mr. Hawson said that Berggren's paper dealt with the problem of how to combine in a vertical cross-section, the extended front, the two or more tropopauses usually seen on vertical soundings, and the discontinuities observed in the stratosphere.

From observations in November 1949 Berggren constructs idealized soundings representing tropical and polar air. The temperature difference between these two air masses increases with height to about 400 mb. Above the tropopause the polar air is isothermal, and at about 250 mb. both air masses have the same temperature. Above this level the polar air is warmer than the tropical air and the temperature difference increases to about 130 mb.

Berggren also observes that a decided northward movement of tropical air is often connected with strong winds in the higher troposphere, but that the wind speed usually decreases rapidly above about 9 Km. He therefore believes it may be reasonably assumed that, as seen in a vertical cross-section, the tropical air invades the polar air as a wedge with its axis at about 9 Km. Further, Berggren considers that the air immediately above the tropopause has in many cases the same geographical origin and the same life history as the air in the higher troposphere. The tropopause, he concludes, ought not to be regarded as a boundary between two different air masses, but as a phenomenon localized within one air mass.

From these hypotheses, Berggren puts forward a frontal model in which both tropical and polar air are regarded as high-reaching air masses separated by the polar front, which can generally be assumed to reach well up into the stratosphere. In those cases where the polar front is a warm front in the troposphere, it acts as a cold front in the stratosphere, and *vice versa*. At the level of zero temperature difference, the front is vertical, and the horizontal wind shear through the front attains its maximum value. A reasonable value for this shear seems to be about 40–50 m./sec./100 Km.

Berggren analyses specific fronts and shows them to be not inconsistent with his model, making particular reference to the following points:—

(i) distribution of wind in the layer between 400 and 200 mb., especially the horizontal shear at about the level of vanishing temperature difference between tropical and polar air;

(ii) distribution of temperature between 500 and 100 mb.;

(iii) vertical stability on both sides of the front between 400 and 200 mb.;

(iv) change in time of wind and temperature in the layer between 500 and 100 mb. when the polar front passes a station.

To illustrate Berggren's model Mr. Hawson presented Berggren's detailed analysis of the Atlantic warm front of November 7–8, 1949 with the aid of cross-sections and showed Berggren's model for a warm-front occlusion. He particularly emphasized the scale of frontal zones, 70–150-Km. wide in Berggren's example, and quoted J. S. Sawyer's suggestion of an average 130 miles (200 Km.) with wide variations.

In addition to the discussion of particular examples Berggren constructs mean soundings, typical of each 100 Km. either side of a front at 500 Km. He uses these soundings to produce a mean vertical cross-section through a warm front, and also to obtain idealized soundings of tropical and polar air. Using these idealized soundings, he constructs an idealized frontal model with uniformly sloping fronts which he discusses in relation to real cases. The following points emerge:—

(1) The maximum temperature difference between idealized polar and tropical air, found at about 400 mb., should give the jet-stream centre above the point where the central part of the frontal layer intersects the level, if all the baroclinity is concentrated to the front. A displacement to a lower layer is usually found, brought about by the distribution of baroclinity and sometimes by the wind distribution in the lower layers.

(2) A dip in the lower tropopause of the tropical air towards the front is often observed. This causes a rather great horizontal temperature gradient, which, having the opposite direction to the one in the troposphere, entails a rapid decrease of the wind speed above the tropopause level. At the lower tropopause of the polar air, the opposite phenomenon may occur, and a wind increase ensues.

(3) The position of the stratospheric part of the front changes considerably with respect to the position of the front at 500 mb. Berggren does not suggest that his model is applicable to all cross-sections but he thinks his special solution is rather common. He points out that every part of a high-reaching front is subject to frontolytic processes. This is especially the case near the surface of the earth and in the stratosphere. In the first case the destruction of the front is brought about by the exchange of heat between the air and the surface of the earth and in the latter case by the vertical motions. Although only an indirect reference to the problem is made in his main paper, Berggren in his preliminary paper suggests that clear-air turbulence might be associated with the frontal zones of his model, and claims that his model may provide a possible way of attacking the prognostic problem.

Mr. Hawson, in giving his own opinion of Berggren's paper, said that studying the paper left him with the impression that the examples had been carefully selected, but that even so the observations had been stretched to their limits. In the detailed example for which Berggren's analysis had been given earlier, he showed that some of Berggren's tropopauses do not accord with current British practice; and that the routine British tropopause analysis placed the tropopause of the tropical air coincident with the tropical boundary of Berggren's stratospheric front in the only two places where this front was directly observed.

Nevertheless he believed that as a working hypothesis for an experienced meteorologist Berggren's model is an aid to clear visualization of the atmosphere, whether the boundary zones be called tropopauses, fronts, or sloping baroclinic zones. Broad divisions of the kind described by Berggren do exist, and the possibility of the occasional occurrence of clear-cut surfaces of a frontal nature in the lower stratosphere cannot be ruled out. Far more frequently, however, the frontal surface is not clear cut even in the higher troposphere, and detailed frontal analysis becomes too subjective to be profitable to the forecaster.

Observations of the Meteorological Research Flight can throw light on the detailed frontal structures, and although no flights have so far been undertaken specifically to explore stratospheric fronts, recent papers of the Meteorological Research Committee by J. S. Sawyer and R. Murray, giving analyses of the observations of meteorological research flights in the vicinity of fronts and jet streams, make illuminating reading. These authors do not carry frontal analysis into the stratosphere, and indeed consider their detailed observations in many cases do not justify carrying the frontal analysis into the higher troposphere.

Mr. Bannon said he had read Berggren's preliminary paper* with interest. He had been struck by the fact that, in the examples given, no two simultaneous ascents pass completely through the stratospheric part of Berggren's front. The same could be said of the examples shown this afternoon. The observational

*BERGGREN, R.; The distribution of temperature and wind connected with active tropical air in the higher troposphere and some remarks concerning clear air turbulence at high altitude. *Tellus, Stockholm*, **4**, 1952, p. 43.

evidence for Berggren's analysis he thought was thin. Could the opener say if Berggren gave any better examples? Turning to the question of Berggren's tropopause analysis Mr. Bannon said that when the preliminary paper was published he wrote* pointing out that the tropopause analysis did not accord with the definitions in use in the British Meteorological Office. Berggren agreed this was so, but said the limiting lapse rate of 2°C./Km. in current use is quite arbitrary and carries no great weight. In conclusion Mr. Bannon said there was no doubt that a good deal of clear-air turbulence occurs in the regions indicated by Berggren, but a great deal also occurs elsewhere. In his view it was wrong to attempt to tie the turbulence to the Berggren front, and the prognostic problem was mainly one of forecasting upper wind shears. Mr. Hawson, in reply, said that from the point of view of observations the best example of a cross-section in Berggren's papers is that of the warm front over the British Isles at 0300 on November 9, 1949, given in the preliminary paper.

Mr. Veryard asked if Berggren gave his definition of the tropopause. Mr. Hawson replied that he did not know of any special definition proposed by Berggren; none was given in the paper.

Mr. V. R. Coles said that on the slide showing the surface analysis at 0000 G.M.T. on November 8 he noticed a frontal system to the north-east of Iceland much nearer to Keflavik than the Atlantic warm front for which the detailed analysis was given. Would not the other frontal system affect Berggren's upper air analysis? He was also unhappy about the magnitude of the discrepancy between the winds as observed and as adopted by Berggren at 200 and 170 mb. at 0300 on November 8 at ocean weather station J. In reply, Mr. Hawson said that Berggren does not give a surface analysis for 0000 on November 8, only one for 0300 on the 9th which serves for other cross-sections as well. This is not the most convenient for the example under review. He had therefore prepared the slide shown from the 0000 chart for November 8, 1949, published in the *Daily Weather Report*. As Mr. Coles so rightly noticed, this contains the additional frontal system to the north-east of Iceland which might well complicate the analysis. This frontal system is a very old one, however, with an inverted warm sector. Berggren does not mention it; it might not even appear on Berggren's surface charts, and it was soon dropped from the British analysis. There is no sign of this frontal system on the upper air soundings, although there is evidence on the Keflavik sounding for an arctic front which does not appear on the British analysis. With reference to the winds at station J, the errors attributed to the winds at 200 and 170 mb. by Berggren are about three times the probable error of British ocean-weather-ship wind observations. An individual observation can show such a large error, especially if the observation is made at long range, as in this case, and the sea is rough. The discrepancy is certainly disturbingly large, but not impossible on instrumental grounds.

Mr. Peters wondered whether the frequency and accuracy of upper air observations were sufficiently high to justify conclusions being drawn about the finer structure of troposphere and stratosphere. He thought it important that the principle of continuity in tropopause analysis should be recognized and studied, and suggested that, in the daily routine of upper air analysis, tropopauses determined by assistant staff should be checked by upper air analysts for

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*BANNON, J. K. and BERGGREN, R.; Jet streams and clear air turbulence. *Tellus, Stockholm*, 4, 1952, p. 385.

consistency with the evolution of the general situation. He considered that many of the doubtful assessments of tropopause depending on small changes in lapse rate would thereby be eliminated, whilst some, that now result from an uncritical application of the existing definitions and have little or no physical significance, would be suppressed. The problem of devising new definitions of the tropopause had been under study in the Meteorological Office for several years past, and it was now being examined by the World Meteorological Organization. He hoped a satisfactory solution would not be unduly delayed.

Mr. Matthewman said he had drawn a number of cross-sections through fronts while at Dunstable. He thought the general pattern of the isotherms around a well marked warm front were often very similar to those displayed by Berggren, but there was insufficient evidence to say that the pattern was exactly like Berggren's around and above the tropopauses. There was evidence of well marked fronts in the upper troposphere on occasions. Meteorological research flights suggested a frequency of about one such front a month in the vicinity of the British Isles. Another model analysis he had found useful, was one in which the boundaries of the frontal zone were extended to link with the tropopauses of the two air masses. The model looked rather like a waterspout.

Mr. Sawyer said he thought that analyses such as Berggren's were useful for fixing ideas, even if only as a basis for discussion. The small-scale fluctuations of temperature found in the atmosphere made objective analysis difficult, since these were easily capable of masking the large-scale structure. Small-scale temperature changes of the order 5°F. in 6–10 miles had been observed by the Meteorological Research Flight on several occasions. In some cases the irregularities of the temperature profile, observed by research flights through fronts, were such that an analysis into a definite frontal zone containing a strong temperature gradient separating two more or less homogeneous air masses represented a considerable idealization of the observed curve, and could not be carried out objectively. In other cases the analysis in terms of a frontal zone appeared simple and natural. He was unconvinced by Berggren's analysis.

Mr. Gold said he first wished to thank the Director for his kind invitation for guests to attend Meteorological Office Discussions, a privilege which is very much appreciated. On behalf of the guests he extended sincere Christmas and New Year good wishes to the Director and members of the Meteorological Office. Mr. Gold recalled that he had been "in" at the birth of fronts and said he was now beginning to wonder if he were present at their death. He thought in tropospheric analysis it is essential to consider the synoptic history, and that rigid definitions of the tropopause are inappropriate in research work. The British tropopause definitions were drawn up 40 yr. ago, when upper air observations were as far as a month apart and relatively little was known of the upper atmosphere. The term tropopause was introduced to describe something they found in their early observations. If modern observations show that such a phenomenon does not always exist, it is wrong to insist on labelling a tropopause on each ascent. He suggested that the humidity observations should be used to assist in the identification of the tropopause. Turning to Berggren's paper, he asked if the winds were in agreement with the temperature gradients, and if not, which should be believed. Further, he was unconvinced by Berggren's statement that the trajectories of the air immediately above and below the tropopause are often similar. Wherever the tropopause slopes, there is a more or less rapid change of wind from the upper troposphere to the lower stratosphere. Air masses in these layers which today are in juxtaposition, will have been yesterday 500–1,000 miles apart. Mr. Hawson, in his reply, said that as temperature falls the lag of the humidity unit on the British radio-sonde becomes greater and the observations decline rapidly in value. The decline is such that when the temperature falls below a certain value (−40°F.) reporting of the humidity observations is discontinued. Humidity observations therefore usually fail to provide a routine basis for tropopause analysis. With the exception of the winds at 200 and 170 mb. at station J already mentioned, the winds and temperature gradients in Berggren's analysis are in good agreement. He wished to emphasize that Berggren himself drew attention to the discrepancy. The general question of conflict between observed winds and observed temperature or contour gradients is a broad one, depending upon the distribution of the observing stations, the type of the instruments used and the altitude. For British land stations the probable error of a wind observation is about 5 kt. and changes little with height unless extreme range is reached. British ocean-weather-ship wind observations have probable errors two or three times greater. For British radio-sonde contour-height observations, the random probable error increases with altitude and is about ± 50 ft. at 300 mb. For stations spaced as in Great Britain and a westerly wind the corresponding probable error of the geostrophic wind between two adjacent stations is between about 20 and 30 kt. At 100 mb. the corresponding probable errors are about twice as great. The problem of the trajectories of air above and below the tropopause is a difficult one to settle. He had examined a few examples of track analysis available in the research section at Dunstable and found some support for Berggren's claim. The closer one approached the tropopause the easier it was to believe the claim. He fully agreed with Berggren's hypothesis that the tropopause should not be regarded as a boundary between two different air masses but as a phenomenon localized within one air mass.

Dr. Farquharson referred to the fact that a number of years ago he had used PAMPA records in a study of fronts, and had been disappointed to find how rarely a front could be traced on upper air records above about 10,000 ft. Mr. Matthewman when working in the Forecast Research Division on fronts had given the impression that he also found it hard to find fronts above about 10,000 ft. He (Dr. Farquharson) was not convinced by Berggren's case for fronts in the stratosphere.

Mr. Gold said he was still unconvinced on the question of similar trajectories above and below the tropopause. If the trajectories are similar, how does the change from damp to dry air across the tropopause arise. The frost point falls with increasing height in the troposphere mainly because the air gets colder; that cause does not operate in the stratosphere. The plausible and probable explanation of the low values of the frost point in the stratosphere is that the air has come from lower latitudes (or in the polar night from polar regions) where correspondingly low temperatures have occurred. Some of this very dry (absolutely) air could naturally get mixed with the layer around the tropopause, and so account for the frost point in these layers being below the air temperature. Without such interchange the air at the tropopause would necessarily be saturated. The alternative suggestion of dissociation of the water vapour seems less likely. Mr. Hawson, in his reply, said that he believed the atmosphere to be generally baroclinic; by the action of pre-existing pressure systems and geography the baroclinity is given character and, in particular, sloping zones of relatively strong baroclinity are produced. These give rise to strong upper wind fields of considerable character, which produce major convergence and divergence and associated vertical motions within the atmosphere, largely in accordance with the theories of Sutcliffe and his collaborators. In their turn these modify the pressure systems and baroclinity to renew the cycle, the vertical motions reacting with the atmosphere to determine the weather. If divergence is concentrated at the tropopause level, vertical motion takes place upwards and downwards to this level. The air above the level is warmed and becomes dry (i.e. the relative humidity becomes low). The air below the level is cooled, becomes damp and approaches the saturated adiabatic lapse rate. If the divergence level does not coincide with the tropopause level a similar effect occurs and in addition the character and height of the tropopause is modified. The tropopause is dragged towards the divergence level and in time a new tropopause is formed at this level. Mr. Hawson said he did not claim this to be an authoritative account of what happens but simply a statement of what he personally believed. It was offered as a possible explanation to meet Mr. Gold's point.

Dr. Sutcliffe referred to the Canadian adoption of a system of synoptic analysis with three distinct frontal surfaces more or less continuous. He said one's reactions depended on one's point of view. It was possible to define a variety of models and then attempt to explain the behaviour of the atmosphere in terms of any chosen model. As time went on and unexplained features were discovered various adjustments had to be made to the original ideas or the model rejected and a new one developed. On the whole he thought that models too often attempted to "straight-jacket" the atmosphere. He recognized the necessity for objective definitions of the tropopause for some statistical work which must deal with the raw data. These definitions would not always satisfy the synoptic analyst's tests of continuity in space and time.

Dr. Farquharson said that senior forecasters in the Forecasting Division had envisaged with horror the possibility of certain suggestions as to fronts in the upper air being adopted by the World Meteorological Organization. Problems in analysis abounded, but these were best dealt with by giving considerable freedom to the scientists who were the senior forecasters at Dunstable. He would like to make it clear that denigration of frontal analysis in the high atmosphere was in no sense a depreciation of the Bjerknes school of thought whose ideas, in his view, constituted the greatest contribution to practical forecasting of the present century.

Dr. Frith said that the observations made by the Meteorological Research Flight showed that it was the relative humidity which fell sharply across the tropopause. As a rule absolute humidity simply went on falling more or less steadily with increasing altitude. These observations favoured the idea that the stratosphere and the troposphere either side of the tropopause are one air mass. Mr. Hawson said he was glad to echo the pleas which had been made for continuity in analysis but must sound a note of warning. Air masses are not static things, but living dynamic entities constantly changing character by the processes of subsidence and convection, as well as advection and radiation. He recalled the case of a front which passed through Dunstable as a well marked cold front, yet, having traversed the North Sea, approached southern Scandinavia as a warm front. The air to the west of the front apparently first subsided rapidly to become the warmer air, and then picked up moisture from the North Sea.

Mr. Davies suggested that Berggren might find similar trajectories immediately above and below his tropopauses because he placed them within one air mass, according to the British analysis. Mr. Hawson replied he did not think this likely. Although he had pointed out examples where Berggren's tropopause analysis differed from the routine British analysis there were plenty of cases where the two were in agreement.

Mr. Harley said that the fact of briefing those who fly through the atmosphere compels the forecaster, while using simplified ideas such as fronts, to keep close to the realities of atmospheric behaviour. He has to try to maintain a scientific attitude, remembering how much these working ideas are but hypotheses, and to struggle to form a clear conception of atmospheric circulations in three dimensions, which is essential to real forecasting. Mr. Harley supported Mr. Hawson in his declaration of his beliefs in this respect.

Mr. Lumb said that at Preston they had been forecasting the height of the tropopause for some time, in connexion with their high-level wind forecasts. They found the "waterspout" model described by Mr. Matthewman of value.

The Director, in closing the meeting, said that he had been most interested by the discussion. He was quite used, in mathematics, to problems which had been dealt with in different ways, but the answer always was the same. This did not seem to hold for upper air analysis, which had a large subjective element. However, even if this discussion had shown the weakness or failure of a model, we should not worry unduly. Physics progresses by proposing hypotheses, finding where they fail and constructing new hypotheses. As Jeffreys said: "It is the exception which improves the rule".

LETTER TO THE EDITOR

Rate of rise of pilot balloons

In your issue of October 1953 Mr. F. H. Ludlam discusses some experiments he has carried out in the Albert Hall on the rate of ascent of pilot balloons. Amongst others, four 20-gm. balloons were inflated to give free lifts varying between 62 and 91 gm. and on release were all found to ascend at the same rate, within the observational error, of 150 m./min. This result appears to me remarkable, and from it Mr. Ludlam concludes that small variations of lift such as may be produced by intermittent sunshine or a slow leak will have a negligible effect on the rate of ascent of balloons. He adds that "this effect was discovered by J. S. Dines in his original work on the rate of ascent of pilot balloons". The reference is to a paper of mine in the *Quarterly Journal of the Royal Meteorological Society* of 1913, but I do not think that this can fairly be deduced from my paper. On the contrary, I found that the change in the rate of ascent of a balloon inflated to increasing diameters agreed closely with that expected from the assumptions that the resistance to rising varies as the square of the velocity and directly as the cross-sectional area. From these assumptions it is easy to calculate that any increase in free lift due to expansion of the gas by heating or decrease due to a slow leak will lead to a corresponding increase or decrease in the rate of ascent.

The behaviour of balloons is known to be erratic, and the rate of rising through the height available in the Albert Hall may well differ between one ascent and another so that a considerable series of measurements is desirable to give a reliable mean. Is it possible that Mr. Ludlam trusted to results obtained from too few ascents and that a longer series would have shown that the balloons with the larger lift did in fact rise with the greater velocity? The only other explanation which I can think of is that with these particular balloons (20 gm.) rising at this particular rate (150 m./min.) some factor comes in, such as a change in the instability of the wake, which over a limited range prevents an increase of free lift leading to an increase in the rate of ascent. My own experiments did not suggest any discontinuity of this kind, but it should be pointed out that I did not use balloons of this particular size.

J. S. DINES

The Yews, Hermitage, Newbury, Berks., November 13, 1953

[I agree with Mr. Dines that the results of our tests are remarkable, and would say also that they are consistent and reliable even though few in number. It appeared to us that the shape of the balloons when inflated was important. Increased inflation can distort a balloon considerably from a spherical shape; it then ascends with its major axis roughly horizontal and the characteristics of the wake may change. It is certainly implied that formulae for the rate of ascent can be applied only to balloons of particular construction, inflated into a particular shape.—F. H. LUDLAM]

NOTES AND NEWS

Napier Shaw Centenary

The centenary of the birth of Sir William Napier Shaw falls on March 4, 1954.

One of Shaw's actions as Director of the Meteorological Office was the establishment in 1905 of the Monday discussions. One may imagine with what great interest he would have attended the discusssion of February 15, 1954, on the work on the numerical prediction of the pressure distribution which is being carried out in the laboratory at the Central Forecasting Office which bears his name.

The discussion of January 18, 1954 on the services provided by the Office to agriculture would have been equally interesting to him, for Shaw did much to encourage agriculturists to use meteorological knowledge and meteorologists to make the observations agriculturists need and arrange them in the most suitable way.

Observations aboard "selected" ships

The series of photographs in the centre of this magazine, beginning with those facing p. 80 shows how the observations are made aboard ship. The photographs were taken on board M.V. *Ruahine* with the assistance of Mr. J. Cosker, Third Officer, and Mr. R. Baker, Third Radio Officer, and by permission of Capt. Youngs, the Marine Superintendent of the New Zealand Shipping Co. Ltd.

Frequency distribution of wind speeds

Summaries of meteorological observations are commonly presented in the form of frequency distributions which may, in some cases, be represented concisely by frequency curves or their Cartesian equations. Brooks and Carruthers[1] fit a Pearson curve of Type I to observations of Beaufort wind force at Boscombe Down, 1932–38, and they quote Sherlock as having successfully fitted a Pearson Type III curve to frequencies of wind speed in America[2]. According to Jacobs, however, the frequency distributions of wind forces in the British Isles are expressible by a law of exponential form[3]. If n_v is the percentage of observations which exceed the wind speed v the relation found by Jacobs is

$$n_v = e^{a-bv^2}$$

or

$$\log_e n_v = a - bv^2 .$$

At any particular place b is constant for all directions of wind and is equal to the slope of the straight line obtained by plotting the natural logarithm of the mean values of n_v (i.e. for all directions) as ordinate against the quantity v^2 as abscissa. The relation expressed by the equation given above holds good for the frequencies of wind force in each cardinal direction owing to the constancy of b, and hence it is clear, when putting v equal to zero, that e^a is the total percentage of winds of all speeds from any given direction. The quantity a will therefore vary according to the direction of wind which is under consideration. In his memorandum, however, Jacobs does not give the experimental evidence on which his assertion of the constancy of the coefficient b for all directions is based.

The equation given by Jacobs has been found to be of great value in estimating the usability of airfields as limited by the force of the wind, especially at places where wind statistics are only available in the form of separate summaries of wind force and of wind direction. Crossley has shown (in an unpublished manuscript) that this equation corresponds to a frequency curve of the form

$$P(v) = 2b\, v\, e^{-bv^2} ,$$

and he deduces from it that the mean value of the wind speed v is equal to $\sqrt{(\pi/b)}/2$. The average wind speed is thus constant for all directions. We may make the further deduction that the variance of the wind speed is equal to $(1 - \pi/4)/b$ or approximately $1/5b$.

It would appear, however, that Jacobs's law is not of universal validity. In studying the wind observations at Kabete Observatory, Nairobi, for the 10 yr. 1934–43, the writer found that the wind forces observed at 1500 local time conformed to the linear relationship between $\log_e n_v$ and v^2 required by the law, but that those observed at 0900 did not. The proportion of light winds observed at Kabete at 0900 was much higher than at 1500, and there were also about

TABLE I—WIND STATISTICS AT KABETE OBSERVATORY, 1934–43

v	v^2	0900 n_v	0900 $\log_{10} n_v$	1500 n_v	1500 $\log_{10} n_v$
m.p.h.		%		%	
0·5	0·25	88·3	1·94547	100	2·00000
3·5	12·25	64·3	1·80821	97·3	1·98811
7·5	56·25	25·0	1·39794	78·2	1·89321
12·5	156·25	3·4	0·53403	34·3	1·53466
18·5	342·25	0·4	$\bar{1}$·61909	7·7	0·88930
24·5	600·25	...	...	0·6	$\bar{1}$·76567

Calms: 0900, 11·7 per cent.; 1500, zero.

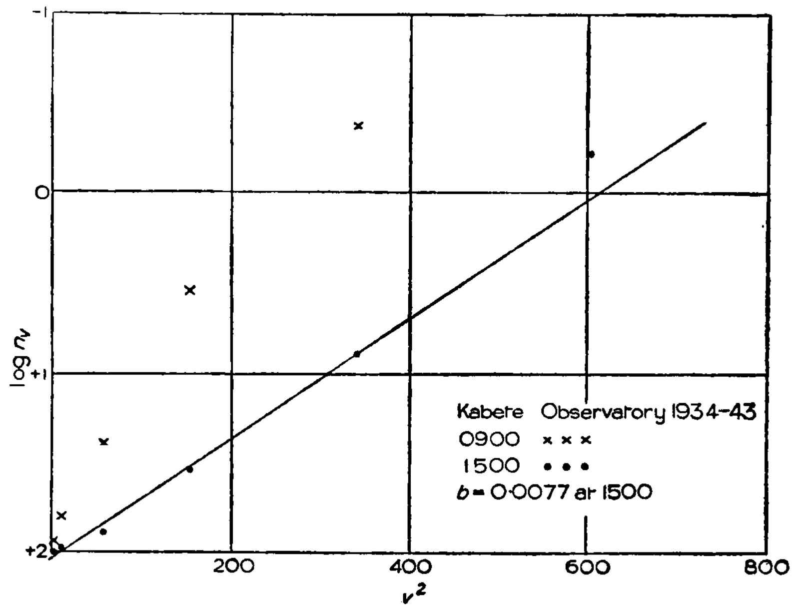

FIG. 1—WIND STATISTICS FOR KABETE OBSERVATORY, 1934–43

12 per cent. of calms at 0900, whereas no calms were recorded at all at 1500. The observations at Kabete therefore suggest that the law formulated by Jacobs is only valid for wind forces observed in conditions of turbulent motion and that laminar motion in the surface layers of the atmosphere apparently vitiates it.

J. WADSWORTH

REFERENCES

1. BROOKES, C. E. P. and CARRUTHERS, N.; Statistical methods in climatology. London, 1944.
2. BROOKES, C. E. P. and CARRUTHERS, N.; Handbook of statistical methods in meteorology. London, 1953.
3. JACOBS, L.; The planning of runway layouts from the point of view of weather. Unpublished; copy in Meteorological Office Library, London, 1944.

METEOROLOGICAL OFFICE NEWS

Retirements.—*Mr. R. A. Watson*, Principal Scientific Officer, retired on January 10, 1954. He joined the Office in 1919; during his 35 years' service he worked at several aviation outstations, at Eskdalemuir Observatory, at Edinburgh and at Headquarters where he was Head of the Branch concerned with meteorological training in the Royal Air Force and with the meteorological requirements of the War Office and Ministry of Supply. At the time of his retirement he was Superintendent of the Meteorological Office, Edinburgh. Mr. Watson was seconded as Director of the Royal Alfred Observatory, Mauritius during 1927–30. Mr. Watson has accepted a temporary appointment in the Meteorological Office.

Dr. A. W. Lee, Senior Scientific Officer, retired on January 31, 1954, because of ill-health. He joined the Office in 1923 and served at Lerwick, Kew and Eskdalemuir Observatories until 1939. During the Second World War he served at Headquarters, Bomber Command and as Senior Meteorological Officer, No. 12 Group of the Royal Air Force. From 1946 to 1948 he served at Headquarters. During the past five years Dr. Lee worked at Kew Observatory.

Mr. W. A. Toms, Senior Experimental Officer, retired on December 31, 1953, on medical grounds. He joined the Office in 1918 when he was attached to the Observatory at Falmouth. The whole of his career in the Meteorological Office was spent at outstations and included two tours of duty overseas.

Academic successes.—Information has reached us that the following members of the staff have been successful in recent examinations; we offer them our congratulations.

Intermediate B.Sc.: pure and applied mathematics, geography, J. N. Brand, M. F. Lee.

General Certificate of Education (Advanced Level): pure and applied mathematics, physics, J. A. Gregson; pure mathematics, physics, D. C. Davis, W. H. Mills; pure mathematics, A. Lambley; physics, J. H. F. Childs.

University Bursaries for Assistant Experimental Officers.—We congratulate Mr. P. Goldsmith on his selection for an award of a bursary, to be taken up in 1954, for full-time study at a university.

Ocean weather ships.—o.w.s. *Weather Watcher* and *Weather Explorer* spent Christmas at sea. An aircraft of R.A.F. Coastal Command from Kinloss, on a navigation exercise, dropped mail and parcels, including fresh milk! The aircraft was able to drop the containers close to the ships, which was perhaps fortunate, as owing to heavy swell it was not possible to lower any boats. Seasonal greetings were exchanged between the aircraft and the ships. On Christmas Day, after the evening meal, impromptu concerts were held in which all hands joined.

Sports activities.—The Ariel Club Wintle Cup for the annual Billiards Handicap has been won this year by Mr. R. A. Ogden of M.O.8. This trophy has not been won by a member of the Meteorological Office staff for nearly 30 years when it was held by Mr. W. G. Davies, who is now at Watnall. Mr. Ogden also reached the semi-finals of both the Snooker Handicap and the Snooker Doubles Handicap.

WEATHER OF JANUARY 1954

Mean pressure was above normal over the eastern United States, the North Atlantic and north-west Europe but below normal over central Europe and the Mediterranean. The greatest excess of mean pressure above normal occurred in the region just west of Ireland and reached 10 mb. in places. The highest value of mean pressure, 1026 mb., was in the region between the Azores and Portugal while the lowest mean pressure, 999 mb., was recorded by the ocean weather ship between Greenland and Iceland. Mean pressure over the Mediterranean varied between 2 and 6 mb. below normal, the lowest mean pressure, 1010 mb., being in southern Italy.

Mean temperature was below normal over most of Europe, including the Mediterranean region; in south-east Europe it was as much as 12°F. below normal, but elsewhere it was between 2° and 5°F. below normal.

In the British Isles the weather was changeable; for the first ten days the general type of weather was northerly; subsequently a mild, unsettled westerly type prevailed for the most part until the 20th. South-easterly winds set in on the 22nd and from the 24th onwards it was very cold; in the last few days the wind was north-easterly.

On the 1st a large anticyclone was centred over south-west Ireland; this moved westward while a ridge to the north of it moving east resulted in rather cold N.–NE. winds over most of Great Britain. Another outbreak of northerly winds on the 6th caused an occlusion to break through the ridge, and wet snow fell over much of England and Wales and wintry showers in Scotland and Northern Ireland. Frost followed and frozen snow and ice affected many areas for 48 hours; on the 8th, Topcliffe in Yorkshire had a screen minimum temperature of 9°F. and Houghall, County Durham, one of 8°F. Later on the 8th milder air came round the anticyclone centred off south-west Ireland, with a general thaw, and a rather mild north-west current lasted until the 11th, with scattered slight rain or showers. An unsettled, mostly mild, south-westerly type of weather, with rain at times set in on the 12th culminating in the widespread gale of the 15th, which was most severe in the north, with gusts of 84 kt. and 79 kt. at Renfrew and Flamborough Head, respectively. During the gale, trees were blown down, buildings suffered considerable damage and many people were injured and a few killed. The westerly wind, of long fetch over the Atlantic, was unusually mild and temperature rose to 55°F. or above at most places in England and Wales on the 15th; 57·7°F. at Kew Observatory was the highest in January since records started there in 1871. On the 17th to 18th a ridge of high pressure moved east across the country giving widespread frost, but during the 18th mild south-westerly winds returned and heavy rain fell in the north-west (3·35 in. at Ardgour, Argyllshire). Between the 20th and 22nd there was a major change of type. On the 20th temperature reached 55–57°F. in many places in the south but there was an anticyclone to the north-east of Iceland and colder air was encroaching over the north-east districts of the British Isles. During its advance there was heavy rainfall and some flooding in south Scotland and north England (3·40 in. at Stonyhurst, Lancashire, 3·11 in. at Bolton Waterworks, Lancashire and 2·64 in. at Stocks Reservoir, Yorkshire on the 20th). By the 22nd the anticyclone had moved to Scandinavia, and on the 23rd its central pressure reached 1048 mb. and it was the dominant feature for the remainder of the month. Frost occurred over much of England on the 24th and from this time onwards the weather was severe. A trough over Ireland and west Scotland gave heavy rain locally in these areas on the 24th (2·50 in. at Gruline, Isle of Mull). The trough developed into a depression over Ireland on the 25th, which, moving south-east, gave considerable snow locally over most western districts of Great Britain and also in southern England excluding Kent and the London area (snow lay to a depth of 1 ft. at Bwlchgwyn, Denbighshire on the 26th). Snow fell during the last few days in most areas, mainly in small amounts. Temperature remained continuously at 32°F. or below at some low-level stations from the 25th to the 28th inclusive, for example at Watnall in Nottinghamshire, while at Bwlchgwyn (1,267 ft. above M.S.L.) air frost began at 1300 on the 24th and continued for the rest of the month. On the 28th South Farnborough registered a screen minimum temperature of 10°F. and at Boscombe Down the maximum on the same day was only 23°F.

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 ...	59	8	−1·9	88	−3	117
Scotland	56	9	−0·1	101	−1	112
Northern Ireland ...	55	17	−0·3	93	+1	78

RAINFALL OF JANUARY 1954

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square	1·04	56	*Glam.*	Cardiff, Penylan	2·66	72
Kent	Dover	2·33	109	*Pemb.*	Tenby	..	..
,,	Edenbridge, Falconhurst	1·69	67	*Radnor*	Tyrmynydd	5·83	93
Sussex	Compton, Compton Ho.	2·20	69	*Mont.*	Lake Vyrnwy	5·90	102
,,	Worthing, Beach Ho. Pk.	1·26	54	*Mer.*	Blaenau Festiniog	10·38	102
Hants.	Ventnor Park	1·86	71	,,	Aberdovey	4·07	105
,,	Southampton (East Pk.)	1·45	54	*Carn.*	Llandudno	2·17	90
,,	South Farnborough	1·43	68	*Angl.*	Llanerchymedd	2·85	90
Herts.	Royston, Therfield Rec.	0·81	47	*I. Man*	Douglas, Borough Cem.	4·25	127
Bucks.	Slough, Upton	0·89	47	*Wigtown*	Newton Stewart	4·59	111
Oxford	Oxford, Radcliffe	1·29	71	*Dumf.*	Dumfries, Crichton R.I.	4·01	125
N'hants.	Wellingboro' Swanspool	0·93	50	,,	Eskdalemuir Obsy.	5·55	103
Essex	Shoeburyness	1·33	99	*Roxb.*	Crailing	2·36	122
,,	Dovercourt	1·67	104	*Peebles*	Stobo Castle	4·45	148
Suffolk	Lowestoft Sec. School	1·55	93	*Berwick*	Marchmont House	2·53	112
,,	Bury St. Ed., Westley H.	1·52	85	*E. Loth.*	North Berwick Res.	1·85	108
Norfolk	Sandringham Ho. Gdns.	1·93	99	*Midl'n.*	Edinburgh, Blackf'd. H.	2·24	127
Wilts.	Aldbourne	2·08	90	*Lanark*	Hamilton W. W., T'nhill	4·91	149
Dorset	Creech Grange	1·77	54	*Ayr*	Colmonell, Knockdolian	3·77	87
,,	Beaminster, East St.	2·34	67	,,	Glen Afton, Ayr San.	6·30	124
Devon	Teignmouth, Den Gdns.	1·63	56	*Renfrew.*	Greenock, Prospect Hill	7·59	117
,,	Ilfracombe	2·39	73	*Bute*	Rothesay, Ardencraig	5·49	122
,,	Princetown	4·11	52	*Argyll*	Morven (Drimnin)	7·36	116
Cornwall	Bude, School House	2·24	74	,,	Poltalloch	..	..
,,	Penzance, Morrab Gdns.	3·65	96	,,	Inveraray Castle	9·09	111
,,	St. Austell	3·09	72	,,	Islay, Eallabus	6·37	136
,,	Scilly, Tresco Abbey	2·68	85	,,	Tiree	6·24	147
Somerset	Taunton	1·81	76	*Kinross*	Loch Leven Sluice	3·57	113
Glos.	Cirencester	1·69	67	*Fife*	Leuchars Airfield	1·36	75
Salop	Church Stretton	2·71	104	*Perth*	Loch Dhu	9·23	101
,,	Shrewsbury, Monkmore	2·33	119	,,	Crieff, Strathearn Hyd.	3·39	84
Worcs.	Malvern, Free Library	1·65	75	,,	Pitlochry, Fincastle	3·71	106
Warwick	Birmingham, Edgbaston	1·08	53	*Angus*	Montrose, Sunnyside	1·10	55
Leics.	Thornton Reservoir	1·23	62	*Aberd.*	Braemar	2·29	72
Lincs.	Boston, Skirbeck	1·26	78	,,	Dyce, Craibstone	1·11	47
,,	Skegness, Marine Gdns.	1·49	86	,,	New Deer School House	1·72	74
Notts.	Mansfield, Carr Bank	1·75	81	*Moray*	Gordon Castle	1·14	56
Derby	Buxton, Terrace Slopes	4·64	104	*Nairn*	Nairn, Achareidh	1·35	75
Ches.	Bidston Observatory	2·48	117	*Inverness*	Loch Ness, Garthbeg	3·57	81
,,	Manchester, Ringway	2·70	113	,,	Glenquoich	..	..
Lancs.	Stonyhurst College	5·63	132	,,	Fort William, Teviot	7·99	82
,,	Squires Gate	2·89	111	,,	Skye, Broadford	7·61	101
Yorks.	Wakefield, Clarence Pk.	1·94	101	,,	Skye, Duntuilm	4·87	92
,,	Hull, Pearson Park	1·68	93	*R. & C.*	Tain, Mayfield	2·00	82
,,	Felixkirk, Mt. St. John	2·69	135	,,	Inverbroom, Glackour	5·82	108
,,	York Museum	1·36	77	,,	Achnashellach	7·38	81
,,	Scarborough	1·80	90	*Suth.*	Lochinver, Bank Ho.	3·45	81
,,	Middlesbrough	2·41	151	*Caith.*	Wick Airfield	1·86	76
,,	Baldersdale, Hury Res.	3·71	111	*Shetland*	Lerwick Observatory	3·74	88
Norl'd.	Newcastle, Leazes Pk.	2·87	145	*Ferm.*	Crom Castle	2·31	69
,,	Bellingham, High Green	3·13	109	*Armagh*	Armagh Observatory	1·87	74
,,	Lilburn Tower Gdns.	2·92	141	*Down*	Seaforde	2·69	85
Cumb.	Geltsdale	3·04	109	*Antrim*	Aldergrove Airfield	2·74	100
,,	Keswick, High Hill	4·58	91	,,	Ballymena, Harryville	3·82	103
,,	Ravenglass, The Grove	2·99	89	*L'derry*	Garvagh, Moneydig	3·74	109
Mon.	A'gavenny, Plâs Derwen	3·80	102	,,	Londonderry, Creggan	4·09	114
Glam.	Ystalyfera, Wern House	3·70	59	*Tyrone*	Omagh, Edenfel	3·24	92

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

Wt. 34. K16

M.O. 581 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 83, No. 982, APRIL 1954

WORLD METEOROLOGICAL ORGANIZATION

There are eight Technical Commissions of the World Meteorological Organization, each responsible, in its own sphere, for "(a) keeping abreast of and promoting meteorological developments; (b) standardizing methods, procedures and techniques". Each Commission must meet at least once every four years; all eight will have met during the 20 months July 1952 to February 1954—six of them during the five months July 1953 to November 1953.

Combined Meeting of the Commissions for Instruments and Methods of Observation and for Aerology

The Commission for Aerology and the Commission for Instruments and Methods of Observation met at the same time, in Toronto, from August 10 to September 5, 1953—and experienced the hottest August for 50 years. Both meetings were held in the Economics Building of the University of Toronto, and, as far as practicable, it was arranged that sessions of the two Commissions did not clash. This was quite important because of the 18 countries represented six were represented on both Commissions by only one man.

The British representatives on the Commission for Aerology were Dr. R. C. Sutcliffe, Miss E. E. Austin and Prof. P. A. Sheppard; and on the Commission for Instruments and Methods of Observation, Dr. D. N. Harrison, Dr. R. Frith and Capt. S. W. C. Pack.

The subjects discussed by the Commission for Instruments and Methods of Observation ranged over a very wide field and a great many Recommendations and Resolutions were made. The vast majority of these were concerned with "keeping abreast of and promoting meteorological developments", only three or four being concerned with the "standardization of methods, procedures and techniques". The most important of these were: Technical Regulations; Barometer Conventions; Comparison of radio-sondes.

In the Technical Regulations are those rules, governing the performance of instruments and methods of observation, which must be observed by all Member States to ensure that the observations from all countries are strictly comparable (e.g. that surface wind reports refer to the same height above the ground and to the wind averaged over the same length of time—which is by no means the case at present).

The new Barometer Conventions are intended to tidy up the present confusion, whereby millibar barometers are adjusted to read correctly at 12°C. in England, at 0°C. in Europe, and at 54°F. in Canada; and inch barometers are made to read correctly at 32°F. for one purpose and at 62°F. for another. There is similar confusion in the "standard" gravity values used. Under the new Conventions all mercury barometers will read correctly when the temperature is 0°C. and the value of gravity is 980·665 cm./sec.^{2}

It is difficult to assess the absolute accuracy of radio-sonde data. It is therefore all the more important that any differences in the readings obtained from different types of radio-sondes, especially between those types used in neighbouring countries, should be known. To investigate these differences one series of comparison trials has already been held in Switzerland; it is now planned to carry out a second, and later a third, series of trials.

The Commission for Aerology is more closely connected with research than the other Commissions, and among the most important of its recommendations were those aimed at lightening the task of assembling data for research, by ensuring that all aerological data are made available in the form of daily values, monthly means and long-period averages, and by drawing up specimen forms to secure as much uniformity as possible in the method of presentation.

The subjects for study during the international geophysical year were also carefully considered, the selection being based on the principle that attention should be given first to problems of world-wide significance. Special importance was attached to obtaining cross-sections of the upper air from pole to pole along certain meridians, and to additional sections in tropical regions in view of the special need for a comprehensive study of tropical meteorology and its bearing on the general circulation.

Another important part of the work of the Commission was that dealing with the study of atmospherics. Many recommendations were put forward for extending the network of stations, comparing techniques, and standardizing terminology.

The Commission for Aerology was concerned also with more theoretical subjects such as the definitions of various physical quantities (thermodynamic wet-bulb temperature, relative humidity, etc.) and the details of aerological diagrams and tables; important recommendations on these subjects were put forward.

The increasing interest in the higher levels of the atmosphere was reflected in the Recommendation that 150 mb. and 100 mb. should be added to the list of standard isobaric surfaces, and that new definitions of the tropopause should be brought into use on an experimental basis in order to provide for reports of a double tropopause.

In order to help the Commission for Aerology in its task of keeping abreast of meteorological development, nine scientific lectures were arranged outside the plenary meetings; these were well attended by members of both Commissions, and gave rise to interesting discussions.

The members of both Commissions were impressed by the difficulty of saying precisely the same thing in two or more languages; and by the confusion which can be caused by an incorrect translation.

Delegates were entertained to dinner by the Government of Canada, and, as guests of the Hydroelectric Power Commission, paid a most enjoyable visit to Niagara, where they saw not only the Falls but also something of the enormous new hydroelectric project now being developed.

At the close of the meetings M. Perlat (France) was elected President (in succession to Dr. J. Patterson who had retired), and M. Malet (Belgium) Vice-President of the Commission for Instruments and Methods of Observation. Prof. van Miegham (Belgium) was re-elected President and Dr. Sutcliffe (United Kingdom) elected Vice-President of the Commission for Aerology.

Commission for Agricultural Meteorology

There was a good attendance at the first session of the Commission for Agricultural Meteorology which was held in Paris from November 3 to November 20, 1953. Some 30 delegates representing 22 member States were present, together with several observers and representatives of such organizations as the Food and Agriculture Organization and the United Nations Educational, Scientific and Cultural Organization.

Mr. L. P. Smith represented the United Kingdom at this session.

As meteorology has a bearing on every aspect of agriculture, horticulture and forestry, the discussions ranged over a wide field of pure and applied research. It was the need of agricultural science in general, and food production in particular, for help from all branches of meteorology that prompted the Conference to reject a proposal for a merger with the Climatological Commission; it was considered that only about a third of the work of an agricultural meteorologist was concerned with climatology.

Co-operation was planned with important internal bodies such as the Food and Agriculture Organization and with the work being done by the United Nations Educational, Scientific and Cultural Organization on Arid Zone Research. It was clearly realized that advance could best be made by collaboration with other agricultural scientists, and many of the recommendations and choices of working parties stressed this important point. The fight against pests and diseases, such as locusts and the diseases of potatoes, cereals and vines for example, demands considerable meteorological aid to the entomologists, pathologists and mycologists to ensure adequate protection of plants and animals.

The problems of altering the weather, either by erecting shelter, using frost-protection methods, or attempting to create artificial rain were discussed in considerable detail. The importance of the exchange of ideas and the dissemination to other scientists and the agricultural industry of the results of pure and operational research was not lost sight of, and the most promising impression of the meeting was the practical attitude to the problems of many of the delegates.

During the three weeks, visits were made to the Station Centrale de Bioclimatologie et de Physique Agricole at Versailles and to the Bergerie Nationale at Rambouillet.

At the conclusion of the session, Prof. J. J. Burgos of the Argentine was re-elected President and Dr. H. Geslin of Versailles was elected Vice-President.

Commission for Bibliography and Publications

The Commission for Bibliography and Publications of the World Meteorological Organization held its first session in Paris from November 24 to December 12, 1953, under the chairmanship of its President, M. Mézin of *La Météorologie Nationale de France.*

Mr. G. A. Bull represented the United Kingdom at this session.

The Commission is responsible for the preparation of a lexicon of meteorological terminology with definitions and of a multi-lingual dictionary of equivalent terms, for the revision of systems of classifying meteorological subjects, and for recommending the general methods in which meteorological publications should be compiled, catalogued, preserved, reproduced, and exchanged.

The first matter dealt with at the meeting was the bringing up to date of the meteorology section, 551.5, of the Universal Decimal Classification. The section was discussed in detail and a number of changes were recommended. These changes need to be agreed between the World Meteorological Organization and the International Federation of Documentation, which is the central co-ordinating body of the Universal Decimal Classification, before they can be published. The major changes proposed are in 551.509 (Weather forecasting and other applications), 551.511 (Mechanics and thermodynamics of the atmosphere), and 551.551 (Wind, structure, microvariations, gustiness, turbulence).

The meeting considered a draft "Guide to meteorological library practice" which had been written some years ago by Dr. C. E. P. Brooks in conformity with a decision of the International Meteorological Organization Commission for Bibliography and Publications taken at its meeting at Toronto in 1947, and prepared a revised text which it is hoped will eventually be published by the World Meteorological Organization. This work gives general guidance on methods of classifying, cataloguing and preserving meteorological documents.

A draft lexicon of meteorological terminology with definitions and a polyglot dictionary of equivalents were submitted to the meeting by the French delegation, and an international working group was established to examine these important works and to act as a standing group to consider questions of the definitions of meteorological words as they arise.

Other matters considered at the meeting were the preparation of a periodic world meteorological bibliography of new literature and the exchange of meteorological publications between members.

At the close of the meeting M. Mézin was re-elected President of the Commission, and Mr. Bull (United Kingdom) was elected Vice-President.

MEAN MAXIMUM AND MEAN MINIMUM TEMPERATURES AS CRITERIA OF TEMPERATURE CHARACTERISTICS OF A MONTH

By W. A. L. MARSHALL

Cool days and warm nights of June–July 1953.—Low day-time temperatures and relatively warm nights were notable features of the weather in London during the months of June and July 1953. At Kew Observatory the mean maximum temperature in June was 1·8°F. below average and the mean minimum 1·1°F. above average, giving a mean temperature deficiency over the whole month of 0·4°F. In July the mean monthly deficiency of 1·5°F. was brought about entirely by the cool days, the mean maximum value being 3·1°F. below average while the mean minimum figure was in exact agreement with the long-period July average. Apart from a week or so at the end of June and a few isolated warm days at other times, day maximum temperatures were consistently below average. In contrast, the nights were predominantly warmer than usual from June 11 onwards. Daily values are shown in Fig. 1 in which the maximum temperature and minimum temperature for each day are given by the top of the black column or the bottom of the hatched column in their respective diagrams. The average maximum and minimum values used for Fig. 1, and throughout this note, are those for the 30-yr. period 1906–35.

It is clear from Fig. 1 that for most purposes the difference of the mean maximum temperature from the average gives a better representation of the temperature characteristics of June and July 1953 than any other single value. Night-time temperatures are not of popular interest during the summer. The object of this investigation is to ascertain with what frequency the orthodox mean monthly temperature is substantially unrepresentative of conditions by day and by night, and to discuss the usefulness of the mean maximum and mean minimum as bases for comparing one particular month with the same month in other years in respect of temperature.

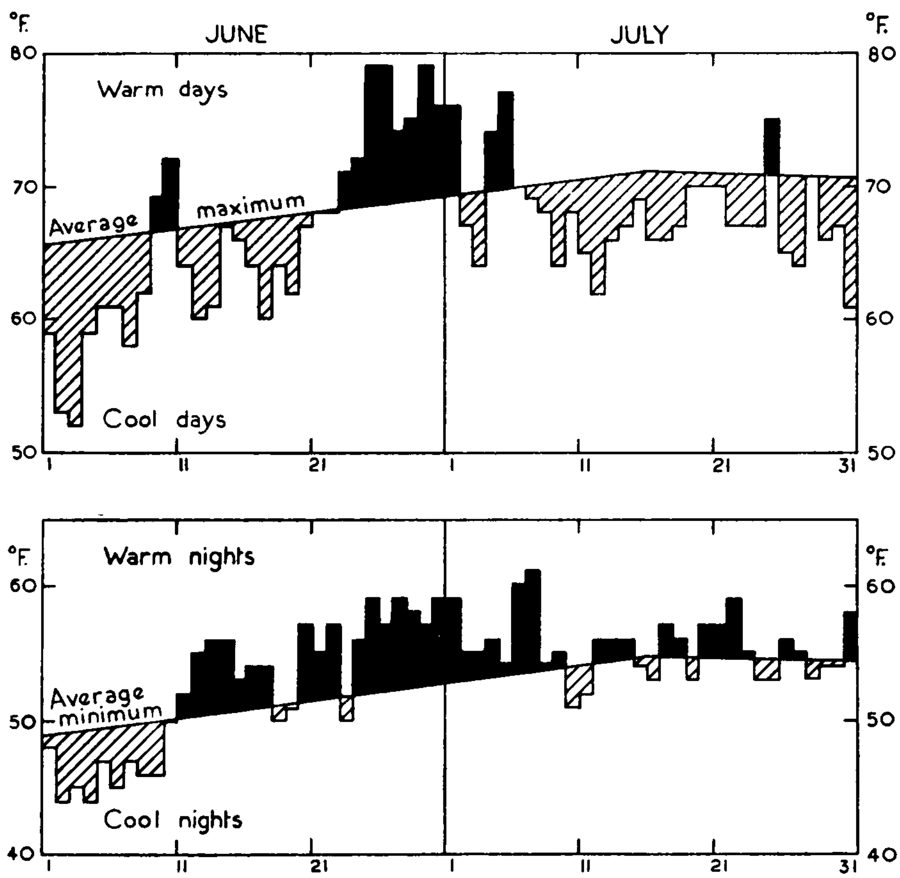

FIG. 1—DAILY READINGS OF MAXIMUM AND MINIMUM TEMPERATURE AT KEW OBSERVATORY, JUNE AND JULY 1953

Readings above average are given by the top of the black column, readings below average by the bottom of the hatched column.

Mean maximum, minimum and monthly temperatures.—Mean maximum, mean minimum and mean monthly temperatures are published in Table III of the *Monthly Weather Report* of the Meteorological Office, although departures from the average are given only for mean monthly values. The differences from their respective averages of the mean maximum (T_x), mean minimum (T_n) and mean monthly (T_m) temperatures at Kew Observatory

TABLE I

T_x = Difference of monthly mean maximum temperature from average maximum temperature.
T_n = Difference of monthly mean minimum temperature from average minimum temperature.
T_m = Difference of monthly mean temperature from average temperature.

	January			February			March			April			May			June		
	T_x	T_n	T_m	T_x	T_n	T_m	T_x	T_n	T_m	T_x	T_n	T_m	T_x	T_n	T_m	T_x	T_n	T_m
	degrees Fahrenheit																	
1928	+2·4	+0·1	+1·2	+4·5	+2·0	+3·2	+1·2	+2·3	+1·8	+0·7	+1·0	+0·9	−2·3	−1·3	−1·8	−2·0	−1·8	−2·0
1929	−6·1	−4·2	−5·2	−7·6	−8·1	−7·9	**+3·9**	*−3·8*	0·0	−2·2	−2·9	−2·5	0·0	−1·4	−0·6	−1·1	−1·3	−1·2
1930	+3·8	+2·8	+3·2	−3·1	−0·5	−1·8	+0·3	0·0	+0·2	−1·3	+1·0	−0·1	−2·7	+0·2	−1·2	+2·7	+2·1	+2·4
1931	−1·4	−1·8	−1·6	−0·7	−1·4	−1·1	−1·7	−2·5	−2·1	**−2·4**	*+0·8*	−0·8	−1·0	+0·5	−0·2	+0·9	+2·0	+1·4
1932	+3·5	+2·8	+3·1	−3·4	−2·0	−2·8	−1·3	−2·9	−2·1	−2·2	−0·1	−1·1	**−3·4**	*−0·2*	−1·8	−0·3	−0·2	−0·3
1933	−3·4	−2·9	−3·2	+0·2	+0·4	+0·2	**+5·0**	*+1·2*	+3·1	+3·1	+1·2	+2·2	+1·1	+1·1	+1·2	+3·1	+1·6	+2·3
1934	−0·5	−1·3	−1·0	−1·6	−3·8	−2·8	−0·6	−0·9	−0·8	+1·3	+1·6	+1·5	+0·8	−0·2	+0·4	+2·7	+1·2	+1·9
1935	+0·1	+1·1	+0·6	+2·7	+3·6	+3·1	+1·6	+1·8	+1·7	−0·5	+1·4	+0·5	−3·6	−2·3	−2·9	+1·8	+3·0	+2·4
1936	+0·1	+0·7	+0·4	−3·1	−2·7	−3·0	+2·3	+3·6	+3·0	−3·6	−1·5	−2·5	−0·3	−0·4	−0·3	+1·5	+2·9	+2·2
1937	+2·0	+1·9	+1·9	+2·3	+3·4	+2·8	−4·2	−2·2	−3·2	+1·8	+3·7	+2·8	+0·6	+2·0	+1·4	+1·1	+1·2	+1·1
1938	+3·5	+2·8	+3·1	+0·5	+1·6	+1·0	**+8·8**	*+3·6*	+6·2	−0·4	−1·1	−0·7	−2·8	−1·6	−2·2	+1·8	+2·0	+1·8
1939	+0·6	+2·3	+1·4	+2·3	+1·6	+1·9	−0·9	+1·6	+0·4	+1·3	+1·6	+1·5	−2·1	−1·4	−1·7	−1·2	+0·5	−0·4
1940	−9·1	−9·0	−9·1	−3·8	−1·6	−2·8	+0·5	+1·2	+0·8	+1·4	+2·3	+1·9	+2·6	+0·7	+1·7	+4·3	+3·6	+3·9
1941	−7·1	−4·2	−5·7	−1·6	−0·4	−1·0	−1·1	−0·6	−0·8	−3·6	−0·8	−2·2	−6·3	−4·5	−5·4	+2·0	+2·0	+2·0
1942	−6·8	−6·3	−6·6	−8·8	−6·5	−7·7	−1·5	−0·7	−1·1	+2·0	+3·4	+2·8	−1·4	−0·2	−0·8	+2·4	+0·3	+1·3
1943	+1·0	+2·1	+1·5	+2·5	+1·1	+1·8	+2·8	+1·4	+2·1	+5·8	+5·7	+5·8	+0·9	+1·8	+1·4	−0·5	+1·4	+0·4
1944	+3·1	+3·7	+3·4	−2·7	−0·4	−1·6	−0·8	−1·6	−1·2	+4·5	+4·8	+4·7	+1·1	−1·8	−0·4	−2·5	+0·2	−1·2
1945	−7·3	−6·0	−6·7	+5·0	+5·0	+5·0	+4·8	+3·4	+4·1	+5·2	+3·7	+4·6	+1·5	+2·0	+1·8	−0·9	+2·0	+0·5
1946	−2·8	−1·3	−2·0	+2·7	+4·0	+3·3	−2·2	−0·7	−1·4	+5·2	+2·6	+4·0	−2·8	−1·6	−2·2	**−3·8**	*+0·2*	−1·8
1947	−4·4	−4·9	−4·7	**−12·8**	*−8·5*	−10·7	−3·6	−0·7	−2·2	+1·8	+1·9	+1·9	+2·9	+2·2	+2·6	+2·4	+3·0	+2·6
1948	+3·3	+3·2	+3·2	+0·3	+1·1	+0·6	+6·1	+3·6	+4·8	+3·8	+2·5	+3·2	+0·4	−0·7	−0·1	−2·0	+0·9	−0·6
1949	+2·2	+1·4	+1·8	**+3·0**	*−0·7*	+1·1	−1·5	−0·6	−1·0	+4·9	+4·4	+4·7	−1·4	−1·3	−1·3	+2·5	+1·4	+1·9
1950	−0·3	+1·0	+0·3	+3·4	+2·3	+2·8	+3·7	+3·2	+3·4	−0·2	+1·0	+0·4	−1·6	+0·2	−0·6	+4·3	+3·8	+4·0
1951	−0·3	+0·9	+0·2	−1·5	−0·5	−1·0	−2·9	−0·6	−1·7	−1·2	−1·1	−1·1	**−4·5**	−1·4	−2·9	−0·3	−0·4	−0·4
1952	−1·4	−1·3	−1·4	−1·6	−2·0	−1·8	+0·7	+3·0	+1·9	+4·3	+3·2	+3·8	+3·3	+3·2	+3·3	+1·5	+1·1	+1·3

	July			August			September			October			November			December		
	T_x	T_n	T_m	T_x	T_n	T_m	T_x	T_n	T_m	T_x	T_n	T_m	T_x	T_n	T_m	T_x	T_n	T_m
	degrees Fahrenheit																	
1928	+3·7	+0·9	+2·3	−0·8	−0·3	−0·5	**+0·3**	*−3·3*	−1·4	+0·8	−0·1	+0·3	+3·4	+3·4	+3·4	−2·2	−3·4	−2·8
1929	+2·5	−0·4	+1·1	+0·4	−0·3	+0·1	**+7·8**	*+3·9*	+5·9	−0·8	−1·3	−1·1	+2·0	+0·5	+1·3	+2·5	+1·7	+2·0
1930	−1·8	−0·4	−1·1	+0·8	+0·4	+0·6	**−0·4**	+2·6	+1·2	+1·0	+1·4	+1·2	+1·5	+0·5	+1·0	−0·7	−1·2	−1·0
1931	−1·7	+0·3	−0·7	−3·4	−0·5	−1·9	**−4·9**	−1·7	−3·2	−1·6	−2·8	−2·2	+2·5	+2·3	+2·4	+0·5	+1·1	+0·8
1932	−0·8	+0·3	−0·3	+5·1	+3·6	+4·3	−0·6	+1·2	+0·4	−2·1	−1·5	−1·8	+0·2	+1·8	+1·0	+1·1	+1·3	+1·2
1933	+4·8	+3·2	+4·0	**+6·0**	*+2·5*	+4·3	+3·7	+3·9	+3·8	+0·4	+1·4	+0·9	−1·4	0·0	−0·7	−7·2	−5·2	−6·2
1934	+5·7	+2·8	+4·3	−0·1	−0·5	−0·3	+3·7	+1·5	+2·6	+0·6	+2·4	+1·5	−0·7	+1·4	+0·3	+5·2	+7·0	+6·0
1935	+3·9	+2·7	+3·3	+3·1	+0·2	+1·7	+0·5	+1·5	+1·0	−1·0	+0·3	−0·3	+1·5	+1·9	+1·7	−2·7	−1·4	−2·1
1936	−2·6	*+0·5*	−1·1	+1·1	+0·4	+0·7	**+0·5**	+3·7	+2·2	−1·4	−1·7	−1·5	−0·5	+0·3	−0·1	+1·1	+0·7	+0·8
1937	−0·4	+1·9	+0·7	+4·0	+2·9	+3·5	+0·1	−0·4	−0·1	+0·8	+2·1	+1·5	−2·0	−1·5	−1·7	−3·1	−2·5	−2·8
1938	−1·1	+0·1	−0·5	+1·7	+1·6	+1·7	+1·0	+1·4	+1·2	−0·3	+0·8	+0·3	+5·6	+6·3	+5·9	−1·3	−2·0	−1·7
1939	**−3·6**	*+0·3*	−1·7	+0·6	+1·8	+1·2	+1·0	+3·5	+2·3	−3·5	−0·8	−2·1	+4·0	+5·9	+4·9	−4·0	−3·2	−3·6
1940	−2·9	−1·1	−2·0	+0·8	−0·3	+0·3	+0·1	−1·0	−0·4	−1·6	+0·1	−0·7	+1·8	+0·9	+1·3	−1·6	−1·8	−1·8
1941	+3·2	+2·5	+2·9	**−4·3**	*−0·3*	−2·3	+0·8	+3·2	+2·0	−0·1	+1·2	+0·5	+0·7	+1·0	+0·9	+0·7	+0·7	+0·6
1942	−2·4	+0·3	−1·1	+0·4	+2·0	+1·2	−0·1	+2·4	+1·2	+0·8	+2·1	+1·5	−2·0	−1·1	−1·5	+2·3	+3·4	+2·8
1943	+0·7	+1·2	+0·9	+0·2	+0·9	+0·5	−0·8	+0·5	−0·1	+1·0	+2·1	+1·5	−0·3	−0·8	−0·5	−1·8	−1·8	−1·8
1944	**−1·1**	*+2·1*	+0·5	+3·1	+3·8	+3·5	−2·8	−0·3	−1·5	−2·8	*+0·3*	−1·3	0·0	+1·0	+0·5	−2·9	−3·0	−3·0
1945	+0·9	+1·6	+1·3	−1·0	+0·9	−0·1	**−0·8**	*+4·2*	+1·8	+2·8	+2·8	+2·8	+1·5	+3·9	+2·7	+0·5	+0·2	+0·3
1946	+0·3	+0·3	+0·3	−3·4	−0·7	−2·1	**−1·7**	*+2·4*	+0·4	−1·0	+1·5	+0·3	+2·5	+4·8	+3·7	−3·8	−4·7	−4·3
1947	+1·6	+3·6	+2·6	+7·4	+4·4	+5·9	+3·7	+2·6	+3·2	+2·0	−1·0	+0·5	+1·9	+3·8	+2·9	+0·3	+1·1	+0·6
1948	−1·5	+0·1	−0·7	−2·1	0·0	−1·1	−0·1	+1·7	+0·8	−0·3	−1·2	−0·7	+1·6	+1·6	+1·6	+2·3	+2·4	+2·3
1949	+4·5	+2·5	+3·5	+3·7	+1·8	+2·7	+6·6	+7·1	+6·9	+4·0	+3·2	+3·6	+0·2	0·0	+0·1	+2·3	+2·0	+2·1
1950	−0·9	+1·4	+0·3	−0·5	+0·7	+0·1	**−2·8**	*+1·7*	−0·5	−1·0	+0·5	−0·3	−0·3	+1·4	+0·5	−6·7	−4·3	−5·6
1951	+1·2	+1·2	+1·2	−2·8	0·0	−1·4	+0·3	+2·6	+1·5	−0·1	−0·8	−0·4	+4·2	+5·0	+4·6	+2·0	+1·8	+1·9
1952	+1·6	+1·8	+1·7	−0·1	+2·2	+1·1	−4·9	−2·8	−3·8	−2·6	−0·4	−1·5	−3·2	−2·7	−2·9	−3·3	−3·6	−3·5

over the past 25 yr. are given in Table I. Cases in which $T_x \sim T_m$ amounted to more than 1·5°F. are printed in bold figures and cases in which $T_n \sim T_m$ exceeded the same amount are printed in italics.

Usefulness of the mean maximum.—Taking day-time temperatures first, the number of occasions on which the mean maximum departure in Table I differed from the monthly mean departure by specified amounts is given in Table II.

The two values were in fairly close agreement in late autumn and winter. As a first approximation therefore the mean maximum temperature had no obvious advantage over the monthly mean as a standard on which to judge the

TABLE II

Difference $T_x \sim T_m$	Frequency in 25-yr. period 1928–52											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
°F.	*Number of occasions*											
0·0–0·5	17	12	10	12	11	13	7	10	7	11	17	20
0·6–1·0	6	6	7	7	10	7	9	7	3	9	6	4
1·1–1·5	2	5	5	5	2	4	7	6	7	5	2	1
1·6–2·0	...	1	1	1	2	1	2	2	5	...	...	...
2·1–2·5	...	1	...	...	...	...	...	...	2	...	...	...
2·6–3·0	...	...	1	...	...	...	...	...	1	...	...	...
3·1–3·5	...	...	...	...	...	...	...	...	...	...	...	...
3·6–4·0	...	...	1	...	...	...	...	...	...	...	...	...

broad day-time temperature characteristics from October to January. But over the remainder of the year, and especially in the equinoctial months of March and September, the mean monthly values sometimes differed by large amounts, and on those occasions the mean maximum temperature would be preferable to the monthly mean as a brief expression of day-time temperature. March 1929 was an outstanding example. Mean temperature over the month as a whole agreed exactly with the long-period average, but frequent warm days during that month resulted in the mean maximum value being 3·9°F. above average. The reverse position obtained in September 1946. Cool days until the 23rd of the month resulted in a mean maximum temperature 1·7°F. below average, yet the mean temperature over the month as a whole was above average. July 1944 and September 1928, 1930 and 1945 are further instances of differences of sign between T_x and T_m.

Monthly range of day maxima.—The mean maximum, in common with any other single mean temperature value in the British Isles, frequently masks large changes. The magnitude of the monthly range of daily maxima at Kew Observatory during the period dealt with in this investigation is summarized in Table III.

TABLE III

	Range of day maximum temperatures in 25-yr. period 1928–52											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	degrees Fahrenheit											
Largest	25	29	31	33	37	33	36	26	27	28	26	30
Smallest	13	10	13	12	14	14	10	13	13	11	13	11
Average	19	17	21	22	25	23	20	19	18	19	18	19

Temperature characteristics by day.—Despite these fluctuations the curves of daily maximum temperature at Kew Observatory usually fall into one of ten main types and the classification of each month in the 25 yr. 1928–52 is shown in Table IV. There were some months for which none of these classifications was strictly appropriate. In such cases the figure selected was to a certain extent a matter of personal choice.

Use of the maximum-temperature index figure.—The index figure in Table IV amplifies the overall picture of day-time temperature given in Table I by making it possible to visualize the temperature changes which are included in the mean maximum value. From the information given in Table I alone the Januaries of 1931 and 1952 might appear to have had closely similar day-time temperature characteristics. In fact, the two months were very different. January 1931 began with cold weather and then became much milder, while mild weather in the first half of January 1952 gave way to a cold spell later in the month. Taking

TABLE IV—CLASSIFICATION OF MONTHS BY CONSIDERATION OF MAXIMUM TEMPERATURE

Index Number	Description	Characteristic relation of daily readings to average*
0	Average.	Often ±2°F.
1	Rather warm.†	Mainly 3–5°F. above average.
2	Rather cold.†	Mainly 3–5°F. below average.
3	Warm.	Often 6–9°F. or more above average.
4	Cold.	Often 6–9°F. or more below average.
5	Brief cold periods.	Mainly above average but colder interludes.
6	Brief warm periods.	Mainly below average but warmer interludes.
7	Warm then colder.	Two well defined and contrasting temperature régimes.
8	Cold then warmer.	(as 7)
9	Changeable.	Alternating warm and cold periods.

Kew Observatory Period: 1928–52

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1928	1	3	9	9	6	6	5	6	7	5	5	6
1929	4	6	5	6	8	6	5	8	3	0	5	5
1930	1	2	9	8	6	9	7	6	0	9	9	6
1931	8	6	8	6	9	5	6	2	6	7	5	9
1932	5	6	8	6	9	9	9	3	7	2	6	9
1933	7	7	3	5	9	9	3	3	3	7	6	4
1934	9	9	0	9	5	5	3	9	5	0	0	3
1935	9	9	8	6	9	8	3	9	0	6	7	8
1936	9	6	8	8	9	8	6	8	7	8	7	9
1937	5	5	6	5	8	9	9	5	7	0	9	6
1938	8	9	3	6	9	5	8	7	9	0	3	7
1939	5	8	9	9	6	7	6	8	7	7	5	6
1940	4	8	9	8	1	3	2	9	7	2	9	6
1941	4	9	9	6	4	6	5	4	5	7	9	9
1942	6	4	9	5	6	9	2	9	7	0	6	5
1943	8	5	1	3	8	9	6	0	7	0	6	2
1944	1	7	8	3	9	2	6	5	6	2	6	6
1945	4	3	3	5	9	8	9	9	6	1	0	5
1946	9	7	8	3	2	2	9	4	8	9	0	6
1947	4	4	8	9	9	7	8	3	1	7	9	1
1948	9	7	3	1	9	9	8	2	9	7	9	7
1949	1	3	8	3	9	5	9	3	3	7	9	1
1950	7	3	3	9	9	3	2	9	2	9	2	4
1951	9	2	6	6	4	9	9	2	9	9	1	5
1952	7	8	7	9	5	9	9	9	4	2	7	6

* The average for this purpose is the value obtained from a smooth curve joining the average monthly values when these are plotted to the 15th of the month.

† The terms warm and cold are used in the broad sense, "warm" becomes "mild" in winter, for instance.

a summer month it would be reasonable to deduce from Table I that the month of June 1930 was similar to June 1934, but the index figure in Table IV shows that apart from the final mean maximum value there was little similarity between the temperatures experienced in the two months. June 1930 was a month of frequent and often large temperature variations, amounting to 10°F. or more from one day to the next on several occasions. Maximum temperatures in June 1934, on the other hand, were above average on most days, the mean value being brought down to the same level as that of 1930 by some short but markedly colder interludes.

Usefulness of the mean minimum.—The shortcomings of the monthly mean as an expression of day-time temperatures apply equally to its suitability as an indication of temperatures at night. The amateur gardener is no less interested in night-time temperatures during the spring and autumn than the professional horticulturist, yet it is just at those times that the monthly mean can be seriously misleading. The figure for March 1929 given in Table I suggests an average month at Kew Observatory. In fact, the nights were exceptionally cold with air frosts on 13 nights. Mean temperature over the month of October 1944 as a whole was below average, yet the nights were rather mild with slight air frost on only one night.

The number of occasions on which the mean minimum departure in Table I differed by specified amounts from the mean monthly departure is given in Table V.

TABLE V

Difference $T_n \sim T_m$	Frequency in 25-yr. period 1928–52 Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
°F.	*Number of occasions*											
0·0–0·5	16	11	11	11	8	13	6	8	5	11	16	19
0·6–1·0	7	7	6	10	13	9	10	9	6	9	6	5
1·1–1·5	2	5	5	3	3	2	6	6	9	4	3	1
1·6–2·0	...	1	1	1	1	1	3	2	3	1	...	...
2·1–2·5	...	1	...	...	...	...	...	...	2	...	...	...
2·6–3·0	...	...	1	...	...	...	...	...	...	...	...	...
3·1–3·5	...	...	...	...	...	...	...	...	...	...	...	...
3·6–4·0	...	...	1	...	...	...	...	...	...	...	...	...

The mean minimum temperature, as in the case of the mean maximum, differed most from the monthly mean in spring and early autumn and least in the winter months. Noteworthy instances in which the differences of the mean minimum and mean monthly temperatures from their respective averages were of opposite signs were February 1949, April 1931, June 1946, July 1936 and September 1950. In most of these cases the mean minimum temperature was above average and the mean monthly temperature below average. The mean minimum is therefore frequently preferable to the monthly mean as a brief representation of temperatures at night during the period to which the mean value refers.

Monthly range of night minima.—The mean minimum and the mean maximum are alike in occasionally concealing large temperature ranges. The figures given below show that the monthly range of night minima at Kew in the period examined was usually greater in late autumn, winter and early spring than at other times of the year.

TABLE VI

	Range of night minimum temperatures in 25-yr. period 1928–52 Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	degrees Fahrenheit											
Largest	37	32	30	25	30	23	21	19	23	30	34	33
Smallest	13	10	14	9	6	8	9	11	14	16	14	13
Average	22	20	20	16	18	15	13	14	18	23	20	21

Temperature characteristics at night.—It is difficult to devise a straightforward scale of classification as a means of amplifying the mean minimum temperature analagous to that used in Table IV to supplement the mean maximum. Any such scale should take into account the occurrence of frosts and their severity, in addition to giving an indication of the general characteristics of the monthly curve of night minimum temperature readings in relation to the average for the time of year. The scale adopted for the present purpose and the monthly classifications for Kew Observatory over the past 25 yr. are given in Table VII.

Use of the minimum-temperature index figure.—The index figures in Table VII enable a truer appreciation to be made of the bare mean minimum values given in Table I. Taking a spring month as an example, mean minimum temperatures in the Aprils of 1937 and 1945 were both 3·7°F. above average, but the details of the night-time temperatures in these two months were dissimilar in many respects. Nights were cold in early April 1937 with air frost on one night, but warmer weather later in the month offset the initial coldness. April 1945 on the other hand had consistently warm nights for the first three weeks, and although colder weather set in during the last week of the month there were no air frosts at Kew Observatory. The Septembers of 1948 and 1950, too, had identical

TABLE VII—CLASSIFICATION OF MONTHS BY CONSIDERATION OF MINIMUM TEMPERATURE

Index Number	Description	Intensity of air frost May–September	Intensity of air frost October–April
0	Mainly above average.	None.	Slight or keen.
1	Mainly above average.	Slight or keen.	Hard or severe.
2	Above average then colder.	None.	Slight or keen.
3	Above average then colder.	Slight or keen.	Hard or severe.
4	Below average then warmer.	None.	Slight or keen.
5	Below average then warmer.	Slight or keen.	Hard or severe.
6	Changeable.	None.	Slight or keen.
7	Changeable.	Slight or keen.	Hard or severe.
8	Mainly below average.	None.	Slight or keen.
9	Mainly below average.	Slight or keen.	Hard or severe.

An index figure, 0, 2, 4, 6 or 8, in brackets indicates "ground frost but no air frost" in the months May–September and "no air frost" in the months October–April.

Kew Observatory Period: 1928–52

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1928	6	6	6	6	(8)	(8)	6	6	(8)	4	4	8
1929	9	9	5	8	9	6	6	4	0	6	4	6
1930	0	8	6	(6)	(0)	0	6	6	0	6	6	6
1931	4	8	7	(0)	(0)	0	6	6	6	2	0	7
1932	1	8	5	(6)	(6)	6	6	0	2	(6)	0	4
1933	3	2	6	6	0	0	0	0	0	2	6	8
1934	7	9	6	4	(6)	0	0	6	6	6	6	(0)
1935	6	0	0	(0)	7	0	0	0	(6)	6	6	4
1936	7	9	6	6	(6)	4	0	6	2	(4)	2	6
1937	6	0	8	4	(0)	0	0	0	6	(0)	2	6
1938	(0)	6	0	8	9	0	4	2	4	(2)	0	3
1939	6	6	6	6	(8)	6	9	4	(0)	(2)	0	3
1940	9	7	6	6	(0)	0	9	6	(2)	6	6	8
1941	5	7	6	6	(8)	4	0	6	0	(6)	4	2
1942	9	9	6	(0)	(6)	(6)	6	4	0	(6)	8	0
1943	4	6	6	(0)	(0)	0	0	6	(2)	(6)	8	6
1944	0	8	6	(0)	(8)	(0)	0	0	(6)	0	6	7
1945	9	0	0	(2)	(0)	0	0	4	(2)	(0)	0	6
1946	7	3	4	6	(8)	(0)	6	6	0	(2)	(0)	9
1947	7	9	5	0	(0)	0	0	0	(0)	6	7	1
1948	6	3	(0)	(0)	(6)	0	4	6	(6)	6	6	3
1949	0	5	4	0	(6)	6	6	0	0	2	6	0
1950	3	0	0	6	(0)	0	0	0	0	2	6	8
1951	6	6	6	(8)	(8)	(4)	0	6	0	6	(0)	6
1952	3	8	0	0	0	6	0	0	(8)	4	2	5

mean minimum temperature values, but while the September of 1948 consisted of alternating warm and cold periods with some ground frosts, night minima in September 1950 were fairly consistently above average for the time of year and the month was completely free from ground frosts.

Summary.—The long-established climatological importance of the mean monthly temperature is unquestioned. Nevertheless, the mean value over the month as a whole is sometimes unrepresentative and occasionally misleading, both as a measure of the day-time or night-time temperatures of which it is composed and as a basis for comparing one particular month with the same month in other years. The mean maximum and mean minimum temperatures, together with their respective differences from the average, are much better criteria of the temperature characteristics of a month than the monthly mean, while index figures summarizing the changes in the monthly curve of day maximum and night minimum readings give considerable assistance in the interpretation of the mean values.

BUOYANT MOTIONS AND THE OPEN PARCEL

By C. H. B. PRIESTLEY, Sc.D.
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Summary.—The model of the open parcel, in which a moving parcel of air is subject to continuous mixing of heat and momentum with its environment, is put forward to formalize the close connexion between turbulent and convective phenomena. The device is of considerable power, and the results of some of its applications to problems in convection and turbulent heat transfer are indicated.

Introduction.—*Closed parcel.*—In a recent review[1], where turbulence was regarded primarily as a process of interaction between motions at different scales, attention was drawn to the importance not so much of what was different, but of what was common, between the many problems in turbulent transfer which arise in meteorology. A similar outlook will be applied here to the closely related class of problems which concern atmospheric motions in which buoyancy is the dominant motive influence. These range in scale from the complex multi-cellular motions in cumulonimbus clouds, many miles in extent, through single-cell convection bubbles, down to the problem of heat conduction from ground to air on a sunny day when the path of an individual element may be measured in centimetres.

Great though their differences, until the last few years these problems have all been attacked by means of the same conceptual device. This device has become most widely familiar to meteorologists through the work of Sir Charles Normand on the parcel model of convection. The parcel was conceived as a uniform mass of air, of unspecified size, which was displaced from its original level and then moved through the medium without undergoing any mixing with the environment. Because of this latter feature, the device will be referred to here as the closed parcel. A subsequent development, the slice method, did not represent any fundamental change in outlook, for, as Normand himself pointed out[2], the slice method added no information to that provided by a large number of parcels moving both up and down.

From this last point it is only a short step to realize that the basic tool for study of turbulent heat transfer, the mixing-length theory, is in effect a statistical counterpart of the same device, the individual element of the turbulence being conceived with the same properties as the closed parcel of convection theory. Thus it may be claimed that a unified concept at one time underlay the whole structure of studies of buoyant motions at all scales. Despite, or perhaps because of, the great simplicity of the concept it was immensely fruitful, allowing us for example to understand and identify the different forms of instability which arise in convection problems, and estimate the vertical velocities generated, and, in the turbulent field, providing the very backbone of a whole complex subject.

In recent years in all these problems, from the thunderstorm to the small-scale turbulence, advances have been made and added complexities brought to light with which the closed-parcel device has appeared inadequate to deal. Modern research has tended to underline the peculiar nature of each of the separate problems, and to stress the importance of the new features (though in convection theory, in particular, there appears a strong cleavage of opinion as to which of these features are the important ones). The attacks on the different problems are tending to diverge more and more widely, and the general meteorologist, who is not a specialist in any one of them, is robbed of the unifying idea which is so helpful towards an understanding of the whole. Inevitable as these tendencies are, the task of science is to synthesize as well as to analyse, and it is equally important to look for features in common and see whether some new unified idea can be found to take the place of the closed parcel. Such an idea properly formalized, though inclined to represent an over-simplification in special cases, might nevertheless make some positive contribution to each; and would at any rate serve as a root stock on to which the cuttings from the detailed problems may be grafted.

Open parcel.—With this specific unifying need in mind, the formal concept is put forward of what will here be called the open parcel. Like the closed parcel, the open parcel is regarded as having a level of origin where its physical properties (and motion) can be given any assigned value but which will usually be taken as those of its environment; as it moves, however, it is subject to continuous bombardment by turbulent motions on a smaller scale, and so to continuous mixing of its properties with those of the surrounding air. Thus whereas a closed parcel of dry air, displaced vertically, will change its temperature at the adiabatic rate, the rate for the open parcel will depend on the rate of mixing and on the lapse rate of the environment. The open parcel is composed of a changing set of fluid particles, and its motion at any instant is defined as the mean motion of the fluid parcels which comprise it at that instant. To complete the specification of the body of air which is under consideration, we are free to define the manner in which the parcel changes its size as it moves, and to achieve the simplest mathematical formulation we elect that the size shall remain constant. It is clear from the definition that the treatment will have much in common with the American treatment of entrainment[3], save that the latter deals with the whole of the buoyant mass as it grows, and the present treatment, on the other hand, with a fixed volume thereof. The equations which govern the mean vertical velocity w and mean temperature T of the parcel may then be taken in their simplest form as (Priestley[4])

$$\frac{dw}{dt} = \frac{g}{T_e}(T - T_e) - kw \qquad \ldots\ldots (1)$$

$$\frac{dT}{dt} = -w\Gamma - k(T - T_e) \qquad \ldots\ldots (2)$$

where T_e is the temperature of the environment, Γ is the dry adiabatic lapse rate, and k is the mixing rate; k is allied to the turbulent interchange coefficient K between parcel and surroundings, for it has the form K/R^2 where R is representative of the linear dimensions of the parcel. From the work of Richardson[5] and also the more modern ideas on turbulence, k will be large for a small parcel and small for a large one; following an individual parcel (which remains of constant size) it is treated as a constant.

In problems where changes in water phase are important, e.g. in saturated ascent, a third equation must be added for the mixing of water content, but though this complicates the analysis it does not affect it fundamentally.

The problem is now the mathematical one of the solution of these simultaneous equations in a known environment. The condition for a steady environment is

$$\frac{dT_e}{dt} = w\frac{\partial T_e}{\partial z} \qquad \ldots\ldots (3)$$

which allows $T - T_e$ (or alternatively w) to be eliminated from the equations, leaving for example a single equation of motion in the form

$$\frac{d^2w}{dt^2} + 2k\frac{dw}{dt} + \left[\frac{g}{T_e}\left(\frac{\partial T_e}{\partial z} + \Gamma\right) + k^2\right]w = 0 \qquad \ldots\ldots (4)$$

where $(T - T_e)/T_e$ has been neglected as small, as it always is in nature. No restriction whatever has been placed on the possible magnitude of w.

Basic modes of single-cell convection.—In a layer of constant lapse rate, equation (4) takes the form familiar as the equation of damped motion with a disturbing or restoring force proportional to displacement. There emerge* three basic modes of behaviour: asymptotic motion, where the parcel eventually approaches an equilibrium level at an exponentially decreasing rate, oscillatory motion, where it executes damped oscillations about the equilibrium level, and absolute buoyancy, where w eventually increases exponentially with time. $T - T_e$ behaves in a similar fashion. The first mode probably occurs most frequently in convection, though it is the one which the closed parcel fails to indicate. The criteria determining the type of motion can readily be obtained and will not be reproduced here, but they must clearly be entirely in terms of the coefficients in equation (4). That is to say, the question of which type of motion will occur is decided entirely by the lapse rate and k (the size of parcel and level of small-scale turbulence), and is independent of the initial temperature and velocity of the parcel on entering the layer. The scale of the motion, on the other hand, does depend on these initial conditions.

Each of these types of motion is actually observed in single-cell convection, and from the derivation it is seen that the motion occurring at a given level at a given moment must belong to one of these three basic types, or to certain transitional modes (i.e. those which occur for particular combinations of values of k and lapse rate which separate the ranges of values where the basic

*In the space available it is not possible to provide full details of certain derivations, but these either have appeared or will appear elsewhere[4,6].

modes apply). The three therefore form a useful and complete set for describing single-parcel convection. Absolute buoyancy requires that the lapse rate be superadiabatic, and so will occur in practice only in layers of limited vertical extent. On the other hand, a superadiabatic lapse rate does not necessarily imply absolute buoyancy, for the solution is seen to be asymptotic for parcels below a certain critical size (k large): an element of sufficiently small size which is at rest will experience no tendency to move, so that the description "unstable", as applied to superadiabatic lapse rates, is true only for parcels above a certain limiting size.

To provide illustrations of the basic modes of motion, the curves of Fig. 1 show the upward velocity as a function of time for an element which enters a layer of constant lapse rate with $w = +100$ cm./sec. and $T' = +1$°C., g/T_e being taken as $3 \cdot 3$ cm./sec.^{2} °A. Values of k and lapse rate were chosen as follows:—

$$\text{I} \quad k = \tfrac{1}{3} \text{ min.}^{-1}, \qquad \frac{\partial T_e}{\partial z} + \Gamma = +10^{-4} \text{ °C./cm. (isothermal)}$$

$$\text{II} \quad k = \tfrac{1}{3} \text{ min.}^{-1}, \qquad \frac{\partial T_e}{\partial z} + \Gamma = 0 \text{ (adiabatic)}$$

$$\text{III} \quad k = \tfrac{1}{3} \text{ min.}^{-1}, \qquad \frac{\partial T_e}{\partial z} + \Gamma = -0 \cdot 94 \times 10^{-5} \text{ °C./cm.}$$

$$\text{IV} \quad k = \tfrac{1}{4} \text{ min.}^{-1}, \qquad \frac{\partial T_e}{\partial z} + \Gamma = -0 \cdot 94 \times 10^{-5} \text{ °C./cm.}$$

$$\text{V} \quad k = \tfrac{1}{2} \text{ min.}^{-1}, \qquad \frac{\partial T_e}{\partial z} + \Gamma = -0 \cdot 94 \times 10^{-5} \text{ °C./cm.}$$

Those in II and III are such as to give transitional conditions between oscillatory and asymptotic, and asymptotic and absolutely buoyant respectively. All the curves have been calculated directly from the appropriate solutions of equation (4); the temperature behaviour may thence readily be obtained from equation (1).

Scorer and Ludlam[7] have drawn attention to the apparent frequency of a mode of motion in which the velocity rises to a maximum value and then remains steady, as for instance with III of Fig. 1. In explanation, however, they appeal to equation (1) while ignoring equation (2); this is not acceptable, since turbulent mixing of momentum must be accompanied by mixing of other properties. It is more satisfactory to use both equations, whence it is seen from equation (4) that a solution of the form

$$w = w_\infty - Ce^{-2kt} \qquad \ldots\ldots (5)$$

occurs under the special condition that

$$k^2 = -\frac{g}{T_e}\left(\frac{\partial T_e}{\partial z} + \Gamma\right) \qquad \ldots\ldots (6)$$

which implies that, in a given environment, the parcels must be of a specified size. This condition occurs at the transition from asymptotic motion to absolute buoyancy, and the empirically-based relation similar to equation (5) given by Scorer and Ludlam turns out to be a transitional rather than a principal form of solution. The frequent observation of this special case may be explained by combining the present theory with the picture that Scorer and Ludlam have themselves drawn. Small bubbles will rise to an equilibrium level but leave a

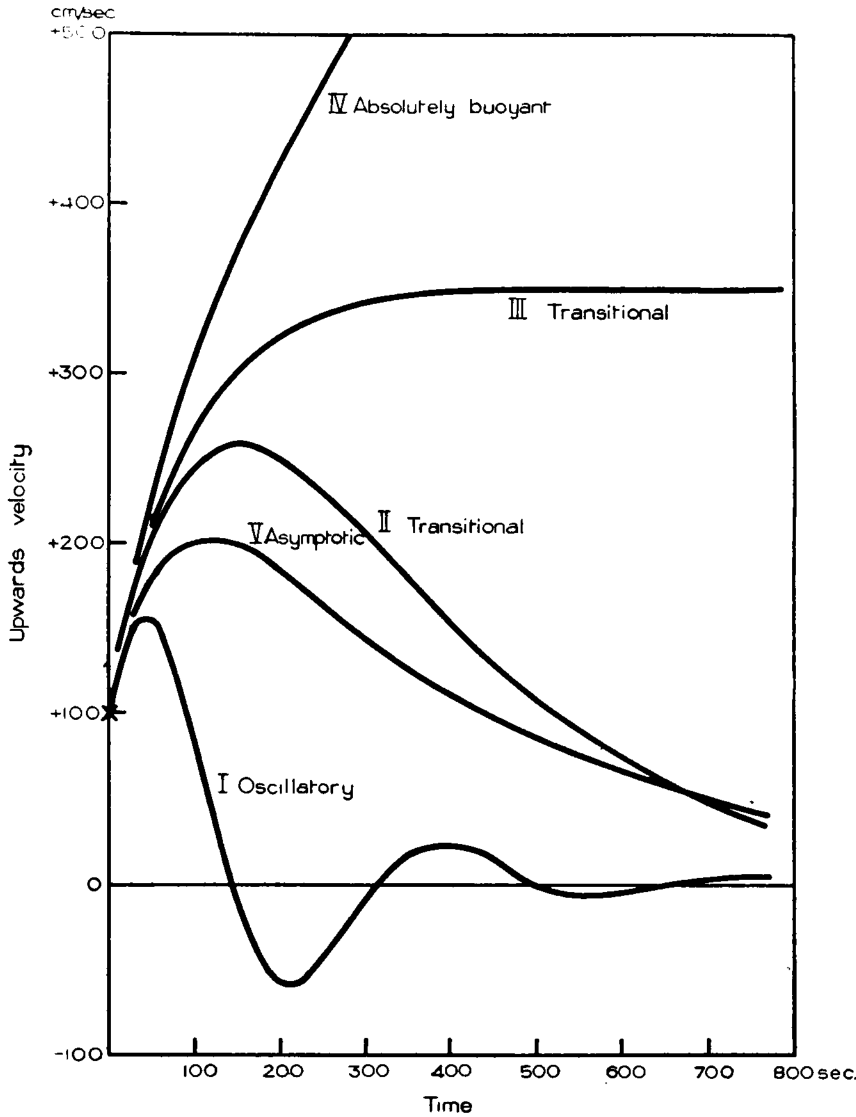


FIG. I—MODES OF CONVECTION FOR AN OPEN PARCEL

residual wake, and repetitions of the process will leave successively larger wakes until the critical size for absolute buoyancy is just realized. The parcel will then penetrate, and there is little tendency for growth beyond this size; whilst smaller parcels in the asymptotic mode will be abundant they are less easy to observe. Thus from a programme of visual observations of cloud behaviour in a super-adiabatic* layer, motions close to the transitional mode may be expected to stand out.

The oscillatory mode is of damped harmonic form, with an interval of exactly

$$\frac{\pi}{\sqrt{\left\{\frac{g}{T_e}\left(\frac{\partial T_e}{\partial z} + \Gamma\right)\right\}}}$$

between successive zeros of w and approximately the same between successive turning points*. Oscillations of cloud tops have been observed and their periods

*In these two applications, Γ of course refers to the saturated adiabatic lapse rate.

measured by Dr. E. G. Bowen and his colleagues near Sydney, and the latter agree with the formula within the limits of experimental accuracy. For sufficiently large clouds (k small) the damping becomes negligible, and we recover the formula for simple-harmonic gravity oscillations which was given many years ago by Brunt[8], but which does not appear to have been invoked in discussion of cloud behaviour.

Heat flux and temperature profile near the ground.—Application of the open parcel to the problem of heat transfer from ground to air on sunny days can be illustrated by Fig. 2. It is recognized that the profile under these

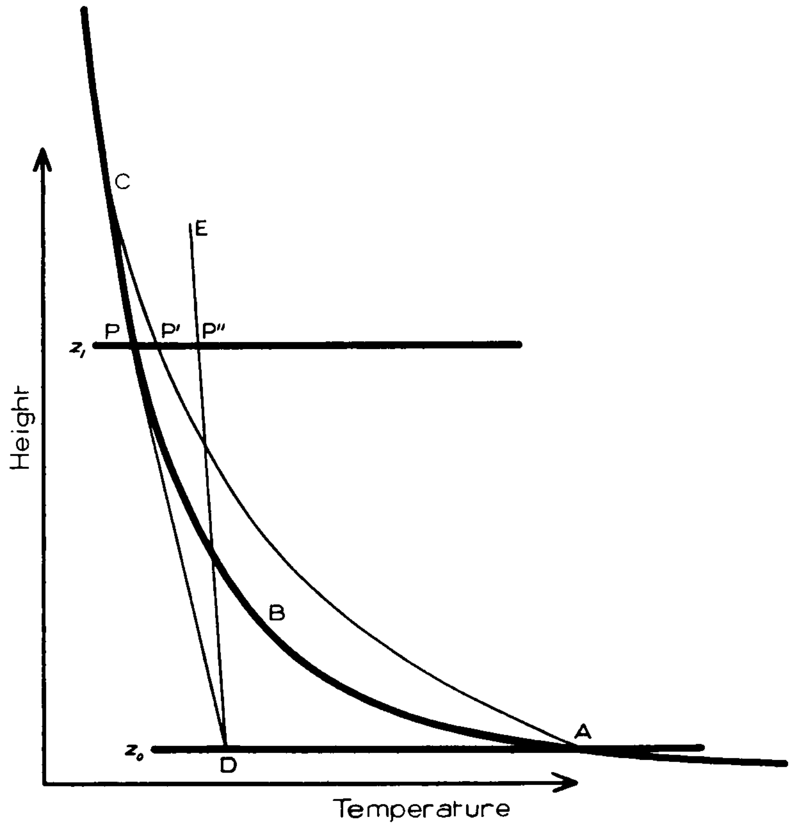


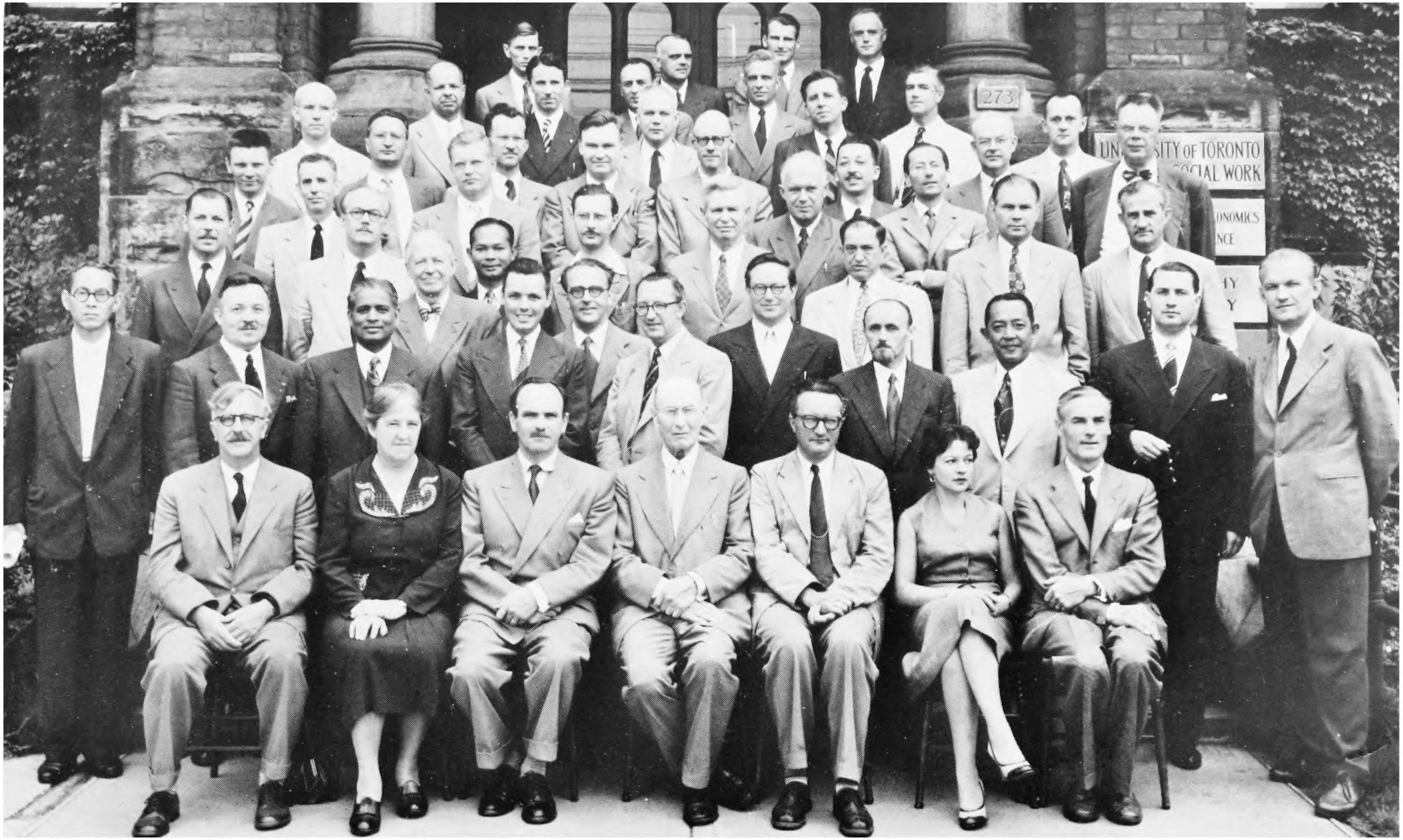
FIG. 2—DIFFERENCE BETWEEN MIXING-LENGTH AND OPEN-PARCEL THEORIES

conditions is strongly curved, and it is assumed to be represented by the equation

$$\frac{g}{T_e}\left(\frac{\partial T_e}{\partial z} + \Gamma\right) = -Cz^{-\delta} \qquad \ldots\ldots (7)$$

where δ characterizes the shape of the profile and C the general intensity of lapse rate. Such a profile is shown by the thick curve ABPC. The temperature behaviour of an individual element may then be calculated from equations (1) and (2), a typical result being indicated by the thin curve AP′C, and PP′ will then measure the excess temperature at level z_1 of an element starting from z_0. To derive the temperature excess PP″ given by the classical model (mixing-length theory) one would construct the tangent at P and, through the point D where this cuts the level z_0, draw a line DP″E of lapse rate Γ. It is evident that the present model is the more realistic, since the classical approach allows neither for the curvature of the profile nor for the mixing of the element.

[*To face p. 112*

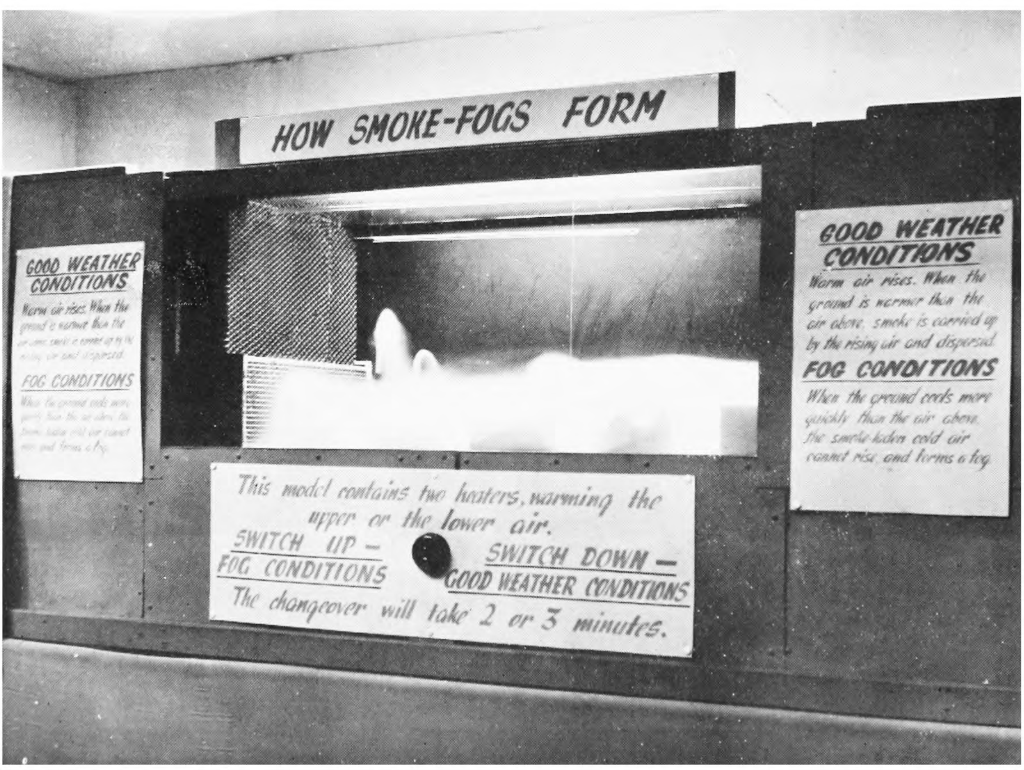


COMBINED MEETING OF THE COMMISSIONS FOR INSTRUMENTS AND METHODS OF OBSERVATION AND FOR AEROLOGY, TORONTO, AUGUST–SEPTEMBER 1953
(see p. 97)

DUST CLOUD AT ABOUT 49,500 FT.

These two photographs are selected from a special series taken over Defford, near Worcester, on July 30, 1953, between 1500 and 1510 G.M.T., at about the same height as the cloud.
(see p. 115)

Lapse conditions



Inversion conditions

MODEL TO ILLUSTRATE THE FORMATION OF SMOKE FOG
(see p. 114)

When equation (7) is substituted in equation (4) the form of the solution for w for a given value of k can be found*, and hence the solution for $(T - T_e)$ from equation (1). The heat flux through the level z_1 is then obtained by suitably averaging the product of these solutions over all possible values of k and of starting levels z_0. The mathematical treatment becomes rather involved, but there emerge three quite simple results (Priestley[6]): (i) that δ must in practice be close to $\frac{4}{3}$ and equal to it under steady conditions, except in layers where radiational heating is large, where δ will be smaller; (ii) that the rate of heat loss varies as $C^{3/2}$; and (iii) that the root-mean-square temperature fluctuations are proportional to $Cz^{-1/3}$.

A number of measurements of these last two quantities have been made by the writer's colleagues, and the agreement is most encouraging. In view also of the clear-cut prediction concerning the shape of the temperature profile, the large amount of published evidence on lapse profiles has been examined. Here the agreement is, from most sites, as good as the accuracy of the data permits. The discrepant profiles come from sites where the nature of the surface round the instrument is markedly different from that of the surrounding country, or where the exposure is otherwise impaired. At such sites, since wind and hence advection effects are rarely completely absent, one in effect measures, at different heights, samples of profiles typical of different conditions of ground cover, and no unified theory could be expected to provide satisfactory predictions.

Hot spots in a stable layer.—All the above results follow from the simple model of the open parcel, and suggest that the device is of some power and worthy of further application. Another novel result which may be mentioned in conclusion may be of practical importance to both scales of phenomena discussed above. Imagine a layer at a stable lapse rate in which a number of "hot spots" are created by some external agency, e.g. from heated ground or by penetration from an unstable layer below. The buoyant motions of the hot parcels will bring about an upward flow of heat through the layer. Small hot parcels will soon mix, and the heat flux due to them will be slight; large hot parcels will execute large oscillations approaching the simple harmonic in form with w and $T - T_e$ exactly $\pi/2$ out of phase, and the heat flux will again be slight. In between there will be an optimum size of parcel which, for a given intensity of temperature disturbance, will maximize the heat flux. The condition for the optimum has been found to be*

$$k^2 = \frac{1}{3} \frac{g}{T_e} \left(\frac{\partial T_e}{\partial z} + \Gamma \right),$$

and the upper limit to the heat flux given in terms of the root-mean-square temperature fluctuation σ_T by

$$F_H = \frac{\rho c_p \sigma_T^2}{\sqrt{\left\{ \frac{3T_e}{g} \left(\frac{\partial T_e}{\partial z} + \Gamma \right) \right\}}}$$

where ρ is the density and c_p the specific heat at constant pressure of the air. The last formula shows that very considerable upward flows of heat may occur in stable layers in the free atmosphere when these are penetrated by cumulus tops.

* see footnote on p. 109.

REFERENCES

1. PRIESTLEY, C. H. B., and SHEPPARD, P. A.; Turbulence and transfer processes in the atmosphere. *Quart. J.R. met. Soc., London,* **78,** 1952, p. 488.
2. NORMAND, SIR CHARLES; Energy in the atmosphere. *Quart J.R. met. Soc., London,* **72,** 1946, p. 145.
3. AUSTIN, J. M.; Cumulus convection and entrainment. Compendium of Meteorology, Boston Mass., 1951, p. 694.
4. PRIESTLEY, C. H. B.; Buoyant motion in a turbulent environment. *Aust. J. Phys., Melbourne,* **6,** 1953, p. 279.
5. RICHARDSON, L. F.; Atmospheric diffusion shown on a distance-neighbour graph. *Proc. roy. Soc., London,* A, **110,** 1926, p. 709.
6. PRIESTLEY, C. H. B.; Convection from a large horizontal surface. *Aust. J. Phys., Melbourne* (in the press).
7. SCORER, R. S., and LUDLAM, F. H.; Bubble theory of penetrative convection. *Quart. J.R. met. Soc., London,* **79,** 1953, p. 94.
8. BRUNT, D.; The period of simple vertical oscillations in the atmosphere. *Quart. J.R. met. Soc., London,* **53,** 1927, p. 30.

MODEL TO ILLUSTRATE THE FORMATION OF SMOKE FOG

By K. H. STEWART, Ph.D.

The Royal Sanitary Institute held an exhibition on "Atmospheric pollution—causes, effects, prevention" from November 9 to December 5, 1953. The Meteorological Office contributed a working model (illustrated facing p. 113) intended to show how weather conditions affect smoke from factories and houses.

The model is in the form of a small wind tunnel. A fan at the right-hand end draws air through the tunnel at a mean speed of about ½ ft./sec. At the left-hand end two electric heaters are arranged so that one of them can heat the upper layers of air or the other the lower layers. A switch in the centre of the front panel is used to change from one heater to the other. Smoke is let into the model through chimneys near the left-hand end. When the upper heater is on the model simulates foggy, inversion conditions and the smoke forms a dense flat-topped layer near the floor. When the lower heater is on the smoke is carried aloft in convection currents, as on a clear day with steep lapse conditions.

At first sight the simplest way of making the model would have been to have used a closed box with heaters on the floor and ceiling for lapse and inversion conditions respectively. This does simulate inversion conditions well, but in lapse conditions the whole model fills with smoke unless there is a fairly strong air current to extract the smoke. It was felt that it would be too unrealistic to change the mean air speed between lapse and inversion conditions, but that a steady flow must be maintained.

With air flowing through the model, a ceiling heater could no longer be used to give an inversion because the heat would be conducted downwards so slowly as to warm only a very shallow layer. Instead, a wire-asbestos "mat" heater had to be used near the intake end, with the air flowing through it. Various arrangements of the heater were tried. Most of them produced strong convective circulations inside the model instead of the desired flat-topped inversion; in the final arrangement an extension was fitted to the intake end, with the air inlet aperture in its roof and the heater wires fixed over this aperture. This arrangement gave a smooth inflow of hot air which automatically confined itself to the upper part of the model. The air in the lower part was found to remain relatively cool and to move more slowly than the upper air, thus giving a realistic representation of inversion conditions. The wind shear was further increased by putting model buildings on the floor of the model and baffles in the lower part of the outlet end.

For lapse conditions, heating of the floor was not found to be very effective; convection currents were certainly set up, but owing to the restricted size of the model they merely served to mix the smoke throughout the model rather than to disperse it. Better results were obtained from a single heater at the bottom left-hand end of the model. This produced a simple convection system with one main current rising across the model to the outlet end, carrying most of the smoke with it.

To show the temperature conditions inside the model, two thermometers are suspended horizontally near the top and bottom, with their bulbs near the intake end. In inversion conditions the upper layers reach about 100°F. and the lower layers 75°F.; in lapse conditions the values are about 80°F. and 90°F. respectively.

The smoke is produced by burning sawdust (in a small tin can) with a regulated air supply. The smoke is passed through a 2-ft. metal tube before reaching the model, to cool it towards room temperature. This smoke generator runs for one or two hours without attention, but does require refuelling and cleaning too often to be really satisfactory. Various chemical methods of making smoke are available, but none gives a smoke sufficiently non-poisonous to be used for long periods without elaborate ventilating arrangements.

When properly adjusted the model gives a realistic demonstration of the difference between lapse and inversion conditions. It is difficult to use it to demonstrate or investigate more detailed points, such as the effect of variations of wind speed or small changes in lapse rate, because changes in wind speed affect both the temperature rise produced by the heaters and the turbulence structure in the model, and because the behaviour of the smoke depends rather critically on its temperature and speed of emission in relation to the air temperature and speed in the model.

The model was constructed at Kew Observatory. The work of the workshop staff and of Mr. A. J. Lander, who supervised the making of the model and contributed much to its development, is gratefully acknowledged.

DUST CLOUD IN THE STRATOSPHERE

By L. JACOBS, M.A., M.Sc.

On the morning of July 27, 1953, a Defford (near Worcester) pilot, Flt-Lt Munday, flying in a Canberra aircraft over the Peterborough area at 40,000 ft. was very surprised to find that there was a thin broken sheet of roll-type cloud well above him. He estimated that the cloud was at about 45,000 ft. and stretched from the Manchester area to the Pennines; it did not have the usual crystalline appearance of cirrus and was well defined on the eastern edge. (The height of the tropopause at this time and place was deduced from radio-sonde ascents—about 28,000 ft.) When this report was received at Gloucester, from whence it was transmitted to the Central Forecasting Office for general distribution on the teleprinter network, it was suspected that the high cloud might well be the residual dust cloud from a volcanic eruption over Alaska on July 9, a message on the meteorological teleprinter network on July 11, 1953 having read "Information has been received that dust cloud from a volcanic eruption from Alaska on July 9 expected to cross north-east United States beginning July 11. Atlantic weather ships are to be asked to note particulars including time leading edge of cloud arrives overhead and any associated optical phenomena."

While weather (or other) ships did not observe this dust cloud (the Marine Branch of the Meteorological Office made a search later through all available logbooks) high-level cloud was observed from the meteorological office at Lichfield on the evening of July 27, the observer noting "its first appearance was at 1930 G.M.T. as streaks of white light, having an unusual appearance and not being readily explainable. It became apparent that the sun had been illuminating the underside of a layer of dust or haze for, as the sun gradually sank, the white streaks took on a dirtier appearance. At the point of sunset it became unquestionably evident that there was a layer of haze, and its underside exhibited a roll form reminiscent of stratocumulus cloud, the orientation of the rolls being roughly north–south. For a time shortly after sunset the haze layer could have been confused with cirrus or cirrostratus, had it not been kept under continuous observation."

On receipt of a further report of very high cloud from a Defford pilot on July 29, a request was made to all stations on the British meteorological teleprinter network to look out for such cloud. This request yielded many aircraft reports both for that day, the next day and also two for the previous day (i.e. for July 28–30). No further reports were received of very high cloud till Lichfield meteorological office reported some on the evening of August 4.

With the co-operation of the Superintendent at Defford a special flight was arranged on July 30 to obtain the exact height and thickness of the cloud and to take photographs. It was found that the cloud was quite thin, the base varying between 49,000 and 49,250 ft. and the top varying between 49,500 and 49,650 ft. Two of the photographs taken of the cloud are reproduced in the centre of this magazine. The following details are summarized from the observer's account: "While the high cloud could be seen from the ground owing to reflected light it could not be seen between 2,000 and 20,000 ft. but it was clearly visible from above 20,000 ft. It was not until the aircraft had reached 40,000 ft. (above some pre-frontal cirrus, base 35,000 ft., top 37,000 ft.) that it was possible to see how extensive the cloud was, with long drawn-out streaks in every direction for about 100–200 miles. The cloud was, however, only visible obliquely or from a distance. The photographs were taken between 49,500 and 50,000 ft. so that the top layer of cloud had a wider span in proportion to its thickness than the cirrus (top 37,000 ft.) or the cumulus (top 12,000 ft.). The photographs were taken about 30–40 miles away from each patch because the high cloud layer seemed to disappear whenever the aircraft entered it."

The high cloud reports were all from aircraft flying at 40,000 ft. or above, apart from the Lichfield surface reports mentioned above, and reports from the meteorological office at Waterbeach of very high cloud seen from ground level on the evening of July 27 and again at 1200 G.M.T. on July 30. Pilots' estimates of the base of the cloud, which, except in one case, was above the aircraft, varied from 46,000 to 55,000 ft. The only other aircraft, apart from the above-mentioned special Defford flight, reaching the cloud base was in the Wyton area at 1430–1500 on July 29, when the pilot reported thin layers of cirrostratus with base at 48,000 ft. and temperature there $-56°$F.

The first report from the Defford pilot on the morning of July 27 of very high cloud, having a sharp eastern edge over the Pennines, and that of a Wyton pilot, of a complete sheet of cirrostratus estimated 5,000–10,000 ft. above his aircraft when flying at 45,000 ft. over the route Wyton–Stuttgart–Frankfurt–Wildenrath–Wyton, 0530 to 0900 on July 28, is consistent with the same cloud sheet being observed, the upper wind at about 50,000 ft. being around 30 kt. From all the reports it appears that this thin, very high, cloud was extensive over England, Wales and southern Scotland from about the evening of July 27 till it was reported, at 1300–1400 on July 30, to be thinning slightly to the west of Wales and over north-west England. The cloud seen from Lichfield on August 4 might have been the last of this thinning cloud but is more likely to have been a separate later portion—it was first noticed at 1930 as a very high layer of rather close-grained stratocumulus-roll-type appearance above a band of definite cirrus; the high layer could only be seen towards the setting sun at an elevation of 20–40° and vanished by 2036.

Nearly all observers stated that the cloud did not look like ordinary cirrus, had a non-crystalline appearance and a streaky, hazy nature. There was general comment that the cloud base appeared to be wavy, rather like strato-cumulus cloud, and that if it was not looked at obliquely it could not be seen, the latter point being consistent with the thinness of the cloud; all pilots reported smooth flying conditions.

Synoptic situation.—From July 27 to 29 the British Isles remained under the influence of an upper cold pool which had been dominant in the area since July 14. Winds were westerly. On July 27 there were scattered showers with some thunderstorms; in the Defford area a pilot reported cumulonimbus tops with a pronounced anvil at 30,000 ft. with patches of anvil cirrus to 32,000 ft. (this cloud thus extending well above the tropopause) but the air became more stable in the south at night as a wave depression passed over northern France. On the 28th the weather was fair over the British Isles with a slack westerly gradient wind. In the same slack gradient wind a weak occlusion crossed Wales overnight, July 28–29, and England during the 29th, giving only occasional slight rain. On the 29th an upper warm ridge was spreading eastwards on the Atlantic in association with a shallow surface depression. Ahead of this system was a north-westerly jet stream. By 1500 G.M.T. on the 30th the jet stream (maximum speed 118 kt. at 300 mb., speed at 50,000 ft. 30 kt.) had reached the Liverpool area; the rain of the depression reached west Wales by 1800. It was the cirrus cloud of this depression that was observed by the Defford pilot at 1500 below the very high cloud. This depression, moving eastwards, cleared the east coast of England soon after midday on the 31st. It was followed by a developing ridge bringing fine warm weather over the British Isles which lasted till further Atlantic fronts moved eastwards on August 4, a cold front clearing Lichfield, where the last of the very high cloud was observed that evening soon after 1800 that day. The tropopause height at Defford rose steadily during the period July 27–30, the 1500 daily values being respectively 28,000, 32,000, 34,000 and 35,000 ft. The tropopause height at Lichfield on the evening of August 4 was about 39,000 ft.

Conclusion.—The present type of high dust cloud may have been mixed with thin ice-crystal cloud such as was observed at around 47,000 ft. on August 10, 1951[1] and discussed by Farquharson[2] since some observations described it as cirrus or cirrostratus. No optical phenomena or colouration of sun or moon were reported—unlike the high, very thick, dust cloud (base 31,000 ft., top about 40,000 ft.) of September 26, 1950, which gave a blue appearance to sun and moon[3]. Discontinuities in the tephigrams in the present case were rather minor and irregular and may well have been due to the minor fluctuations discussed by Sawyer[4].

Although the pilot who found the cloud on August 10, 1951 stated "I have never before seen cloud above 42,000 ft. in this country whilst flight-testing to altitudes of 50,000 ft. over the last three years" yet Farquharson[2] reports a further observation on August 25, 1952, and following discussions after the present series of reports had been received, further aircraft reports of cloud above 40,000 ft. were obtained for August 12 and 18, 1953 and for October 2, 1953. Murgatroyd and Goldsmith[5] in an account of cirrus cloud over southern England, based on reports by the Meteorological Research Flight, Farnborough, from January 1949 to August 1953, mention that cirrus cloud above 40,000 ft. was observed on May 4 and 5, 1953 and August 7, 1953 as well as on the days, July 27, 29 and 30, mentioned in the present account. It may well be that thin and very high ice-crystal or dust cloud is more common than is thought at present.

REFERENCES

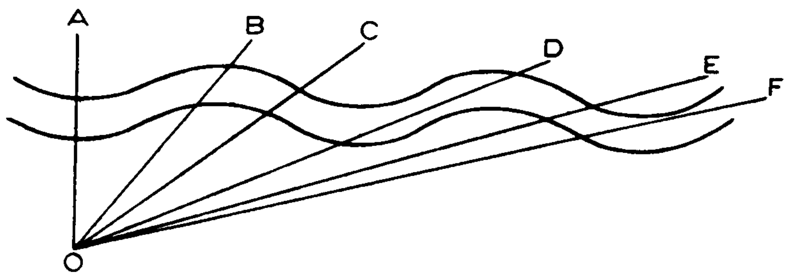
1. London, Meteorological Office. Very high cloud layer, August 10, 1951. *Met. Mag., London*, **80**, 1951, p. 365.
2. FARQUHARSON, J. S.; Cloud in the stratosphere. *Met. Mag., London*, **81**, 1952, p. 341.
3. BULL, G. A.; Blue sun and moon. *Met. Mag., London*, **80**, 1951, p. 1.
4. SAWYER, J. S.; Effect of atmospheric inhomogeneity on the interpretation of vertical temperature soundings. *Met. Mag., London*, **82**, 1953, p. 257.
5. MURGATROYD, R. J. and GOLDSMITH, P.; Cirrus cloud over southern England. *Met. Res. Pap., London*, No. 833, 1953.

[Mr. D. H. Johnson, who examined all reports and studied the original 100-mb. charts at the Central Forecasting Office, comments: The air at 100 mb. over Wyton on July 29 probably entered the North Atlantic area from the north or north-west over the Denmark Strait on July 25 or 26 (assuming no vertical motion) and subsequently flowed south and south-east, later turning east to cross the British Isles. The air at 100 mb. over Defford on July 27 and 28 and over Stuttgart at about 0900 G.M.T. on July 28 was probably almost stagnant above a cold pool near ocean weather station INDIA from July 24 to 26, subsequently moving south-east and later east. It is just possible, however, that at 50,000 ft., allowing for the wind speed being 8–10 kt. greater than at 100 mb. (about 54,000 ft. on this occasion) that the Defford and Stuttgart cloud came from the north or north-west to the west of this cold pool during July 25 and 26. It may be significant that the ship at INDIA reported only anvil cirrus at the main hours from July 24 to 26. Very high cloud was apparently not observed.

In the absence of definite reports of the phenomenon from ships on the Atlantic or North American or Greenland stations it will, of course, be out of the question to attempt to track the haze or cloud back to its suggested source in Alaska.

Not the least interesting feature of the observations is the reference in every report to the cloud having a wave or roll form. Since most of the reports stress that the cloud was only visible when observed obliquely, it is just conceivable that it consisted of a series of discrete "rolls" of dust, the clear lines between the rolls consisting of clear air brought up or down from some neighbouring dust-free level. However, the Wyton report (July 28) mentions that the sheet of "cirrostratus" was visible above the aircraft over the whole route. There were shallow waves observed in the cirrostratus base when observed obliquely.

Also when observed obliquely there were apparent lanes but these were not seen when viewed vertically. This last observation strongly suggests that the "roll form" and the clear lanes mentioned in several reports may have been to some extent an optical illusion there being in fact a continuous, though waved, sheet of dust. None of the reports gives an estimate of the wave-length, but it seems reasonable to assume that it was long compared with the 500-ft. and 1,000-ft. thicknesses mentioned. A cross-section through the cloud would then look like this



An observer at O looking along OA, OB, OC or OE would be looking through a thin layer of haze; along OD or OF he would be looking at a much greater thickness of cloud. Hence the apparent "lanes" and "rolls".]

METEOROLOGICAL RESEARCH COMMITTEE

The Physical Sub-Committee met on November 12, 1953, and the Main Committee on November 26, 1953.

At the meeting on November 12 the Physical Sub-Committee considered a paper by Mr. Goldsmith[1] which discussed some aircraft and surface observations made at Khartoum in July 1952, the aircraft observations of frost point being the first of their kind to be made in the tropics, and a paper by Mr. Blackwell[2] which discussed five years' continuous recording of daylight illumination at Kew Observatory. Methods of forecasting the length, density and persistence of contrails were also considered.

The 66th meeting of the Meteorological Research Committee was held on November 26. The Committee reviewed the progress made during the past six months, and Dr. Sutcliffe gave a brief summary of the work on numerical forecasting which was being done within the Meteorological Office.

ABSTRACTS

1. GOLDSMITH, P.; Some aircraft and surface meteorological observations made at Khartoum in July 1952. *Met. Res. Pap., London,* No. 789, S.C. III/147, 1953.

Part I describes aircraft measurements of temperature and frost point between 20,000 and 39,000 ft. on 3 flights. Tephigrams are drawn. Frost points about −80°F. were found near 38,000 ft. with air temperature about −60°F. It was found that the Dobson-Brewer frost-point hygrometer can be operated in the tropics. In Part II ground measurements of direct solar radiation, reflected short-wave, atmospheric and ground long-wave radiation are briefly summarized.

2. BLACKWELL, M. J.; Five years continuous recording of daylight illumination at Kew Observatory. *Met. Res. Pap., London,* No. 831, S.C. III/162, 1953.

The paper discusses autographic measurements of illumination on a horizontal surface since 1947, including standardization, sources of error and their correction. Variation is tabulated by 10-day and hourly means. The greatest values (up to 200 kilolux/hr. for 1–2 min.) are given by clouds near but not obstructing the sun. Diurnal variation is shown for all and for cloudless days. Luminous efficiency (lumens/watt), daylight/radiation intensity, varied from 112 in December to 137 in September (year 128·5), showing a rough linear relation to water-vapour content of the atmosphere.

OFFICIAL PUBLICATION

The following publication has recently been issued:—

PROFESSIONAL NOTES

No. 108—Comparison of wind recorded by anemometer with the geostrophic wind. By W. A. L. Marshall

The commonly accepted forecasting rule that the surface wind speed is one third of the geostrophic wind inland and two thirds of the geostrophic wind at sea is broadly valid over the whole range of synoptic conditions met with in the British Isles. Similarly, wind direction near the surface is usually backed from the mean-sea-level isobars by about 30° inland and by about 10° at sea. But this general connexion between wind and pressure distribution is by no means invariable. The wind measured at four anemograph stations has been compared with the estimated geostrophic wind at six-hourly intervals over the year 1946. Abnormalities of wind speed and direction are discussed in relation to the existing synoptic situation, the temperature lapse rate, the exposure of the anemograph and the time of day.

LETTERS TO THE EDITOR

Oscillations of barometric pressure

I should like to suggest with reference to the article entitled "Recurrence tendencies in Kew surface pressure" in the October 1953 number of the *Meteorological Magazine* that the negative conclusion arrived at by the authors is perhaps attributable to the fact that Kew Observatory may lie on an amphidrome or line of nodes. According to the theoretical investigations of Margules the pattern at any time on the earth's surface of a pressure oscillation in the atmosphere consists of a number of adjacent high-pressure and low-pressure regions separated by lines of zero amplitude. The lines of zero amplitude may also intersect each other.

The theoretical results of Margules, which are naturally limited by his initial assumptions such as absence of vertical motion, relatively small amplitude of pressure variation and isothermal changes, have nevertheless found some practical confirmation—at least, so it is claimed—in the work of Lettau on a 36-day period in pressure oscillation in north-west Europe and of Mäde on an oscillation of a 20-day period of almost world-wide extent.

The nodal character of the littoral region of north-west Europe relative to the annual oscillation of pressure is well shown by a chart constructed by Stumpff. He finds that the amplitudes of the annual pressure oscillation are greatest over the Continent and over the Atlantic Ocean near Iceland, where they are respectively in opposite phase, and they are small in the coastal regions, where the lines of like phases are crowded together.

J. WADSWORTH

London, October 30, 1953

REFERENCES

1. KOSCHMEIDER, H.; Physik der Atmosphäre. Bd 2: Dynamische Meteorologie. 3. Auflage, Leipzig, 1943, § 43, p. 306.
2. LETTAU, H.; Theoretische Ableitung und physikalischer Nachweis einer 36 tägigen Luftdruckwelle. *Veröff. geophys. Inst. Univ. Leipzig*, 2. Serie, **5**, 1931, p. 107.
3. MÄDE, A.; Ein Beitrag zur Symmetrieerscheinung von Luftdruckgängen des Winters 1928–29. *Veröff. Reichsamts. Wetterd., Berlin*, **10**, Heft 6, 1935.
4. STUMPFF, K.; Die Periodenforschung in der Geophysik. *Zbl. Geophys., Berlin*, **4**, 1939, p. 145.

Science and forecasting

Mr. B. C. V. Oddie has recently given an interesting review of the Pope Memorial Lecture on the subject "The scientist's place in the Services"*. Having quoted a statement by Dr. Wansbrough-Jones that the scientist "will never commit himself to an answer until he is at least nearly sure that he is right", Mr. Oddie concludes that the weather forecaster "is in a special category, and, perhaps, needs his own philosophy of science".

In reaching this conclusion, I think Mr. Oddie is interpreting science in too narrow a sense. The whole vast range of natural and social phenomena (inanimate matter, living organisms, human society) can be studied in a scientific manner. The essence of the scientific method is to collect and analyse the factual data in such a way as to reveal and define the relations between events, concepts or processes. Defined relations can then be used to predict future events. However, only in a very restricted field of knowledge (the so-called exact sciences) is it possible to plan future events or to make precise forecasts. In synoptic meteorology, as in many other fields of natural and social science, on account of the inadequacy of the data and the complexity of the relations between events, concepts or processes, sound scientific judgement demands that predictions be made in terms of trends, probabilities, approximations.

Nevertheless such predictions can often be useful as guides to action, and I do not think it is an exaggeration to say that the weather forecaster who on the basis of a careful scientific analysis of a complex changing synoptic situation issues a forecast for the next 24 hours qualified by such words as "may", "perhaps", "probable", is just as worthy of the proud title of scientist as the astronomer who predicts months ahead that a total eclipse of the moon will begin at 0050 G.M.T. and end at 0414 G.M.T. on January 19, 1954. Both are behaving in a manner consistent with "the general philosophy of science".

Preston, December 31, 1953 F. E. LUMB

[I did not intend to suggest that a synoptic meteorologist is not a scientist, and still less that he is useless. But he does occupy an unusual (though not unique) position, because he is often compelled to bet heavily on mere probabilities. This arises from the nature of his audience rather than of his science—above all things, he must be comprehensible. Therefore he says "Tomorrow will be . . . ". It would be much more truly "scientific" to give a table of probabilities, but it would not endear him to the B.B.C. Obviously this kind of thing—and every forecaster can think of other examples—presents the meteorologist with a special kind of ethical problem.—B. C. V. ODDIE]

Cleveland Abbe

I heard recently from Dr. Truman Abbe that he had completed and sent to the publisher the biography of his father Cleveland Abbe.

All English-speaking meteorologists owe a debt, direct or indirect, to Cleveland Abbe for his collections of classical papers on the mechanics of the earth's atmosphere, and the story of his efforts to raise the standard of meteorological science in the second half of the nineteenth century should be a notable contribution to meteorological literature. E. GOLD

8 Hurst Close, London, N.W.11, December 21, 1953

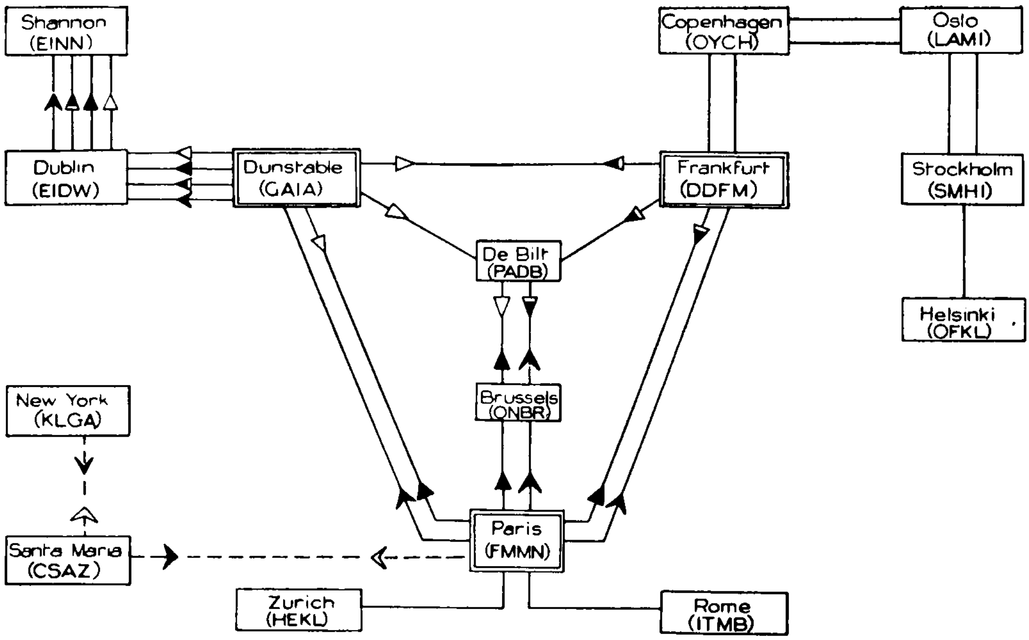
*ODDIE, B. C. V.; Royal Sociey of Arts. *Met. Mag., London,* **82,** 1953, p. 312.

NOTES AND NEWS

A new international meteorological communications centre at Frankfurt

In earlier days of synoptic meteorology, as in fact in many countries today, dependence upon radio communication with its uncertainties resulted in forecasters not being at all sure whether a particular station report would be available for plotting on charts. In the United Kingdom we have become so accustomed to the regular and accurate receipt of six-hourly, three-hourly and hourly reports by teleprinter from a very dense network of stations in western Europe that we tend to take for granted the complex telecommunications organization which exists to ensure that the exchange of basic information shall be as complete and perfect as possible. The engineering of circuits and operation of terminal equipment has to be arranged in such a way as to fit in with the framework of the meteorological network, and much ingenuity, planning and collaboration with various telecommunications authorities is required to accomplish this with the utmost economy and efficiency. The exchange of data must go on continuously throughout the 24 hours for 365 days of the year, and arrangements must be made for reserve routings to be provided and brought into operation at a moment's notice in the event of a break-down in a channel normally used. From time to time a major reorganization is called for. One example was the switch-over of the "hub" of the United Kingdom teleprinter network from Birmingham to Dunstable in the early days of the last war. The transfer involved much preparatory work which led to such a smooth change-over that comparatively few recipients of the broadcasts were aware of it. Another example is the reorganization of circuits forming the western European teleprinter network which has recently been effected. This network was built up by international co-operation after the last war, and was based upon exchange centres at Dunstable, Paris and the Headquarters of the British and United States Forces in the Occupied Zones of Germany as described in World Meteorological Organization Publication 9, Fascicule III. Each of the four centres originated a broadcast of about 30,000 five-figure groups a day comprising data collected from its own "area of responsibility". At noon on January 4, 1954, the basic network, which had been termed a "ring" or "quadrilateral", became a triangle with Frankfurt, Paris and Dunstable as its apexes, the Frankfurt centre (DDFM) being operated by the Federal German Meteorological Service.

The change-over was accomplished without any hitch or break in the supply of data, and completely revised schedules which had been carefully prepared and agreed beforehand were introduced to accord with the changed "areas of responsibility" assigned to the centres. The international network includes two sub-centres at De Bilt and Brussels, and the smoothness with which the machinery of reorganization worked was the result of close co-operation between six national services with the World Meteorological Organization Regional Association VI, Working Group for Weather Transmissions, co-ordinating the overall planning. One result has been the speeding-up of North American information which is now rediffused from the Paris centre by tape-relay uninterrupted by the inclusion of any European data which are now carried by an independent broadcast. Reports exchanged on the basic triangle are, of course, "fed" by land-line to many other western European countries



Land-line teleprinter circuit.
Radio-teleprinter circuit.
DUNSTABLE BROADCAST: United Kingdom, Ireland, Iceland, Greenland, Netherlands, U.S.S.R. in Europe, eastern Mediterranean, Ships' reports.
FRANKFURT BROADCAST: Austria, Bulgaria, Czechoslovakia, Denmark, Faeroes, Greenland, Federal German Republic, Eastern Germany, Finland, Greece, Hungary, Norway, Poland, Romania, Siberia, Sweden, Yugoslavia, Ships' reports.
PARIS BROADCAST: Belgium, France, Italy, north Africa, Portugal and Azores, Spain, Switzerland, Ships' reports.
North American data to Europe.
European data to North America.
Circuits not annotated carry selected data.

WESTERN EUROPEAN METEOROLOGICAL TELEPRINTER NETWORK

including the Irish Republic, Denmark, Finland, Norway, Sweden, Switzerland and Italy. Several other countries are at present developing internal national networks so that in the next few years it is expected that the great majority of western European countries will be in a position to receive data for the compilation of synoptic charts covering a wide area by land-line at the teleprinter speed of working, instead of having to intercept many morse-radio broadcasts which have to be made at a speed of only 18–20 five-figure groups a minute.

C. V. OCKENDEN

United Nations technical assistance in meteorology

British meteorologists and the Meteorological Office figure prominently in the latest announcements about the administration by the World Meteorological Organization of the United Nations scheme of technical assistance in meteorology to under-developed countries.

Dr. C. A. Lea, Director of the Meteorological Service of Malaya, appointed United Nations technical assistance expert to advise the Government of Libya on the organization of a meteorological service, took up his duties in November 1953.

Mr. J. Cochemé has been nominated to advise the Government of Jordan on the organization of a meteorological service with special reference to agricultural meteorology.

Three members of the Israeli Meteorological Service are to study in the Meteorological Office under the scheme; one will study meteorological instruments, and two synoptic meteorology and forecasting.

REVIEW

Linkes Meteorologisches Taschenbuch. Edited by F. Baur. $8\frac{1}{2}$ in. × 6 in., pp. Bd I viii + 360, Bd II xvi + 724, *Illus.*, Akademische Verlagsgesellschaft Geest & Portig K.-G., Leipzig, 1953. Price: *DM* 30, *DM* 38.

The publication of a new edition of Linke's "Meteorologisches Taschenbuch" is very welcome. The new edition is in two volumes.

The seven sections of the first volume cover:—

I. Weather reporting (synoptic codes, symbols, W/T transmitters).

II. A table of equivalents of meteorological words in German, English, French, Italian, Spanish and Russian apparently unchanged from the pre-war edition.

III. The International Meteorological Organization (as at 1949).

IV. Monthly and annual means of pressure and temperature for 207 stations.

V. The cloud classification of the "International cloud atlas" (1932).

VI. The meteorology section of the Universal Decimal Classification.

VII. A summary of meteorological history.

The value of the section on codes, transmitters, etc. in a publication of this kind is rather doubtful. Such information changes rapidly, and it is always necessary to refer to the current World Meteorological Organization, or national, publications which are kept up to date by amendment notices. A brief statement inserted in proof points out that Section III is obsolete, and gives the principal officers and a list of Commissions of the World Meteorological Organization.

The second volume contains six sections:—

I. List of symbols for quantities occurring in meteorological literature according to the system of the German organization for units and symbols.

II. Mathematics and methods of calculation for the meteorologist. This section is a summary of higher mathematics including integral equations, the calculus of variations, vector and tensor calculus, interpolation, harmonic analysis, probability, and mathematical statistics.

III. Practically applicable equations of dynamical meteorology. A summary of the mechanics and thermodynamics of the atmosphere in general including the theory of turbulence.

IV. The evaluation of aerological measurements. This section covers the subject briefly from the correction of radiation errors of radio-sondes to the use of the various aerological diagrams, construction of upper air contour and thickness charts, isentropic analysis, construction of cross-sections, and has an appendix on methods of observation with high-altitude rockets.

V. Climatological meridional cross-sections of the free air. Mean cross-sections for January and July for the northern hemisphere along the 75°W. and 120°W. meridians giving mean isopleths of temperature, potential temperature, zonal wind and tropopause.

VI. Tables divided into eleven sets.

A. Astronomy and geodesy.

B. General physics and geophysics.

C. Atmospheric statics and pressure (barometer reduction etc.).

D. Atmospheric thermodynamics, humidity, cloud physics.

E. Atmospheric dynamics.

F. Radiation and atmospheric optics.

G. Atmospheric electricity.

H. Ionosphere.

J. Long-period series of observations. A miscellaneous collection including a table showing whether the synoptic situation over Germany was cyclonic or anticyclonic on every day from 1881 to 1950 and information on sunspots from 1749 to 1951.

K. Mathematical tables.

L. Conversion tables.

The mathematical summary of section II would be very useful to any meteorologist who can read German, but much of the section on methods of evaluation of aerological methods necessarily has a limited value to meteorologists of other countries.

A reviewer naturally compares the splendid collection of tables in section VI with the recently published 6th edition of the "Smithsonian meteorological tables". Each has something that the other has not got. The latest Smithsonian tables are more complete in purely meteorological tables; they have, for example, tables for gradient (as distinct from geostrophic) wind and for humidity mixing ratio which are not in the latest Linke. On the other hand Linke has tables on subjects, such as atmospheric electricity, not touched by the Smithsonian tables and provides also general physical and mathematical tables. Neither the Smithsonian nor Linke's tables are complete in themselves; the meteorologist who has both will not often need to search outside them.

The price of nearly £3 for the second volume is not excessive as prices for German books go.

G. A. BULL

BOOKS RECEIVED

Schweizerisches Forschungsinstitut für Hochgebirgsklima und Tuberkulose in Davos. Tätigkeitsbericht für die Betriebsjahre 1949–51 and 1952. Schweiz. med. Wschr., Basel, **82,** Nr. 46 and 48, 1952, and **83,** Nr. 6, 1953.

Kennzeichen und Beurteilung des Hochgebirgsklimas. By Dr. W. Mörikofer. *Medizinische,* **9,** Nr. 19, Physikalisch-Meteorologischen Observatorium, Davos, 1953.

METEOROLOGICAL OFFICE NEWS

Retirements.—Mr. M. T. Spence, Senior Principal Scientific Officer, retired on February 28, 1954. He joined the Office in 1912 and was attached to the Statistical Branch. During more than 40 years' service Mr. Spence has worked both at Headquarters and aviation outstations as well as at Valentia Observatory and the Branch Office, Edinburgh. During the Second World War he was Senior Meteorological Officer at Headquarters No. 2 Group and later Chief Meteorological Officer to Bomber Command. In 1946 he was posted to the Personnel and General Services Branch at Headquarters and from 1948 until the time of his retirement was Assistant Director responsible for Personnel matters, Meteorological Training and General Services. During the First World War Mr. Spence served in the Royal Naval Volunteer Reserve. He was awarded the O.B.E. (Civil) in 1943. At a meeting in the Conference Room at Victory House on February 26, Dr. Stagg presented Mr. Spence with a cheque subscribed by his colleagues and this he intends to use towards the purchase of a television set. In expressing his thanks Mr. Spence recounted some interesting recollections of the people and events with which he had been connected. Mr. Spence has accepted a temporary appointment in the Meteorological Office.

With reference to the announcement in the March number of the retirement of Mr. R. A. Watson, a present in the form of field glasses, bought with donations from many of those with whom he had been associated was handed to Mr. Watson at Edinburgh on February 27. At the presentation he expressed his thanks to all who had contributed to the gift of his choice.

WEATHER OF FEBRUARY 1954

Mean pressure was above normal over Scandinavia and also over the North Atlantic between 40°N. and 50°N. Mean pressure was below normal in the region extending from Iceland south-eastward to Europe and the Mediterranean; mean pressure was also below normal over the eastern half of North America. The mean pressure reached 1027 mb. in Finland where it was 14 mb. above normal; the mean pressure at the Azores, 1026 mb., was 3 mb. above normal. The mean pressure in the central Mediterranean fell to 1008 mb. and was 9 mb. below normal in places.

Mean temperature was below normal over the whole of Europe, as much as 10°F. in the east; in the Mediterranean region the mean temperature was generally 2°F. below normal. Most of the United States had mean temperatures above the normal.

In the British Isles the very cold north-easterly winds experienced at the end of January persisted over England and Wales during the first few days of February and were followed by a ridge of high pressure moving south. From the 6th–7th onwards changeable, predominantly cyclonic, conditions prevailed.

An anticyclone situated over southern Scandinavia on the 1st was joined on the 2nd by another westward of Ireland and subsequently the whole belt of high pressure moved slowly south. Very cold weather prevailed with some snow, mainly slight, and temperature remained continuously at 32°F. or below locally in the south from the evening of January 29 to the morning of February 7. Very low screen minimum temperatures were registered during this spell; for example 7°F. at Thetford, Norfolk, on the 1st, −4°F. at Welshpool, Montgomeryshire, 0°F. at Hawarden Bridge, Flintshire, 3°F. at Moor House, Westmorland, 5°F. at Kielder Castle, Northumberland, and 6°F. at Alston on the 2nd, 3°F. at Moor House and 8°F. at Houghall, County Durham, Kielder Castle and Welshpool on the 6th. The snowfall of late January still lay on the ground and the fresh north-easterly winds in the south caused deep drifts in places; roads were blocked and villages isolated, particularly in Kent; at Throwley, a village four miles south-west of Faversham, Kent, there were drifts up to 7 ft. on the 1st. Rivers, canals and lakes were frozen or partly frozen. On the 6th–7th a deep depression was centred north of Scotland and an occlusion crossed the British Isles giving rain in the south and extreme west but snow in many northern districts and in Lincolnshire. Further depressions brought more snow to northern and eastern areas on the 8th–10th and smaller falls in south-eastern and Midland areas. Keen frost occurred in northern districts on the 8th and 9th; 9°F. was registered in the screen at Houghall and 10°F. at Moor House on the 8th and 10°F. at Kielder Castle on the 9th. On the 10th a depression off the west of Ireland moved south-east giving precipitation in most places; there was a temporary rise in temperature over much of England, Wales and Ireland, 50°F. being reached at a number of places in the south and west, but fog kept temperature below 40°F. locally, for example at West Raynham, Norfolk and at Watnall, near Nottingham. Further depressions moved south-east over our south-west districts during the next few days giving rather cold easterly winds over much of the country with some precipitation; a good deal of fog occurred in eastern districts. On the 15th and 16th a ridge of high pressure moved south-east over the British Isles, with more fog in eastern and Midland districts. From the 17th to the 19th small wave depressions moved east-north-east over southern England bringing widespread rain. Subsequently a changeable, rather mild, south-westerly type of weather prevailed, with temperature reaching or somewhat exceeding 50°F. locally at times; for example, 55°F. at Aldergrove on the 21st and 56°F. at Mildenhall on the 22nd. Rainfall was fairly heavy at times in the north (2·06 in. at Patterdale, Westmorland on the 24th). Between the 25th and 27th a complex, deep depression moved from south of Iceland to the North Sea. Strong winds and gales occurred in England, Wales and Ireland on the 26th, with gusts of 68 kt. at Bidston and 66 kt. at Speke. Showery weather, with snow or sleet in many places, prevailed in the colder air coming round the rear of the depression, particularly in the northerly current on the 28th.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	58	−4	−3·1	131	+3	88
Scotland	56	0	−2·7	98	+2	82
Northern Ireland ...	56	18	−2·1	149	+4	65

RAINFALL OF FEBRUARY 1954

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·22	133	*Glam.*	Cardiff, Penylan ...	4·30	146
Kent	Dover	2·81	146	*Pemb.*	Tenby, The Priory ...	5·58	192
,,	Edenbridge, Falconhurst	2·08	94	*Radnor*	Tyrmynydd	5·67	108
Sussex	Compton, Compton Ho.	3·87	147	*Mont.*	Lake Vyrnwy	5·50	121
,,	Worthing, Beach Ho. Pk.	2·34	118	*Mer.*	Blaenau Festiniog ...	9·68	118
Hants.	Ventnor Cemetery ...	3·59	166	,,	Aberdovey	3·91	131
,,	Southampton, East Pk.	3·19	139	*Carn.*	Llandudno	2·33	119
,,	South Farnborough ...	2·77	147	*Angl.*	Llanerchymedd ...	3·83	151
Herts.	Royston, Therfield Rec.	1·74	113	*I. Man*	Douglas, Borough Cem.	5·17	162
Bucks.	Slough, Upton	2·24	132	*Wigtown*	Newton Stewart ...	4·51	120
Oxford	Oxford, Radcliffe ...	2·34	143	*Dumf.*	Dumfries, Crichton R.I.	4·18	128
N'hants.	Wellingboro' Swanspool	2·03	126	,,	Eskdalemuir Obsy. ...	4·33	87
Essex	Shoeburyness	1·72	140	*Roxb.*	Crailing	1·28	69
,,	Dovercourt	1·89	149	*Peebles*	Stobo Castle	2·85	103
Suffolk	Lowestoft Sec. School ...	1·81	129	*Berwick*	Marchmont House ...	2·18	105
,,	Bury St. Ed., Westley H.	2·01	134	*E. Loth.*	North Berwick Res. ...	1·52	97
Norfolk	Sandringham Ho. Gdns.	2·68	162	*Midl'n.*	Edinburgh, Blackf'd. H.	1·54	93
Wilts.	Aldbourne	3·02	140	*Lanark*	Hamilton W. W., T'nhill	3·31	114
Dorset	Creech Grange... ...	3·64	127	*Ayr*	Colmonell, Knockdolian	4·13	107
,,	Beaminster, East St. ...	3·79	125	,,	Glen Afton, Ayr San. ...	4·43	101
Devon	Teignmouth, Den Gdns.	3·08	116	*Renfrew*	Greenock, Prospect Hill	6·36	120
,,	Ilfracombe	4·84	175	*Bute*	Rothesay, Ardencraig ...	3·93	98
,,	Princetown	8·67	115	*Argyll*	Morven (Drimnin) ...	5·60	106
Cornwall	Bude, School House ...	4·10	164	,,	Poltalloch	3·70	86
,,	Penzance, Morrab Gdns.	5·88	176	,,	Inveraray Castle ...	5·40	80
,,	St. Austell	5·65	147	,,	Islay, Eallabus	5·15	123
,,	Scilly, Tresco Abbey ...	4·43	159	,,	Tiree	3·73	108
Somerset	Taunton	2·18	105	*Kinross*	Loch Leven Sluice ...	2·96	105
Glos.	Cirencester	3·07	136	*Fife*	Leuchars Airfield ...	2·31	132
Salop	Church Stretton ...	3·06	131	*Perth*	Loch Dhu	7·86	106
,,	Shrewsbury, Monksmore	2·15	137	,,	Crieff, Strathearn Hyd.	4·53	129
Worcs.	Malvern, Free Library...	2·19	122	,,	Pitlochry, Fincastle ...	3·09	105
Warwick	Birmingham, Edgbaston	2·70	160	*Angus*	Montrose, Sunnyside ...	2·03	110
Leics.	Thornton Reservoir ...	2·41	144	*Aberd.*	Braemar	3·01	106
Lincs.	Boston, Skirbeck ...	2·17	149	,,	Dyce, Craibstone ...	2·81	123
,,	Skegness, Marine Gdns.	2·33	152	,,	New Deer School House	3·02	142
Notts.	Mansfield, Carr Bank ...	2·30	119	*Moray*	Gordon Castle	1·47	77
Derby	Buxton, Terrace Slopes	4·31	115	*Nairn*	Nairn, Achareidh ...	0·94	58
Ches.	Bidston Observatory ...	2·46	146	*Inverness*	Loch Ness, Garthbeg ...	2·47	72
,,	Manchester, Ringway...	2·69	142	,,	Glenquoich	...	...
Lancs.	Stonyhurst College ...	2·79	83	,,	Fort William, Teviot ...	4·77	64
,,	Squires Gate	2·95	139	,,	Skye, Broadford ...	4·80	74
Yorks.	Wakefield, Clarence Pk.	2·20	129	,,	Skye, Duntuilm ...	4·50	98
,,	Hull, Pearson Park ...	2·10	127	*R. & C.*	Tain (Mayfield) ...	1·77	77
,,	Felixkirk, Mt. St. John...	2·43	144	,,	Inverbroom, Glackour...	3·11	61
,,	York Museum	2·16	143	,,	Achnashellach	5·21	76
,,	Scarborough	1·84	110	*Suth.*	Lochinver, Bank Ho. ...	3·27	82
,,	Middlesbrough... ...	1·28	98	*Caith.*	Wick Airfield	1·88	83
,,	Baldersdale, Hury Res.	1·93	66	*Shetland*	Lerwick Observatory ...	5·43	172
Norl'd.	Newcastle, Leazes Pk....	1·65	108	*Ferm.*	Crom Castle	4·71	160
,,	Bellingham, High Green	1·80	71	*Armagh*	Armagh Observatory ...	3·68	166
,,	Lilburn Tower Gdns. ...	2·47	124	*Down*	Seaforde	4·88	160
Cumb.	Geltsdale	1·69	65	*Antrim*	Aldergrove Airfield ...	3·95	164
,,	Keswick, High Hill ...	4·77	97	,,	Ballymena, Harryville...	4·13	127
,,	Ravenglass, The Grove	4·30	140	*L'derry*	Garvagh, Moneydig ...	4·21	135
Mon.	A'gavenny, Plâs Derwen	4·23	121	,,	Londonderry, Creggan	3·85	121
Glam.	Ystalyfera, Wern House	7·97	155	*Tyrone*	Omagh, Edenfel ...	4·75	159

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

Wt-34. K16.

M.O. 581 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 83, No. 983, MAY 1954

SIR NELSON K. JOHNSON, K.C.B., D.Sc., A.R.C.S.

The death is recorded, with deep regret, on March 23, 1954, of Sir Nelson K. Johnson, who retired in September 1953 from the post of Director of the Meteorological Office.

All who knew Sir Nelson, and especially those who worked in close contact with him during the anxious years of the war and the reconstruction period which followed, will deeply regret the passing of this hard-working and most conscientious of Civil Servants.

His scientific and official careers were described in the *Meteorological Magazine* of October 1953. Now it is appropriate to dwell more on his personal qualities of devotion to duty, his insight into complicated scientific and administrative problems and ability to resolve them into their essential constituents, his unassuming manner, unfailing courtesy and ability to get the best work out of his staff. In international meteorology, among his fellow Directors and the senior staff of the World Meteorological Organization, the quality of his control as President over difficult and delicate meetings was renowned.

The sympathy of all Sir Nelson's colleagues will be extended to Lady Johnson and her son and daughter in their great loss.

CHANGES IN THE STRUCTURE OF THE METEOROLOGICAL OFFICE

By THE DIRECTOR OF THE METEOROLOGICAL OFFICE

The Meteorological Office has a dual responsibility: first, to provide the national weather service and second, to undertake investigations in the science of meteorology. This two-fold task necessitates an organization which is efficient both as a public service and as a scientific institution. Like any other large organization, public or private, the Office must adjust its structure from time to time to ensure that these requirements are met.

Since taking up my duties in September 1953 I have given much time and thought to the problems which the Office has to face and solve, both now and in the future. It is probably fair to say that in the past 30 years meteorologists everywhere have been more preoccupied with the exploration of the upper air and with the consequences of the rapid development of aviation than with other problems. Today we are faced with a growing demand for services for the general public and for agriculture and industry. This is a challenge which the Office is glad to accept.

To meet all these requirements necessitates some changes in the chain of responsibility and the creation of some new senior posts. The operational and investigational sides must be able to develop on their own and yet exchange ideas freely. To allow this to be done efficiently I have re-allocated certain responsibilities. The operational side of the Office is now entirely the responsibility of the Deputy Director (Forecasting) and the Deputy Director (Services), and the Deputy Director (Research) takes charge of all investigations. Climatology has been divided into two groups, one under the Assistant Director (Climatological Research) who is responsible to D.D.M.O.(R) and one under the Assistant Director (Climatological Services), who comes under D.D.M.O.(F) (this underlines the fact that the provision of climatological advice to industry, agriculture, etc., is becoming more closely linked with forecasting than before). The three Senior-Principal-Scientific-Officer posts in the Forecasting Division have been abolished, and in future the operations room at Dunstable will be controlled by the Assistant Director (Central Forecasting) under D.D.M.O.(F).

The substantial increase in the past few years of specialized forecasting and advisory services for Government departments, public corporations, industry and commerce, and recent developments in the use of broadcasting, both sound and television, have shown the need for an officer of senior grade, on the staff of D.D.M.O.(F), to devote his undivided attention to these matters. It is only by the establishment of personal relationships with inquirers and users that their meteorological problems can be fully appraised. A new post, that of Assistant Director (Public Services) has therefore been created. A.D.M.O.(P.S.) will be given the responsibility of watching, on behalf of D.D.M.O.(F), the public need and how it is being met. It is my hope that in this way it will be possible to make our work of greater use, and greater interest, to the nation as a whole.

On the research side, the Forecasting Research Division will come under D.D.M.O.(R), but the Assistant Director (Forecasting Research) will continue to give advice to the Forecasting Division when requested. The Marine Superintendent and the Marine Branch will, in future, be directed by D.D.M.O.(F), but with the provision that research in marine climatology will be supervised by D.D.M.O.(R), when requested to do so by D.D.M.O.(F).

The general effect of these changes is to give expression to the principle that meteorology, although covering an enormous field, is essentially a whole. To separate one branch of the subject from another is to restrict progress everywhere—the climatologist has much to give the synoptician and the forecaster can contribute greatly to climatology. I believe this to be true in both the operational and investigational sides of the Office, and the present re-allocation of posts is, I hope, a step in the right direction.

WEATHER WISDOM BY TELEVISION

By J. S. FARQUHARSON, M.A., D.Sc.

Introductory.—The presentation on television broadcasts of meteorological information and forecasts by co-operation between the Meteorological Office and the B.B.C. was begun on July 29, 1949, as described by Mr. Bilham in the *Meteorological Magazine* for October 1949. The form of this presentation was largely determined by the resources of the B.B.C. and was certainly not regarded as wholly satisfactory by the Meteorological Office. The latter wanted a more personal and "live" form. Early last year the B.B.C. indicated that an increase in their resources was expected such that an improved form of presentation could be considered. This was an opportunity which was welcomed by the Meteorological Office, and work was immediately begun on devising something better than had hitherto been possible. A tenet of the Forecast Division has long been that if only the forecaster could speak to his "client", as is done, for example, when a forecaster briefs a pilot at an airport, then that "client" is far more likely to be satisfied than through an intermediary who is a layman, even if that layman is a B.B.C. announcer reading a carefully prepared script. Early in the planning stage the idea was revived, strongly backed by the new Director of the Meteorological Office, that the forecaster himself should appear in the television studio and impart his forecast personally. There were considerable difficulties in the way of this idea, an example of which is that forecasters are generally chosen for their scientific and professional ability as meteorologists and not normally with any eye to their photogenic or histrionic attributes.

Technical resources.—What were the new technical resources which the B.B.C. had to offer? In Mr. Bilham's article, referred to, it was stated that three cameras were used, and for the new presentation, we had only two. But one of these was a "split-beam" camera which essentially could be regarded as two fixed cameras suitable only for "viewing" stationary objects at fixed distances, such as weather charts on easels. The other camera was the movable camera normally used for viewing the announcer. But the most important addition to resources was a special announcer's studio which would also be used as a "weatherman's" studio. Early attempts to use the split-beam camera for work other than that for which it was designed had to be abandoned, and any suggestions that it should be so used could only be rejected. With only one movable camera to juggle with, an urgent problem was how to move from forecaster to announcer without the deplorable gaffe of "panning" from one to the other. To get over this it was essential to interpose a chart (split-beam camera) between any presentation of the forecaster and the announcer so that there may be a picture sequence: forecaster, chart, announcer. In assessing the technique of the new form of presentation, it is imperative to have in mind the rigid technical limits within which work must be carried on.

Purpose of broadcasts.—This is to impart to ordinary folk, who happen to have a television set, the ideas of a professional forecaster concerning the weather of today and tomorrow, the latter leading on from the former—in the serial-story form mentioned by the Director in the March *Meteorological Magazine*. The language used is of the easy conversational style one might employ at a friendly fireside chat. But since all the world enjoys being given a peep behind the scenes, a certain limited technicality is permissible to give the listener the feeling he is sharing in the process of forecasting. Incidentally also this technicality has an educational intention, a pill which the skilful expositor can coat with jam, and, finally, it may give some clues to the technically informed. Hence, for example, the references to fronts rather than to troughs of low pressure. The diversity of points of view of his audience, which the television forecaster must keep in mind, is such that he cannot aim to satisfy fully the technically informed, but must aim to give satisfaction to the greatest number.

Form of presentation.—For the benefit of those who have not seen it, the form of presentation, in outline, is:—

1. The forecaster, after greeting his audience, turns to a simplified version of the 1500 G.M.T. chart of the day on a scale specially devised for the purpose, and describes the weather of the day by reference to it, high-lighting outstanding items and harking back to the forecast of the previous day to bring out any relevant points.

2. Following on from 1, he slides in another chart, the 1200 G.M.T. prebaratic chart of the next day, on the same scale as the previous one, and after dealing with the general synoptic situation as a continuation from his previous discourse, he proceeds to give area forecasts for broad areas of the British Isles.

3. The camera then leaves the charts and turns exclusively to the forecaster who gives a "Further outlook" in brief general terms for the day following tomorrow, and after bidding his audience "Goodnight" he refers them to:

4. A "fair copy" of tomorrow's prebaratic and forecast chart.

This last item, viewed by the split-beam camera, is introduced as a "cover-up" to allow the mobile camera, used for all the other items, to turn from the forecaster to the B.B.C. announcer.

The charts are specially prepared at Victory House before the broadcast, and the epoch to which the chart of "today" refers is dictated by the time necessary for this.

As the Director mentioned in his article in the March Magazine, the forms of presentation in other countries were considered, but, partly for technical reasons, it was decided to evolve our own. We in this country have a different broadcasting technique from that in America, and the taste of our listening public is probably also different from that in America.

The form of presentation had certain desiderata: the forecaster should appear in the picture as much as possible, and the static nature of the charts should be enlivened as much as possible by illustrating movement. Now to present both the forecaster and a readable chart on the television screen while at the same time preserving a technique of presentation acceptable by the standards of the B.B.C. is difficult. The difficulty can only be partially overcome by bringing chart and forecaster into the picture more or less alternately, though parts of the forecaster can be seen for most of the presentation. On the chart itself legibility can often be obtained only by the sacrifice of detail, and for this the forecaster has to try and make up by exposition. Fronts are delineated in symbolic form, but a forecaster cannot diverge too far from his immediate task to go into detailed explanation of the symbols. Otherwise his audience may confuse his explanation with his description of the weather of today and his forecast of tomorrow's weather. Strictly, the forecaster should refer to nothing which is not being looked at by his audience, if a good technique is to be followed. Pressures on a very few isobars are marked in millibars, but such markings must be kept to a minimum. The problem of showing wind direction and strength on charts has yet to be solved satisfactorily, but the forecaster indicates from time to time how this may be deduced, and by reference to fronts or otherwise he frequently indicates the broad general movement of air masses.

Development.—Sufficient letters have been received from owners of television sets to justify the belief that the new form of presentation is preferred by the majority to the old, and one may, with proper caution, say that the reception by our "clients" of this new service is encouraging. Some suggestions for improvement are impracticable because of the technical difficulties of presentation. Others have already been incorporated in the presentation.

The Director in his article in the March Magazine indicated that the present period was regarded as one of experimentation, and it is certainly true that the service is constantly under surveillance with a view to its improvement. At present only four minutes is allowed for the broadcasts, but this may be increased to five minutes, with decided advantage to the broadcaster. However, it is better that there should be requests for more time to be given to the broadcasts rather than for less.

It may be that the scale or the area of the charts now used could be modified with advantage, and this is a point which will receive attention. As for the general technique, the television forecasters themselves are building up day by day a volume of experience not hitherto available, and in course of time that experience may dictate changes for the general improvement of the service. The best is sometimes the enemy of the good, and it is probably true to say that had we waited for the best service we should still be waiting. The new presentation on television, achieved with the friendly and assiduous co-operation of Mr. Clive Rawes of the B.B.C., gives the Forecast Division of the Meteorological Office a great opportunity of which it is fully conscious and of which it intends to make the most.

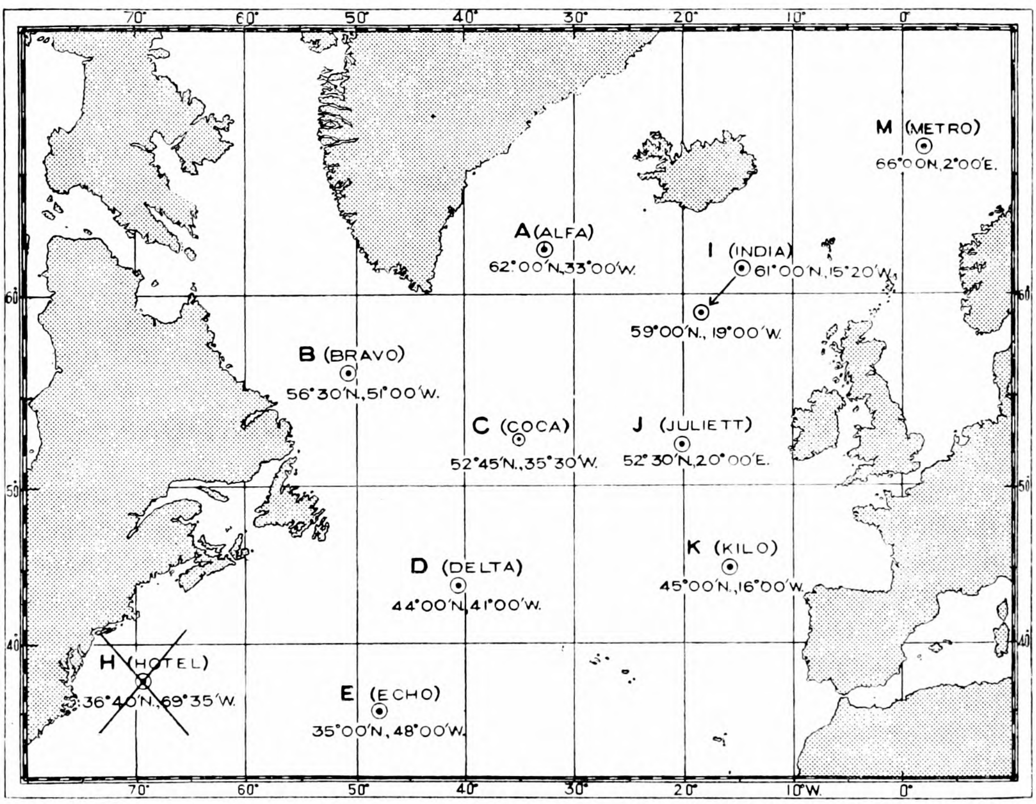
Since the above was written a further innovation has been made by showing at the end of each television programme the fair copy of the forecast chart, while the allied forecast and outlook, prepared by the television forecaster, are read by the announcer on duty. This addition was made for the first time on April 15, 1954.

NORTH ATLANTIC OCEAN WEATHER STATIONS

By Cmdr C. E. N. FRANKCOM, R.N.R. (Retd)

The Fourth North Atlantic Ocean Station Conference held under the auspices of the International Civil Aviation Organization opened in Paris on February 9 and ended on February 25, 1954. This was a full-scale technical and financial conference, and it took place as the result of a recommendation made by the Third Conference (the terms of reference of which were restricted to financial matters) which was held at Brighton in June 1953. At the Third Conference it became obvious that owing to financial considerations some reduction in the network would be inevitable, but the limited terms of reference of that conference prevented any technical discussion, which was an essential preliminary to any modification to the network, and it was for this reason that the Fourth Conference took place. The statement, issued by the United States Authorities in October 1953, that they contemplated withdrawing all their vessels from the scheme even though it was followed by a later statement (in December 1953) that they would co-operate in a limited network, combined with the need of all the participating countries to economize, and the consequent difficulties of finding the finance necessary for manning sufficient stations on the European side did not seem to augur well for the success of the Conference.

As it happened, it can be said with justification that international goodwill and a ready spirit of compromise prevailed with the result that a very satisfactory agreement was signed. All the national authorities present at the conference recognized the meteorological importance of this network, not only for the safety and efficiency of transatlantic aviation but also for meteorological research and for general meteorological purposes. There was general agreement among those present that for technical reasons it was important that the network should be reduced as little as possible, bearing in mind the necessity for economy and the number of ships available for manning the network. It was clearly shown in the technical discussions that, because of the complex meteorological situation in the North Atlantic, as soon as one station was removed from the network the consequent displacement of other stations which became necessary tended to destroy the balance of the network as a whole. After considerable discussion it was agreed that, as it was obvious for financial reasons that some reduction in the network was essential, the elimination of station H (situated between Bermuda and New York) would cause the least harmful effect upon the network, but that it was extremely desirable that the remainder of the network should remain as it was. It was agreed that station I should be moved somewhat to the south-west of its present location.



NORTH ATLANTIC OCEAN WEATHER STATIONS

To be manned by European vessels, A, I, J, K, M.
To be manned by North American vessels, B,C, D, E.

After taking into account the number of Atlantic crossings of aircraft belonging to the various States, and taking also into consideration non-aeronautical benefits, an agreement was reached whereby Europe would operate the "eastern" chain of stations (A, I, J, K and M) while the United States and Canada would between them operate the "western" stations (B, C, D and E). Non-aeronautical benefits are simply those benefits which are derived from the network by other interests than civil aviation. Although past conferences have been unable to devise any method of taking these into account and although no precise method of evaluating them has yet been developed, the Paris Conference agreed that they should be given weight in distributing responsibilities among States even though only a rough and ready assessment could be made. It was agreed that the ratio of aeronautical to non-aeronautical benefits derived from the network would be assessed in the ratio of 80 to 20, and that the aggregate non-aeronautical benefits for the United States and Canada as against those for European States would be in the proportion of 1 to 3, with the realization that the weather tends to move from west to east across the Atlantic and that Europe therefore tends to benefit more from certain sections of the network than does North America. In making this assessment it was agreed that benefits to meteorological research should not be taken into account as this benefited all countries. Nor should benefits to shipping be considered, owing to the international nature of shipping and the fact that ships contribute so much voluntary meteorological information.

A major consideration was the number of vessels available to man the network, and it soon became obvious that the maximum number of vessels which Europe could provide and yet keep within reasonable financial bounds was 10 (France 2, Netherlands 2, Norway and Sweden combined 2, and the United Kingdom 4).

After a somewhat lengthy discussion by the European operating countries, an ingenious "rotation" scheme was developed (by Dr. Bleeker of the Netherlands), and accepted by the countries concerned, whereby stations A, I, J, K and M could be operated by the available 10 European vessels. The United States and Canada at the same time agreed that they would operate the remaining stations B, C, D and E with 11 vessels. A generous gesture was made here by the North American operators agreeing to undertake somewhat more than their calculated responsibility. This arrangement meant, nevertheless, a heavy task for the European operators, because the 5 "European" stations had previously been operated by a total of 12 vessels (10 European and 2 United States). However, the "Bleeker schedule", although it will mean some increase in operating costs for all European operators, does enable the European States to discharge their task in the new scheme without going to the considerable expense of bringing additional vessels into service.

Under the new agreement it is the responsibility of the operating countries to provide vessels as follows: United States and Canada combined 11, Netherlands 2, Norway and Sweden combined 2, France 2 and United Kingdom 4. Belgium, Denmark, Israel, Italy and Switzerland agreed to make substantial cash contributions, which will be shared among the European operating countries. Iceland and Spain were not immediately in a position to adhere to the prescribed new agreement, but there is every reason to hope that they will adhere before long, as cash contributors. Ireland agreed to contribute a token payment of £1,000. As a result of this, the United Kingdom continues to operate her 4 vessels but receives a substantial cash payment. After taking into account the cost of the greater extent to which the United Kingdom vessels will need to be operated, the eventual net cost of the new agreement to the British taxpayer will be about £30,000 a year less than before.

The new agreement comes into force when the present one expires at 0001 on July 1, 1954, and lasts for two years, after which it may be extended automatically from year to year in the absence of twelve months notice of objection by States having specified responsibility.

For the operation of the "European" stations during the first six months of the new agreement the 2 Norwegian vessels will occupy station A, the Netherlands vessels station M, the United Kingdom vessels stations I and J and the French vessels will remain at station K. On the completion of the first six months the Norwegian vessels will return to station M, and the French, British and Netherlands vessels will occupy stations A, I, J and K in rotation. The exception to this rotation scheme is that whenever a French vessel would be assigned to duty at station I at the same time as a British vessel at station K two vessels will switch round so that the British vessel goes to station I and the French vessel to station K. Under this arrangement station A is obviously the most difficult to operate, and this will be occupied by each of the 8 vessels concerned (4 British, 2 Netherlands and 2 French) in strict rotation. Thus in a year, 4 British vessels will do 8 voyages at station A and 4 voyages at station K. Owing to their small size and limited fuel capacity, whenever a British vessel occupies stations A or K they will need to re-fuel at Reykjavik or Milford Haven respectively, both outward and homeward bound. In order to carry out the rotation scheme effectively and provide sufficient time in harbour at the end of each voyage to undergo repairs, give leave, etc., each vessel will need to spend 24 days on station in future instead of 21 days as at present. The average time in harbour at the end of each voyage will be about 16 days. It was decided that the meteorological programme of the network was already satisfactory, and that no changes should take place. Some minor changes were approved by the Conference concerning air/sea rescue equipment and communication arrangements between the ocean weather ships and aircraft in flight, and the international aspect of the oceanographical programme of the network was somewhat modified.

The Chairman of the Conference was Dr. Dekker (Netherlands) who is Chairman of the Netherlands Weather Ship Committee and had also been Chairman of the Third North Atlantic Ocean Station Conference at Brighton. Dr. Sutton (United Kingdom) was elected Chairman of the Financial Committee and Capt. Meaux (France) Chairman of the Technical Committee. International organizations representated at the Conference included the World Meteorological Organization, the International Association of Physical Oceanographers, the International Air Transport Association, and the International Federation of Airline Pilots Association.

From the British viewpoint it can be stated that the new agreement is not unsatisfactory. A reasonable meteorological network in the North Atlantic is essential if we are to provide satisfactory meteorological information for transatlantic aircraft leaving United Kingdom airfields, and such a network is extremely valuable from the viewpoint of general forecasting and for meteorological research in this country. Such a network has been achieved at the expense of some greater effort on the part of the ocean weather ships themselves, and, as already noted, owing to the greater cash contributions provided by non-operating countries the cost of British participation has been reduced. From the operational viewpoint and particularly for those who serve aboard the ocean weather ships, the longer distance the ships will have to go at times to man the stations and the somewhat longer time they will have to spend at sea each

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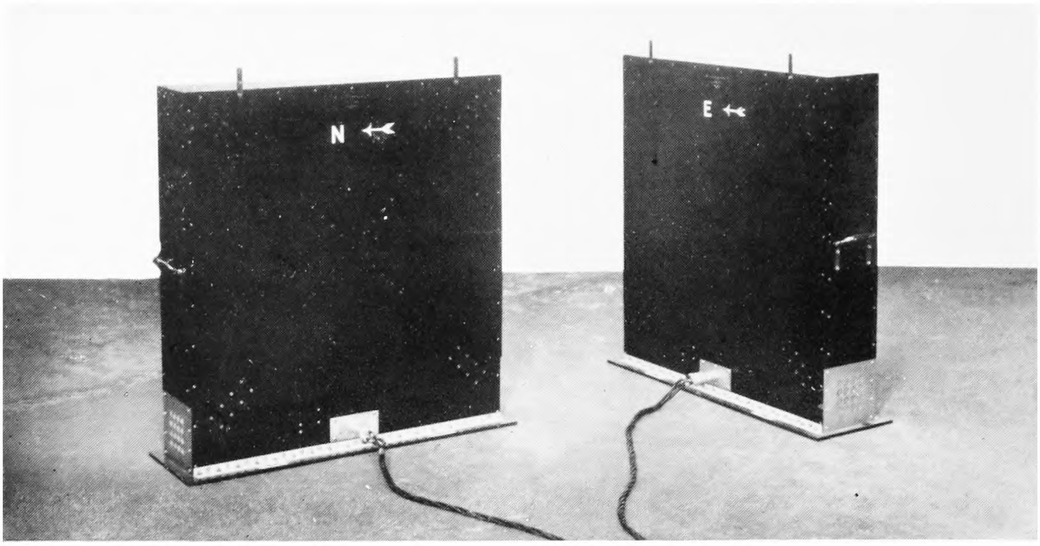
THE DIRECTOR OF THE METEOROLOGICAL OFFICE SIGNING THE NEW AGREEMENT ON NORTH ATLANTIC OCEAN STATIONS IN PARIS, FEBRUARY 1954

Mr. E. Weld, Assistant Secretary-General of the International Civil Aviation Organization is on the Director's right

(see p. 133)



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LOOP AERIALS AND CONSOLE OF THE NEW DESIGN OF RADIO DIRECTION FINDER FOR LOCATING THUNDERSTORMS (SFERIC) voyage, combined with the shorter aggregate time in harbour will raise some problems and cause some inconvenience—but it does not seem that any of these problems are insoluble.

This new agreement is necessarily somewhat more complicated than its predecessors, but it does provide a rather striking example of international co-operation in a businesslike and practical manner, which contributes not only to the safety of air navigation but to the whole cause of meteorological science.

NEW DESIGN OF RADIO DIRECTION FINDER FOR LOCATING THUNDERSTORMS

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Abstract.—The instrument described is a twin-channel cathode-ray direction finder for use at frequencies of about 10 Kc./sec. and is designed for locating thunderstorms. Its performance is similar to that of earlier designs, but it is smaller, easier to use, cheaper to manufacture, and suitable for use in tropical climates. The description includes only the main features of the design; a more complete account is in preparation.

General.—The location of thunderstorms by radio means has now become an established part of meteorology, and it seems likely that additional networks of observing stations for location at long ranges will be required. In anticipation of possible future demands for twin-channel cathode-ray direction finders of the type used by the British Meteorological Office[1,2], the re-design of the apparatus has been undertaken. The equipments in present use were designed to have the highest possible accuracy, but they are bulky and unnecessarily complex for routine use. Moreover the experience gained with these instruments has shown that their high instrumental accuracy cannot be fully used because of errors introduced by external factors such as imperfections of the sites. Little use is made, in practice, of the wide tuning range provided, and the sensitivity is greater than is normally required.

In re-designing the equipment, therefore, the main emphasis was placed on simplification and improved convenience of operation, ease of servicing, and reduction in weight, size and manufacturing cost. These objects have been achieved with no significant reduction in accuracy and with a small but acceptable reduction in sensitivity.

New design.—The equipment consists of two enclosed loop aerials and a console housing all other units, shown in the photographs opposite. The loops are wound in two layers about 1 m. square, and are orientated in north–south and east–west directions. They are connected by coaxal cables to the twin amplifiers in the upper section of the console. These amplifiers are normally tuned to a frequency of 10 Kc./sec., but may be tuned to other predetermined frequencies by means of switched condensers. Signals from the amplifiers are applied to the deflection plates of the cathode-ray tube in the central display unit and produce a diametral trace, the bearing of which corresponds to the direction of arrival of the atmospheric. A perspex cursor is used in reading the bearings.

On the right of the display unit is a brilliance-modulator unit which is actuated by the atmospheric and momentarily increases the brilliance of the trace; only those atmospherics with amplitudes greater than a predetermined level trigger the modulator. On the left of the display unit is a test-signal generator which is used for matching the characteristics of the two amplifiers. The unit below the writing shelf is the power pack.

Simplification of the equipment has been achieved by restricting the frequency range and by using only radio-frequency amplification (the previous design incorporated superheterodyne receivers). Each amplifier consists of a cathode-follower input stage, two resistance-capacitance coupled amplifier stages, a phase-splitter and a push-pull output stage. Only the loop-aerial circuits and the output transformers are tuned; the variable condensers in these circuits have small capacitance and serve mainly to adjust the phase response. The gains of the amplifier are adjusted by means of a pair of matched attenuators which are ganged.

For the alignment of the apparatus, test signals are injected into the aerials, and corresponding stages in the two amplifiers are adjusted to have the same gain and phase-shift characteristics over a small band of frequencies. These adjustments are carried out stage-by-stage and switches between corresponding stages of the two amplifiers enable the grids of the valves to be connected or either one earthed. The substantial reduction in the number of switches and adjustments greatly simplifies the alignment procedure.

An automatic selector is provided for use in the co-ordination of observations at several stations. This device, originally developed for research investigations, was adapted by the Meteorological Office for use in routine observations with the older type of direction finder[3]. In the new instrument it is an integral part of the built-in telephone equipment. At any one station each atmospheric of sufficient intensity to trigger the brilliance modulator causes an audible pulse to be passed over the telephone network and serves as a signal for the other observers to read the bearings. The pulse is followed by a quiescent period long enough for the bearings to be recorded.

To resolve the 180° ambiguity in the bearings a sense channel has been designed, to be used with a short vertical aerial. The inclusion of this unit is optional; it is not normally required in a network of several stations.

The equipment is suitable for use in a vehicle and in tropical climates. The prototype has in fact been installed in a Meteorological Office van, equipped with radio-communication apparatus and plotting facilities, and has been used on a number of temporary sites.

About ten equipments have been made commercially to this design, and a more detailed description is in preparation.

Acknowledgements.—The direction finder was developed for the Meteorological Office by the Radio Research Organization of the Department of Scientific and Industrial Research, and this description is published by permission of the Director of Radio Research in that Department, and of the Director of the Meteorological Office. Messrs. C. Clarke and V. A. W. Harrison were largely responsible for the detailed design, construction and testing of the instrument.

REFERENCES

1. ADCOCK, F. and CLARKE, C.; The location of thunderstorms by radio direction-finding. *J. Instn elect. Engrs, London*, **94**, Part III, 1947, p. 118.
2. OCKENDEN, C. V.; Sferics. *Met. Mag., London*, **76**, 1947, p. 78.
3. MAIDENS, A. L.; Methods of synchronizing the observations of a "sferics" network. *Met. Mag., London*, **82**, 1953, p. 267.

MEASURES OF SUCCESS IN FORECASTING

By A. F. CROSSLEY, M.A.

Part II.—Forecasts of elements subject to continuous variation

An index of success.—An index of success for use with forecasts of scalar or vector elements was proposed by Priestley[6]. Let ε denote the standard error of the forecasts, i.e. the root mean square of the differences between the forecast and the actual values at time t, this being the period of the forecasts. Also let σ_t denote the root mean square of the variation between the values of the element initially and after time t. Then if there is no correlation between the forecast value and the forecast error, i.e. assuming the variations are not consistently under- or over-estimated, the variance of the element may be expressed as

$$\sigma_t^2 = \varepsilon^2 + S^2,$$

where S^2 is the part which is successfully forecast. S may be termed the success, and its variance is given by

$$S^2 = \sigma_t^2 - \varepsilon^2.$$

From this the index of success is written as

$$P = \frac{S}{\sigma_t} = \left(1 - \frac{\varepsilon^2}{\sigma_t^2}\right)^{\frac{1}{2}}. \qquad \ldots\ldots (10)$$

Priestley discusses the effect of errors in the observations and also in the analyses on which the forecasts are based, and shows that disregard of the errors tends to make the formula under-estimate the success. It is not however practicable to include the errors in a useful manner, owing to the uncertainty of those arising from analysis, so that the formula is best used in the form given although it will necessarily be subject to some limitation. It is seen that it is applicable to both scalars and vectors, provided that in the latter case ε and σ_t are taken to be the standard vector error and standard vector variation respectively.

The upper limit of the index is unity, and this is reached when the variance of the forecast errors becomes negligibly small in comparison with the time variance. Now suppose the forecast value of the element at time t is always the same as the initial value; then ε is by definition identical with σ_t. Thus for persistence forecasting, the value of the index is zero. On occasions a forecast will give a greater error than that which would occur by use of persistence. If this were to happen often enough, it would lead to ε becoming greater than σ_t, so that P would become imaginary. This implies merely that the forecasts are worse than those obtained by the use of persistence. In cases where forecasting is of value, the limits of the index are 0 and 1. As the index is non-dimensional, and, as seen, measures the improvement over forecasting solely by persistence, it therefore constitutes an appropriate index for the measurement of success in forecasts of continuously varying elements.

The improvement of one technique over another.—Since the maximum value of the index P is unity, the improvement of one method of forecasting over another, as a fraction of the maximum possible improvement, is given by

$$\frac{P' - P}{1 - P}. \qquad \ldots\ldots (11)$$

This expression is of the same type as the formula (9) for "black and white" forecasts. For persistence forecasts, P is zero and the above formula reverts simply to P'.

Applications to forecasts of continuous elements.—*Forecasts of height of pressure surface.*—An evaluation of the index of success for forecasts of contour heights was made by Priestley[6]. Forecasts for 12-hr. periods at Larkhill were made four times daily from prognostic contour ("prontour") charts, and the results compared with direct observations. Values of ε, σ_t and P were derived for each month from August to December 1944, for pressures of 750, 500 and 300 mb. These figures show no marked difference in the success between the three levels, but there is considerable variation of the index from month to month. This suggests that in order to derive a satisfactory value of the index, the average should be taken over a number of months, or over a number of years for the same month. The causes of the variations were discussed by Priestley, and it is clear that they are due to circumstances which cannot be eliminated by choice of index, but only by averaging over a longer period. Combined figures for three months have been derived and are given in Table IX as an illustration.

TABLE IX—12-HR. FORECASTS OF HEIGHT OF PRESSURE SURFACE AT LARKHILL
September–November 1944

Pressure	Standard deviation Forecast error	Standard deviation 12-hr. variation	Index of success
mb.	*feet*		%
300	263	358	68
500	162	240	74
750	108	149	69

Forecasts of upper wind.—12-hr. forecasts of upper wind at Larkhill were also dealt with by Priestley[6] in a manner similar to that just described for the heights of pressure surfaces, and for the same periods. As with the height forecasts, there is no systematic variation of the index with height, while the variation from month to month is less marked in this case, although still considerable. It is clear that figures for individual months are influenced by the varying meteorological conditions, and that longer periods are required to give reliable estimates. Figures for three months have been combined to give Table X.

TABLE X—12-HR. FORECASTS OF UPPER WIND AT LARKHILL
September–November 1944

Pressure	Standard vector deviation Forecast error	Standard vector deviation 12-hr. variation	Index of success
mb.	*knots*		%
300	36	44	57
500	24	29	56
750	15	22	73

Forecasts of equivalent tailwinds.—An analysis of forecasts of equivalent tailwinds on the great circle route Shannon–Gander has been given by Harley[7]. From figures given for the standard deviation of the forecast errors and for the variation of equivalent tailwind with time, Priestley's index of success may be computed. The results are shown in Table XI.

In interpreting these figures, it is necessary to consider the method by which they were obtained. The forecast equivalent tailwinds were derived from composite contour charts, the time of flight being about 9 hr.; the mid time of

TABLE XI—FORECASTS OF EQUIVALENT TAILWINDS, SHANNON–GANDER

April 1949–May 1951

	Standard error of forecasts 700 mb.	Standard error of forecasts 500 mb.	Standard deviation of 24-hr. variation 700 mb.	Standard deviation of 24-hr. variation 500 mb.	Index of success 700 mb.	Index of success 500 mb.
	knots		*knots*		*per cent.*	
Winter	8·7	12·5	10·2	14·8	52	54
Spring	7·8	10·5	9·7	13·5	59	63
Summer	6·5	8·5	8·3	9·6	62	47
Autumn	8·1	10·5	10·0	12·3	59	52
Year	7·9	10·7	9·5	12·5	56	52

these charts was about 24 hr. ahead of the time of the basic charts from which they were prepared. On the other hand, the "actual" equivalent tailwinds, with which the forecasts were compared, were derived from ordinary contour charts for a fixed time which agreed approximately with the mid time of flight. The 24-hr. variations were similarly derived from the fixed-time charts. The errors introduced by this use of fixed-time charts were examined and found to be small. Further, all the winds used were geostrophic, but this approximation is held to be satisfactory when the results are averaged over a long route, since the ageostrophic components then tend to cancel out. It appears therefore that the results given in Table XI are reasonably accurate.

With the aid of known correlation coefficients, R_t, between equivalent tailwinds at times 0 and t, Harley[7] also derives values of the standard errors which would be expected if the forecasts were made statistically on the basis of a regression equation

$$v_t' = R_t v_0 \qquad \ldots\ldots (12)$$

where v_0 is the vector departure from the mean equivalent tailwind at time 0 and v_t' is the expected departure at time t. In each season the standard errors so found exceed those associated with the conventional forecasts so that the index of success is reduced. It may be shown on the other hand that the statistical forecasts necessarily improve on the persistence forecasts, i.e. those for which v_t' is assumed equal to v_0. Thus from the regression equation, the mean square error of the statistical forecasts, n in number, is:

$$\varepsilon^2 = \frac{1}{n}\Sigma(v_t' - v_t)^2 = \frac{1}{n}\Sigma(R_t v_0 - v_t)^2$$

but since $\frac{1}{n}\Sigma v_0^2 = \frac{1}{n}\Sigma v_t^2$

and $\Sigma v_0 v_t = R_t \Sigma v_0^2$

$$\varepsilon^2 = \frac{1}{n}(1 - R_t^2)\Sigma v_0^2.$$

For persistence forecasts, the mean square error is given by

$$\sigma_t^2 = \frac{1}{n}\Sigma(v_0 - v_t)^2$$

$$= \frac{2}{n}(1 - R_t)\Sigma v_0^2.$$

Therefore $$\varepsilon^2 = \frac{1}{2}(1 + R_t)\sigma_t^2. \qquad \ldots\ldots (13)$$

So that ε is less than σ_t, since R_t is less than 1 for t greater than 0.

The extent of the improvement is shown by the values of the index of success which are given in Table XII, it being recalled that the index for persistence forecasts is zero. It will be noted also that each value of success in Table XII is less than the corresponding value in Table XI.

TABLE XII—STATISTICAL FORECASTS OF EQUIVALENT TAILWINDS

	Standard error of forecasts		Index of success	
	700 mb.	500 mb.	700 mb.	500 mb.
	knots		per cent.	
Winter ...	9·3	13·5	41	41
Spring ...	9·2	12·6	32	36
Summer ...	7·6	8·9	40	37
Autumn ...	9·4	11·8	35	28
Year	8·9	11·7	35	35

The standard deviation of the 24-hr. variation is the same as in Table XI.

Wind expectations for 36 hr.—At the present time, the equivalent tailwinds expected 36 hr. ahead on various air routes over Europe are being supplied to airline operators on the basis of the regression equation (12). In Table XIII is given a statistical summary for two of the routes, namely Northolt to Barcelona with diversion to Nice, and Northolt to Copenhagen with diversion to Hamburg, for the period January–May 1952.

TABLE XIII—COMPARISON OF 36-HR. WIND EXPECTATIONS WITH ACTUAL WINDS FOR CERTAIN AIR ROUTES AT 10,000 FT.

	Northolt–Barcelona–Nice			Northolt–Copenhagen–Hamburg		
	Standard error of forecast winds (ε)	Standard deviation of 36-hr. variation of wind (σ_t)	Index of success	Standard error of forecast winds (ε)	Standard deviation of 36-hr. variation of wind (σ_t)	Index of success
	kt.	kt.	%	kt.	kt.	%
Jan. ...	9·7	11·2	50	12·6	14·6	51
Feb. ...	7·0	7·4	32	8·7	9·6	42
Mar....	7·5	8·9	54	7·2	7·5	28
Apr. ...	7·1	7·7	39	7·7	8·4	40
May ...	4·8	5·3	42	6·8	7·2	33
5 months	7·4	8·3	46	8·9	9·8	44

From equation (13) the index of success is given by

$$P^2 = 1 - \frac{\varepsilon^2}{\sigma_t^2}$$

$$= \tfrac{1}{2}(1 - R_t). \qquad \ldots\ldots \quad (14)$$

In the case under discussion the value of R_t is 0·60, and in consequence one would expect the value of P to be 45 per cent. This agrees with the average value actually found over the five months, so confirming that the average success over a period of several months can be calculated in advance from the known value of the correlation coefficient of equivalent tailwinds with time.

Forecasts of night minimum temperature.—The following modification of the index of success in equation (10) for elements subject to diurnal variation was suggested by F. E. Lumb. In this case σ_t is to be interpreted as the root-mean-square difference between the forecast value of the element and the observed value on the day (night) preceding that to which the forecast refers. It will be seen that in other respects the characteristics of the index remain unchanged.

For the three months January–March 1953 forecasts of minimum air temperature made at Liverpool (Speke) airport at 1600 G.M.T. daily for the ensuing night gave the following values: $\varepsilon = 3 \cdot 38$°F., $\sigma = 4 \cdot 77$°F., percentage success 71.

Part III.—Summary

An index of the usefulness of forecasts of the "black or white" type is adopted in the form $I = \frac{1}{2}(c + c')$, where c,c' are the forecast accuracies of blacks and whites respectively. The success of this type of forecast, defined as the improvement beyond the point reached by persistence, is given by $J = (I - I_0) / (1 - I_0)$, where I_0 is the value of I corresponding with persistence forecasts.

For forecasts of continuously varying elements, Priestley's index is adopted, $P = (1 - \varepsilon^2/\sigma_t^2)^{\frac{1}{2}}$, where ε^2 is the variance of the forecast errors and σ_t^2 the time variance of the element. This index measures the improvement over persistence, the latter corresponding with $P = 0$.

The improvement of one method of forecasting over another is given by $(I' - I)/(1 - I)$ or $(P' - P)/(1 - P)$, where I' and I or P' and P are the individual indices.

REFERENCES

6. PRIESTLEY, C. H. B.; Accuracy of upper air forecasts. *Met. Res. Pap., London*, No. 222, 1945.
7. HARLEY, D. G.; Equivalent tailwinds on the Shannon to Gander route. *J. Inst. Navig., London*, 7, 1954, p. 16.

EXCEPTIONAL WEATHER OF NOVEMBER 1953 TO EARLY FEBRUARY 1954

By L. F. LEWIS, M.Sc.

The exceptional mildness of November and December 1953 in the British Isles has aroused widespread interest. In England and Wales the mean temperature in November 1953 was 1°F. lower than that in 1938 and almost the same as in 1939, otherwise it was higher than in any November since comparable figures are available, that is since 1901; in Scotland, apart from November 1920 when the mean value equalled that for 1953, it was higher than in any November since before 1901. December was the mildest December both in England and Wales and in Scotland since 1934. It was, however, the combined temperature for the two months which was so exceptional. The graph in Fig. 1 shows the mean temperature for these two months at Oxford in each year from 1815 to 1953. It will be seen that the value for 1953 is higher than in any year since 1852, that is for more than 100 years. The values for England and Wales as a whole going back to 1901 give a similar curve. Incidentally, the Oxford graph illustrates the great variability of the climate in the British Isles, particularly as the figures refer to the mean temperature over a period of two months. Several temperature records were broken in 1953 at individual places; at Oxford the lowest minimum temperature in November, 35°F., was the highest for November in a record going back to 1881. In the period December 2–4, there were exceptionally high maximum temperatures, 64°F. at Llandudno on the 2nd was the highest temperature for December since before 1901, while 59°F. at Falmouth on the 2nd was the highest there in December since before 1871, and the same value at Kew Observatory on the 4th equalled that on December 4, 1931, which was the highest since before 1871. At Oxford no air frost was recorded throughout the four months September–December 1953; the previous latest date for the first air frost of this period was November 22, 1898.

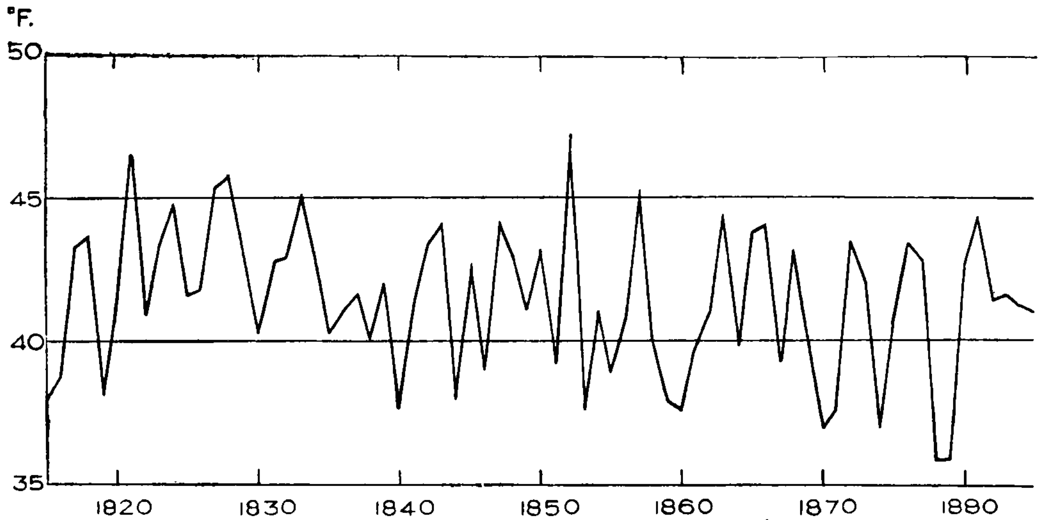


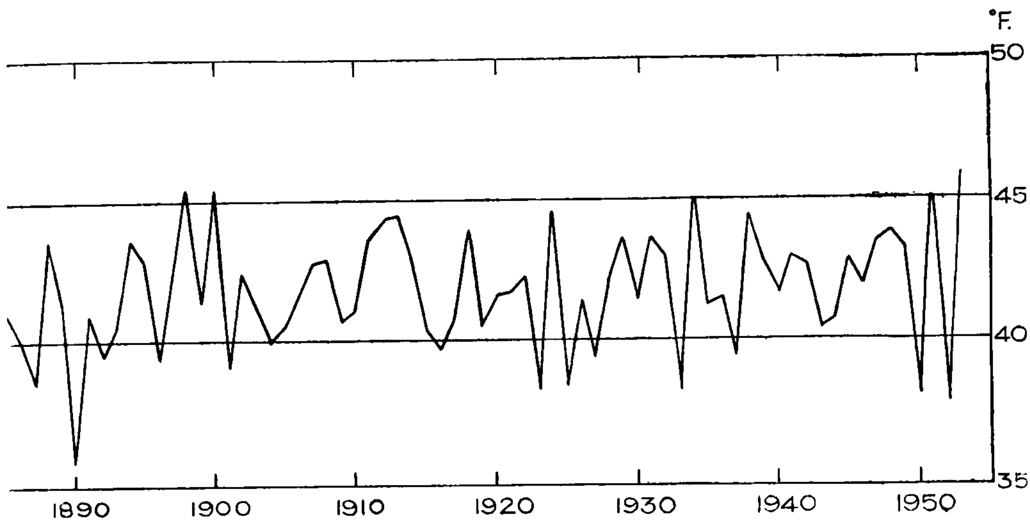
FIG. 1—MEAN TEMPERATURE AT OXFORD,

The table below gives the weekly deviations from average temperature for south-east England for November to early February during 1938–39, 1939–40 and 1953–54. The averages used for 1938–39 and 1939–40 refer to the period 1906–35, while those for 1953–54 refer to the period 1921–50 but on the whole the changes are relatively small.

No. of week	Week ending about	1938–39	1939–40	1953–54
			degrees Fahrenheit	
44	November 5	+ 4·4	− 0·6	− 1·9
45	November 12	+ 7·9	+ 5·8	+ 4·5
46	November 19	+ 8·2	+ 6·3	+ 2·4
47	November 26	+ 1·5	+ 1·1	+ 4·3
48	December 3	+ 0·6	+ 7·6	+ 8·8
49	December 10	+ 3·3	− 0·3	+ 6·3
50	December 17	+ 5·8	− 1·1	+ 6·2
51	December 24	−13·7	− 6·0	+ 2·9
52	December 31	− 2·9	− 8·1	− 0·5
1	January 7	− 2·7	− 6·3	− 4·5
2	January 14	+ 2·8	− 5·1	+ 3·9
3	January 21	+ 8·1	−12·8	+ 3·2
4	January 28	− 0·4	− 9·4	−10·2
5	February 5	− 3·5	− 8·7	−13·5

It shows that the exceptionally mild November of 1938 was followed by mild weather during the first half of December but the week ending on December 24 (week 51) was extremely cold, the deviation from the average temperature for the week being −13·7°F. November 1939 was followed by a rather cold December, the latter half of the month being very cold, while the following month, January 1940, was one of the coldest Januaries on record. In 1953 the mild weather persisted for the most part throughout November and December. The first nine days of January were mainly cold; this was followed by a long mild spell, and it was not until the 23rd that an extremely cold, wintry spell set in and persisted into the first part of February.

Over most of England, particularly in the south, another interesting feature of the weather of November and December 1953 was the deficiency of rainfall,



NOVEMBER AND DECEMBER COMBINED, 1815–1953

December being notably dry. In contrast, in England in 1938, November and December were both wetter than usual, while in 1939 November was excessively wet and December dry, though not so dry as in 1953.

The exceptionally long mild spell was responsible for many anomalies in bird and insect life and in the early flowering of plants. There were widespread observations of spring flowers and shrubs being in flower, and of birds nesting much earlier than usual. The writer saw a butterfly on a window of a house in Clifton, Bristol, on December 27.

COASTAL FOG PATCHES

By L. JACOBS, M.A., M.Sc.

Wales is an area where the topography particularly lends itself to local weather variations, and studies such as those made by Howe[1,2] are invaluable, if considered with the synoptic charts, for giving information regarding the local synoptic climate.

The distribution of temperature round the frost hollow shown by Howe[2] as existing on the night of November 29, 1952, appears to be fairly normal, but it is rather surprising that, on a radiation night, the warming effect of the Aberystwyth built-up area, and of the nearby sea could so exactly balance the radiation loss that the temperature at Dinas School remained constant, at about 32°F., for the six hours of observations. Some records of local winds on this occasion would have been interesting.

The shallow fogs mentioned by Howe[2] as drifting from the sea, must have been either existing sea-fog patches or coastal-fog patches forming *in situ* by uplift of nearly saturated air over the coastline, the fog being brought over land by the sea-breeze setting in at the end of the fine morning, which Howe mentions as preceding the fog.

It is clear from Lamb's accounts of North Sea haars[3] and of sea-breezes[4] that there are many local features to be considered both for the sea-breeze formation and the drift and persistence of the fog, and local investigations into these factors would be useful.

Howe[2] gives three examples of the appearance of sea-fog at Aberystwyth: on May 18, 1952, August 2, 1952 and February 27, 1953. As the synoptic chart showed fog to be impossible on the second date, the writer wrote to Mr. Howe who now agrees that this date is wrong, and states that he cannot trace the correct date.

Examination of the synoptic charts for the period round May 18, 1952, suggests that this was a case of fairly extensive sea-fog being formed on that day as the light south-easterly air flow on the previous day was replaced by a light, decreasing, westerly air flow with increasing dew points over Wales. At Pembroke Dock it was calm with no low cloud (2 oktas of upper cloud) and visibility 4 miles at 0600 G.M.T.; at 0900 the wind was WNW., force 2, the visibility was 2½ miles with fog in sight, the cloud 5 oktas at 100 ft., the dew point having increased from 52°F. at 0600 to 55°F. at 0900 (the average sea-surface temperature for May is 51°F. off south Wales and 49–50°F. off north Wales). At 0900 none of the stations, Aberporth, Harlech or Valley reported fog or low cloud, although all recorded light winds off the sea and showed dew points well above sea-surface temperatures. However, by 1200 Aberporth and Valley both reported fog; it is presumably about this time that the fog came in to Aberystwyth with the sea-breeze. The non-appearance of fog at Harlech may well have been associated with the formation of large cumulus cloud in the early afternoon. The synoptic charts for 1200 and 1500 G.M.T. for May 18, 1952 show that sea-breezes had set in on many coasts of England and Wales; the sea-breeze at Spurn Head had brought in fog from the North Sea between 0900 and 1200.

The Aberystwyth fog of February 27, 1953 appears to be a case of sea-fog or very low stratus, which was originally present from February 21 to 25 in a moist south-westerly air stream with strong winds, persisting in patches over the sea in the slackening gradient on February 26–27, and coming over land with the sea-breeze of the late morning of February 27 (Howe gives no wind observations except in the statement "the mist advanced slowly eastward"). Radiation from the top of the fog (or of the low stratus falling to the surface) must have helped the fog to persist, the fog, from Howe's figures, becoming some 4°F. colder than the sea-surface temperature. Douglas[5] has discussed, with examples, how land radiation fogs can persist and become colder over the sea, drifting back to land after a change of wind, and Jacobs[6] has given instances of the persistence and drift of sea-fog patches over the Gulf of St. Lawrence for some time after the main fog or low stratus has cleared away.

February 27 is early in the year for a sea-breeze, and the topography of the district round Aberystwyth must have aided the setting in of the sea-breeze, first at 200 ft. up on Constitution Hill and 15 min. later on the lower ground. Sea-breezes did not occur at the other (synoptic) reporting stations in west Wales, Pembroke, Aberporth, Harlech and Valley (where the temperature rose higher that day than at Aberystwyth); early morning (probably radiation) fog at or near the first three stations had cleared by 1200, while low stratus at Valley cleared by 1500. That there was indeed fog present at sea that morning was shown by the 0600 observation at St. Goven lightship (off south-west Wales), by the fog at Scilly at 0300 and by the formation of fog at Midleton (near Cork) between 0300 and 0600 with a light wind off the sea, the dew point rising from 35° to 42°F.

In the absence of wind observations it is difficult to give the exact reason for the dispersal of the Aberystwyth fog at 2000. It seems most likely that the sea-breeze had died out long before then and that a slight land-breeze drove the fog out to sea.

Ruck's cases[7] of very low stratus appearing in the early afternoon over St. David's Head and a few miles out to sea, which are quoted by Howe[2], appear to be due to the sea-breeze ("SW. wind of about 10 m.p.h.") either bringing in a patch of existing low stratus, the clearance out to sea being due to subsidence at the origin of the sea-breeze, or causing sufficient turbulence in nearly saturated air ascending near the coastline. Without study of the synoptic charts—no dates or times are given—it is not possible to be more precise about the reason for the formation and later dispersal of the cloud. The clearance "before evening" in Ruck's cases could have been a combined effect of the subsided air arriving at the coastline in the sea-breeze circulation and of the afternoon heating over land.

REFERENCES

1. HOWE, G. M.; A Cardiganshire frost hollow. *Weather, London*, **8**, 1953, p. 69.
2. HOWE, G. M.; Observations on local climatic conditions in the Aberystwyth area. *Met. Mag., London*, **82**, 1953, p. 270.
3. LAMB, H. H.; Haars or North Sea fogs on the coast of Great Britain. London, 2nd edn, 1943.
4. London, Meteorological Office. Sea-breezes and land-breezes. Unpublished, copy in Meteorological Office Library. London, 1943.
5. DOUGLAS, C. K. M.; Cold fogs over the sea. *Met. Mag., London*, **65**, 1930, p. 133.
6. JACOBS, L.; The meteorology of the Gulf of St. Lawrence and Prince Edward Island. Unpublished, copy in Meteorological Office Library. London, 1943.
7. RUCK, F. W. M.; Mist over St. David's. *Weather, London*, **4**, 1949, p. 360.

METEOROLOGICAL OFFICE DISCUSSION

Some applications of meteorology to agriculture

A discussion on some applications of meteorology to agriculture was held at the Royal Society of Arts on Monday, January 18, 1954. The opener was Mr. L. P. Smith of the Agricultural Meteorological Branch. He pointed out that the Agricultural Branch was a branch engaged on work of applied meteorology and operational research, not pure research. They had taken as their model the methods by which meteorology had been applied to aviation problems, especially during the recent war. For successful application it was necessary for the meteorologist to have a good working knowledge of the sciences and subjects with which he was dealing. Members of the Branch, one of whom was stationed at a provincial headquarters of the National Agricultural Advisory Service at Bristol, acquired their knowledge of agriculture by constant liaison and discussion with agriculturists, horticulturists and foresters. This contact arose in the course of visits to research stations, experimental farms, universities, county institutes and National Agricultural Advisory Service establishments; the visit was always welcome and the only complaints received were to the effect that the visits were too infrequent.

Meteorology entered into every farming operation and the difficulty was the choice of a subject for investigation. A policy was adopted of attacking the problems in which some good chance of success seemed possible. The aim of the lecturer in the present discussion was to give some details of four problems in which considerable advance had been made. It was not meant to be a comprehensive survey, but it illustrated the principles of collaboration and application on which the work of the Branch was based.

The first two problems were those of plant pathology and frost; both had been the subjects of articles in the *Meteorological Magazine*[1,2,3] and would therefore only be treated in outline. Co-operation between reporting stations, Dunstable, Harrow and the Plant Pathology Laboratory at Harpenden enabled the Ministry of Agriculture to issue press notices of potato-blight forecasts. Slides were shown illustrating how use of hourly observations of weather and detailed disease assessments were combined. In 1953 the warning system had been very successful. In regard to frost the main aim was to help in the selection of frost-free sites, and the method described by Mr. Lawrence[3] was applied to a Ministry of Agriculture farm near Stratford. Observations of minimum temperature over the spring-frost period (April–May) suggested that a drop of 56 ft. in altitude from the side of a hill to the Avon valley resulted in a decrease of average minimum temperature of about 1·5°F. and an increase in the probable frequency of damaging May frosts from 1 year in 10 to 7 years in 10.

The speaker then dealt with problems of wind and shelter. The work of Mr. Gloyne at Bristol had gathered together all the accessible evidence regarding wind flow over obstacles, and as a result much was now available for application to crop-husbandry and animal-husbandry problems. Slides were shown of the wind pattern behind barriers, the effect of barriers on other meteorological elements, and the effect of wind on trees and plants. It was emphasized that any problem of shelter was one that could only be solved by co-operation with other scientists such as foresters, soil chemists, husbandry experts and so on. Shelter was not an unmixed blessing, and correct planning was essential to obtain maximum benefit. Experiments were now in progress relating to the protection of horticultural crops from wind.

With respect to irrigation the theory due to Dr. Penman[4] had been applied with the aid of data from synoptic stations to obtain the averages of potential transpiration for all areas in Great Britain. Using the known pattern of variation of rainfall about the average it was thus possible to estimate the frequency and extent of irrigation need. An example was quoted of the rainfall-transpiration balance at a Somerset dairy farm, showing that good dairy areas were those in which most years gave adequate rain for the growth of grass. The theory thus was not contradicted by ecological facts. The simplification of the calculations by use of regression equations on sunshine was explained, and two examples of irrigation plans in a current year were shown. The method was thus suitable for long-term planning and for practical use to a fair degree of field accuracy[5].

Dr. Penman (Rothamsted), opening the general discussion, expressed the appreciation of the agricultural scientists for the help they were receiving from the Meteorological Office. He mentioned the effects of increased yield that could be obtained by correct irrigation, and felt that, even if the figures for transpiration had to be modified slightly at a future date, the correct order of differences had been established.

Mr. Large (Plant Pathology Laboratory) gave further details of the potato-blight investigation and warning service. He showed slides which illustrated the build-up of the disease, and thanked the observers of the Meteorological Office outstations for their co-operation; further work was continuing on the problem and the techniques might be applied to other important diseases.

Dr. Ångström (Sweden) expressed his interest in the slides concerning the effect of shelter, and mentioned examples of this type of problem which arose in his country.

The Director asked questions relating to Dr. Thornthwaite's method of planning the sowing of peas at Leabrook Farms, New Jersey, and to the souring of milk. Mr. Smith, in reply, outlined the principles underlying the timing of planting and harvesting of peas, namely that the growth rate is linked to the potential transpiration, the monthly averages for which are known; both he and other speakers suggested that high temperatures (and possibly high humidities) were the predominating factor in milk going sour.

Mr. Gloyne outlined methods and instruments which might be used in considering the problem of local climate so that a valid assessment of the agricultural potential of a site could be made. From information of this type, the question of land utilization could be approached.

Mr. Gold inquired regarding the spraying of potatoes and asked whether the problem of water supplies had been considered. The effect of protective spraying and the "burning-off" of haulms was explained, and Mr. Smith said that the implications of the calculated water needs were realized, and the aim of the Branch was to provide adequate statistics so that they could be considered in any national policy decision; a working party was examining the problem. This was confirmed by Mr. Hudson (National Agricultural Advisory Service) who said that the advisory services were very grateful for the assistance of the agricultural meteorologists in many diverse aspects of their work.

Major Dobb (Agricultural Land Service) spoke of the help that was given in relation to forestry and estate management, and quoted the United States of America as an example of large-scale irrigation undertakings.

Dr. Glasspoole outlined the work of Sir Napier Shaw in relation to agricultural meteorology and his inception of the crop-weather scheme of observations.

Mr. Jacobs (Gloucester) gave figures showing the increased demand of farmers for forecasts by telephone, and emphasized the growing interest of firms of agricultural contractors in accurate short-term forecasts.

Dr. Stagg mentioned the use of dew ponds and raised the question of dew-gauges. He inquired whether it was possible for plants to absorb water through the leaves and transmit it to the soil via the roots. In reply, Mr. Smith said he thought that dew ponds were small catchment areas with low evaporation, and that any form of water conservation was an advantage. Plants certainly could absorb liquids through the leaves, and it was an accepted practice to spray trees to relieve certain mineral deficiencies in the soil.

Shortage of time rather than topics occasioned the end of the meeting, and in conclusion the Director thanked all who had taken part in the discussion which had been of unusual interest. He said that the application of meteorology to agriculture was an example of what could be done for the general public.

REFERENCES

1. SMITH, L. P.; Forecasting outbreaks of potato blight. *Met. Mag., London,* **82,** 1953, p. 113.
2. LAWRENCE, E. N.; Frost investigation. *Met. Mag., London,* **81,** 1952, p. 65.
3. LAWRENCE, E. N.; Estimation of weekly frost risks using weekly minimum temperatures. *Met. Mag., London,* **81,** 1952, p. 137.
4. PENMAN, H. L.; Natural evaporation from open water, bare soil and grass. *Proc. roy. Soc., London,* A, **193,** 1948, p. 120.
5. London, Ministry of Agriculture and Fisheries. The calculation of irrigation in need. *Tech. Bull. Minist. Agric., London,* No. 4, 1954.

METEOROLOGICAL RESEARCH COMMITTEE

At the meeting on November 24 the Synoptic and Dynamical Sub-Committee considered a paper by Mr. Sawyer[1] on the rainfall of depressions which move eastward near the English Channel (the third contribution to a tetralogy), a paper by Messrs. Bannon and Gilchrist[2] which gives a statistical study of the variation of temperature in the troposphere and lower stratosphere, and a paper by Mr. Jenkinson[3] which discussed the average vector distribution of the upper air in temperate and tropical latitudes. Two other papers of synoptic interest were also discussed, one by Dr. Farquharson[4] dealing with vorticity and synoptic development and one by Messrs. Murgatroyd and Goldsmith[5] which discussed observations of cirrus cloud over southern England.

ABSTRACTS

1. SAWYER, J. S.; Rainfall of depressions which move eastward near the English Channel. *Met. Res. Pap., London,* No. 816, S.C. II/153, 1953.

Rainfall distributions over Great Britain were drawn for depressions moving east along or near the English Channel during 1941–50. Average map is shown, also profiles of relation to distance from track, frequency diagrams, etc. Variations in individual depressions are related to track, speed and central pressure, and expressed as a regression equation; 1000–500-mb. thickness is also considered.

2. BANNON, J. K. and GILCHRIST, A.; A statistical study of the variation of temperature in the troposphere and lower stratosphere. *Met. Res. Pap., London,* No. 819, S.C. II/154, 1953.

To find latitude and season for which Dines's model applies, correlations were evaluated for stations from 73°N. to Malta between height of 300-mb. level (H_{300}), tropopause pressure (P_T) and temperatures at 500–60 mb. Results are set out in detailed tables. Causes of variable stratosphere coefficients are discussed, including different effects of vertical motion and advection in different latitudes, seasons and years. Relation between temperature in lower stratosphere and P_T or H_{300} decreases with height. Dines's model holds only in regions affected by travelling depressions and anticyclones.

3. JENKINSON, A. F.; The average vector wind distribution of the upper air in temperate and tropical latitudes. *Met. Res. Pap., London,* No. 823, S.C. II/156, 1954.

Revised charts are presented for levels of 500, 300, 200 and 100 mb. for the world between 60°N. and 50°S. for January, April, July and October. They show stream-lines and isotachs (lines of equal vector speed), based on geostrophic vector winds computed from mean M.S.L. pressure charts with the addition of thermal vector winds in a succession of layers, constructed from upper air temperature charts recently prepared in the Meteorological Office. A grid of 234 points was used, checked by upper air wind data.

4. FARQUHARSON, J. S.; Vorticity and synoptic development. *Met. Res. Pap., London,* No. 829, S.C. II/157, 1953.

Difficulties in application of Sutcliffe's 1947 ideas are discussed. Relative divergence between pressure levels is important but comparing developments in the thicknesses 1000–700, 1000–500, 1000–300 mb. in a deepening depression (February 4, 1951) shows that the area of maximum development varies with thickness of atmosphere considered. The term $\mathrm{curl}(\partial \mathbf{V}/\partial p . dp/dt)$ is shown as possibly important for forecasting. Sutcliffe's form of the vorticity equation is evaluated for 950 and 500 mb. for February 4, 1951; an area of increasing cyclonic vorticity was followed by development of a small secondary depression. A similar development was found on October 3, 1952.

5. MURGATROYD, R. J. and GOLDSMITH, P.; Cirrus cloud over southern England. *Met. Res. Pap., London,* No. 833, S.C. II/158, 1953.

Frequencies of cirrus observed at three ground stations are tabulated and the reality of peculiarities such as peaks at dawn and dusk in summer and night minimum are discussed. Frequencies of various types of cirrus are tabulated. Aircraft observations, 1949–52, are summarized; in only 27 per cent. are large areas found clear of cirrus. Base mostly 25,000–30,000 ft. at temperatures −40° to −50°F. (−40°F. is limit of spontaneous nucleation). Tops near tropopause at −40° to −75°F. A "moist layer" is generally found at 28,000–32,000 ft. Part 3 gives notes on forecasting high cloud and condensation trails.

OFFICIAL PUBLICATION

The following publication has recently been issued:—

GEOPHYSICAL MEMOIRS

No. 92.—Day-to-day variations in the tropopause. By J. S. Sawyer, M.A.

A series of 6-hourly charts has been drawn in detail showing the topography of the tropopause over a period of one month. The features of this series of charts are compared with previous studies of the tropopause, and the existence and behaviour of discontinuities in the tropopause surface are illustrated; these are most marked in association with the jet stream but minor disturbances occur elsewhere. The tropopause "funnels", reported by Palmén, are described and discussed. An analysis of the movements of the tropopause with the aid of estimated air trajectories suggests that the tropopause usually moves as a material surface embedded in the air current, and that of the changes of tropopause height at one place about half are to be explained by horizontal advection and about half by vertical air movements.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on January 20, 1953, the President, Dr. O. G. Sutton, in the Chair, a discussion was held on the subject of smog with special reference to the fog of early December 1952.

Mr. H. W. L. Absalom, Meteorological Office, described the meteorological conditions associated with fog. He described first the climatology of fog in Great Britain, pointing out with the aid of charts from the "Climatological atlas of the British Isles" that the higher frequencies of fog occurred in industrial districts and discussing the loss of sunshine in the centres of large cities. Next, he described the meteorological situation associated with the fog of early December 1952, and the meteorological observations made in the fog following the account by Douglas and Stewart in the *Meteorological Magazine* of March 1953.

Dr. E. T. Wilkins, Fuel Research Station, described the atmospheric-pollution observations made during the fog. No unusual substance was found in the pollution though the amount of pollution by smoke and sulphur compounds was very high. The smoke and sulphur-dioxide concentrations in the worst areas at respectively 4–5 and 1·3 mg./m.^{3} were appreciably greater than in the latest previous severe fog of November 1948 and were about ten times the normal. The curves of smoke and sulphur-dioxide concentrations and of deaths were shown in a slide to be nearly parallel with deaths lagging a little on the pollution. A striking fact was that the pollution at Lewisham, though high for the area, was only about equal to the normal at Westminster. Calculations of the amount of sulphur dioxide in the air over London during the fog compared with the amount produced by fires showed the efficiency of removal of the gas from the atmosphere was about 97 per cent. If this was right a fall from almost 100 per cent. to 97 per cent. efficiency was a disaster. Dr. Wilkins discussed methods of removal of sulphur dioxide, and concluded that atmospheric turbulence was more important than sedimentation of water droplets containing the dissolved gas or diffusion from the top of the fog.

Dr. N. Oswald, St. Bartholemew and Brompton Hospitals, discussed the physiological effects of smog. He said that the victims of chronic bronchitis suffer most during smoke fogs. In bronchitis there was an increase in the excretion of mucus in the lung passages. The excessive excretion of mucus and an associated inflammation of the walls of the passages restricted the flow of air in the lung, and led to certain degenerative changes in the lung from which recovery was slow and which could lead, in severe cases, to death from heart failure. He said many deaths occurred weeks after the fog which would probably not have occurred without the fog. There were no firm conclusions as to the manner in which the air pollution affected the lung, and the question was very complex. The annual rate of deaths ascribed to bronchitis was about twice as great in cities as in rural areas, but the greater ease of transmission of infection in cities may be at least as important as air pollution.

Many speakers took part in the subsequent discussion. Mr. E. Gold gave calculations to show that in traffic jams in city streets during calm weather the concentration of carbon monoxide might rise to levels sufficient to have deleterious effects. Mr. Whiten and Mr. Bonacina said London fogs were not nearly so thick and black as they were 50 years or more ago, and could not believe the concentrations of pollution were so large. Dr. A. R. Meetham discussed phenomena such as absorption of sulphur dioxide by smoke which might affect the measurement of concentration, and Dr. C. J. Regan said the London County Council's observations of carbon monoxide in streets and tunnels did not show any concentration of physiological importance.

LETTERS TO THE EDITOR

Unusual condensation-trail phenomena at Cranwell

On January 1, 1954 two aircraft forming dense persistent condensation trails in clear air entered cirrus cloud over Cranwell. When they entered the cloud they appeared to clear a lane in it leaving a trail of blue sky behind them.

Observations were made by Mr. A. Blackham at Cranwell; a summary, in chronological order, of what Mr. Blackham saw is as follows:—

At 1210 G.M.T. a very small patch of cirrus, isolated in a blue sky, showed a brilliant parhelion.

At 1350 the sky to the south was blue in the eastern sector and there was thin cirrus only in the western sector, mainly around the sun. Two aircraft flying from east to west were leaving well marked and persistent contrails.

At 1355 a brilliant parhelion was seen on one of the contrails (this was still visible when a photograph was taken later and is indicated at A on the diagram below the photograph facing this page).

At 1400 it was noticed that the contrails were still plainly visible in the blue sky, but where the aircraft entered the cirrus there were, in place of the contrails, "blue lanes" in the cloud. The dividing line between the cirrus and blue sky was at that time well marked and coincided with the change from contrail to "blue lane".

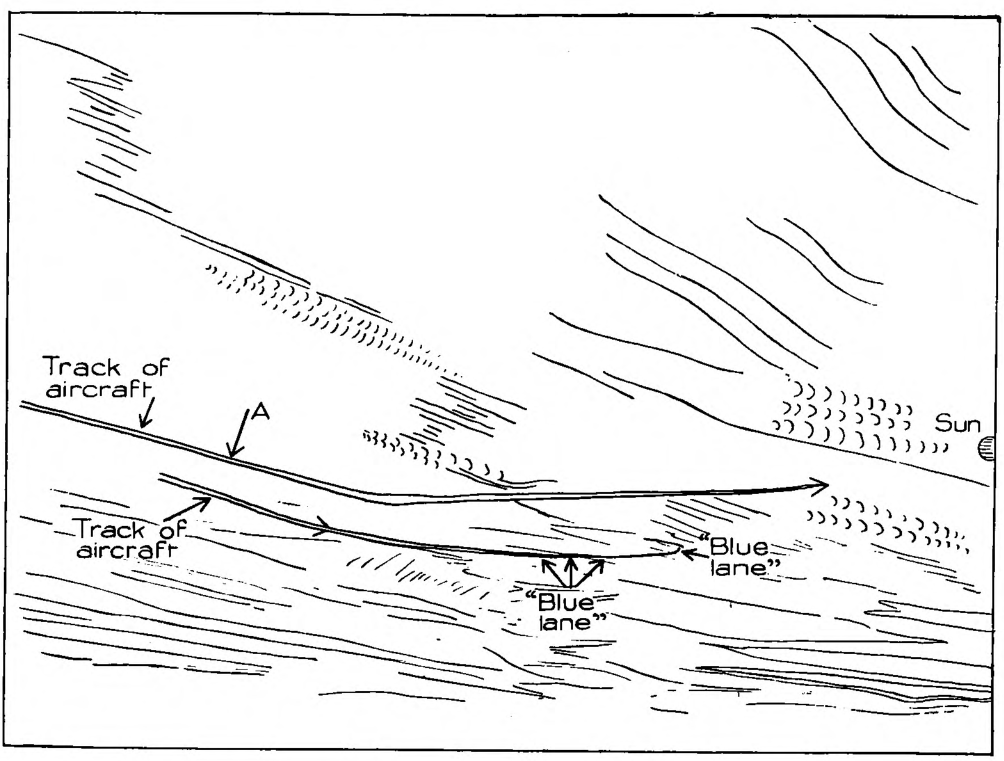
A few minutes later the upper edges of cirrus immediately below the sun (about 10°) were seen to be brightly coloured, the brightest colour being purple.

Although the contrails were very persistent, the "blue lanes" began to fill up quickly (the cirrus was spreading rapidly), and by the time a photograph was taken at 1410 most of the "lanes" had vanished.

Despite inquiries it proved impossible to find out the height of the aircraft.

In the *Meteorological Magazine* for January 1953, R. S. Scorer put forward a tentative explanation of a somewhat similar phenomenon which he had observed. In his case the aircraft formed a contrail with a clear lane on each side but all the phenomena took place in a cloud, and Scorer's explanation hinged on the possibility that part of the cloud was composed of ice crystals and part of water droplets.

Reproduced by courtesy of A. Blackham



CONTRAILS AND DISTRAILS OVER CRANWELL, JANUARY 1, 1954

(see p. 152)

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FRAZIL ICE FORMATION AT SHOEBURYNESS, JANUARY 25, 1954

In the Cranwell case the contrail formed in clear air and the distrail in cloud. A parhelion was observed on both contrail and cloud strongly suggesting that both were composed largely of ice crystals. It seems unlikely therefore that Scorer's explanation could apply in this case.

The only reasonable explanation which occurs to me is as follows. The contrail formed in the normal way in clear air. The addition of extra water vapour to the cloud where ice crystals were present resulted in the growth of these crystals and to the subsequent precipitation of the larger particles so formed out of the cloud layer into drier air below thus clearing a lane behind the aircraft. Mr. Blackham did not notice precipitation virgae below the cloud when the blue lanes were forming, but he was not watching through field glasses and it is doubtful whether such a phenomenon would be observed by the naked eye unless one was watching specially for it. The process suggested would take appreciable time to operate so that the cloud would hardly clear instantaneously behind the aircraft, but as Mr. Blackham never actually saw the aircraft this is not contrary to the observations.

On the afternoon of January 1, 1954, an anticyclone of 1043 mb. was centred just south-west of Ireland while a weak warm front moved slowly south-east across Scotland. There is no upper air ascent which can be described as typical of the air over Cranwell at 1400 G.M.T. Cranwell is almost midway between Hemsby and Liverpool, and from a study of the 1400 G.M.T. radio-sonde ascents from these places it is probable that the tropopause height was about 36,000 ft. with a temperature of about −80°F. The mintra level was about 22,000 ft. (−28°F.). The upper air ascent from Hemsby is fairly dry up to the limit of humidity observations (21,000 ft.). Liverpool shows a shallow isothermal layer around 21,000 ft. with near saturation at that level, but this is just below the mintra level. Winds were between N. and NNE. about 20 kt. at 2,000 ft. increasing fairly steadily to about 65 kt. at the tropopause.

R. A. S. RATCLIFFE

Morton Hall, January 22, 1954.

Frazil ice formation at Shoeburyness

The photographs opposite were taken between 1300 and 1330 G.M.T. on Monday, January 25, 1954, following two days of fresh E.–SE. winds, with day temperatures only a few degrees above freezing and frost at night. The day maxima on the Saturday and Sunday preceding had been 38°F. and 35°F. respectively and night minima for the previous two nights 30°F. and 29°F., the minimum on the grass being 26°F. on both occasions.

On the day on which the photographs were taken, the sky had been covered all morning by a continuous layer of cirrostratus and the temperature did not rise above 32°F. until after midday, when the cloud sheet commenced to break slowly, decreasing to 4 oktas by 1500. The wind was 120–140°, 12–18 kt., during the morning. The temperature at the time of the photograph was 33°F. and the humidity 71 per cent.

The depth of the ice formation varied between 12 and 18 in., and was not covered by snow—in fact, up to that time, no snow had fallen. It consisted of soft, friable ice into which the feet sank as into fresh snow, and was interspersed with lanes of clear water.

It extended at that time for about 200 yd. towards the sea, though this distance tended to vary considerably during the period through which the formation persisted, and stretched continuously along the whole length of the shore as far as could be seen. The frazil ice tended to break up to some extent as the tide came in, and detached portions floated on the surface of the water, but it re-formed as the water receded. The phenomenon persisted throughout that week and the following week until February 8, with similar weather conditions continuing, though there were considerable variations in the depth and extent of the ice from day to day.

R. O. HARRIS

Shoeburyness, March 22, 1954.

NOTES AND NEWS

Low tropopause temperature

The report of the Meteorological Officer-in-Charge aboard *Weather Recorder* for voyage 49, mentions that whilst at 61°N., 15°05′W. (station INDIA), a temperature of −108°F. was recorded at the tropopause (pressure 160 mb., height 42,800 ft.) at 1400 G.M.T., January 9, 1954. This equals the lowest temperature so far recorded in January at Lerwick, which is at a comparable latitude 60°N.

The following figures supplied by the Upper Air Climatology Branch give the lowest temperatures recorded at the tropopause over Lerwick in each month up to the end of 1950:—

	°F.		°F.
January	−108	July	− 86
February	−107	August	− 81
March	−110	September	− 89
April	− 91	October	− 97*
May	− 88	November	−104
June	− 86	December	−111

The *Daily Aerological Record* quotes the Lerwick tropopause temperature as −101°F. (pressure 183 mb., height 39,700 ft.) at 1400 G.M.T. on January 9, 1954.

C. E. N. FRANKCOM

REVIEWS

The restless atmosphere. By F. K. Hare. *Hutchinson's University Library.* 7½ in. × 5 in., pp. 192, *Illus.*, Hutchinson & Co., London, 1953, Price: 8*s.* 6*d.*

"The restless atmosphere", as the author explains, is written for geographers and its main purpose is to give a description of the "dynamic" climatology of a large area of the world. "Dynamic" implies that the day-to-day processes of the weather are described and their effects on regional climates, instead of the more statistical descriptions of climate given by many textbooks on climatology.

The author has achieved considerable success in this different approach to the explanation of world climates, and his book will be welcomed by geographers as well as being well worth reading by professional meteorologists.

In the first part of the book the author discusses briefly the physical processes which go to the making of the weather. The discussion is intentionally almost

* Taken from frequency tables of early observations at Lerwick; this is the lower value of a 2° range.

completely non-mathematical, and should be understood by any one with only a moderate knowledge of physics. The second part of the book describes certain regional climates. Chapter I deals with the "energy budget" of the atmosphere and the exchange of radiant energy between the earth and its atmosphere. Chapter II deals with moisture in the atmosphere. The various quantities used in describing the humidity of the atmosphere are explained lucidly and simply. In this chapter, too, there is also a brief description of rain-making processes by seeding cloud with dry ice and other nucleants. The processes of cloud and fog formation are also described. Chapter III deals with convective processes, and Chapter IV with the relation between wind and the pressure gradient.

In Chapters V and VI the author treats ably and at some length with air-mass analysis, fronts, etc., and the depressions of middle latitudes. In the latter chapter, however, one statement needs partial correction. Commenting on the work of the Bergen school of meteorologists, the author says "there was some conservative reluctance on the part of the official forecast services of the world to accept these revolutionary ideas and methods; it was not until 1934, for example, that the British Service began drawing fronts on its working charts." In fact, the British Meteorological Office fully realized the importance of the work of the Bergen school at an early date, and in the winter of 1925–26, at the invitation of the British Meteorological Office, J. Bjerknes spent some months in London demonstrating the new ideas and methods. Similarly T. Bergeron spent the winter of 1928–29 at the Headquarters of the British Meteorological Office at Malta for the same purpose. J. Bjerknes also spent a further period in London during the winter of 1935–36. Although it was not until 1934 that fronts were inserted regularly on the official published reports of the British Meteorological Office, fronts were drawn on certain types of working charts as early as 1926. Caution was justified since it is now known that the idealized pictures of fronts as depicted originally by the Bergen school are frequently not realized. Furthermore it took time to achieve a sufficiently high standard of frontal analysis.

In this first section of the book the author has drawn upon his experience in the British Isles and North America to illustrate his statements. The reader may not realize, however, from the text that it is the more usual course of events that is described, and that variations from this are not uncommon, otherwise weather forecasting would be relatively easy.

The second part of the book, which the reviewer found most interesting, deals with the climates of different regions of the world from the "dynamic" or "synoptic" aspect.

The chapter on the intertropical belt provides interesting reading. As the author explains, the original over-simplified idea of weather in the tropics has been abandoned; in fact the synoptic climates of these regions are often very complicated and sometimes difficult to explain. It must be remembered that the descriptions in this chapter apply to the oceans themselves. Heavy orographic rainfall can and does occur in favourable localities when the trades are blowing.

In the chapter on intertropical Africa the treatment is mainly based on "A study of the atmospheric circulation over tropical Africa" by C. E. P. Brooks and S. T. A. Mirrlees, while the work of Hamilton and Archbold on the climate of west Africa is also treated at some length.

The chapter on North America deals with the air masses and depressions affecting that region, and a regional climatic division of the continent is proposed, based on the source of rainfall, namely the rainy Pacific coastal area, the semi-arid western plateaux and plains, and the rainy eastern area or Atlantic province.

The monsoonal climates of the East are next dealt with. The descriptive treatment follows the lines of work done by the author when he was a member of the staff of the Meteorological Office during the late war. The author does not, however, make it clear to the reader that within the compass of a single chapter only the broad outlines of the climate of such a vast area can be dealt with, and that detail is inevitably lost. In no other part of the world, perhaps, are the effects of topography so marked and the variation between the winter and summer monsoons so great as in many localities of this vast region. The final chapters deal with Europe and the Mediterranean. The air masses affecting these regions are described, and a brief summary of the main weather types is also given. In the chapter on the Mediterranean the author gives a description of the formation of Alpine lee-depressions. Mention is also made of Atlas lee-depressions about which the author has written in an unpublished memorandum.

In the preface to "The restless atmosphere" the author pays a tribute to Mr. C. S. Durst under whom he served during the war and to whom the book is dedicated. He explains that most of the ideas presented in the later chapters of the book were acquired while working in the Investigations Branch of the Meteorological Office, of which Mr. Durst was the head. L. DODS

English weathervanes, their stories and legends from mediaeval to modern times. By A. Needham. $8\frac{1}{2}$ in. × $5\frac{1}{2}$ in., pp. iv + 102, *Illus.*, Charles Clarke (Haywards Heath) Ltd., 1953. Price: 10*s.* 6*d.*

In this book, weather-vanes are described from the literary and artistic rather than the technical point of view. The meteorologist or amateur mechanic seeking instruction on how to make a wind vane which will operate remotely a wind-direction dial in his house will not find it here; but those who are interested in the appearance and history of weather-vanes will enjoy this book.

After a brief preface the author gives what is described as "a brief history of English weathervanes", but which is in fact a good deal more than this; it refers to early Egyptian, Greek and Roman vanes, and then quotes a number of references to weather-vanes in English literature from the eighth century onwards.

Next there is a short section giving hints on the best ways to observe, photograph and draw existing weather-vanes.

In the following section, on construction, erection and use of weather-vanes, a 100-year-old recording instrument at Greenwich Observatory is described, though no reference is made to modern wind-recording instruments; a cup anemometer is wrongly described as a wind vane, and an obsolescent pattern of a Meteorological Office wind vane illustrated. Methods of strengthening large sheet-metal vanes, and several ways of mounting the rotating part of the vane to ensure free rotation, are shown; and some brief notes on the exposure and orientation of the vane are given.

After this the book is devoted to illustrations and descriptions of all kinds of weather-vanes observed and recorded by the author; they are classified under four headings by the types of buildings on which they are mounted: churches, public buildings, business premises and private dwellings; they are quite fascinating, and their variety is enormous. Cocks, dragons, ships, fishes, wyverns, locomotives, arrows, armorial bearings, lions, policemen, classical dancers, fox and geese, monks drinking ale, are but a few of the subjects for the weather-vane maker's art; there are some fine examples of metal work in the scrolls supporting the vanes and their direction letters.

With each illustration, and there are 275 of them, the author gives some descriptive or historical note which adds greatly to the interest and pleasure of the reader.

Altogether, a most entertaining book; and it is hoped that at a future date more weather-vanes will be collected, recorded and published.

G. E. W. HARTLEY

Tables of barometric pressures at varying temperatures. By J. D. W. Ball. $8\frac{1}{2}$ in. × $5\frac{1}{2}$ in., pp. 24. Constable & Co. Ltd, London, 1953. Price: 5*s*. net.

These tables are for the engineer. They are tables for the conversion from a measured height of mercury in inches, or millimetres, and at a known temperature, to a pressure expressed in kilogrammes per square centimetre, pounds per square inch, or pounds per square foot. There are subsidiary tables converting kilogrammes per square centimetre to bars at standard gravity or at Greenwich gravity. There are no tables which allow this conversion to be made for any other value of gravity.

R. FRITH

ADDENDUM

April 1954, PAGE 114, reference 6; *for* "(in the press)" *read* "**7,** 1954, p. 176".

METEOROLOGICAL OFFICE NEWS

Retirements.—Mr. C. E. Britton, Principal Scientific Officer, retired on April 8, 1954. He joined the Office in 1919 and, during nearly 35 years' service, his work has been mainly concerned with meteorological services for the Army at Shoeburyness and Larkhill. In 1939 he was posted from Shoeburyness to Headquarters to take charge of the arrangements for the Meteorological Section, Royal Air Force Volunteer Reserve, and on the partial militarization of the Meteorological Office in 1943 he continued to serve in the Personnel and General Branch with particular responsibility for matters relating to Service personnel and meteorological training. In 1947 he was posted to Larkhill where he has remained until his retirement. During the First World War 1914–18 he served in the Royal Army Medical Corps and later in the Meteorological Section, Royal Engineers. Mr. Britton has accepted a temporary appointment in the Meteorological Office. A retirement gift is being made to Mr. Britton to which those with whom he has been associated have contributed.

Mr. T. F. Twist, Senior Experimental Officer, retired on March 25, 1954. He joined the Office in 1920 and during his 34 years' service he has worked at several aviation outstations and in the Forecast Division at Headquarters. From 1947 until his retirement he served at Trinidad. He served four years in the Infantry in the First World War 1914–18, was wounded and was a prisoner of war in Germany. Mr. Twist has accepted a temporary appointment in the Colonial Service and returns to the West Indies for further service with the British Caribbean Meteorological Service. A retirement gift is being arranged for Mr. Twist to which contributions have been made by those with whom he was associated.

Academic success.—To the lists published in the March *Meteorological Magazine* should be added:

Intermediate B.Sc.: pure and applied mathematics, physics, D. J. Clark.

Nuffield Foundation Research Fellowship.—We congratulate Mr. L. P. Smith on the award of a Nuffield Foundation Research Fellowship tenable from June 1, 1954, for 10 months. Mr. Smith intends to study the application of meteorology to agriculture in France, Ireland, Scandinavia, New Zealand, Australia, South Africa, the Low Countries and Germany.

Five shillings reward.—The finder of a radio-sonde transmitter has sent a humorous letter in the shape of a formal claim for £12 10*s.* 2½*d.* (the reward offered is five shillings) to meet damages and expenses under such headings as £2 for the shock of finding a potentially dangerous weapon while searching for mushrooms, £2 for eye-strain caused by reading the partly obliterated label, and 4*s.* 8*d.* for refreshments incurred in telling the tale of the finding in the village "locals".

Sports activities.—On February 26, 1954, Mr. G. M. Band successfully defended his title as Road Walking Champion of the Iraq Command of the Royal Air Force over a seven-mile course.

Mr. B. L. Wood, Assistant at Bovingdon, gained third place in the Air Ministry Backstroke Swimming Championship held on March 12, 1954.

WEATHER OF MARCH 1954

Mean pressure was below normal over an exceptionally large area including most of Europe (except Scandinavia), the North Atlantic and the eastern United States. The greatest deficit of mean pressure, 9 mb., occurred in the region south of Iceland at about 60°N.; the mean pressure here was 998 mb. Over western Europe and the west Mediterranean, mean pressure was generally between 3 and 7 mb. below normal.

The mean temperature over most of Europe was generally 2°F. above normal, associated with the mean pressure gradient for S.–SW. winds. The mean temperature over the United States, however, was generally 4°F. below normal.

In the British Isles the weather was very changeable. Unusually cold wintry conditions during the first few days were followed about the 5th by a milder westerly type of weather. From the 10th to the 12th mild southerly winds prevailed with temperature rising to 60°F. locally. These were followed by dull cold easterlies which continued until the 18th. From this time onwards a south-westerly to westerly type of weather predominated.

On the 1st a small depression off our south-west coasts turned eastward along the English Channel and there was widespread snow in south Wales and much of southern England during the day or the following night; at 0900 on the 2nd snow lay 5½ in. deep at Wootton Courtenay, near Minehead, and 4½ in. deep at Dale Fort, Pembrokeshire. On the 1st and 2nd, temperature in the screen fell below 20°F. at a number of places, notably 6°F. at Burnley and 7°F. at Chapel-en-le-Frith, Derbyshire on the 1st and 7°F. at Eskdalemuir and Kielder Castle, Northumberland on the 2nd. Between the 2nd and 4th a complex, deep depression moved eastward from the Atlantic to near the Scottish Border and thence to the North Sea. Snow occurred widely, except in the south-west, on the night of the 2nd–3rd but it soon melted over much of England and turned to sleet on low ground in the north of the British Isles. There were strong winds or gales at exposed places, and snow drifts were 4½ ft. deep at 0900 on the 3rd at Bwlchgwyn, 1,267 ft. above M.S.L., in Denbighshire. There was snow over much of the high ground also on the 3rd and 4th, and in north-east Scotland the snowfall was heavy with deep drifts. The 5th was a sunny day generally, with north-westerly winds and scattered showers. On the 6th a deep depression south of Iceland moved slowly east to the north of Scotland and later turned north-east. Milder south-westerly to westerly winds prevailed, reaching gale force in places; rain fell generally and was heavy locally (2·25 in. at Watendlath Farm, Cumberland and Swansea Waterworks, Brecknockshire and 2·11 in. at Llyn-y-fan-Fach, Carmarthenshire on the 6th), and the weather was mainly showery with long bright periods in most places on the 7th. On the 8th and 9th a ridge of high pressure moved north over the country giving long sunny periods in most areas on the 8th and locally in northern districts on the 9th. During the 10th–12th there was a mild southerly type; mild, sunny weather in the south-east on the 10th spread to most districts by the 12th; there was, however, a good deal of fog locally on the north-east coast, which kept temperatures low. Maxima of 60°F. or above were registered in many parts of England on the 11th and locally in west and north-west Scotland on the 12th (64°F. at Camden Square on the 11th and 62°F. at Prestwick on the 12th). With the development of an anticyclone over Scandinavia on the 12th, cold, mainly dull easterly winds set in on the 13th and lasted until the 18th; there was little rain during this spell except in the south-west. The fall in temperature with the onset of the easterly wind was marked; at Cranfield, Bedfordshire, the maximum on the 13th was 19°F. below that on the 12th. On the 19th–20th a depression moved east over southern districts and during the 22nd–24th a deep depression moved slowly north-east into Ireland and then moved away south-south-east and filled; rain fell fairly generally during this period, particularly on the 19th, 21st and 22nd. Rainfall was rather heavy locally in north-west England and south Scotland on the 21st, and in west Scotland and north-west Ireland on the 22nd–23rd (1·96 in. at Ambleside on the 21st). During the rest of the month there was a changeable south-west to west type of weather; the 26th and 27th were mostly sunny, but rain occurred fairly frequently and was rather heavy locally, for example on the 25th and 29th (1·13 in. at Point of Ayre, Isle of Man on the 25th and 2·06 in. at Loch Dhu, Perthshire and 1·94 in. at Ramsey, Isle of Man, on the 29th). The last two weeks were mainly mild; temperature rose to 62°F. at York on the 21st and 63°F. at Llety-evan-Hen near Aberystwyth on the 22nd, but there was slight air frost locally at times in the last week. Thunderstorms occurred locally on the 30th and 31st.

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 ...	64	6	−0·1	117	0	87
Scotland	62	4	−1·0	89	−4	97
Northern Ireland ...	59	21	−0·2	117	−2	94

RAINFALL OF MARCH 1954

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·15	117	*Glam.*	Cardiff, Penylan ...	5·03	160
Kent	Dover	2·95	141	*Pemb.*	Tenby	4·53	146
„	Edenbridge, Falconhurst	3·20	129	*Radnor*	Tyrmynydd	4·87	91
Sussex	Compton, Compton Ho.	4·11	148	*Mont.*	Lake Vyrnwy	5·83	130
„	Worthing, Beach Ho. Pk.	3·36	175	*Mer.*	Blaenau Festiniog ...	8·71	101
Hants.	Ventnor Park	3·96	189	„	Aberdovey	3·38	102
„	Southampton (East Pk.)	3·28	144	*Carn.*	Llandudno	2·06	101
„	South Farnborough ...	2·35	118	*Angl.*	Llanerchymedd ...	3·28	110
Herts.	Royston, Therfield Rec.	1·83	100	*I. Man*	Douglas, Borough Cem.	3·90	132
Bucks.	Slough, Upton... ...	2·21	126	*Wigtown*	Newton Stewart ...	3·90	113
Oxford	Oxford, Radcliffe ...	2·54	154	*Dumf.*	Dumfries, Crichton R.I.	3·16	106
N'hants.	Wellingboro' Swanspool	2·20	123	„	Eskdalemuir Obsy. ...	4·44	91
Essex	Shoeburyness	2·02	150	*Roxb.*	Crailing...	1·32	61
„	Dovercourt	1·36	88	*Peebles*	Stobo Castle	2·77	96
Suffolk	Lowestoft Sec. School...	1·99	124	*Berwick*	Marchmont House ...	1·99	75
„	Bury St. Ed., Westley H.	2·39	126	*E. Loth.*	North Berwick Res. ...	1·12	60
Norfolk	Sandringham Ho. Gdns.	2·67	141	*Midl'n.*	Edinburgh, Blackf'd. H.	1·26	64
Wilts.	Aldbourne	3·20	143	*Lanark*	Hamilton W. W., T'nhill	2·33	84
Dorset	Creech Grange... ...	4·80	170	*Ayr*	Colmonell, Knockdolian	4·15	123
„	Beaminster, East St. ...	5·57	190	„	Glen Afton, Ayr San. ...	3·96	94
Devon	Teignmouth, Den Gdns.	3·74	144	*Renfrew.*	Greenock, Prospect Hill	4·34	93
„	Ilfracombe	3·30	115	*Bute*	Rothesay, Ardencraig...	4·22	118
„	Princetown	8·19	120	*Argyll*	Morven (Drimnin) ...	5·19	107
Cornwall	Bude, School House ...	2·49	102	„	Poltalloch	3·44	90
„	Penzance, Morrab Gdns.	4·21	132	„	Inveraray Castle ...	5·74	91
„	St. Austell	3·87	113	„	Islay, Eallabus... ...	3·75	98
„	Scilly, Tresco Abbey ...	2·92	111	„	Tiree	4·65	139
Somerset	Taunton	4·05	195	*Kinross*	Loch Leven Sluice ...	3·81	127
Glos.	Cirencester	3·12	135	*Fife*	Leuchars Airfield ...	2·16	111
Salop	Church Stretton ...	2·26	94	*Perth*	Loch Dhu	7·05	107
„	Shrewsbury, Monkmore	1·69	101	„	Crieff, Strathearn Hyd.	3·10	97
Worcs.	Malvern, Free Library...	2·45	126	„	Pitlochry, Fincastle ...	2·32	84
Warwick	Birmingham, Edgbaston	2·76	145	*Angus*	Montrose, Sunnyside ...	2·42	117
Leics.	Thornton Reservoir ...	2·05	111	*Aberd.*	Braemar	2·51	84
Lincs.	Boston, Skirbeck ...	1·61	103	„	Dyce, Craibstone ...	1·83	69
„	Skegness, Marine Gdns.	1·87	113	„	New Deer School House	1·50	58
Notts.	Mansfield, Carr Bank...	2·36	113	*Moray*	Gordon Castle	1·61	69
Derby	Buxton, Terrace Slopes	3·93	95	*Nairn*	Nairn, Achareidh ...	1·14	62
Ches.	Bidston Observatory ...	2·00	105	*Inverness*	Loch Ness, Garthbeg ...	2·32	70
„	Manchester, Ringway...	2·36	108	„	Glenquoich	6·34	65
Lancs.	Stonyhurst College ...	2·84	77	„	Fort William, Teviot ...	5·44	81
„	Squires Gate	1·80	80	„	Skye, Broadford ...	6·65	110
Yorks.	Wakefield, Clarence Pk.	1·77	98	„	Skye, Duntuilm ...	4·58	104
„	Hull, Pearson Park ...	1·99	109	*R. & C.*	Tain, Mayfield... ...	1·84	81
„	Felixkirk, Mt. St. John...	1·94	98	„	Inverbroom, Glackour...	3·21	65
„	York Museum	1·80	107	„	Achnashellach	5·11	75
„	Scarborough	2·07	115	*Suth.*	Lochinver, Bank Ho. ...	3·44	92
„	Middlesbrough... ...	1·37	87	*Caith.*	Wick Airfield	2·12	93
„	Baldersdale, Hury Res.	1·89	66	*Shetland*	Lerwick Observatory ...	2·63	83
Norl'd.	Newcastle, Leazes Pk....	1·23	60	*Ferm.*	Crom Castle	4·55	147
„	Bellingham, High Green	1·80	61	*Armagh*	Armagh Observatory ...	3·19	136
„	Lilburn Tower Gdns. ...	2·00	75	*Down*	Seaforde	4·16	142
Cumb.	Geltsdale	1·56	56	*Antrim*	Aldergrove Airfield ...	2·73	109
„	Keswick, High Hill ...	3·68	82	„	Ballymena, Harryville...	2·89	92
„	Ravenglass, The Grove	2·93	95	*L'derry*	Garvagh, Moneydig ...	3·18	102
Mon.	A'gavenny, Plâs Derwen	4·92	147	„	Londonderry, Creggan	2·97	93
Glam.	Ystalyfera, Wern House	6·02	112	*Tyrone*	Omagh, Edenfel ...	3·67	117

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

Wt-34. K16.

M.O. 581 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 83, No. 984, JUNE 1954

SOME REMINISCENCES OF THE METEOROLOGICAL OFFICE OF THE YEAR 1902

By R. G. K. LEMPFERT, C.B.E., M.A.

I joined the staff of the Meteorological Office on May 1, 1902, and it has been suggested to me that some account of the Office and its work in those days may be of interest to meteorologists of the present day.

The Royal Society was responsible for the administration which it carried out through a Council, of which Sir Richard Strachey was Chairman. Mr. W. N. Shaw, as he then was, had succeeded R. H. Scott as Secretary of the Council about two years earlier. A Parliamentary Grant-in-Aid of £15,300 provided the necessary finance. The staff on the payroll numbered about 40. I was the first graduate to be appointed to it. We were not on the telephone and I seem to remember one single typewriter in the "office". Outgoing letters were written autograph in copying ink and press-copied before dispatch. Copy for the printer was supplied in long-hand.

The Office was housed in Westminster, at No. 63 Victoria Street, the corner building at the junction with Strutton Ground. The passer-by could recognize it by a display of notice-boards on the first-floor balcony giving the latest reports of the weather and state of the sea in the Strait of Dover. The ground floor was occupied by a piano shop, and we had the four floors above and also the basement for storage. The piano shop and the itinerant musicians of Strutton Ground saw to it that we did not lack for musical entertainment.

On the first floor was the office-keeper's den, which later became my room as Superintendent of Statistics. A large but extremely low room which ran from front to back of the building housed the Statistics Division. I was told that originally it had been two rooms but the dividing partition had been removed and replaced by an iron girder to support the ever-increasing weight of the records accumulating on the floors above. The instrument store was also on this floor.

On the next floor were the rooms of the Secretary and the Marine Superintendent, the "office" and the main working room of the Marine Division. The Secretary's room was a large pleasant room, facing south. It was used for the fortnightly meetings of the Council, and, later on, also for the Monday-evening discussions inaugurated by Mr. Shaw on the model of the *colloquia* which J. J. Thomson held at the Cavendish Laboratory in Cambridge. The room also housed the library which even then had begun to overflow into other parts of the building.

On the third floor two rooms were allotted to the Forecast Division of which more anon. The Observatory Division had the large front room and the Marine Division the remaining small one. On the top floor I had my room. The front room was occupied by four ladies attached to the Marine Division, the only women in an otherwise all-male staff. The best room on this floor, that over the Secretary's room, was tenanted by Mr. and Mrs. Drane, the resident caretaker and his wife. It combined the functions of bedroom, sitting-room, kitchen and scullery. Before her marriage Mrs. Drane had been cook in Mr. Scott's family, and she continued these professional activities by providing for those members of the staff who wanted it (and most of them did) a substantial lunch for 1*s.* 2*d.* The lunches were sent to the recipients on trays and eaten at their desks. Another domestic detail that sticks in my memory is that at about 6 p.m. the cleaners arrived, the fires, if still smouldering, were doused with water (imagine the dust), relaid for lighting next morning, and the rooms swept and garnished.

I saw little of the work of the Marine Division in those early days. Captain Campbell Hepworth was Marine Superintendent with Charles Harding as his principal assistant. Another member of the staff was a retired sea captain, William Allingham, who revised and enlarged the 15th edition of Lecky's "Wrinkles in practical navigation", which enjoyed a considerable sale in its day. Then, as now, the Division's task was to collect and discuss observations from the sea, the purpose for which the Office had been founded in 1854. It had agents in Southampton, Liverpool and other ports, but Port Meteorological Officers had not been thought of. Its current output was *Monthly pilot charts of the North Atlantic and Mediterranean*, which gave the average distribution of the meteorological elements and a lot of interesting miscellaneous information. The *magnum opus* then in hand was "Monthly wind charts of the South Atlantic", which was published by the Admiralty in 1903. The Instrument Division was at this time part of the Marine Division. It was in the main an instrument store for the supply of instruments to the navy, the mercantile marine and the telegraphic reporting stations. Questions of design or of testing new types, when they arose, were mostly farmed to outside bodies for study and report.

In 1902 John Curtis was the head of the Statistics Division with Duncan Bell under him as librarian, in which capacity he was personally responsible for the meteorological section of the Royal Society's "International catalogue of scientific literature". A few years later Curtis succeeded James Harding as Chief Clerk and Cashier and I became the Division's superintendent with Duncan Bell as my principal assistant. Both Curtis and Bell gave much of their private time to municipal politics. Curtis became Mayor of Fulham and Bell an alderman of his borough.

Meteorological observations at stations of the second order was perhaps the Division's most important task. This was a publication issued to comply with a resolution of the International Meteorological Committee which aimed to bring uniformity into the presentation of climatological data. It contained daily observations at 9 a.m. and 9 p.m., under the headings suggested by the committee, for a selection of stations, and monthly summaries for a larger number. No doubt the committee hoped that the data would be published promptly, but in most countries there was a lag of several years and we were no exception. We did however manage to clear off the arrears during the next five years.

The *Weekly Weather Report* was another important part of the Division's work. It gave a statistical resumé of the weather over the country by district values (means for up to ten stations in each district), the week being the time unit. The week ended with the Sunday morning observation, and the returns from most contributing stations reached the Office by first or second post on Monday. Copy for the printer had to be ready by Tuesday afternoon. Proofs came in on Thursday at midday and were returned the same afternoon so that the report might reach subscribers by the end of the week. Weekly publication ceased on the outbreak of war in 1914, but the computation of the district values was continued. They were subsequently published in annual volumes. The *Monthly Weather Report*, at the time I am writing about, was a very slender affair, confined almost entirely to summaries for the telegraphic stations. It grew rapidly during the next few years when it became Office policy to devote a line of print in the report to a summary of all approved observations received. The report formed as it were an index of the information available. The new policy was a result of the transfer to the Office of the supervision of the network of stations supplying information for the Registrar-General's *Quarterly Reports*, which had been run by James Glaisher from Greenwich. This enlargement of the *Monthly Weather Report* rendered the volumes of *Meteorological observations at stations of the second order* redundant as regards monthly summaries, and they came to an end with the volume for 1907.

The Observatories Division, under Richard Curtis, took charge of all records from self-recording instruments, tabulating a selection and scrutinizing the rest. Richard Curtis was the Office expert on anemometry. He and W. H. Dines were the moving spirits on the Wind Force Committee of the Royal Meteorological Society. The stock job of the Division was the tabulation of the records from the six observatories, Kew, Aberdeen, Stonyhurst, Oxford, Falmouth and Valentia, the last the only place outside London where the Office had whole-time staff of its own. The enlistment of these institutions into the service of meteorology and their equipment with similar instruments (photographic recorders of pressure and temperature, Beckley rain-gauge and Robinson cup anemometer) had been one of the first actions of the Meteorological Council when it took charge after Fitzroy's death. The Division had carried through the reproduction of their records in the now defunct *Quarterly Weather Report*. It was a beautiful piece of engraving and the copper plates were kept for many years until they were requisitioned for scrap in 1915. The Division had also carried out the harmonic analysis of the records on Galton's Harmonic Analyser which, its task completed, was on show at the entrance to the Meteorological Office in South Kensington and ultimately found its way to the Science Museum. I never saw the machine in use.

There were not many recording instruments apart from those at the observatories. The cards from a considerable number of Campbell-Stokes sunshine recorders had to be scrutinized and their evaluations checked. There were Robinson cup anemometers at Deerness, Scilly, Yarmouth and Kingstown. The Dines pressure-tube anemograph was a new invention. It had been installed experimentally at Kew, Pendennis Castle (Falmouth) and Scilly. Barographs were not general. They were not issued to the telegraphic stations until barometric tendency became included in the synoptic code some ten years later. When preparing the hourly maps used in "The life history of surface air currents" we had to borrow records from wherever we could get them.

No part of the Office has seen greater changes than the Forecast Division. When I set foot in it Frederic Gaster was still the senior member of its staff. He was then close on the retiring age, and if my information that he joined the Office as a boy is correct he must have been there when telegraphic weather reporting started under Fitzroy in 1865. For the greater part of his life he had been principal forecaster. He was in failing health and took little or no part in the daily routine but he was still, nominally at any rate, the London observer. The London observations given in the *Daily Weather Report* were taken in his garden at Brixton and telegraphed to Victoria Street twice a day.

F. J. Brodie and R. Sargeant were the two forecasters, with G. G. Francis and A. R. Simpkins as their principal assistants. All four had years of experience in plotting synoptic charts and watching the vagaries of British weather which they revealed. Looking back on those days I cannot help wondering how they carried on, for I don't remember any reserve of experienced man-power in the Division to provide for sickness or leave or public holidays. After I had been in the Office for a year I was called on to take a share in forecasting, and about the same time Henry Harries was transferred from the Marine Division. Though the routine of that Division was mainly concerned with statistical work he had had plenty of synoptic experience. The contribution of the Office to the International Polar Year 1881–82 had taken the form of publishing daily synoptic charts of the North Atlantic Ocean from all available information that could be collected, not only from British ships but also from those of other co-operating nations. That task had been assigned to the Marine Division. It was a big job as all data had to be extracted from the logs.

The forecasting was carried on in two rooms on the third floor which were used turn about, morning and evening, to give the cleaners an opportunity for sweeping and dusting. All information was received by Post Office telegram. The messages were paid for at normal rates and had no priority over those of the general public. Liaison with the Post Office was by private wire from Victoria Street to the Central Telegraph Office, but that represented no concession to the importance of meteorology. Anybody doing much business by telegram could hire a private line but had to operate his own end of it himself. That meant that the forecast staff had to be proficient in sending and receiving morse. Teleprinters had not yet been invented.

The hour for opening local post offices, 8 a.m., was the hour for the morning observations. At that hour the morning staff, three strong—forecaster, telegraphist and boy clerk—came on duty and soon after the reports began to trickle in. We received 25 from the British Isles and 30 from the Continent (Norway 4, Sweden 5, Germany 4, Denmark 2, France 10, Holland, Belgium, Spain, Portugal and the Azores each 1) but the latter were very often incomplete as the gaps in the *Daily Weather Report* of those days show. All messages were in the international code which had remained practically unchanged since its adoption by the International Meteorological Committee in 1874. There was, of course, no upper air information, but it is rather surprising that there was no provision for reporting cloud motion or form. Only one figure, ten possibilities, was allotted to "present weather" and "past weather" was ignored. Our own observers were instructed to supplement the code figures by adding groups of Beaufort letters to their inland messages, and they were encouraged to add short notes such as "cirrus rapidly from west" though my recollection is that little use was made of that discretion.

As the reports were received by the telegraphist they were called out by the junior, after conversion of the foreign ones to British units (pressure was still given in inches or millimetres) for the forecaster to plot them on the working chart. The chart was usually reasonably complete by 9.30 a.m. or soon after. If it was not that was unfortunate, but one just had to do one's best. Storm warnings were the first consideration. In doubtful cases one could call on stations for "special reports". A reply to a telegram dispatched about 9.15 might be expected before 11. That disposed of, telegrams were drafted for certain Admiralty addresses and then came the "General inference" and the district forecasts for eleven districts. They were written by the forecaster in the Forecast Book. The instruction was that the inference should indicate the reasons for the district forecasts. The assistants then wrote them out in violet ink on special forms for manifolding by what we called "jellygraph". These press issues were collected by messengers from the news agencies and evening papers soon after 10 a.m.

In the meantime the staff had been reinforced by staff on normal hours of duty, some lent from other divisions, and the preparation of the transfer for the *Daily Weather Report* had been put in hand. There were no typewriters, and everything had to be written and drawn on the transfers in lithographic ink. In addition to being expert telegraphists the staff had therefore to be competent draughtsmen and caligraphists. Fortunately such demands were not made on me or on other graduates who took a hand in forecasting in later years. The transfers had to be ready by 11 a.m. for dispatch by special messenger to Weller and Graham, the lithographers, whose works were somewhere in the City or East End. The reports were delivered at the Office, again by special messenger, during the afternoon. Those for dispatch by post were got away in time for the 5 p.m. collection at the South-Western District Office.

The routine for the evening reports (6 p.m.) followed much the same course. Only a selection of stations reported, and the continental information was very meagre. As there was no *Daily Weather Report* to be prepared, the staff of three could cope with the work even though a map had to be drawn for *The Times*. Incidentally I should mention that that newspaper had started the evening service in 1876, and for several years its cost was shared by *The Times*, the *Standard* and the *Daily News*. It was not until 1880 that the parliamentary grant was increased to enable the Office to provide the service from its own resources.

A few stations reported throughout the year at 2 p.m. as a check on developments for the issue of warnings. During the summer (June to September) the number was increased, and special harvest forecasts were issued for farmers. Anticipations of spells of fine weather were a feature of these forecasts, the forerunners of the "Further outlook".

On Sunday mornings, when press forecasts were not required, two members of the staff attended at the Central Telegraph Office to plot the observations and issue any necessary warnings or special forecasts.

In conclusion, a word about the training of forecasters in those early days. The staff I met on entering the Office had all climbed the ladder—assistant—telegraphist—forecaster, a slow proces of evolution over 15, 20, or more years, and until Sir Napier Shaw joined the Council it does not seem to have been thought that anything more expeditious would ever be required. The general principles that had emerged from the scrutiny of synoptic charts over some 30 years were admirably set out in Abercromby's "Weather" and Clement Ley's "Aids to the study and forecast of weather" and that was all the specialized literature I was offered. For more general reading there was Hann's "Lehrbuch" and some American textbooks, and of course the collection of original papers in the Office volumes of pamphlets. However, all forecasts were carefully checked, district by district, by reference to the observations set out in the *Daily Weather Report* supplemented by those contributed for the *Weekly Weather Report*. For checking storm warnings the wind observations recorded at lighthouses were used, the logs being lent to the Office for the purpose. The summarized results were given each year in the *Annual Reports* presented to Parliament. During my first year I spent a considerable time on this checking, and no doubt I learned a lot from it. It was not until the war of 1914 brought a sudden demand for forecasters that anything formal was attempted.

FURTHER INVESTIGATIONS OF HIGH-LEVEL CLEAR-AIR TURBULENCE

By D. C. E. JONES, B.Sc.

Introduction.—There is a considerable amount of statistical information now available concerning the frequency, vertical and horizontal extent, and levels of occurrence of high-level clear-air turbulence over the British Isles and western Europe up to a height of about 40,000 ft.[1,2] This kind of turbulence has been observed in almost all weather situations, though it is fairly certain that there are two factors, one or other or both of which are usually associated with its occurrence, namely strong shear of wind in the vertical and in the horizontal.

In previous papers[3,4] accounts have been given of attempts made to correlate severe incidents of turbulence with various meteorological situations. It was found that they occurred mostly in the vicinity of jet streams or very strong winds, and to a much lesser extent near upper troughs and lows. This note describes a further analysis of a large number of casual reports of severe turbulence received in the Meteorological Office from various sources during the last two years. An account is also given of some special flights made by jet aircraft of the Royal Air Force and Royal Aircraft Establishment, Farnborough, to investigate further details of turbulence near jet streams.

Method of reporting.—The Royal Aircraft Establishment reports were based on accelerometer readings, but all those from Royal Air Force aircraft were qualitative assessments because none of the aircraft carried an accelerometer. It is difficult to know with certainty whether all pilots adopt the same standard of severity when reporting qualitatively, and there is always the risk that an incident may be described as severe simply because it is severe compared with the usual turbulence at high levels, and not on an absolute scale. In order to try to overcome this possible human error and in an endeavour to achieve consistency and uniformity, all pilots were asked to classify the severity as either "perceptible", "moderate" or "severe" in accordance with the following rough guide which is substantially the same as that recommended by the International Civil Aviation Organization:—

Perceptible ($\pm 0 \cdot 05g$ to $\pm 0 \cdot 2g$)—perceptible difference from steady flying conditions

Moderate ($\pm 0 \cdot 2g$ to $\pm 0 \cdot 5g$)—uncomfortable, slight tendency to be lifted out of seat

Severe (more than $\pm 0 \cdot 5g$)—difficulty in observing flying instruments and/or maintaining aircraft heading; marked tendency to be thrown from seat.

Casual reports of severe turbulence.—147 reports of turbulence encountered over the British Isles and classed as "severe" were examined. Some of the incidents were of unusual severity and the two examples given below may be of interest:—

"Aircraft was pitching and tossing about the sky and one of its instruments was shaken from the instrument panel."

"Crew were lifted from their seats. Aircraft suffered structural damage and several rivets were dislodged."

Most of the reports were received from operational Royal Air Force jet aircraft but some were also received from Royal Navy and civil aircraft. The true speed of the aircraft at the time when the turbulence was encountered varied between about 250 and 450 kt.

Each report was studied in conjunction with the information given in the *Daily Aerological Record*, and an attempt was made to associate the turbulence with broad features of the relevant 300-mb. contour chart, that is with jet streams, strong winds, lows, and troughs, etc. A summary of the cases occurring in various situations is given in Table I.

TABLE I—WEATHER SITUATIONS ASSOCIATED WITH OCCASIONS OF SEVERE TURBULENCE IN CLEAR AIR AT HIGH ALTITUDE

WEATHER SITUATION	NO. OF CASES
Near jet stream	98
Probably near jet stream (i.e. jet stream almost certainly present but details of wind speed, breadth, etc., not available)	7
Upper trough	19
Upper low	3
Discontinuity in tropopause surface at same level as turbulence and within 100 miles of it	1
Discontinuity in tropopause surface at same level as turbulence, within 100 miles of it and near upper trough	2
Discontinuity in tropopause surface at same level as turbulence, within 100 miles of it and near upper low	0
Strong upper winds but no evidence of a well defined jet stream...	4
Unclassified	13
Total	147

Of the 147 cases, 21 occurred in the stratosphere, 2 were almost at the tropopause level and the remainder were in the upper troposphere. The 13 unclassified cases occurred in situations that could not be classed as any one of the above types. A few of them were in the middle of upper ridges and no evidence of vertical or horizontal wind shear could be found, nor a discontinuity of any kind.

As regards the height at which the severe turbulence was encountered, the majority of cases were between 25,000 and 35,000 ft., 25 between 35,000 and 40,000 ft., 7 between 40,000 and 45,000 ft. and 1 was above 45,000 ft. It is not safe to conclude from the above figures that the incidence is less in the lower stratosphere because in all probability the amount of flying at these levels was considerably less than at those below 40,000 ft.

Reports of severe turbulence in the vicinity of jet streams were further analysed with regard to their position relative to the axis of the jet. The

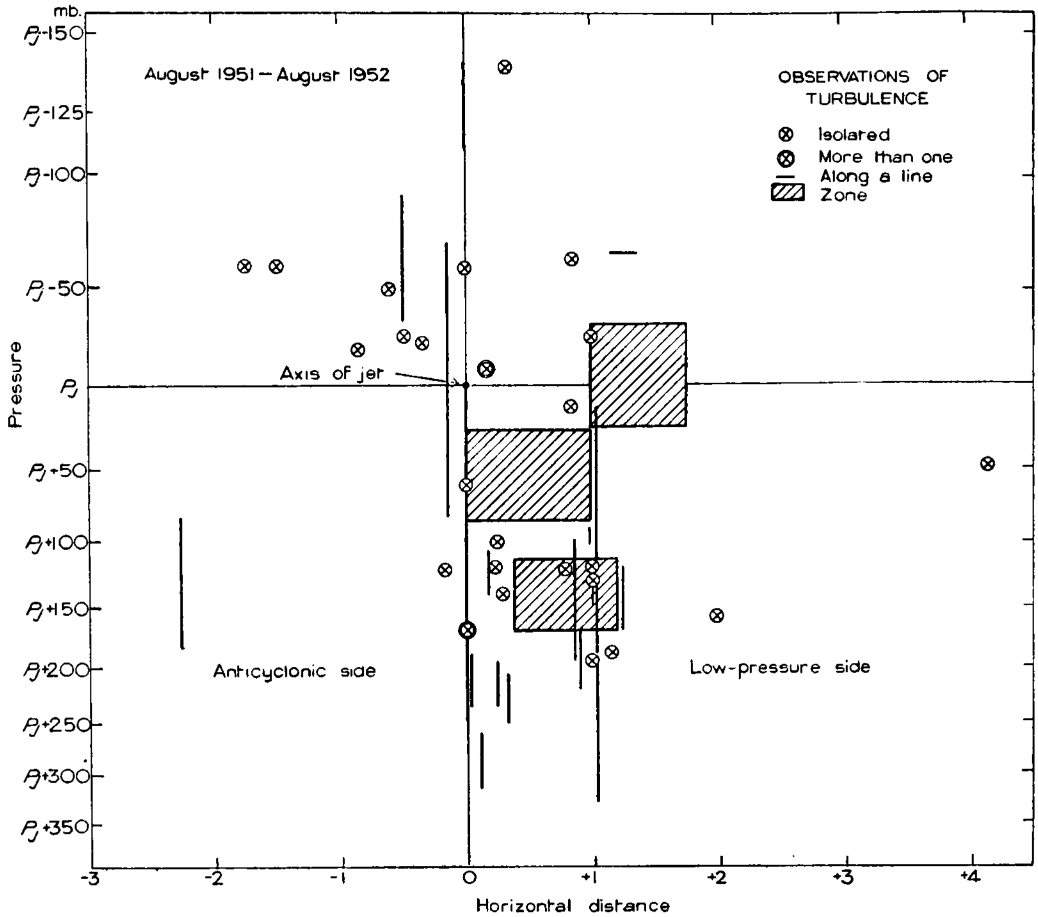


FIG. 1—POSITIONS OF OCCURRENCE OF SEVERE TURBULENCE RELATIVE TO THE JET-STREAM AXIS, AUGUST 1951–AUGUST 1952

method used was the same as that employed in previous work[3,4]. By inspection of the 300-mb. charts and the wind reports given in the *Daily Aerological Record*, the position, orientation and height of the axis of the jet were estimated at the time the turbulence was reported. For this purpose it was assumed that the jet stream had approximately straight and parallel contours with a maximum wind speed of 80 kt. or more. The level of the jet stream was taken as the level of the maximum wind reported in the upper air soundings in the vicinity of the jet and this wind report was taken as the nearest approximation to the maximum speed of the jet. When a report of turbulence did not coincide with the time of routine upper air soundings an allowance was made for movement of the jet axis by using continuity considerations of space and time.

The horizontal unit of measurement was taken as the distance from the centre of the jet stream, on the low-pressure side, over which the wind velocity at the same level as the axis of the jet fell to half the maximum value. The vertical co-ordinate was taken as the difference between the international standard atmosphere pressure equivalent of the reported height and the pressure, P_j, at the axis of the jet.

This method of analysis is rather subjective because the jet stream could not always be placed with a great degree of reliance. However, in view of the fairly large number of cases examined the accuracy obtained should be sufficient to

WEATHER CONDITIONS NEAR THE CENTRE OF A DEPRESSION

The photograph above shows the conditions obtaining near the centre of a depression in the North Sea on July 17, 1942, as seen from a meteorological reconnaissance aircraft in 54° 50′N., 2° 30′E. at 0610 G.M.T. The clouds, as reported by observer in the aircraft, were 7–8 tenths of stratocumulus, base 900 ft., top about 2,500 ft.; there was some cirrostratus above. The depression was formed on the polar front south of Newfoundland on July 12; it moved rapidly across the Atlantic Ocean on the 14th–16th and the centre passed to the north of Scotland reaching the North Sea on the 17th. Rain was reported by the aircraft over the first 50 miles of its route from base at Bircham Newton and also near 56°N., 4°E., but nowhere else on its course.

Reproduced by courtesy of Miss V. Hoare

PRECIPITATION VIRGAE ON A SHOWERY DAY

This photograph was taken from the top of Ben Vrackie near Blair Atholl in Perthshire soon after midday on July 28, 1953. An old depression remained more or less stationary just to the north of Scotland for several days, bringing unstable air with very showery weather to the whole of the country.

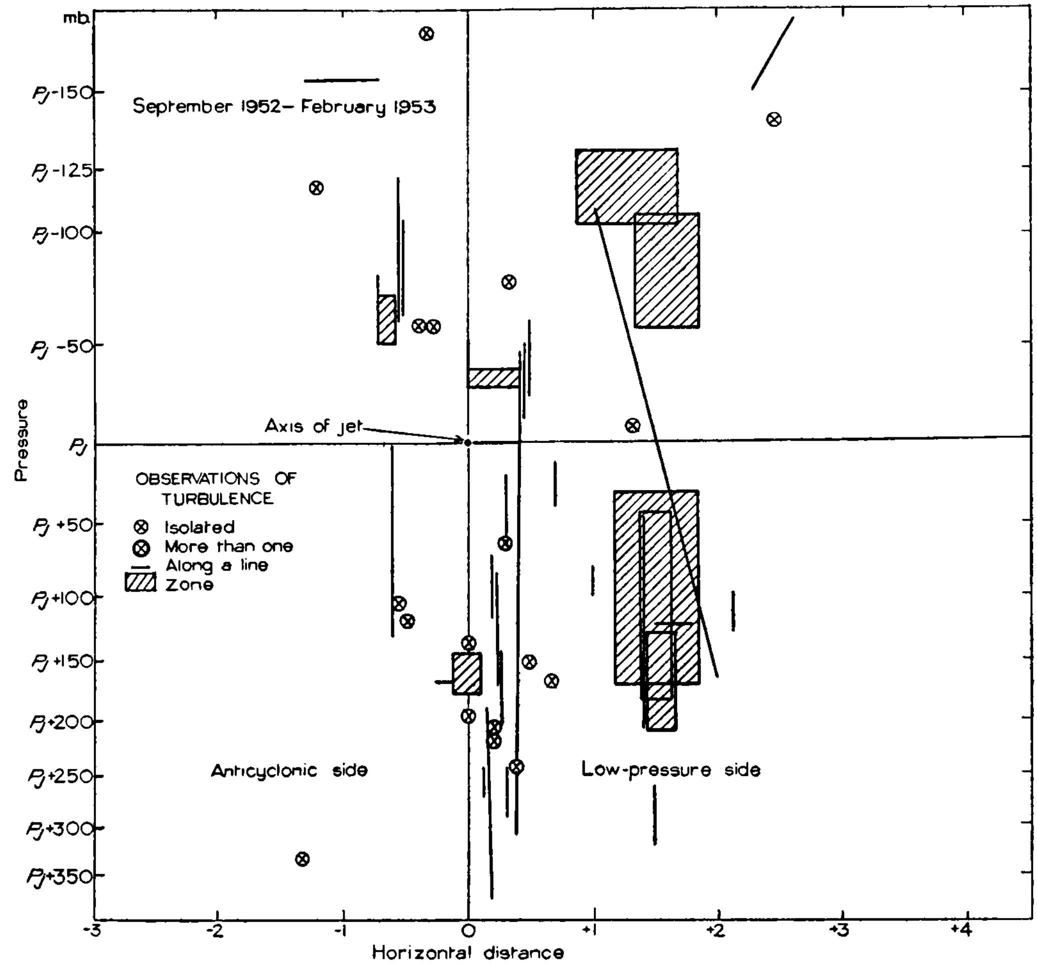


FIG. 2—POSITIONS OF OCCURRENCE OF SEVERE TURBULENCE RELATIVE TO THE JET-STREAM AXIS, SEPTEMBER 1952–FEBRUARY 1953

show the main features, although there may be some uncertainty in any one particular case.

The co-ordinates thus obtained for the positions of the 98 reports (mentioned in Table I) with respect to the jet stream were plotted in Figs. 1 and 2 which show all the cases examined for the periods August 1951–August 1952 and September 1952–February 1953 respectively. Details regarding certain parameters of the jet streams are given in Table II.

TABLE II—MEAN VALUES AND EXTREMES OF VARIOUS PARAMETERS OF JET STREAMS IN WHICH 98 SEVERE TURBULENCE INCIDENTS WERE REPORTED

		Wind speed at jet axis	Pressure at jet axis, P_j	Scale of horizontal units*
		kt.	mb.	nautical miles
August 1951—August 1952	Maximum	170	...	300
	Minimum	80	...	50
	Mean	115	283	147
September 1952—February 1953	Maximum	165	...	360
	Minimum	87	...	70
	Mean	122	315	162

* The horizontal unit is the distance from the axis, at the same level on the low-pressure side, at which the wind speed is half the value at the axis.

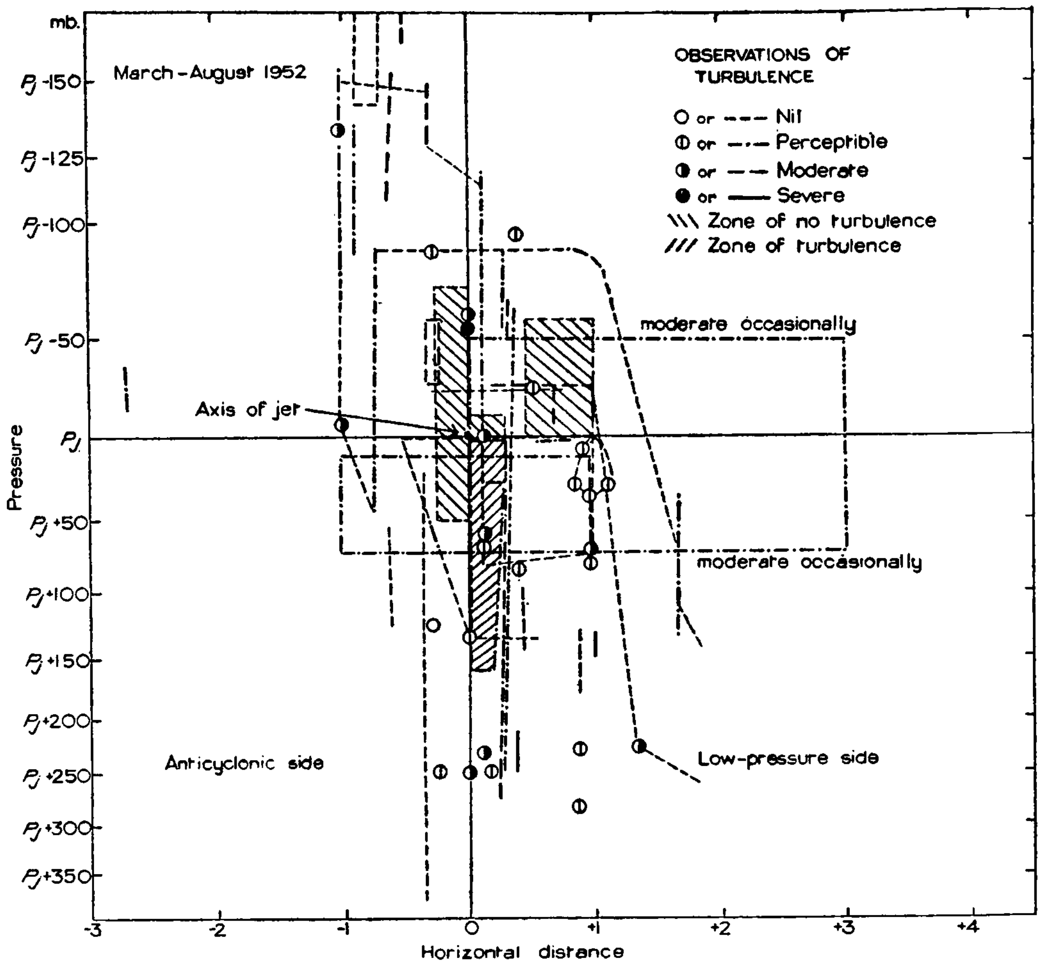


FIG. 3—POSITIONS RELATIVE TO THE AXES OF JET STREAMS OF FLIGHTS MADE BY THE ROYAL AIR FORCE

14 jet streams

The most striking result is that severe turbulence was encountered on less than 10 per cent. of occasions in the quadrant below and on the anticyclonic side of the axis, and 75 per cent. were in the two quadrants on the low-pressure side.

An attempt was made to study any variations with respect to position along the jet stream, but only 3 cases occurred near the entrance and 11 near the exit of a jet stream, and these numbers are too small for any particular significance to be attached to them.

Special investigational flights.—In order to study further the occurrence of turbulence near jet streams it was arranged for the Royal Air Force to carry out special investigational flights. These were made by the dispatch of a special aircraft or by diverting an aircraft already airborne, and at times they were made in conjunction with the normal flying programme. In addition, aircraft of the Royal Aircraft Establishment Flight, Farnborough, also made a similar but rather limited series of investigational flights.

The pilot was expected to note the position and severity of turbulence throughout each flight, observations from heights above 20,000 ft. being the main interest. Reports of no turbulence were regarded as being just as important

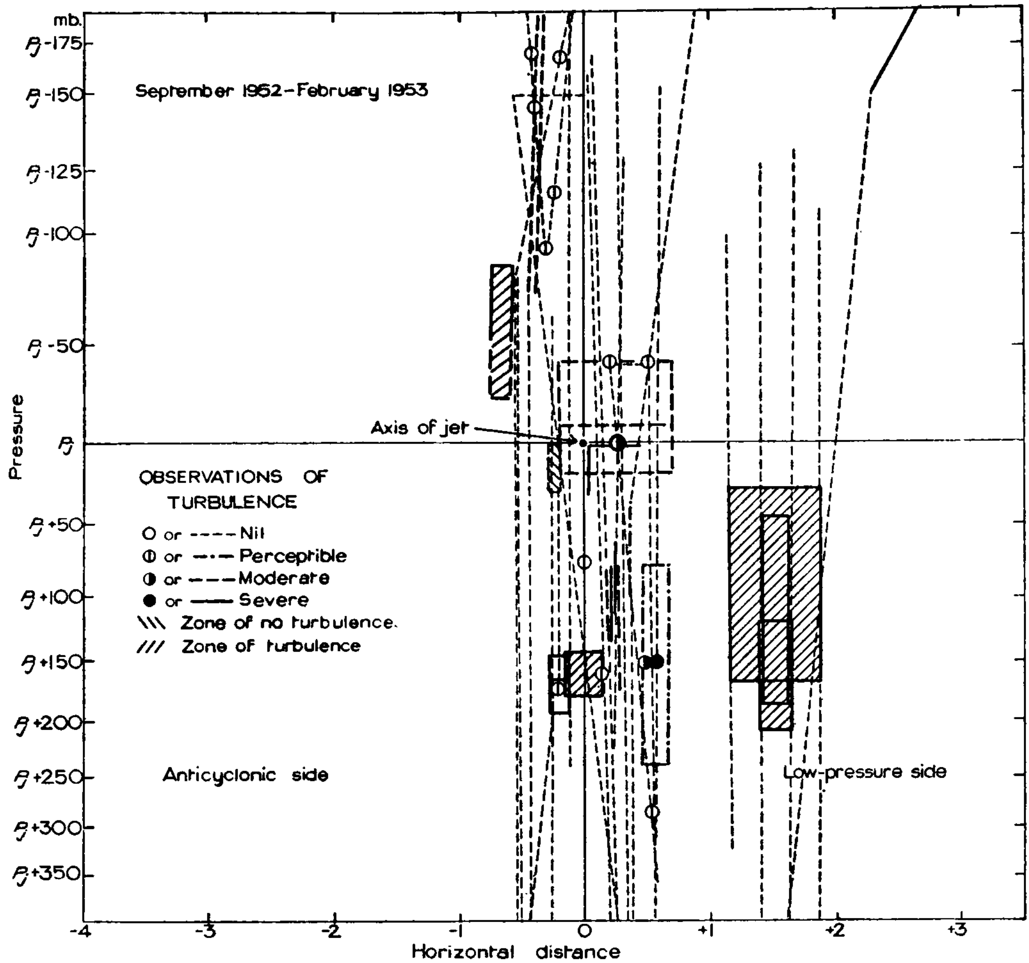


FIG. 4—POSITIONS RELATIVE TO THE AXES OF JET STREAMS OF SPECIAL FLIGHTS MADE BY THE ROYAL AIR FORCE
9 jet streams

as positive reports. Pilots were also encouraged to note and report any special or unusual features of the turbulence and to state if any action was taken either by climbing, or descending, or altering course or speed, to fly out of the turbulent areas. No attempt was made to investigate the variations along the jet streams; only cross-sections of the jets were explored.

A total of 30 jet streams over the British Isles were investigated in this way—23 by the Royal Air Force and 7 by the Royal Aircraft Establishment aircraft. The number of flights made either across or in particular regions of jet streams varied from 1 to 12 per jet stream, the average being about 3.

The track of each flight was plotted on a graph showing the position of the flight relative to that of the jet stream using the same method as that employed in Figs. 1 and 2. Figs. 3 and 4 show diagrammatically all flights by the Royal Air Force during the periods March–August 1952 and September 1952–February 1953 respectively, and Fig. 5 shows the Royal Aircraft Establishment flights.

An attempt was made to classify each jet stream according to vertical and horizontal shear and to ascertain if there was any correlation between these

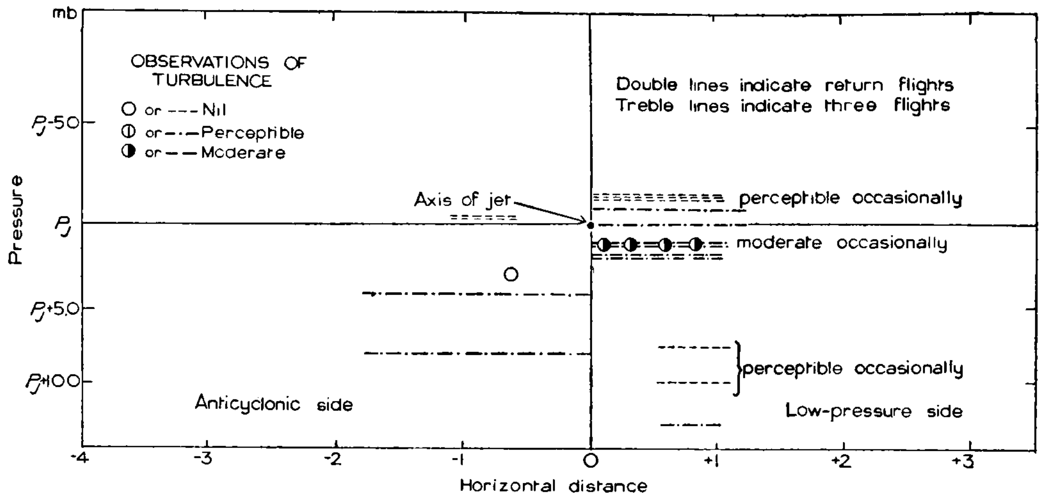


FIG. 5—POSITIONS RELATIVE TO THE AXES OF JET STREAMS OF SPECIAL FLIGHTS MADE BY AERO FLIGHT, ROYAL AIRCRAFT ESTABLISHMENT

7 jet streams

parameters and the intensity of the turbulence experienced. The vertical shear was taken as the shear between the 500-mb. and 300-mb. levels of the jet. These levels were chosen because they are standard levels used for constructing contour charts, and it was thought desirable in this investigation to choose a parameter which is a characteristic of the individual jet stream rather than the actual position where the turbulence was observed. This method of evaluating vertical shear, however, suffers from the disadvantage that it does not give a representative value when the axis of the jet lies about half way between the two levels, but fortunately such cases were few. The horizontal shear was estimated on the low-pressure side of the jet and at the same level as the axis of the jet. The value obtained refers to the average wind shear over the distance which the wind takes to fall to half its maximum value at the axis of the jet. In order to ascertain whether a relationship exists between the shear (both vertical and horizontal) and the severity of turbulence, Fig. 6 was constructed to show the most severe turbulence encountered near each jet stream plotted against the appropriate values of the horizontal and vertical shear.

The worst turbulence encountered near any of the 30 jets investigated is given in Table III.

TABLE III

	NO. OF CASES
Severe turbulence	9
Moderate turbulence ...	10
Perceptible turbulence ...	9
No turbulence	2
Total	30

Conclusions.—Although in the special flights described in the last section the amount of flying varied considerably with different jet streams, and in some of them the flights may not have been made in the most turbulent part of the jet, it can be tentatively deduced that near a jet stream there is an approximately equal probability that the worst bumpiness encountered will be severe or moderate or perceptible in intensity. No decisive result was obtained from the study of

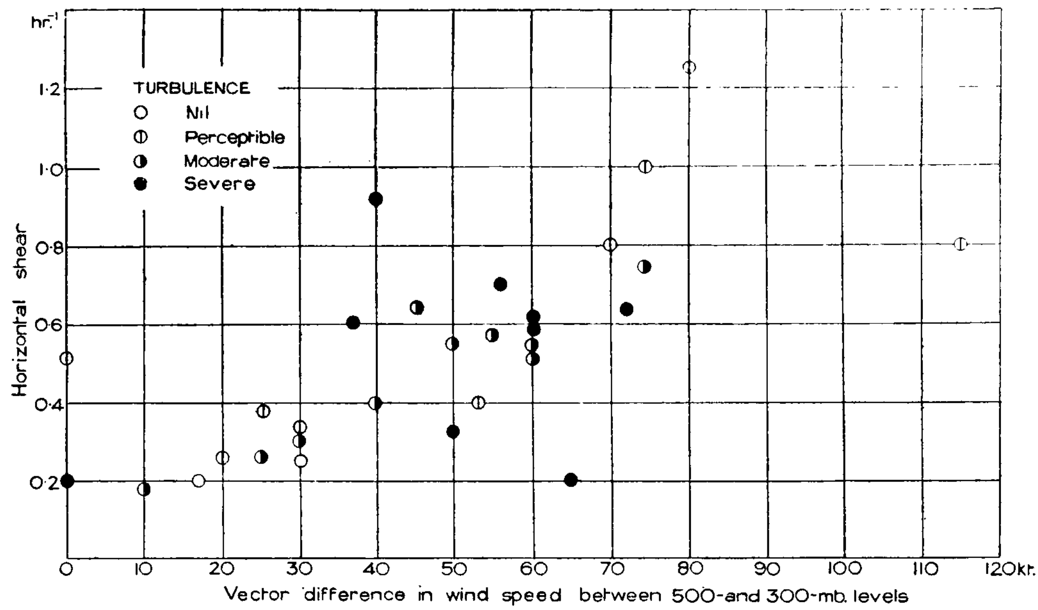


FIG. 6—MOST SEVERE TURBULENCE ENCOUNTERED NEAR THE 30 JET STREAMS

the variation in the severity of the turbulence with the horizontal and vertical shear in the vicinity of the jet streams (Fig. 6). But, in general, it would appear that severe turbulence occurred when the vector difference between the wind at the 500-mb. and 300-mb. levels exceeded 35 kt. and the horizontal shear exceeded 0·2 hr.$^{-1}$

The analysis of the positions of all reports relative to the axis of the jet confirms previous finds on the subject[4]. With only a few exceptions the moderate and severe incidents occurred on the low-pressure side of the jet and to a lesser extent on the anticyclonic side above the axis; there were very few on the anticyclonic side below the axis.

Little further progress has been made in this investigation towards formulating rigid rules to assist the practical forecaster in this task of predicting the occurrence of high-level turbulence in clear air. Turbulence is a state in which the air undergoes rapid and random local fluctuations, and it appears very probable, at this stage, that it is only the statistical properties that can be recognized and subjected to analysis. Recent reports from jet aircraft indicate that severe turbulence can be experienced in practically any weather situation up to a height of about 50,000 ft. and well above the tropopause. But, nevertheless, the results obtained in these investigations should be of some help to the forecaster in recognizing the regions of the high atmosphere where aircraft flying at speeds between 250 and 450 kt. stand the greatest risk of encountering patches of severe bumpiness.

REFERENCES

1. HISLOP, G. S.; Clear air turbulence over Europe. *J. R. aero. Soc., London,* **55**, 1951, p. 185.
2. BANNON, J. K.; Meteorological aspects of turbulence affecting aircraft at high altitude. *Prof. Notes met. Off., London,* **7**, No. 104, 1951, reprinted 1953.
3. BANNON, J. K.; Severe turbulence encountered by aircraft near jet streams. *Met. Mag., London,* **80**, 1951, p. 262.
4. BANNON, J. K.; Weather systems associated with some occasions of severe turbulence at high altitude. *Met. Mag., London,* **81**, 1952, p. 97.

UPPER WINDS FROM NEPHOSCOPE OBSERVATIONS

By A. F. JENKINSON, B.A.

In 1903 Hildebrandsson[1] published for the International Meteorological Committee an historical survey giving average directions of cirrus-cloud motion from all available cloud observations; and in 1905 he summarized[1] the results of the special photometric and nephoscope observations made by stations during the International Cloud Year 1896–97. In this he gave mean winter and summer directions and scalar wind speeds of the motion of various cloud types.

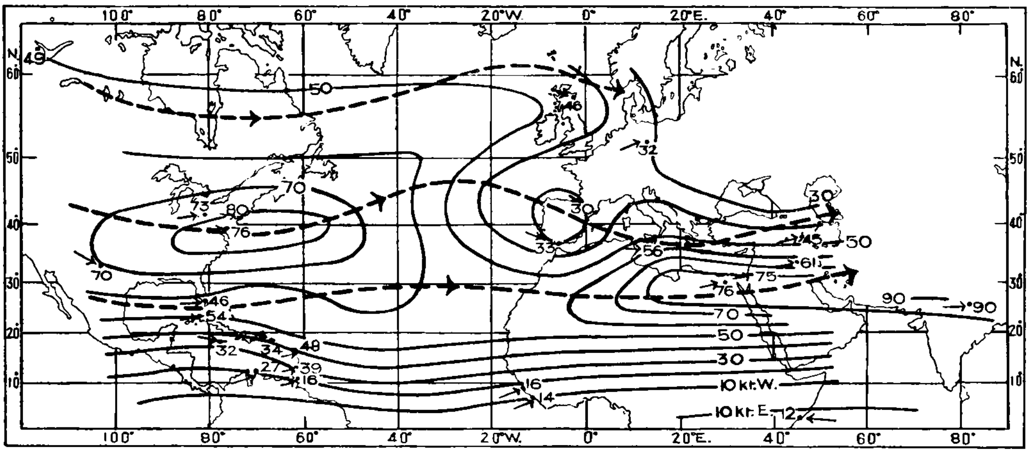


FIG. 1—ISOTACHS AND STREAM-LINES AT CIRRUS LEVEL DURING WINTER (DECEMBER–FEBRUARY)

Resultant vector winds from nephoscope observations are plotted.

Isotachs ——— Stream-lines - - - - - -

In 1904, Bigelow[2] published monthly average vector winds derived from nephoscope observations on various cloud types, including cirrus and cirro-stratus, for stations in the United States and the Caribbean area, and he strongly recommended that similar work should be done all over the world to enable world maps of the average vector winds at cirrus and other levels to be drawn.

Unfortunately, the attention of meteorologists was largely drawn away from research on clouds and winds at high levels to the lower levels, where the needs of aircraft were then more pressing. The winds at these levels could be investigated fairly satisfactorily by pilot-balloon observations; and although nephoscope observations continued to be made no world-wide analysis of the vector resultants of cloud motions of the kind envisaged by Bigelow was ever made. Mention should however be made of the papers by Hildebrandsson[3], van Bemmelen[4] and Harwood[5] giving data of directions of cloud motion and some stream-line maps of cirrus motion.

In recent years the measurement of upper winds by radar seems to have thrown the use of nephoscope observations into further disfavour, although C. F. Brooks[6] has made an eloquent appeal for the reporting of nephoscope observations from all synoptic stations.

In preparing seasonal maps of the average vector-wind distribution at various levels, the present author[7] found that average vector winds computed from nephoscope observations were of very great value.

The value of nephoscope winds as an ancillary aid to radar winds may perhaps be made more plain by showing how useful they are even on their own.

Vector winds from nephoscope observations at cirrus level for the season December to February have been plotted, and using these alone, average isotachs and stream-lines have been drawn for the northern hemisphere south of 60°N. between longitudes 100°W. and 60°E. They are shown in Fig. 1.

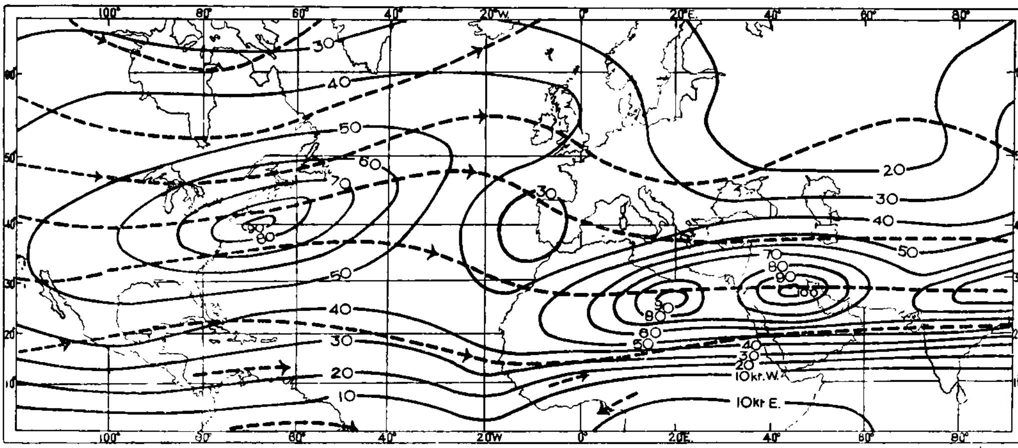


FIG. 2—ISOTACHS AND STREAM-LINES FOR JANUARY AT 300 MB.
Isotachs ——— Stream-lines - - - - - -

The reliability of the nephoscope vector winds may be seen by comparison of Fig. 1 with the vector winds at 300 mb. for January for the same area[7], reproduced in Fig. 2.

REFERENCES

1. HILDEBRANDSSON, H. H.; Rapport sur les observations internationales des nuages au Comité International Météorologique.
   Part I. Historique, Circulation générale de l'atmosphère. Upsala, 1903.
   Part II. Hauteurs et vitesse des nuages. Upsala, 1905.
2. BIGELOW, F. H.; Studies on the circulation of the atmospheres of the sun and of the earth. *Mon. Weath. Rev., Washington D.C.*, **32**, 1904.
   V.—Results of the nephoscope observations in the West Indies during the years 1899–1903. p. 166.
   VII.—The average monthly vectors of the general circulation in the United States. p. 260.
3. HILDEBRANDSSON, H. H.; Résultats des recherches empiriques sur les mouvements généraux de l'atmosphère. *Nova Acta Soc. Sci. upsal., Upsala*, Ser. IV, **5**, No. 1, 1918.
4. BEMMELEN, W. VAN; Der intertropische Teil der allgemeinen Zirkulation nach Beobachtungen in Batavia. *Met. Z., Braunschweig*, **41**, 1924, p. 133.
5. HARWOOD, W. A.; The free atmosphere in India. *Mem. India met. Dep., Calcutta*, **24**, 1924.
   Part VII. Heights of clouds and directions of free air movements. p. 167.
   Part VIII. Upper air movement in the Indian monsoons and its relation to the general circulation of the atmosphere. p. 249.
6. BROOKS, C. F.; The use of clouds in forecasting. Compendium of meteorology. Boston Mass., 1951.
7. JENKINSON, A. F.; The average vector wind distribution of the upper air in temperate and tropical latitudes. *Met. Res. Pap., London*, No. 823, 1954.

METEOROLOGICAL OFFICE DISCUSSION

Dynamical forecasting by numerical methods

The discussion on Monday, February 17, 1954, held at the Royal Society of Arts, was opened by Mr. F. H. Bushby who gave a brief history of the subject and then described the research by staff of the Forecasting Research Division, Dunstable into numerical methods of forecasting.

In spite of the advent of modern electronic computing machinery it is still not practicable to solve directly the fundamental equations of motion, continuity and state in order to compute the future condition of the atmosphere from its known condition at a given instant. These equations refer to gravity waves in addition to the meteorologically important large-scale disturbances, and it would be necessary to proceed in time steps of 10 min. using a 400-Km. grid-length in order that the finite-difference approximation to the equations of motion should converge to the correct answer. Also, it would be necessary to evaluate directly the horizontal divergence of the velocity field, and it frequently happens that the divergence of the large-scale pattern is masked by the divergence of the small-scale disturbances.

Charney[1] points out that the use of the geostrophic approximation effectively filters out these small-scale disturbances, but this approximation cannot be made until the horizontal divergence has been eliminated from the equations. Charney, using the geostrophic approximation and also assuming that the wind was unidirectional with respect to height and that the increase of wind with height was constant along a vertical, derived an equation for predicting the height of an isobaric surface in mid troposphere. He called this surface the "equivalent barotropic level".

As a result of tests at Dunstable and elsewhere it became apparent that although the barotropic model does account for some part of the atmospheric motion it is not an adequate forecasting tool. The equations derived by Sawyer and Bushby[2] combine the ideas of Charney with those of Sutcliffe[3] in an attempt to find a more realistic atmospheric model. Quite independent research by Eady[4], Eliassen[5] and Thompson[6] has led to the derivation of similar sets of results. Meanwhile, Charney and Phillips[7] have been exploring the possibilities of using multi-layer barotropic models. Phillips[8], using two homogeneous incompressible fluids superimposed one upon the other, derives a set of equations which, with suitable interpretation of the dependent variables, is analogous to the set derived by Sawyer and Bushby.

The model of the atmosphere adopted by Sawyer and Bushby consists of a baroclinic fluid in which the thermal wind is constant in direction in any vertical column, but not necessarily parallel to the wind direction at any level, and in which the thermal wind is proportional to the pressure difference through the layer considered. It is also assumed that the atmosphere is bounded by two pressure surfaces corresponding to the upper limit of the troposphere and to a level near the ground, and that the movement across these surfaces is negligible. The geostrophic approximations to the vertical vorticity component and to the horizontal velocity components are made after the elimination of the horizontal divergence. Since the geostrophic wind closely approximates to the actual wind, the state of the model atmosphere is adequately specified by the height of some isobaric surface together with the thickness of a selected layer. The height h_m of the 500-mb. contour surface and the thickness h' of the 1000–500-mb. layer are being used in the present experiments at Dunstable. The terms involving transfer of the horizontal components of vorticity to the vertical component have been omitted from the vorticity equation and the effects of surface friction are neglected. Radiation and convection are not considered in deriving the equation for the thickness tendency, the change of thickness being attributed to a combination of advection and vertical motion. For the purpose of evaluating certain integrals involving the vertical motion as a function of pressure the vertical motion was assumed to be parabolic with respect to pressure, having a maximum in mid troposphere and being zero at the ground and at the tropopause.

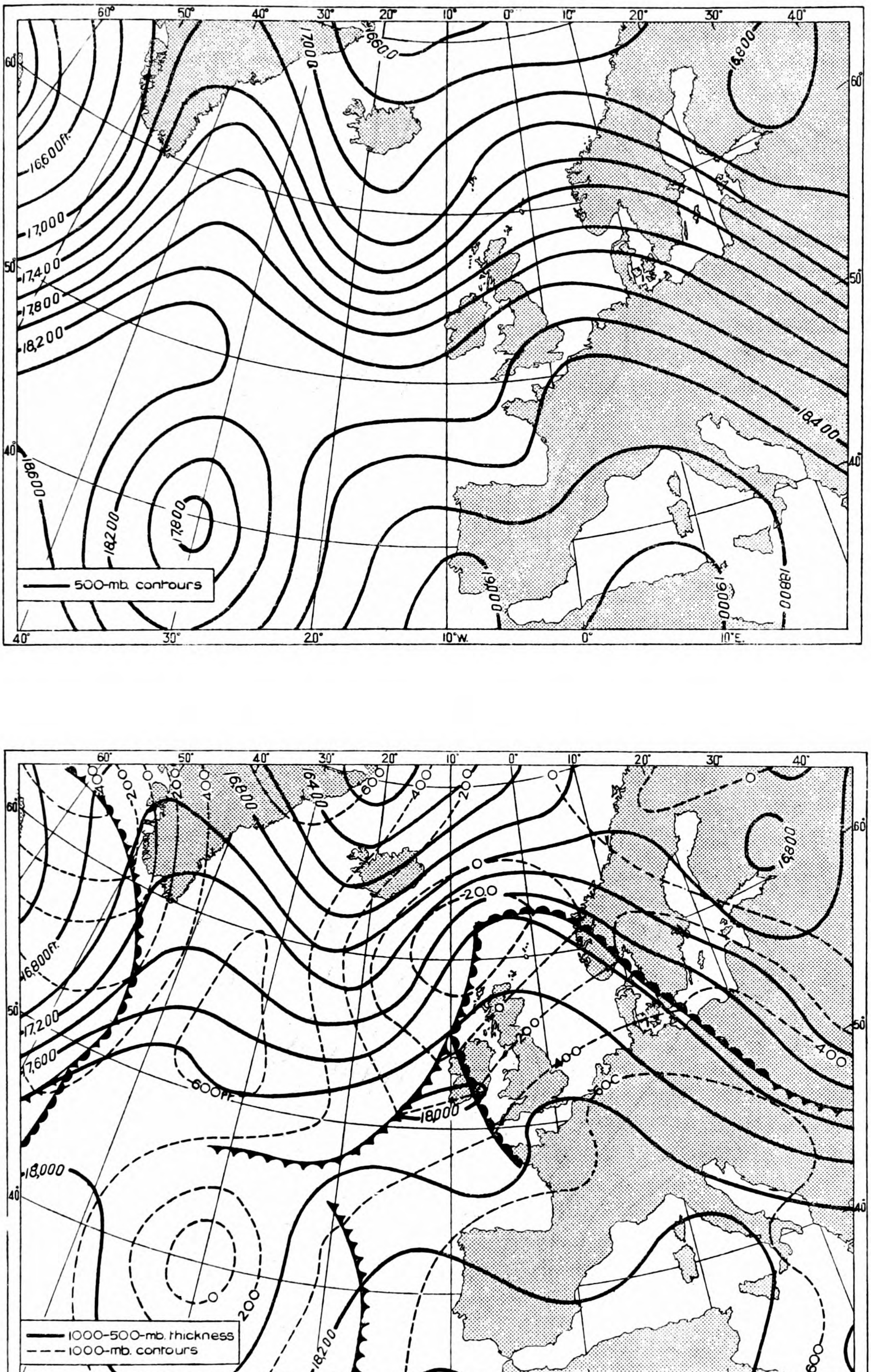
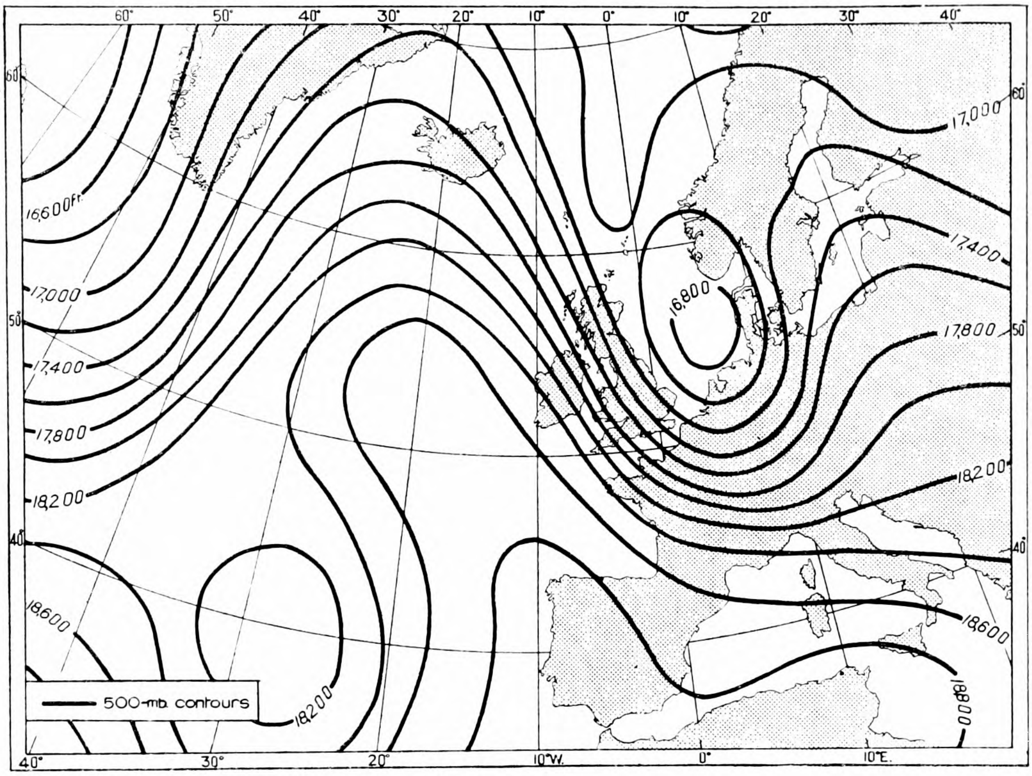
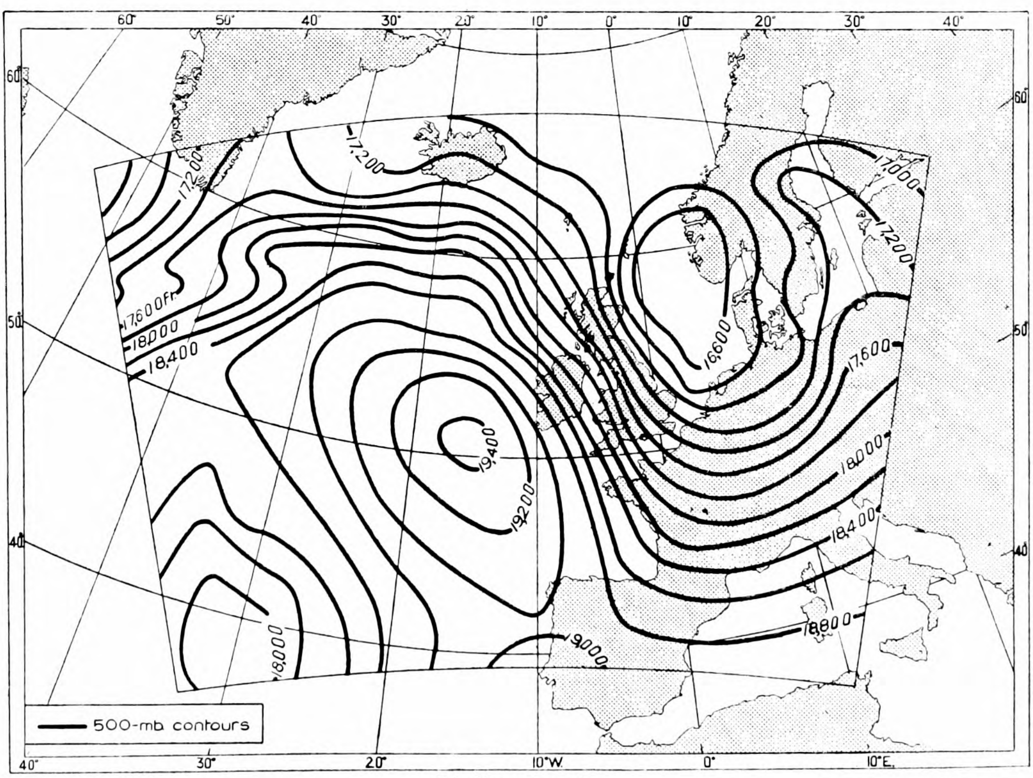


FIG. 1—ACTUAL CHARTS, 1500 G.M.T., JANUARY 30, 1953

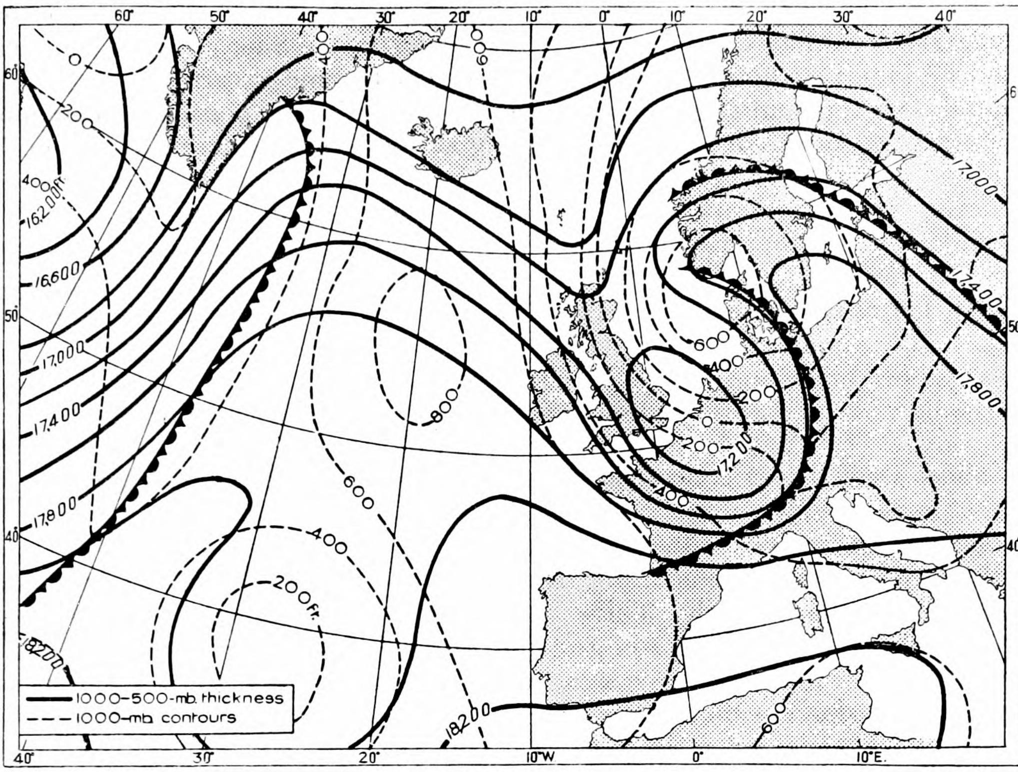


(*a*) Actual

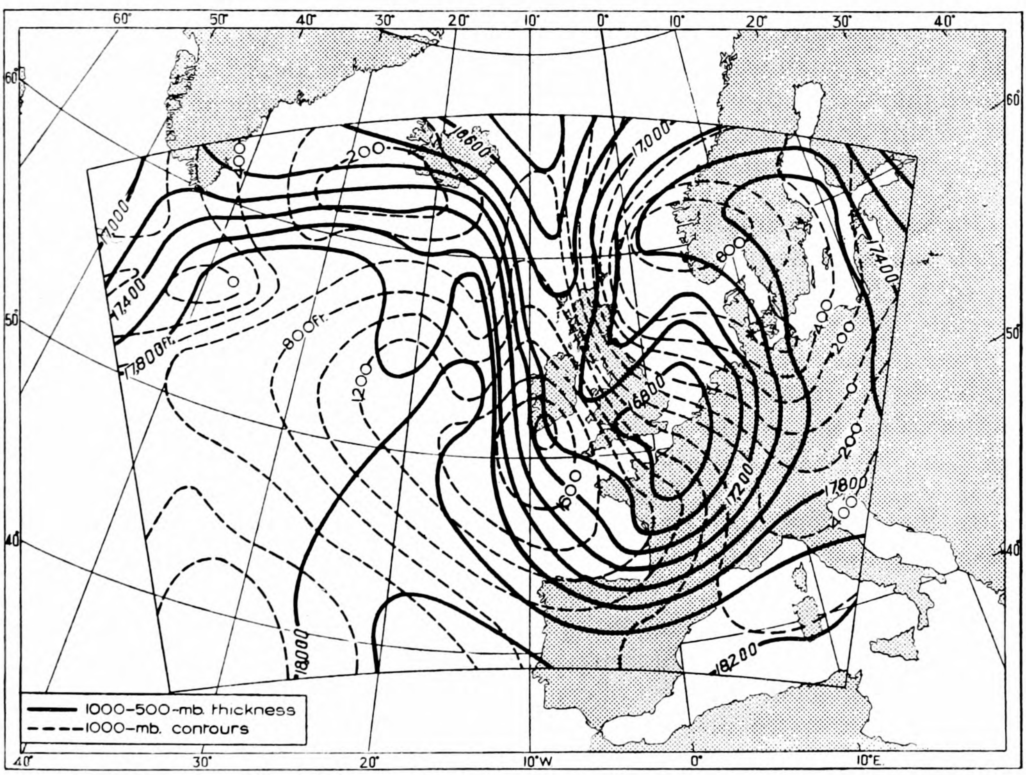


(*b*) Computed

FIG. 2—500-MB. CONTOUR CHARTS, 1500 G.M.T., JANUARY 31, 1953



(a) Actual



(b) Computed

FIG. 3—1000-MB. CONTOUR AND 1000–500-MB. THICKNESS CHARTS, 1500 G.M.T., JANUARY 31, 1953

Mr. Bushby then gave a brief outline of the mathematical derivation of the equations used for computing $\partial h_m/\partial t$ and $\partial h'/\partial t$ in the Sawyer-Bushby model, and he indicated how integration with respect to time is carried out. Using initial data for points of a rectangular 18×14 grid, it is possible to compute values for h_m and h' for some future instant at points of the interior 14×10 grid, but the variations of h_m and h' with time have to be postulated along the two exterior rings of points of the 18×14 grid. A grid-length of 260 Km. is being used for the present series of computations. The computations have been done on two electronic computing machines, LEO owned by Messrs. J. Lyons & Co., and a Ferranti machine installed at Manchester University. A 24-hr. forecast takes approximately 4 hr. of machine time if 1-hr. time steps are used in the integration procedure. However, faster machines are already being built, and it should now be possible to reduce considerably the computing time.

Slides were shown comparing the 12-hr. and 24-hr. computed forecasts of h_m, h' and $(h_m - h')$ for five synoptic situations with the actual conditions that occurred. In four of the five situations there was good agreement between the computed and actual charts, but there was a tendency to overdo anticyclonic development considerably. This could be due to the fact that in anticyclonic regions the two assumptions of geostrophic motion and the neglect of friction both cause errors of the same sign, but this is not the case in cyclonic areas. It was also apparent that in certain areas the 1000–500-mb. thickness was less than the minimum value that had occurred in that region at that time of year during the previous five years. This is probably due to the neglect of the convective processes in cold air over warm sea. A bad result was obtained for the computed forecast starting from the initial data for 1500 G.M.T., January 8, 1951, when a small wave depression in mid Atlantic deepened considerably and moved into the south-western approaches. No such development was computed, but on this occasion the forecast produced by conventional methods was very similar to the computed forecast.

One of the five situations for which forecasts have been computed was that which caused widespread flooding in eastern districts of England on January 31, 1953. The initial and final conditions, together with the computed 24-hr. forecasts, are reproduced in Figs. 1–3. It can be seen that the behaviour of the depression was forecast reasonably well, but unnaturally high pressure to the south-west of Ireland caused much stronger winds than actually occurred to be computed for the vicinity of the British Isles. The cold trough over the North Sea was in the correct position but was too intense.

Mr. Bushby concluded by emphasizing that in this project it was intended to obtain ten 24-hr. computed forecasts, and examine them carefully to see if one could deduce what fundamental assumptions were the most restrictive, and, if possible, remove them. From the results so far obtained it would seem that, although there is an encouraging agreement between computed and actual charts, the neglect of the effect of convective heating over the sea and the use of the geostrophic approximation are two sources of error. Errors of a lesser extent are introduced by the arbitrary choice of boundary conditions and by the effects of topography. There is hope that some of these deficiencies of the two-parameter model can be removed, thus opening a way for operational numerical weather prediction.

Prof. Rossby (Sweden) congratulated the Meteorological Office on being the first official weather service to experiment with numerical forecasting. He mentioned that the electronic computing machine BESK at Stockholm was being used for some forecasts using the simple barotropic model. Three forecasts had so far been made, each relating to a mobile 500-mb. pattern with little development, and in these cases correlation coefficients between 0·8 and 0·9 had been obtained between the actual and computed 24-hr. 500-mb. height change.

Dr. Smagorinsky (United States) said that the United States Weather Bureau were arranging trials to find the most suitable electronic computing machine for meteorological computations based on the three-layer model. He stressed that it was important that most of the information should be taken from the lowest part of the atmosphere, e.g. by using pressure squared as the vertical co-ordinate, as this is the region where most potential energy is available.

Mr. Jenkinson criticized the basic assumptions of the Sawyer-Bushby model regarding the vertical wind structure and the independence of static stability and pressure. He suggested that there were large areas where the thermal wind was not constant in direction with respect to height, especially in the region of jet streams and fronts. He also thought there was a need to compute surface pressure directly and not obtain it from the difference of the 500-mb. height and 1000–500-mb. thickness. In reply, Mr. Bushby said that he did not think that the thermal-wind approximation was frequently a bad one over a large area, but that there certainly were limited regions where this approximation was not good.

Mr. Ludlam inquired how much additional data was needed for perfect forecasts. Mr. Bushby said that it was difficult to give an exact reply, but certainly more rather than fewer ocean weather ships would be of great assistance.

Mr. Eldridge asked whether a new depression could be predicted; Mr. Bushby said that it certainly could if it were caused by local concentrations of vorticity, but not if it were caused by some local instability.

Dr. Scorer asked if Mr. Bushby had anything to say about fronts.

Mr. Douglas said that it was immaterial that fronts were not taken into account. The need was to make a better forecast of the pressure distribution, and very good progress has so far been made.

Mr. Sawyer thought that it was better to try to account for the missing physical factors than to use more parameters.

Mr. Bradbury inquired whether any attempt had been made to compute the development of a blocking high. Mr. Bushby said that such developments usually took much longer than 24 hours.

Prof. Rossby agreed, but said he thought that numerical forecasting would probably be used for forecasting the movement of large-scale features over 2–3 days before it was used for detailed 24-hr. forecasting. Mr. Bushby, in reply, said that as the equations were non-linear it was not obvious that detail could be neglected in preparing a medium-range forecast.

Mr. Veryard said it was important to consider the latent heat of condensation if one was considering convective processes.

Mr. Lumb suggested that once the thermal pattern had been computed, it might be better to fix the centres of depressions and anticyclones by placing them in the most appropriate part of the thermal field. In his opinion this would have given a better forecast for the position of the flood depression.

Dr. Stagg concluded the discussion by saying that the subject of numerical forecasting was still in its infancy, but that considerable progress was being made.

REFERENCES

1. CHARNEY, J. G.; On a physical basis for numerical prediction of large-scale motions in the atmosphere. *J. Met., Lancaster Pa*, **6**, 1949, p. 371.
2. SAWYER, J. S. and BUSHBY, F. H.; A baroclinic model atmosphere suitable for numerical integration. *J. Met., Lancaster Pa*, **10**, 1953, p. 54.
3. SUTCLIFFE, R. C.; A contribution to the problem of development. *Quart. J. R. met. Soc., London*, **73**, 1947, p. 370.
4. EADY, E. T.; Note on weather computing and the so-called 2½-dimensional model. *Tellus, Stockholm*, **4**, 1952, p. 157.
5. ELIASSEN, A.; Simplified models of the atmosphere, designed for the purpose of numerical weather prediction. *Tellus, Stockholm*, **4**, 1952, p. 145.
6. THOMPSON, P. D.; On the theory of large-scale disturbances in a two-dimensional baroclinic equivalent of the atmosphere. *Quart. J. R. met. Soc., London*, **79**, 1953, p. 51.
7. CHARNEY, J. G. and PHILLIPS, N. A.; Numerical integration of the quasi-geostrophic equations for barotropic and simple baroclinic flows. *J. Met., Lancaster Pa*, **10**, 1953, p. 71.
8. PHILLIPS, N. A.; A simple three-dimensional model for the study of large-scale extratropical flow patterns. *J. Met., Lancaster Pa*, **8**, 1951, p. 381.

OFFICIAL PUBLICATION

The following publication has recently been issued:—

PROFESSIONAL NOTES

No. 109—Radar echoes from and turbulence within cumulus and cumulonimbus clouds. By R. F. Jones, B.A.

Accelerometer records obtained on traverses of cumulus and cumulonimbus clouds by Spitfire aircraft have been analysed to give the frequency of gusts encountered of specified magnitudes. It appears that turbulence increases slowly with height in a cumulonimbus cloud until rather less than half way up the cloud, and thereafter remains at or near its maximum value until the top third of the cloud is reached. In the top third of the cloud the turbulence steadily decreases with height to a minimum value near the top of the cloud. The readings obtained are shown not to be inconsistent with statistics of American observations made in Florida and Ohio.

Radar observations, made at the same time as the accelerometer records were obtained, make it possible to relate the turbulence to the characteristics of the radar echo received from the part of the cloud traversed. It is found that the radar-echo characteristics, as shown on a height-range display tube, can be used to indicate the places in a cloud where turbulence is likely to be the most severe. Edges of the echoing volume in particular are shown to be regions of severe turbulence. Severe gusts frequently occur in sequences with the distance between individual gusts less than 400 yd.

Although most of the severe gusts occurred in the echo-producing regions of the clouds there was nevertheless a substantial number of severe gusts experienced in clouds, or parts of a cloud, which failed to give a detectable radar echo.

METEOROLOGICAL RESEARCH COMMITTEE

The Synoptic and Dynamical Sub-Committee met on January 28, the Physical Sub-Committee on February 4, the Instruments Sub-Committee on February 11, and the Main Committee on March 24, 1954.

At the meeting on January 28 the Synoptic and Dynamical Sub-Committee considered a paper by Mr. Lamb[1] which discussed two-way relationships between the snow or ice limit and 1000–500-mb. thicknesses in the overlying atmosphere, a paper by Mr. Sumner[2] on the annual and geographical distribution of cold pools, and a paper by Mr. Sawyer[3] on the rainfall of depressions which move eastward across Scotland.

At the meeting of the Physical Sub-Committee there was a discussion on post-war research in micrometeorology within the Meteorological Office at which the opening speakers were Dr. Robinson, Mr. Rider and Dr. Stewart.

At the meeting on February 11 the Instruments Sub-Committee considered a paper by Dr. Scrase[4] on radiation and lag errors of the Meteorological Office radio-sonde and the diurnal variation of upper air temperature. There was also a discussion on the meteorological elements for radio-sondes at which the opening speakers were Dr. Harrison, Mr. Grant and Mr. Almond.

At these three meetings the Annual Reports to the Meteorological Research Committee from the chairmen of the various sub-committees were discussed and recommendations formulated for the revision of the research programme.

At the 67th meeting of the Meteorological Research Committee the Annual Reports from the chairmen of the various sub-committees were received, the research programme for the following 12 months was approved, and the Annual Report to the Secretary of State for Air was agreed. Mr. L. P. Smith also gave an interesting summary of the application of meteorological research to agricultural problems.

ABSTRACTS

1. LAMB, H. H.; Two-way relationships between the snow or ice limit and 1000–500-mb. thicknesses in the overlying atmosphere. *Met. Res. Pap., London*, No. 834, S.C. II/159, 1953.

Deals first with relations between 1000–500-mb. thickness in British Isles, east Atlantic and north-west Europe and temperature at surface, 850, 700 and 500 mb. Change from rain to snow occurs with thickness about 17,150 ft. (oceanic) or 17,400 ft. (continental). The limit of a snow- or ice-covered surface in Europe had a mean thickness of 17,260 ft.; at normal 0°C. M.S.L. isotherm it was 17,500 ft. Encroachments of greater thickness (up to 18,000 ft.) over snow-covered areas were short-lived; this favours persistence of snow cover. High ground is an effective barrier. Effect of an extensive snow cover on severity of winter is considered.

2. SUMNER, E. J.; The annual and geographical distribution of cold pools. *Met. Res. Pap., London*, No. 837, S.C. II/160, 1953.

In continuation of *Meteorological Research Paper* No. 764 frequency of all cold pools with one or more closed lines in 1000–500-mb. charts is tabulated for annual and geographical distribution. Results are shown graphically and discussed.

3. SAWYER, J. S.; The rainfall of depressions which move eastward across Scotland. *Met. Res. Pap., London*, No. 843, S.C. II/164, 1953.

In continuation of previous *Meteorological Research Papers* rainfall charts were drawn for 49 depressions crossing Scotland in 1941–50. Figures show average rainfall, relation to distance from track, percentage giving no rain, and frequency diagrams for selected stations.

4. SCRASE, F. J.; Radiation and lag errors of the Meteorological Office radio-sonde and the diurnal variation of upper air temperature. *Met. Res. Pap., London*, No. 836, S.C. I/81, 1953.

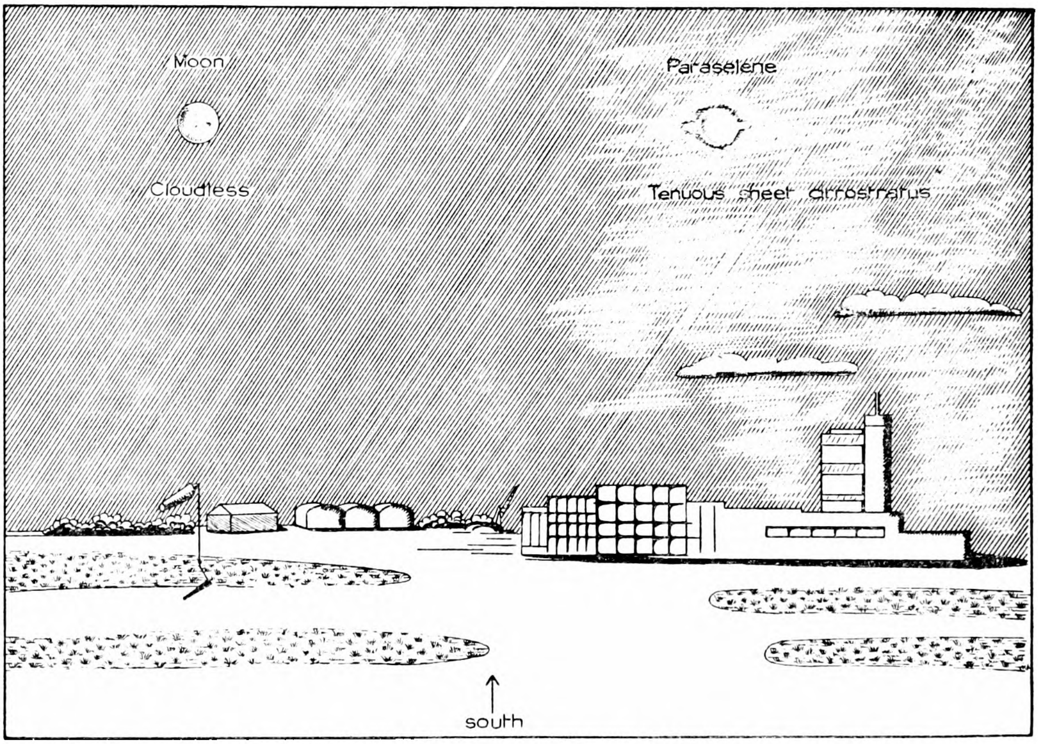
The shielded thermo-element of the radio-sonde may be affected by radiation (direct and reflected from the inner shield) and by air warmed by the shield. The heat transfer for a radio-sonde ascending at 6 m./sec. and swinging through 60° and the absorption of radiation for different solar altitudes, are calculated. In 50°N. the total error varies from 0·7°C. at ground level to 17·3°C. at 30 Km., where heating of the air in the shield accounts for 65 per cent. The error due to lag is also calculated and found to be generally less than 1°C. These results are confirmed by comparison of temperatures during ascent and much faster descent. Some experimental modifications were tried, but the only one which showed appreciable improvement was the substitution of white card for aluminium for the inner shield. The results show that up to 15 Km. radiation errors can account for the whole observed difference between day and night temperatures, but that there is a true diurnal range of about 1·5°C. at 20 Km. and 3°C. at 25 Km.

LETTERS TO THE EDITOR

Paraselene observed at London Airport

A well defined paraselene (mock moon) was observed at London Airport between 2338 and 2345 G.M.T. on Saturday, March 20, 1954. At the time of the observation the moon was one day after full and very bright. The altitude was about 28° and at a bearing 160° from true north.

Prior to the observation the sky had been almost cloudless but a sheet of very tenuous cirrostratus had spread in from the north-west with small amounts of stratocumulus cloud. As this cirrostratus spread towards the position of the moon, a bright paraselene was observed at the position on the paraselenic circle to the west of the moon and at an angular distance of about 28° from the moon. Very small parts of the paraselenic circle were evident as projections on the equator of the paraselene. The edge of the paraselene nearest to the moon had a reddish tinge. There was no trace of any part of the 22° halo or any other halo phenomena.



The paraselene was visible for about seven minutes when it was obscured by increasing low cloud.

An examination of the available upper air data indicates that the tenuous cirrostratus sheet was probably at a height of 29,000 ft. with a temperature of −50°C. The maximum vertical wind shear was in the belt between 350 and 300 mb. with the wind velocity at the cirrostratus level about 284° 35 kt.

T. N. S. HARROWER

London Airport, March 22, 1954 D. C. EVANS

[There is nothing unusual in theory about paraselenae but in practice well defined ones are rarely observed. The absence of a 22° halo indicates that the axes of the hexagonal ice crystals were mainly vertical.—Ed., *M.M.*]

[*To face p. 184*

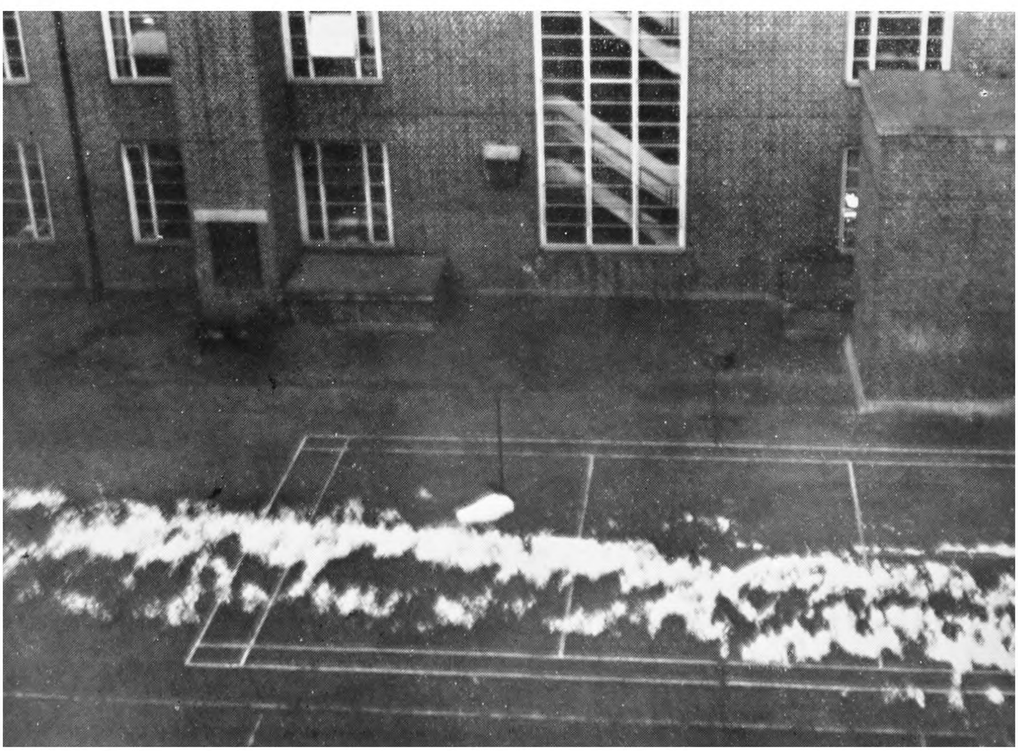
Reproduced by courtesy of the late Mr. W. J. Day

A CORONA TOWARDS SUNSET

To face page 185]

Reproduced by courtesy of the late Mr. W. J. Day

ALTOSTRATUS AND CIRROSTRATUS NEAR SUNSET



QUADRANGLE OF METEOROLOGICAL OFFICE, HARROW, FEBRUARY 1, 1954, 1650 G.M.T.
Looking north-east

Low range for a long period

The thermograph trace for the Nether Park station at Alston, Cumberland, for January 20–23, 1954, showed an almost horizontal line extending across 57 hr. The maximum temperature during this time was 35°F. and the minimum about 33·5°F. The range of only 1·5°F. between 1800 G.M.T. on the 20th and 0300 G.M.T. on the 23rd offered something unique in the Alston record, but whether this is really unusual I cannot say.

The validity of the trace is substantiated by the readings at the Alston climatological station where 2·9°F. was the range recorded on thermometers. The almost invariably lower maxima at Nether Park gives support to the slightly lower range registered by the thermograph.

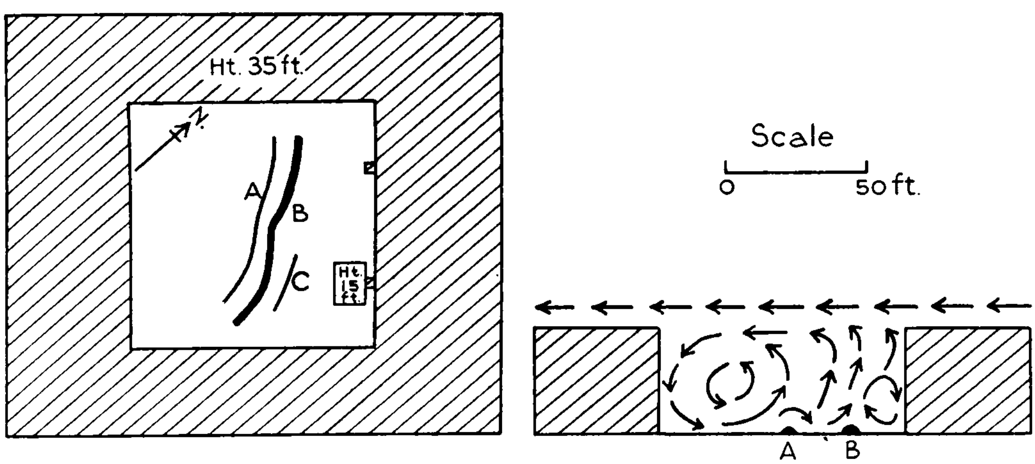
W. E. RICHARDSON

Alston Climatological Station, The Grove, Alston, Cumberland, February 10, 1954.

NOTES AND NEWS

Eddies unusually defined by snow

The lower photograph opposite shows the distribution of dry snow at approximately 1700 G.M.T. on February 1, 1954, in the quadrangle of the Meteorological Office building at Harrow. The anemograph wind was east-north-easterly, 10–15 kt. A plan of the surroundings is shown in Fig. 1; the snow was in the



Plan — Elevation looking north-west (diagrammatic)

FIG. 1—METEOROLOGICAL OFFICE, HARROW

form of two lanes, one of which, at B, was distinctly larger and contained more snow than the other at A. The snow lanes were parallel to the main windward face of the building but curved at one end towards the second most windward face. Snow was restricted to the "lee" side of the quadrangle; and on objects in this region, snow piled up on the side facing the returning "eddy" wind. The double lane suggests that the eddy flow gave an extra "bounce". Assuming this to be the case and that snow accumulated in areas of little wind, the air flow would be roughly as illustrated in Fig. 1. The larger deposition is presumably in the more sheltered region, nearer to the building. In the photograph, there is a slight suggestion of a third snow lane (at C in Fig. 1), particularly where the eddy flow has a longer (that is, more diagonal) path. The number of waves would appear to be a function of this length of path, and of the strength of the general air flow and height of the obstruction.

A further point of interest is that the small building in the quadrangle appears to have caused an irregularity in the snow lanes. The direction of this irregularity from the small building probably indicates the direction of the returning eddy wind.

E. N. LAWRENCE

Halo complex, March 2, 1954

A brilliant halo display, which as seen from some places included phenomena rarely observed, occurred over England, south Scotland and Wales on the afternoon of March 2, 1954. The halo complex was particularly well developed over East Anglia and Lincolnshire. Mr. G. D. Alcock of Farcet, Peterborough, Northamptonshire has sent the following description of his observations and the figure reproduced at Fig. 1:—

An unusual halo phenomenon was seen here on the afternoon of Tuesday, March 2, between 1340 and 1515 G.M.T. A uniform sheet of cirrostratus spread over rapidly from the west. This cloud sheet was quite devoid of any detail, being a uniform milky white, and gradually thickened during the period of observation.

A conspicuous coloured normal 23° halo was first seen with mock suns on either side placed just outside the arc. These mock suns became very brilliant and highly coloured. By 1345 the extreme upper segment of the 46° halo was visible with its upper arc of contact with all spectrum colours brilliantly visible. The mock-sun ring spread equally quickly right round the sky with conspicuous white mock suns at 329° and 90° true bearing (a prismatic compass was used). Then the anthelion became gradually visible. All these three had white arcs through them.

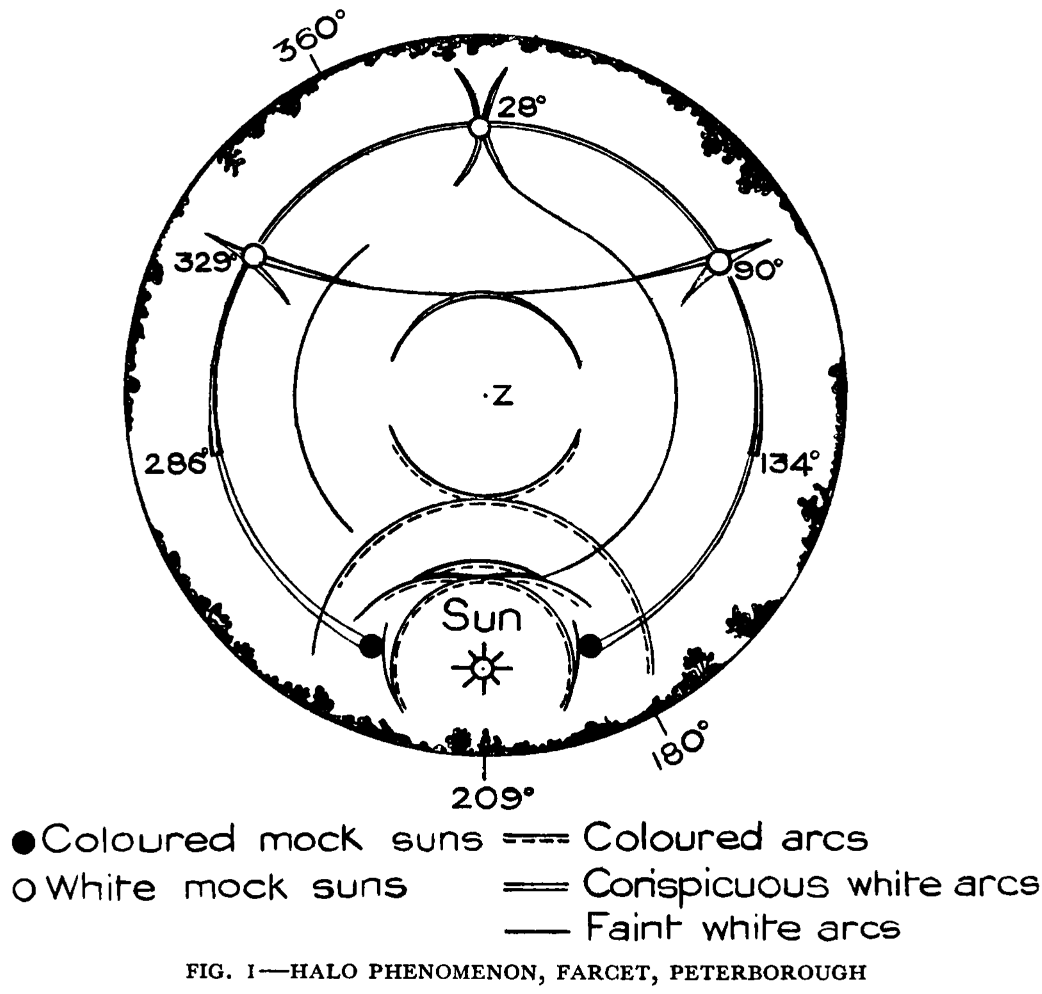


FIG. 1—HALO PHENOMENON, FARCET, PETERBOROUGH
1340–1515 G.M.T., MARCH 2, 1954

From 1415 to 1430 a faint arc connected the mock suns and just touched a white segment of zenithal arc opposite the sun. The 46° halo was now very conspicuous especially to the east of the sun and near the southern horizon, where it looked like a bright very narrow rainbow. The phenomenon was most brilliant at 1422 when all arcs shown on the sketch were visible, including one from above the 23° halo to the anthelion. This dipped in an arc as it approached the anthelion as shown in the sketch.

At positions 286° and 134° on the mock-sun ring were clear-cut lines of brilliance from which the mock-sun ring streamed brilliantly away from the sun like comet tails. There were no mock suns at 286° and 134° true bearing.

I have watched for such phenomena since 1933, and this is quite the most uncommon I have so far witnessed.

Mr. A. Blackham of the Meteorological Office, Cranwell, Lincolnshire has represented the phenomena seen by himself and other members of the Cranwell staff in Fig. 2.

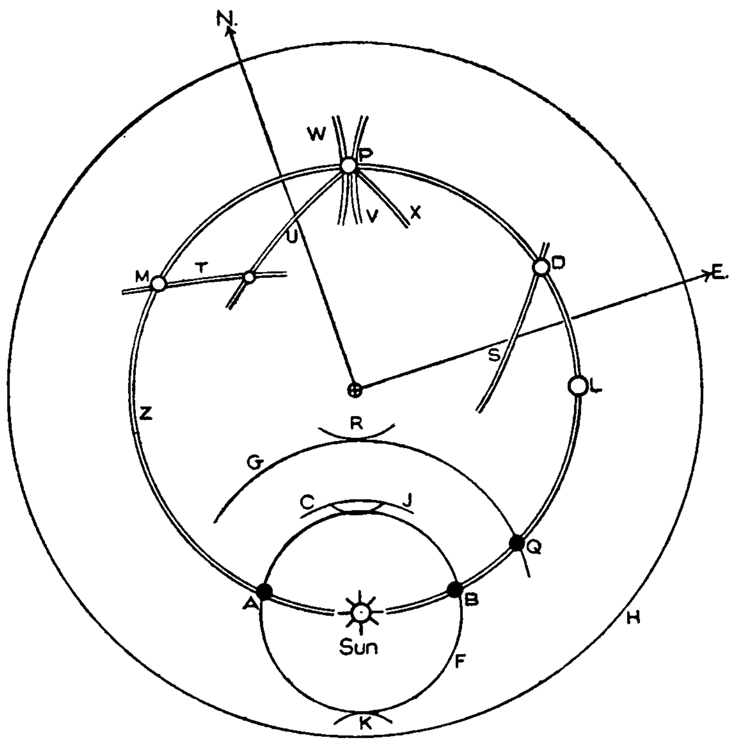


FIG. 2—HALO PHENOMENON, CRANWELL, MARCH 2, 1954

H horizon
A, B mock suns at the intersection of the 22° halo and the parhelic circle, containing the spectrum colours, red nearest the sun
Q mock sun, coloured, at the intersection of the 46° halo and the parhelic circle
P anthelion, white
L mock sun, white, 90° from the sun
D mock sun, white, 120° from the sun
M mock sun, white, 240° from the sun
Z parhelic circle, distinct and white and a complete circle
F 22° halo, complete and faintly coloured
G 46° halo, faintly coloured, but incomplete
R arc of contact of 46° halo, brightly coloured
K lower arc of contact of 22° halo, distinct, faintly coloured
CJ arc of upper contact, appearing to consist of a concave and a convex arc, both coloured, giving a distorted effect to the curve
S, T, U, V, W, X } arcs cutting the parhelic circle, all white and quite distinct.

All colours were spectrum colours, red nearest the sun in all cases. All angles were measured in azimuth round the parhelic circle, from the sun through east.

Mr. S. E. Ashmore reports that at Wrexham about 1000 he observed a halo complex rivalling the Danzig phenomenon of February 20, 1661 as follows:—

22° halo
Two parhelia of the 22° halo
Most of the circumscribed ellipse
Upper Parry arc
Partial halo 9–11°
46° halo unbroken
Infralateral arcs of the 46° halo
Small sun pillar
Circumzenithal arc
Parhelic circle, nearly complete
One parhelion of 90° with part of the 90° halo going through it
One paranthelion with an oblique arc through it.

The halo phenomena were also observed at Dunstable by Meteorological Office staff. As the upper protruding parts of the arc of contact with the 22° halo faded, the combination of this arc with the Parry arc appeared to take a sinuous shape, likened by Mr. A. P. Taylor to a "cupid's bow".

A large number of other reports have also been received; it is impossible to mention all the individual observers to whom we are indebted for information on the display.

Rare phenomena reported were:—

(i) The Parry arc above and concave to the sun bridging the arc of contact to the 22° halo seen by several observers including those at Peterborough, Wrexham, Dunstable and Cranwell.

(ii) Mock suns at 120° and 90° along the parhelic circle on either side of the sun. These were reported by several observers.

(iii) The anthelion and associated arcs. Mr. Alcock saw two nearly closed anthelic arcs running from the arc of contact to the 22° halo to the anthelion on either side of the zenith.

(iv) The rare Kern's arc at the same altitude as the circumzenithal arc above the sun but on the opposite side of the zenith seen by Mr. Alcock.

(v) The rare Lowitz arcs from the parhelia just outside the 22° halo joining the 22° halo in cusps near the horizon as seen by Mr. Alcock.

(vi) The arc seen by Mr. Alcock joining the 120° mock suns. Arcs through the two 120° mock suns are seen rarely, and it is rare for them to join. This continuous arc was, however, seen at Ternhill, Shropshire on March 6, 1941*, and in south Finland on March 10, 1920†. According to Humphreys‡, the arcs through the 120° parhelia are produced by total internal reflections at surfaces inclined at 120° in the same manner as the 120° parhelia. The crystals responsible produce 120° parhelia if their axes are horizontal and arcs if tilted out of the horizontal.

The Napier Shaw Memorial Prize

The Royal Meteorological Society announces the first competition for the Napier Shaw Prize which has been instituted to commemorate the recent centenary of the birth of Sir Napier Shaw. The competition will be open to anyone without restriction of nationality. The prize of £100 is offered on this occasion for an original essay on "The energetics of the general circulation".

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* London, Meteorological Office. Typescript, *Met. Mag., London*, April, 1941, p. 1.
† MEYER, R.; Die Haloerscheinungen. *Probl. Kosm. Phys., Hamburg*, **12**, 1929, p. 4.
‡ HUMPHREY, W. J.; Physics of the air. New York, 3rd edn, 1940, p. 542.

The essay will be expected to treat of the energy transformations of the circulation as a general theme or any particular aspects of that theme. It may be an essay in which the author describes and discusses the salient and essential features of the general circulation and the energy transformations involved; it may be an essay which attempts an adequate synopsis and discussion of the observations, or a study of the thermodynamics and hydrodynamics of the circulation; or the essay may treat of any combination of these within the general theme.

Further particulars can be obtained from the Assistant Secretary, Royal Meteorological Society, 49 Cromwell Road, London, S.W.7. Essays for the competition must be received at the Society's Offices not later than March 4, 1956. All correspondence should be marked clearly "Napier Shaw Prize".

REVIEW

Climatology. By A. Austin Miller. $8\frac{3}{4}$ in. × $5\frac{3}{4}$ in., pp. x + 318, *Illus.*, Methuen & Co. Ltd, London, 8th edition, 1954. Price: 21*s*.

When the third edition of this well known textbook appeared in January 1944 it was pleasing to find that the author had revised his work by adding a chapter on the concept of air masses and fronts. He thus modified, in part, what was originally a mainly statistical approach to the subject by a more dynamical approach. In the latest (1954) edition one finds that there has been further revision, but that this consists chiefly of the refinement of a regional system of climatic classification and an overhaul of the chapter dealing with changes of climate. One could have wished that the author had extended the dynamical approach by including some discussion of the mechanism of climate in the light of studies which have been made in recent years on the general circulation of the atmosphere. However, as is clearly stated in the Preface, the book is intended primarily for geographers who no doubt are more concerned with physical rather than with dynamic climatology, and on the basis of climatic types the author aims at giving a descriptive but reasoned account of the world's climate with special reference to the human aspect.

Although a smaller type has been used the number of pages is about the same and the general layout remains unchanged. After an introductory chapter on the meaning and scope of climatology there follow chapters dealing with the elements and factors of climate. Next there is the chapter on air masses and then the "key" chapter on the classification of climates. Many workers have toyed with the classification of climates and have produced different criteria varying according to the factors considered and the requirements of the user. In this case the intention is to define geographical regions. From a study of types of vegetation and applying specified threshold values for plant growth the author examines, in conjunction with the distribution of surface winds, the available data for the seasonal distribution of rainfall and temperature with particular reference to the length of dry and cold seasons and thereby defines a number of main and subsidiary types of climate. These types are discussed in greater detail, and on a regional basis, in the ten following chapters which include tables of monthly temperature and rainfall for nearly 300 stations. In the light of new knowledge arising, in particular, from the increasing amount of upper air data a meteorologist, especially one with experience in the regions concerned, might differ from the author here and there especially in regard to the causes of various phenomena—but then meteorologists may not yet be able to agree among themselves!

The final chapter relates to changes of climate and gives an outline of the more important work on the subject and a tentative account of the evolution of climate. No mention is made, however, of recent studies, e.g. by H. C. Willett, on the periodic fluctuations of the general circulation of the atmosphere, or of the ocean-bed research described by J. D. H. Wiseman and Hans Petterson, or of the technique of radio-carbon dating as employed by W. D. Urey. In fact in the "Suggestions for further reading" at the end of each chapter—an excellent idea if the references given are up to date—it would appear that some of the interesting publications of recent times have been overlooked, e.g. "Climate in everyday life" by C. E. P. Brooks. Nevertheless it can be said that the author has a right to feel that, in general, he has succeeded in his task.

Apart from one or two slips in the spelling of names and an incorrect reference to Fig. 33 on page 98 the reproduction of text and diagrams is good. It would appear that the index needs bringing up to date. For example, it does not include the name of H. W:son Ahlmann whose glaciological investigations are mentioned on page 303.

R. G. VERYARD

OBITUARIES

John Nelson Bennett.—We regret to announce the death of Mr. J. N. Bennett (Scientific Assistant) on April 22, 1954 as a result of a climbing accident on Sergeants Crag, Langstrath, Cumberland. Mr. Bennett joined the Office in 1947 and practically the whole of his service was spent at radio-sonde stations. At the time of his death he was stationed at Fazakerley.

Leonard William Dolley.—We also regret to announce the sudden death of Mr. L. W. Dolley, Executive Officer at the Ocean Weather Ship Base, Greenock, which occurred at Gourock on March 30, 1954. Mr. Dolley was posted to the Ocean Weather Ship Base in 1948 where he carried out the duties of Base Accountant and assistant to the Shore Captain.

METEOROLOGICAL OFFICE NEWS

Studentships at the Royal Military College of Science, Shrivenham.—We congratulate Mr. J. R. Grundy, Assistant Experimental Officer, Little Rissington, on his selection for an award of a studentship at the Royal Military College, Shrivenham, to be taken up in the autumn of 1954.

Sports Activities.—*Motoring.*—Mr. C. H. R. Lane, Scientific Assistant, London Airport, received a first-class award in the Navigation Rally held by the Civil Service Motoring Association on February 28 last. The navigator was Mr. P. J. Cutting, Scientific Assistant, Kew Observatory.

Football.—The Meteorological Office "A" team defeated the Directorate General of Organization by 6 goals to nil in the final of the competition for the Air Ministry Football Cup at Northolt on May 4. This is the seventh consecutive occasion on which the Office has won the competition. It was unfortunate that the Meteorological Office "B" team from Harrow and Uxbridge were drawn to play the "A" team in an early round of the competition.

WEATHER OF APRIL 1954

Mean pressure was above normal over the whole of Europe, including the Mediterranean and the greatest excess occurred in the west of this region; the mean pressure exceeded 1020 mb. in the north and west of France where it was as much as 9 mb. above normal. The mean pressure at the Azores, 1024 mb., was 1 mb. above normal and it was also above normal over most of North America.

The mean temperature over most of Europe was 4°F. below normal; this was associated with the gradient for north-easterly winds corresponding to the mean pressure distribution. The mean temperature over much of the United States was 5°F. above normal.

In the British Isles the weather was sunny and very dry; mean temperature was about or slightly above the average in Scotland and somewhat below the average in England and Wales; night frost was unusually frequent and there were no notably warm days. A changeable westerly type of weather prevailed for the first few days but afterwards conditions were mainly anticyclonic.

In the opening days Atlantic depressions moved along our north-west seaboard and associated fronts crossed the British Isles; rain fell generally. On the 3rd a deep depression near the north-west coast of Scotland gave rain generally and gales at exposed places on the coasts of north-west Ireland and north Scotland. The depression moved away north-east and in its rear a north-westerly air stream spread over the British Isles and showers occurred with hail, sleet and thunder in places, mainly in the north and west on the 4th and more generally on the 5th. Snow fell on some of the high ground, including Dartmoor, later on the 5th when a small disturbance moved from north-west Ireland to Brittany. A wedge of high pressure moved in over the British Isles from the west on the 6th and later became part of a belt of high pressure from the Azores across England to Scandinavia, which lasted until the 11th. Weak fronts moved east across the country on the 12th but another anticyclone approached south-west Ireland on the 13th and dominated conditions over most of the country until the 19th. Subsequently pressure became high to the north of Scotland, with a ridge extending southward over the British Isles; persistent NE. winds gave cold weather on the east coast up to the 28th but there were sunny periods generally and much sunshine in the west. The dry spell began over England and Wales on the 6th and lasted with small local interruptions until the 29th, amounting to an absolute drought over a substantial area. In Scotland and Ireland, rainfall was not large from the 6th to the 17th, and from the 18th to the 28th the weather was almost entirely dry. On the 29th a slow-moving cold front moved southward over northern districts, with some rain, considerable in amount locally in east Scotland. Snow fell locally in Scotland and thunderstorms occurred at some places in the Midlands and east of England on the 30th.

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 ...	67	20	−1·4	29	−8	121
Scotland	66	20	+0·5	66	−6	127
Northern Ireland ...	61	27	−0·1	35	−8	117

RAINFALL OF APRIL 1954

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square	0·29	19	*Glam.*	Cardiff, Penylan	0·88	35
Kent	Dover	0·22	14	*Pemb.*	Tenby, The Priory	0·87	38
,,	Edenbridge, Falconhurst	0·52	28	*Radnor*	Tyrmynydd	1·20	33
Sussex	Compton, Compton Ho.	0·38	19	*Mont.*	Lake Vyrnwy	1·96	62
,,	Worthing, Beach Ho. Pk.	0·42	27	*Mer.*	Blaenau Festiniog	4·57	74
Hants.	Ventnor Cemetery	0·41	24	,,	Aberdovey	1·68	65
,,	Southampton, East Pk.	0·24	13	*Carn.*	Llandudno	1·37	81
,,	South Farnborough	0·25	16	*Angl.*	Llanerchymedd	1·12	51
Herts.	Royston, Therfield Rec.	0·22	14	*I. Man*	Douglas, Borough Cem.	0·57	23
Bucks.	Slough, Upton	0·36	25	*Wigtown*	Newton Stewart	1·45	57
Oxford	Oxford, Radcliffe	0·39	24	*Dumf.*	Dumfries, Crichton R.I.	0·89	38
N'hants.	Wellingboro' Swanspool	0·22	15	,,	Eskdalemuir Obsy.	1·40	41
Essex	Shoeburyness	0·26	21	*Roxb.*	Crailing	0·72	45
,,	Dovercourt	0·23	18	*Peebles*	Stobo Castle	0·90	43
Suffolk	Lowestoft Sec. School	0·37	25	*Berwick*	Marchmont House	0·70	35
,,	Bury St. Ed., Westley H.	0·41	27	*E. Loth.*	North Berwick Res.	1·60	114
Norfolk	Sandringham Ho. Gdns.	0·43	28	*Midl'n.*	Edinburgh, Blackf'd. H.	1·22	83
Wilts.	Aldbourne	0·40	22	*Lanark*	Hamilton W. W., T'nhill	1·57	84
Dorset	Creech Grange	0·19	9	*Ayr*	Colmonell, Knockdolian	1·11	44
,,	Beaminster, East St.	0·32	14	,,	Glen Afton, Ayr San.	2·36	79
Devon	Teignmouth, Den Gdns.	0·12	6	*Renfrew*	Greenock, Prospect Hill	2·88	84
,,	Ilfracombe	0·70	33	*Bute*	Rothesay, Ardencraig	2·19	73
,,	Princetown	1·61	32	*Argyll*	Morven, Drimnin	..	..
Cornwall	Bude, School House	0·79	42	,,	Poltalloch	2·47	82
,,	Penzance, Morrab Gdns.	0·84	35	,,	Inveraray Castle	4·23	92
,,	St. Austell	0·85	30	,,	Islay, Eallabus	1·65	57
,,	Scilly, Tresco Abbey	0·57	29	,,	Tiree	1·41	57
Somerset	Taunton	0·14	8	*Kinross*	Loch Leven Sluice	1·36	71
Glos.	Cirencester	0·45	24	*Fife*	Leuchars Airfield	1·69	106
Salop	Church Stretton	0·74	34	*Perth*	Loch Dhu	3·54	75
,,	Shrewsbury, Monkmore	0·46	31	,,	Crieff, Strathearn Hyd.	1·38	63
Worcs.	Malvern, Free Library	0·45	25	,,	Pitlochry, Fincastle	0·96	43
Warwick	Birmingham, Edgbaston	0·62	36	*Angus*	Montrose, Sunnyside	0·94	52
Leics.	Thornton Reservoir	0·47	28	*Aberd.*	Braemar	0·96	41
Lincs.	Boston, Skirbeck	0·32	24	,,	Dyce, Craibstone	1·53	74
,,	Skegness, Marine Gdns.	0·44	33	,,	New Deer School House	1·18	59
Notts.	Mansfield, Carr Bank	0·36	21	*Moray*	Gordon Castle	0·81	46
Derby	Buxton, Terrace Slopes	0·88	30	*Nairn*	Nairn, Achareidh	0·86	61
Ches.	Bidston Observatory	0·65	40	*Inverness*	Loch Ness, Garthbeg	1·72	75
,,	Manchester, Ringway	0·58	32	,,	Glenquoich	4·42	68
Lancs.	Stonyhurst College	1·47	54	,,	Fort William, Teviot	3·12	69
,,	Squires Gate	1·06	60	,,	Skye, Broadford	2·43	54
Yorks.	Wakefield, Clarence Pk.	0·28	17	,,	Skye, Duntuilm	2·12	65
,,	Hull, Pearson Park	0·19	12	*R. & C.*	Tain, Mayfield	0·90	49
,,	Felixkirk, Mt. St. John	0·25	15	,,	Inverbroom, Glackour	2·50	67
,,	York Museum	0·22	14	,,	Achnashellach	4·10	77
,,	Scarborough	0·20	13	*Suth.*	Lochinver, Bank Ho.	1·83	64
,,	Middlesbrough	0·16	12	*Caith.*	Wick Airfield	1·10	55
,,	Baldersdale, Hury Res.	0·73	33	*Shetland*	Lerwick Observatory	2·14	93
Norl'd.	Newcastle, Leazes Pk.	0·52	33	*Ferm.*	Crom Castle	0·82	32
,,	Bellingham, High Green	0·53	25	*Armagh*	Armagh Observatory	0·50	24
,,	Lilburn Tower Gdns.	0·63	32	*Down*	Seaforde	0·60	23
Cumb.	Geltsdale	0·82	38	*Antrim*	Aldergrove Airfield	0·38	18
,,	Keswick, High Hill	1·16	38	,,	Ballymena, Harryville	0·61	23
,,	Ravenglass, The Grove	0·86	35	*L'derry*	Garvagh, Moneydig	1·08	44
Mon.	A'gavenny, Plâs Derwen	0·17	6	,,	Londonderry, Creggan	1·51	59
Glam.	Ystalyfera, Wern House	1·88	49	*Tyrone*	Omagh, Edenfel	1·40	53

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

Wt-34. K16.

M.O. 581 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 83, No. 985, JULY 1954

CONFERENCE ON HIGH-SPEED COMPUTING

By the DIRECTOR OF THE METEOROLOGICAL OFFICE

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

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

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

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

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

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

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

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

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

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

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

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

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

APPLICATION OF MATHEMATICAL SERIES TO THE FREQUENCY OF WEATHER SPELLS

By E. N. LAWRENCE, B.Sc.

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

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

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

$$\log F_m = Rm + S$$

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

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

which, again, is a geometric series.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

TABLE I—COMPARISON TEST

Various stations in south-west England

Period: August 1921–46

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

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

TABLE I—*continued*

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

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

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

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

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

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

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

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

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

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

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

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

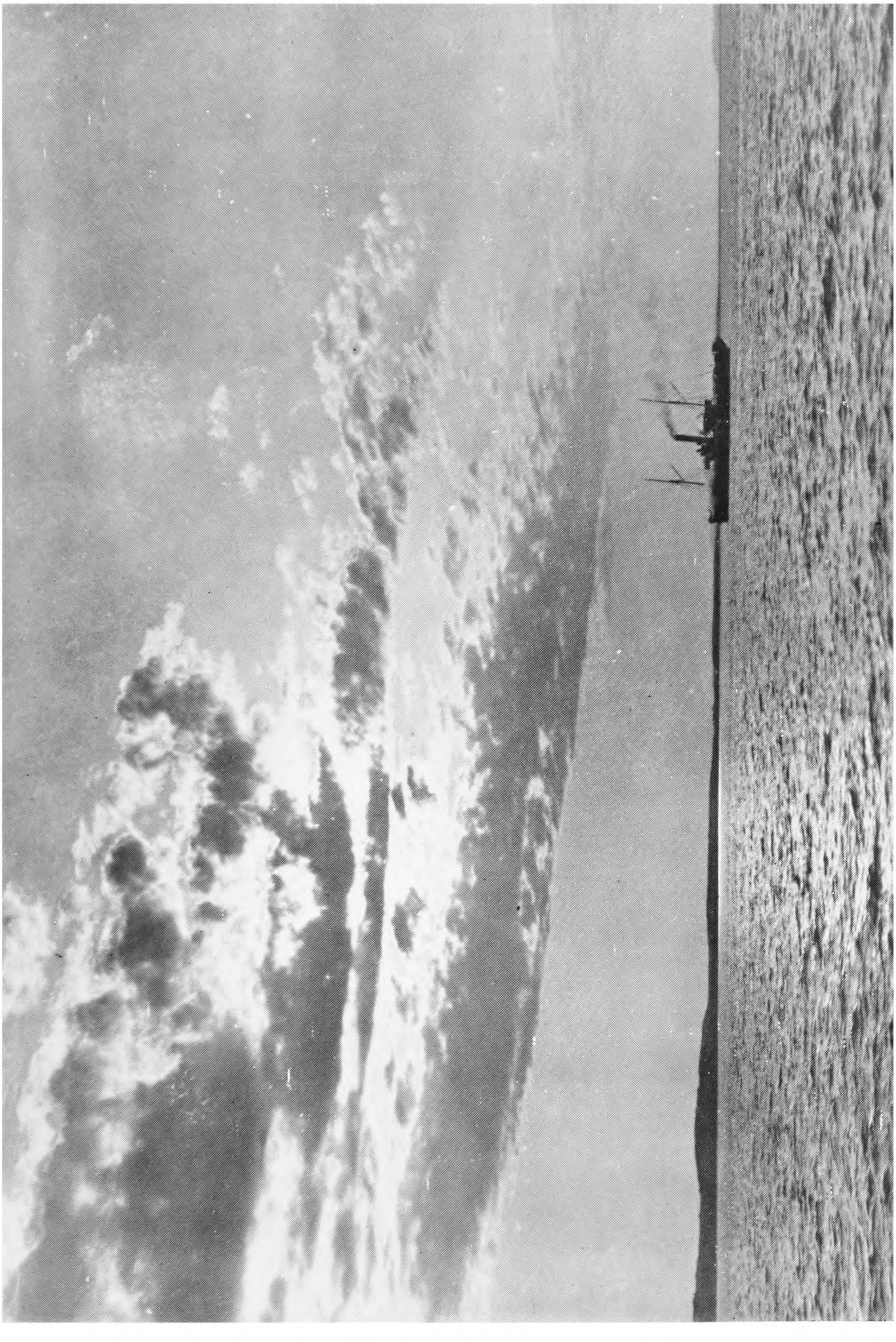
and the corresponding values of "observed minus calculated" frequencies were

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

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

REFERENCES

1. JENKINSON, A. F.; Frequency of spells of light wind. *Met. Mag., London,* **81,** 1952, p. 305.
2. BEER, A., DRUMMOND, A. J. and FÜRTH, R.; Sequences of wet and dry months and the theory of probability. *Quart. J. R. met. Soc., London,* **72,** 1946, p. 74.
3. GOLD, E.; Note on the frequency of occurrence in a series of events of two types. *Quart. J. R. met. Soc., London,* **55,** 1929, p. 307.
4. COCHRAN, W. G.; An extension of Gold's method of examining the apparent persistence of one type of weather. *Quart. J. R. met. Soc., London,* **64,** 1938, p. 631.
5. BILHAM, E. G.; Notes on sequences of dry and wet months in England and Wales. *Quart. J. R. met. Soc., London,* **60,** 1934, p. 514.
6. BILHAM, E. G.; Sequences of dry and wet months in England and Wales. *Quart. J. R. met. Soc., London,* **64,** 1938, p. 324.
7. LAWRENCE, E. N.; Frequency of spells of dry weather in southern and eastern England. Typescript, Meteorological Office, London, 1952.
8. LONGLEY, R. W.; The length of dry and wet periods. *Quart. J. R. met. Soc., London,* **79,** 1953, p. 520.
9. COOKE, D. S.; The duration of wet and dry spells at Moncton, New Brunswick. *Quart. J. R. met. Soc., London,* **79,** 1953, p. 536.
10. WILLIAMS, C. B.; Sequences of wet and dry days considered in relation to the logarithmic series. *Quart. J. R. met. Soc., London,* **78,** 1952, p. 91.
11. NEWNHAM, E. V.; The persistence of wet and dry weather. *Quart. J. R. met. Soc., London,* **42,** 1916, p. 153.
12. BELASCO, J. E.; The incidence of anticyclonic days and spells over the British Isles. *Weather, London,* **3,** 1948, p. 233.
13. UTTINGER, H.; Die Niederschlagsverhältnisse der Südschweiz 1901–1940. *Ann. schweiz. met. Zent-Anst., Zürich,* **82,** 1945, Nr. 6, p. 23.
14. EGGENBERGER, F. and POLYA, G.; Über die statistik verketter Vorgänge. *Z. angew. Math. Mech., Berlin,* **3,** 1923, p. 279.



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STRATOCUMULUS

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EVENING STRATOCUMULUS WITH HIGHER ALTOCUMULUS NEAR SUNSET

CLIMATOLOGICAL OBSERVATIONS AT GREENWICH

By J. G. GLASSPOOLE, Ph.D.

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

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

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

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

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

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

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

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

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

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

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

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

(Museum minus Observatory)

Period: June 1951–May 1952

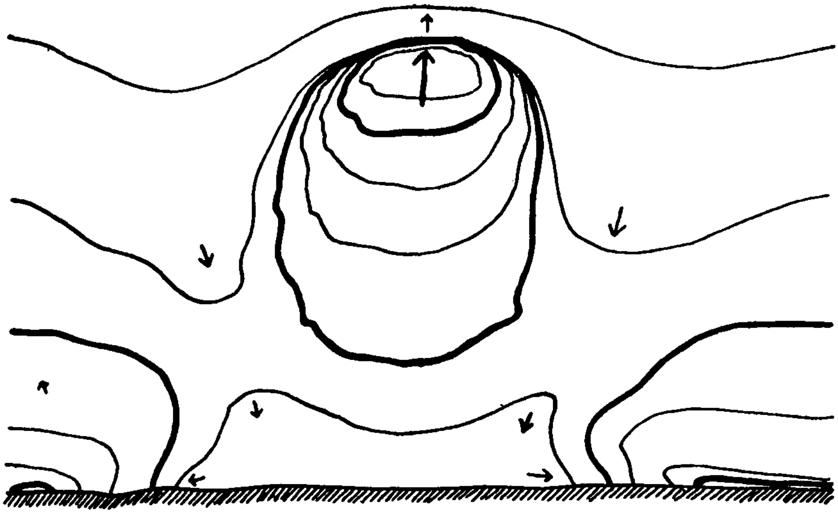
	1951 Summer	1951 Autumn	1951 Winter	1952 Spring
		degrees Fahrenheit		
Mean temperature at 0900 G.M.T.	+0·1	+0·8	+1·0	0·0
Mean maximum temperature	+0·2	+0·5	+1·2	−0·3
Mean minimum temperature	0·0	−0·6	−0·2	−0·6
Mean temperature [½ (max. + min.)]	+0·1	0·0	+0·5	−0·5
		hours		
Sunshine	+11	−3	0	+8

BUBBLE CONVECTION

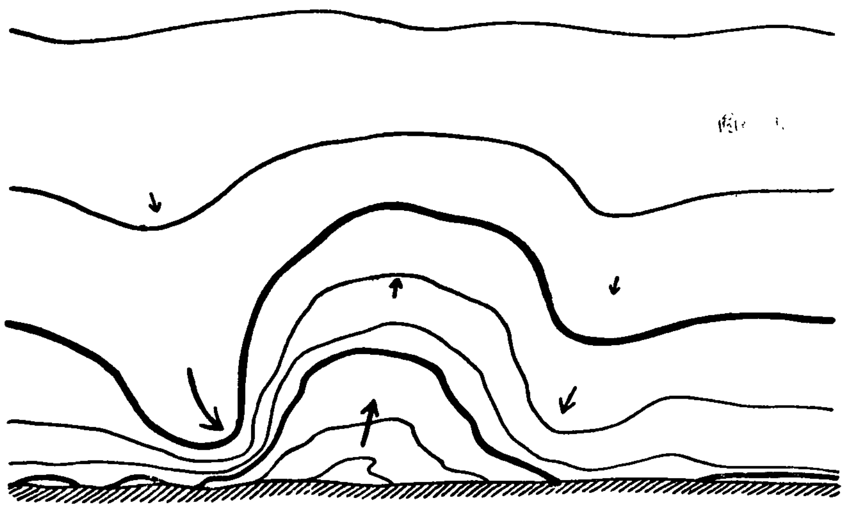
By R. S. SCORER, Ph.D.

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

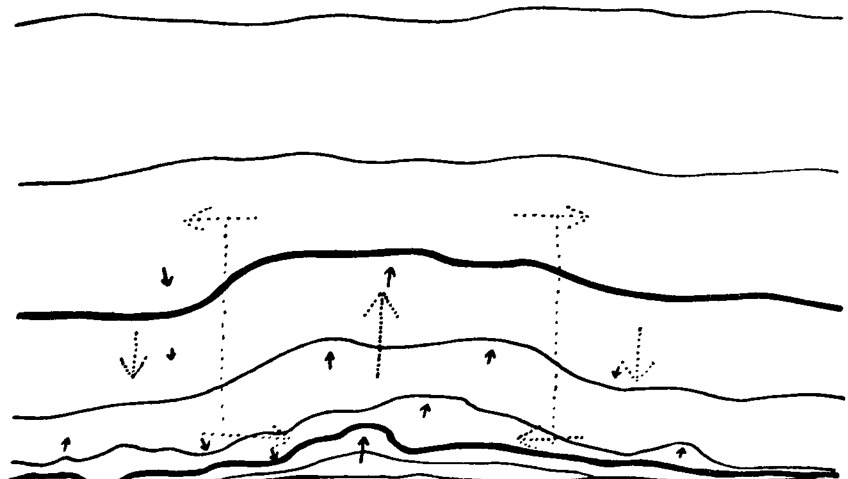
Formation of a bubble.—If a statically unstable layer is formed and it is not horizontally uniform then, in the places where the isotherms bulge upwards and downwards, upward and downward motion begins. This is illustrated in Fig. 1. To begin with, the motion will be somewhat like cellular convection,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



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



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



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

FIG. 1—RELEASE OF BUBBLE FROM SUPERADIABATIC LAYER

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

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

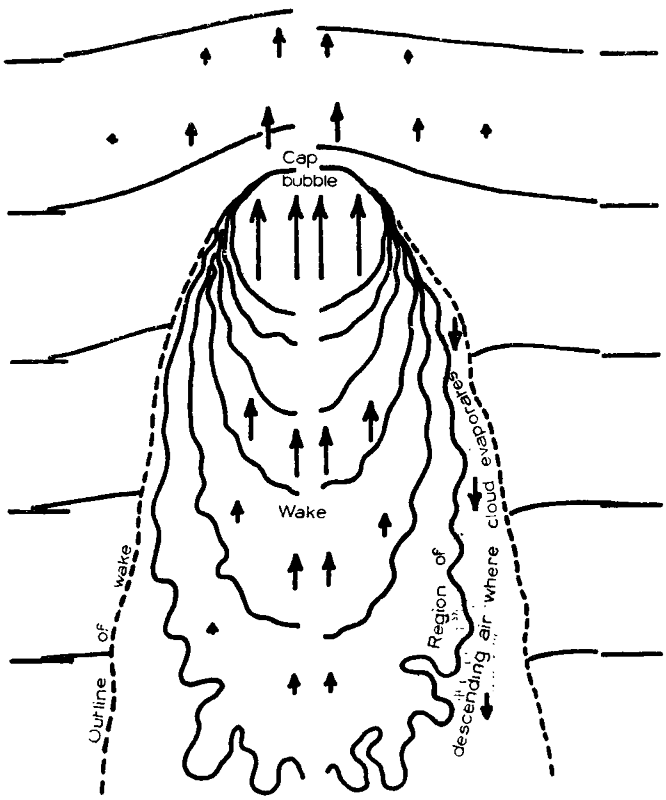


FIG. 2—LONE BUBBLE WITH TURBULENT WAKE

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

TABLE I—BUBBLE CONVECTION OVER LAND

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

*These heights may vary within wide limits.

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

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

REFERENCES

1. MALKUS, J. S. and SCORER, R. S.; The erosion of cumulus towers. *Tech. Rep., Oceanogr. Inst., Woods Hole Mass.*, No. 26 (in the press).
2. SUTTON, O. G.; Convection in the atmosphere near the ground. *Quart. J. R. met. Soc., London,* **74**, 1948, p. 13.
3. SCORER, R. S. and LUDLAM, F. H.; Bubble theory of penetrative convection. *Quart J. R. met. Soc., London,* **79**, 1953, p. 94.
4. LUDLAM, F. H.; The sub-cloud layer over land. *Quart. J. R. met. Soc., London,* **79**, 1953, p. 430.
5. LUDLAM, F. H. and SCORER, R. S.; Convection in the atmosphere. *Quart. J. R. met. Soc., London,* **79**, 1953, p. 317.

METEOROLOGICAL OFFICE DISCUSSION

Investigations of cumuliform cloud

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

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

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

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

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

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

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

The instruments available for this purpose are:—

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

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

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

(iv) aircraft recording accelerometers.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

REFERENCES

1. GRANT, D. R.; An ultra-rapid aircraft thermometer. *Met. Res. Pap., London*, No. 542, 1950.
2. MURGATROYD, R. J. and JAMES, D. G.; Hot-wire anemometers for use on aircraft. *Met. Res. Pap., London*, No. 804, 1953.
3. PALMER, H. P.; An improved automatic frost-point hygrometer. *Met. Res. Pap., London*, No. 774, 1952.
4. BUNKER, A. F., HAURWITZ, B., MALKUS, J. S. and STOMMEL, H.; Vertical distribution of temperature and humidity over the Caribbean Sea. *Pap. phys. Oceanogr., Cambridge, Mass.*, **11**, 1949, p. 1.
5. BYERS, H. R. and HULL, E. C.; Inflow patterns of thunderstorms as shown by winds aloft. *Bull. Amer. met. Soc., Lancaster Pa*, **30**, 1949, p. 90.
6. WARNER, J. and BOWEN, E. G.; A new method of studying the fine structure of air movements in the free atmosphere. *Tellus, Stockholm*, **5**, 1953, p. 36.
7. Washington D.C., United States Weather Bureau. The thunderstorm. Washington D.C., 1949.
8. JONES, R. F.; Five flights through a thunderstorm belt. *Met. Res. Pap., London*, No. 820, 1953.
9. VONNEGUT, B.; Vortex thermometer for measuring true air temperatures and true air speeds in flight. *Rep. Gen. Elect. Res. Lab., Schenectady N.Y.*, No. RL–247, 1949.
10. RUSKIN, R. E., SCHECTER, R. M., DINGER, J. E. and MERRILL, R. D.; Development of the NRL axial-flow vortex thermometer. *Rep. Nav. Res. Lab., Washington D.C.*, No. 4008, 1952.
11. MURGATROYD, R. J.; Methods of measuring liquid water content in cloud. *Met. Res. Pap., London*, No. 737. 1952.
12. LUDLAM, F. H.; The heat economy of a rimed cylinder. *Quart. J. R. met. Soc., London*, **77**, 1951, p. 663.
13. ZAITSEV, V. A.; Liquid water content and distribution of drops in cumulus clouds. *Tech. Trans. nat. Res. Counc. Canad., Ottawa*, No. TT–395, 1953. (Original in Russian, *Trud. glad. geofiz. Obs., Moskva*, **81**, 1950, p. 122.)
14. SCHAEFER, V. J.; The formation of ice crystals in the Laboratory and the atmosphere. *Chem. Rev., Baltimore*, **44**, 1949, p. 291.
15. WOODCOCK, A. H.; Atmospheric salt particles and raindrops. *J. Met., Lancaster Pa.*, **9**, 1952, p. 200.
16. HACKER, P. T. and DORSCH, R. G.; A summary of meteorological conditions associated with aircraft icing and a proposed method of selecting design criterions for ice protection systems. *Tech. Notes nat. adv. Comm. Aero., Washington D.C.*, No. 2569, 1951.
17. PERKINS, P. J.; Preliminary survey of icing conditions measured during routine transcontinental airline operation. *Res. Memor. nat. adv. Comm. Aero., Washington D.C.*, No. E52J06, 1952.
18. PETTIT, K. G.; "The Rockcliffe ice wagon" and its role in Canadian icing research. *Publ. R. met. Soc. Canad. Branch, Toronto*, **2**, No. 5, 1951.
19. LUDLAM, F. H.; Production of showers by the coalescence of cloud droplets. *Quart. J. R. met. Soc., London*, **77**, 1951, p. 402.
20. PETTERSSEN, S., KNIGHTING, E., JAMES, R. W. and HERLOFSON, N.; Convection in theory and practice. *Geofys. Publ., Oslo*, **16**, No. 10, 1946.
21. LUDLAM, F. H.; Production of showers by the growth of ice particles. *Quart. J. R. met. Soc.*, **78**, 1952, p. 543.
22. BATTAN, L. J.; Observations on the formation and spread of precipitation in convective clouds. *J. Met., Lancaster Pa.*, **10**, 1953, p. 311.

ROYAL METEOROLOGICAL SOCIETY

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

[To face p. 216

ALTOCUMULUS CASTELLATUS FROM 18,400 FT.

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

(see p. 219)

To face p. 217]

STRATOCUMULUS OFF CAPE ST. VINCENT

(see p. 219)

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

Symons Memorial Lecture

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

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

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

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

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

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

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

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

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

ROYAL SOCIETY OF ARTS

Meteorological Office and the Commonwealth

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

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

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

ADDENDUM

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

NOTES AND NEWS

Altocumulus castellatus from above

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

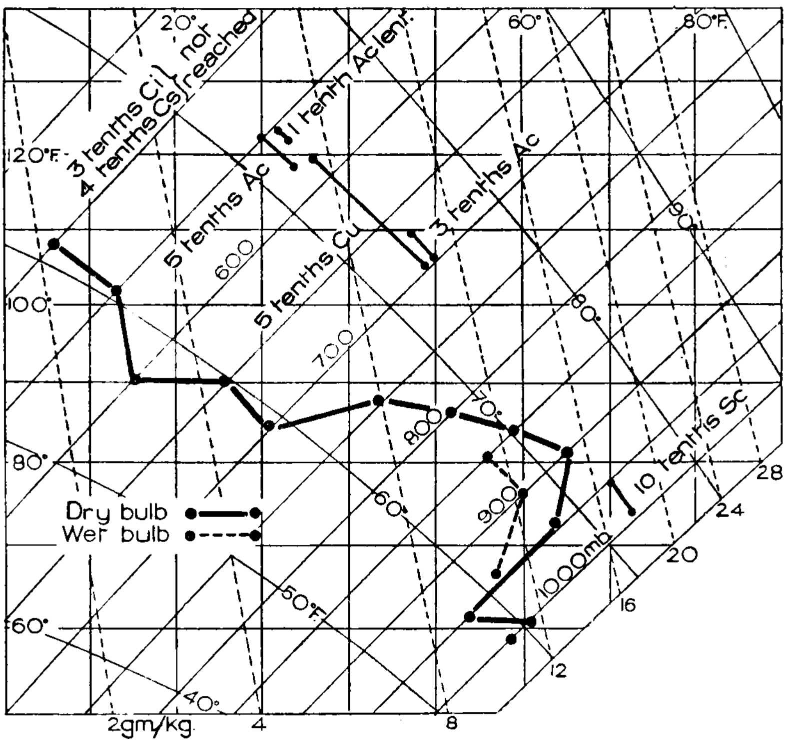

FIG. 1—TEPHIGRAM OF TEMPERATURE OBSERVATIONS MADE BY AIRCRAFT IN DESCENT THROUGH ALTOCUMULUS CASTELLATUS

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

Stratocumulus cloud off Cape St. Vincent

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

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

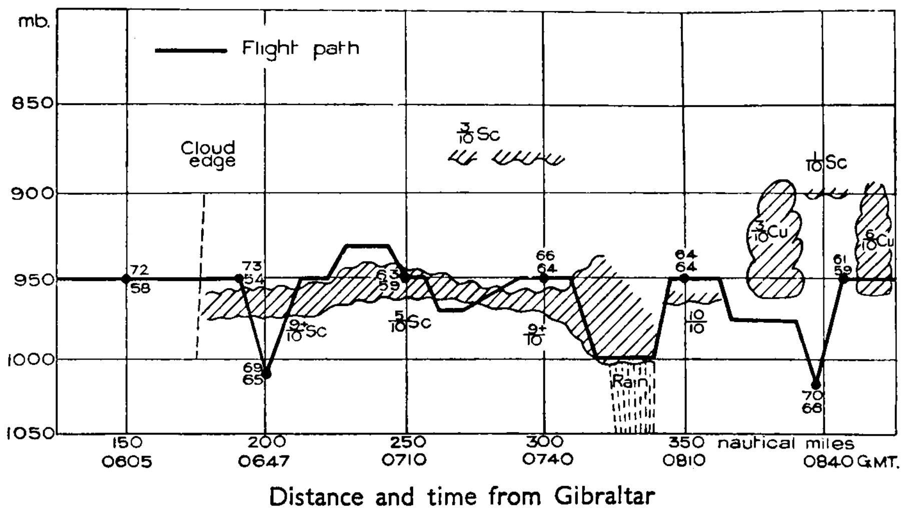

FIG. 1—CROSS-SECTION OF METEOROLOGICAL RECONNAISSANCE FLIGHT

OBITUARIES

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

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

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

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

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

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

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

He is survived by a widow and two sons.

C. E. N. FRANKCOM

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

HONOURS

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

C.B.E.

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

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

O.B.E.

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

M.B.E.

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

BOOKS RECEIVED

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

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

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

WEATHER OF MAY 1954

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

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

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

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

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	84	25	+0·1	130	+1	81
Scotland	76	26	+1·2	160	−1	88
Northern Ireland ...	75	28	+0·5	163	−1	86

RAINFALL OF MAY 1954

Great Britain and Northern Ireland

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

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

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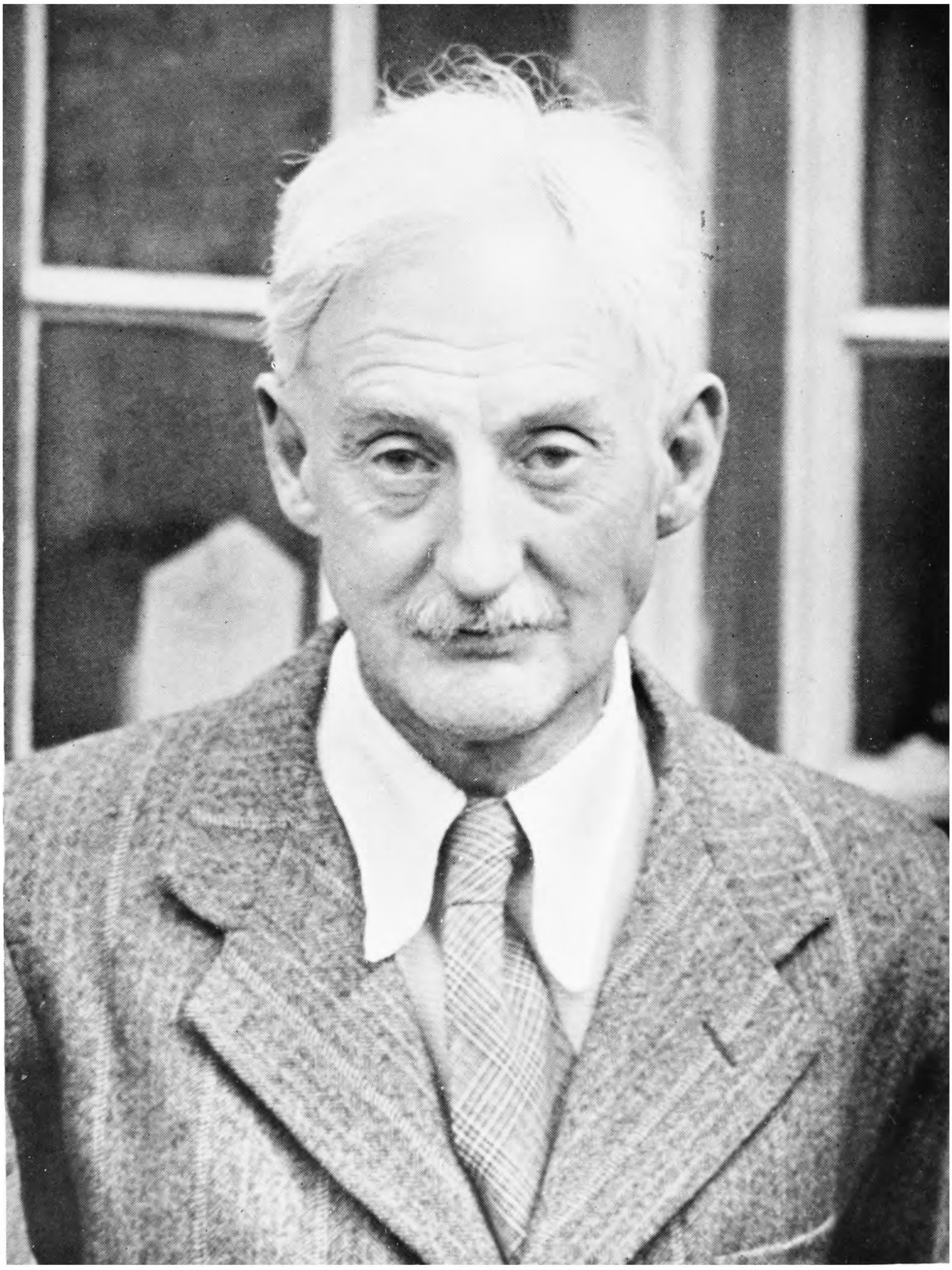
Frontispiece]



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M.O. 581 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 83, No. 986, AUGUST 1954

MR. C. K. M. DOUGLAS, O.B.E., A.F.C., B.A.

Mr. C. K. M. Douglas, Assistant Director of the Meteorological Office (Central Forecasting) retired on May 28, 1954, after 35 years' service.

Mr. Douglas, born in 1893, was educated at Edinburgh Academy and at King's College, Cambridge. His interest in weather began about the age of 11 when one of his schoolmasters introduced him to the *Daily Weather Report*, to which he subscribed from 1912 to 1919. In January 1915 Mr. Douglas was commissioned in the Royal Scots but a few months later he transferred to the Royal Flying Corps in which he served as an operational pilot, reaching the rank of Captain. The urgencies of war did not interfere with his passionate devotion to meteorology, however. In 1916 he wrote his first meteorological paper, its subject being clouds as seen from the air, and this was published in the *Journal of the Scottish Meteorological Society* in 1917. Mr. Douglas joined the then recently formed Meteor flight in April 1918 and he remained with it till May 1919. His pioneering work in the upper air at this time became world renowned because of his cloud photographs taken from an aircraft, and his interest in instability phenomena was stimulated by being able to make his own upper air observations.

In August 1919, after demobilization, Mr. Douglas joined the Meteorological Office as a Senior Professional Assistant, and he served for two years in the Forecast Division. After a spell of training in observatory work at Eskdalemuir and Edinburgh from 1921 to 1923, he was posted as Senior Professional Assistant in charge of the forecasting office at South Farnborough, where he remained till 1925. In that year he was promoted Assistant Superintendent (Senior Forecaster) in the Forecast Division, and there he remained until his retirement except for a brief interlude from 1936 to 1938 when he held a post in the pool for training and special investigations.

In the second World War Mr. Douglas was a tower of strength to forecasters taking part in the daily operational conferences by telephone. When "Overlord" came along and the vital D-day decision had to be made the important contribution made by Mr. Douglas to the forecasts supplied to the Supreme Allied Commander was acknowledged by General Eisenhower in a personal letter of thanks. In 1941 he was appointed an Officer of the Order of the British Empire, a well deserved honour which all his colleagues applauded.

The voluminous output of meteorological papers and articles by Mr. Douglas since 1917 will be well known to contemporary students of synoptic meteorology, and later generations of such students will be familiar with his name in bibliographies and textbooks. His progress from an amateur to a professional meteorologist is reflected to some extent in his papers, beginning with the artistry of cloud studies and proceeding through such papers as "The modification of the strophic balance" (with Sir David Brunt) to forecasting monographs on "Prebaratics" and "Rainfall and thunderstorms"; the latter he finished a day before he retired.

The distinguished contributions of Mr. Douglas to the study of meteorology were acknowledged by the Royal Meteorological Society, first in 1927 when he was awarded the Buchan Prize, and second, this year, when he was awarded the Hugh Robert Mill Memorial Medal and Prize.

Mr. Douglas was widely known throughout the Meteorological Office as "Duggie", a name he disliked but tolerated, probably because he realized there was something of affection in it. None could know Mr. Douglas well or work under him without developing this affection. Having the highest scientific integrity himself he was forbearing to juniors. His complete disinterestedness gave colleagues the greatest confidence in his judgement, and they came to him time and again to test the validity of any proposals they might have affecting synoptic meteorology.

Colleagues throughout the Meteorological Office contributed to a present to Mr. Douglas on his retirement and this was handed over by Dr. J. M. Stagg, Principal Deputy Director, at a large gathering at Dunstable on May 28. Mr. S. P. Peters, Deputy Director (Forecasting), in asking Dr. Stagg to make the presentation referred to the notable contributions of Mr. Douglas to the science of meteorology. Dr. Stagg spoke of his achievements as an air observer and mountaineer. In a delightful reply Mr. Douglas made a pawky reference to the paper he had been disposing of in anticipation of his retirement. All his colleagues wish Mr. Douglas a long and happy retirement.

FORECASTS FOR FARMERS

By R. T. ANDREWS

Each year, at certain seasons, forecasters at some main meteorological offices have to deal with large and increasing numbers of inquiries from the farming population. The effect of weather on farming operations is such that these forecasts are of prime importance to the individual farmer and ultimately to the national food-producing effort. It is therefore appropriate that in content and wording the forecasts issued to the farmer should be especially framed to meet his special requirements. This note is based on the experience of a forecaster working in the south-west of England, and is not a comprehensive article on forecasting for agriculture of all types.

Some farming operations.—The farmer has to reach decisions daily, sometimes more often, regarding employment of his labour and equipment and the weather enters into most operations. Notes on some of these are given below.

Ploughing.—This is carried out during autumn and winter, and the soil must not be flooded or excessively wet and it must not be frozen hard.

Sowing.—This is mainly an operation of early spring. Usually a field is prepared one day, when the soil is in a suitable condition, and sown the next day. Rainfall between these operations will mean wasted labour as the ground will have to be prepared again.

Early potatoes.—The Cornish crop is usually lifted in late May and the ground needs to be fairly dry for this. The importance of timing is illustrated by the fact that when price control operated, if the crop was on rail before June 1 the price obtained would be £35–40 per ton whereas a few days later this would have fallen to £18–20 per ton.

Hay.—Haymaking is carried out in June and July. Small farms may need only a few days dry weather whilst larger farms may spread the operation over a month or six weeks. A dry day is essential for cutting and two or three days are required to dry the grass. Early in this stage some rain will do no harm but at the end of the period the grass must be dry when turned in readiness for carrying or baling on the next day. Rain on hay which has been turned involves at least additional work and may be disastrous. The baler often belongs to a contractor and is only available according to a programme. Baling cannot be carried out when the hay is damped by a shower as the twine will break when the bale is dropped, and even heavy dew will sometimes delay the start of operations until the afternoon. The bales must be dry when stacked or the stack will heat up and burn or blacken. However for silage the grass is cut wet or dry and compressed in pits. Similarly for grass drying, the grass is cut wet or dry and heated with molasses, producing a solid form of fodder. An initial high moisture content increases the fuel costs.

Corn.—The season is from July to September and the operations take from 7 to 14 days or more. Dry weather is required for cutting and stooking. The stooks are left standing for several days to mature, and although occasional rain early in the period will not matter there must be several mainly dry days followed by a dry day for carrying. Appreciable rainfall may lead to the stooks becoming wet inside so that they have to be opened again and dried out. Very unsettled weather will cause growth of grass around the bases of the stooks, preventing them from drying, and it may also cause the grain to begin to sprout.

The combine harvester cuts, threshes and sacks the grain in one operation when the corn is dry. The grain has to have a lower moisture content than for cutting and stooking; the combine can sometimes be used efficiently for only 2–3 hr./day, even in fine weather, owing to excessive moisture.

Root lifting.—This usually occupies two or three weeks in late autumn when the ground must not be saturated and there must not be hard frost. Frosted mangolds may cause colic in animals.

Livestock.—Cattle must be moved from areas liable to flood, and be given cover and extra food during snow. At lambing time shelter from rain and wind is advisable since lambs born on a cold, wet and windy night are more likely to die than those born in dry, frosty weather.

Some aspects of forecasting for farmers.—The extent to which a farmer is dependent on the weather may be readily judged from the account of some of his operations given above. Many farmers have a sound knowledge of weather types and frequencies, coupled with signs of nature and the behaviour of birds and animals, which have been handed down from previous generations who have been similarly subject to the weather. From this background and experience they can often reach surprisingly correct conclusions about the future weather. Farmers have usually been regarded as a most conservative section of the community, inclined to distrust scientific method and language, but times have changed, and nowadays one finds that many of them can discuss at least the main features of a weather map, and are keen to do so. There is no doubt that the forecaster can be of great assistance to the farmer, and, from the farmer's point of view, the telephone discussion with the forecaster is of much greater value than the necessarily more generalized broadcast or press forecast. It is helpful to know in what details the inquirer is interested and his minimum requirements.

The incidence of wet and dry spells is of utmost importance to the farmer, and either of these at the wrong time may lead to great financial loss. Therefore "Spell warnings" are of great significance, especially where a change of type can be foreseen in advance so that the fullest use can be made of favourable conditions and losses due to unfavourable weather mitigated as far as possible. An outlook of unsettled weather should when possible be amplified in accordance with the general synoptic situation. If only comparatively short periods of mainly slight precipitation are likely, it is of great value to the farmer to know that is the general type expected.

It is in the detailed forecasting for the following 24 hr. that the meteorologist is in the best position to help the farmer, in the present state of forecasting knowledge. The first requirement of the forecaster is that he should possess a detailed knowledge of local variations, which may lead to quite appreciable differences over a short distance. In aviation forecasting the meteorologist has this knowledge in regard to airfields for which he is responsible, in matters like cloud base and visibility. To provide the best possible service to the farmer, however, he must, in particular, acquire a similar knowledge of the local variations in rainfall.

Special attention to wording should be given in forecasts of showery types. The effect of showers on farming operations is very variable, depending to some extent on the time of occurrence, frequency and intensity of the showers, as well as upon the state of the crop. The diurnal variation in cloud amount, as between coastal and inland areas, may also have an important bearing on the drying process. Forecasts should not be more definite than the situation warrants, but vagueness must be avoided. Suitable wording for forecasts of showery types is given in the following examples:—

Frequent showers will develop inland, mostly during the afternoon and early evening, with thunderstorms and squally winds in some places. Near coasts it will be bright and sunny and any showers will be only slight. It will become generally cloudless tonight and at first tomorrow.

Showers will develop in most places by the afternoon but will be slight everywhere, except perhaps near the highest parts of Dartmoor and Exmoor. Cloud will disperse during the night.

There will be showers at first this morning near coasts and hills exposed to the W. and NW. winds, but they will have died out by the afternoon when cloud will disperse and there will be a fresh, drying wind.

With regard to frontal rainfall, the annual and diurnal variations in rainfall amounts given by fronts and depressions moving eastwards across the British Isles should be noted particularly[1-5]. Often the rainfall decreases progressively from west to east, becoming much less east of the main hill barriers and almost negligible in some eastern and south-eastern counties. On the other hand, chiefly in summer, a front which causes only slight rain in the south-west, may give much heavier falls in the Midlands and east because of instability developing ahead of it.

The shelter afforded by high ground is especially a feature to remember in connexion with summer warm fronts and warm sectors. Warm frontal rain is much reduced in sheltered areas of east Devon and Somerset, and warm-sector drizzle is often negligible in these areas while quite appreciable further west. The general effect is illustrated by the fact that the average number of days a year with more than 10 mm. of rainfall is 30–35 in much of south-west England, but only 15 in East Anglia.

Again, many parts of the British Isles have rain on 200 or more days a year[6] and some have 225–250 rain-days. In August, at the peak of the harvesting season, there are, on the average, 17 rain-days in south-west England. Hence it is especially important for the farmer that all the dry days are in fact forecast as such. A special watch must be kept for ridge development or subsidence which may cut out showers very quickly.

The duration of rainfall is another important matter. On many occasions, particularly in summer, it could be stated with some assurance that rainfall would be of, say, 4–6 hr. duration near west coasts, but only of 1–2 hr. or less east of a line from Liverpool to Exeter.

Humidity also has an important bearing, and the forecaster can help by giving forecasts of wind strength, and some idea of the amount of moisture present in the air and the extent to which this will be reduced during the day. Early formation of dew on clear evenings may mean an early cessation of work in the fields. The forecaster can at present give only rough guidance on the amount of dew expected (e.g. heavy dew with initially wet grass, high humidity, low wind speed and clear sky), but he can indicate the approximate time of commencement. A heavy dew followed by a cloudy morning with little or no wind may delay the start of field work till after midday.

Finally, the forecaster should be completely frank in dealing with the farmer. It is helpful to explain any failure of an earlier forecast (e.g. the non-arrival of rain previously forecast). Confidence should be expressed when it is justified, and doubts should be introduced when there is good reason for doing so. Only thus can the farmer be helped to decide what chances he can take.

REFERENCES

1. GOLDIE, A. H. R.; Rainfall at fronts of depressions. *Geophys. Mem., London*, 7, No. 69, 1936.
2. SAWYER, J. S.; Rainfall in the British Isles resulting from depressions which pass eastward between Scotland and the Faeroes. *Met. Res. Pap., London*, No. 748, 1952.
3. SAWYER, J. S.; Rainfall of depressions which moved eastwards across the British Isles between the Bristol Channel and the Scottish Border. *Met. Res. Pap., London*, No. 762, 1952.
4. SAWYER, J. S.; Rainfall of depressions which move eastward near the English Channel. *Met. Res. Pap., London*, No. 816, 1953.
5. SAWYER, J. S.; Rainfall of depressions which move eastwards across Scotland. *Met. Res. Pap., London*, No. 843, 1953.
6. London, Meteorological Office. Climatological atlas of the British Isles. London, 1952.

BOOKS RECEIVED

Die Hodochronen von Zagreb für seismische Raumwellen und Erdbeben normaler Tiefen. By J. Mokrović. *Rad. geofiz. Inst., Zagreb*, Ser. III, Br. 2, pp. 52, University of Zagreb, 1952.

Contributions to the theory and the practice of psychrometric tables. By B. Maksić. *Rad. geofiz. Inst., Zagreb*, Ser. III, Br. 4, pp. 60, *Illus.*, University of Zagreb, 1953.

Beiträge zur Untersuchung der Klimafluktuationen in Jugoslavien. By J. Goldberg. *Rad. geofiz. Inst., Zagreb*, Ser. III, Br. 3, pp. 28, *Illus.*, University of Zagreb, 1953.

THE OCCURRENCE OF ICE CRYSTALS IN THE FREE ATMOSPHERE

By G. J. DAY, B.Sc.

At temperatures below freezing point the water in clouds may be either in the liquid or the solid phase, and the likelihood of either phase is initially a function of temperature. The supercooled state is an unstable condition and whenever ice begins to form the cloud tends to change quickly into the solid phase. The frequency with which supercooled droplets are found in clouds is important in studies of aircraft icing, precipitation mechanisms, and the role of nuclei in the ice-forming process.

If supercooled droplets are present in large quantities, then aircraft icing is probable.

If the cloud is wholly supercooled and remains so, the Bergeron process of precipitation cannot start as it requires ice crystals to grow at the expense of supercooled droplets. Similarly if the cloud is entirely ice crystals this process will not operate. Since, however, the probability that ice crystals will appear increases with decrease in temperature, clouds often exist in which the tops are composed of ice crystals and the remainder of a mixture of droplets and crystals, and these are those in which the Bergeron process can operate. A study of the relative frequency with which cloud tops are observed containing ice crystals or supercooled droplets will therefore provide data of the cloud-top temperature at which the Bergeron mechanism is usually initiated. It should be noted that any study of this type must be confined to cases with no cloud above, as seeding with ice crystals from the higher cloud may initiate the process in a cloud which might otherwise remain supercooled.

The probability of occurrence of ice crystals at various temperatures is of interest in studies of the role of nuclei in the ice-forming process. Many laboratory studies of this aspect have been made, for example that of Findeisen and Schulz[1] and more recently that of Bigg[2]. Apart from laboratory studies there is little published observational data available on this topic. In a study of occasions of precipitation from persisting sheets of stratocumulus in Northern Ireland, Mason and Howorth[3] suggested that such precipitation was unlikely with cloud-top temperatures higher than about − 12°C. (+ 10°F.), and it is commonly assumed that shower production commences in temperate latitudes at cloud-top temperatures between − 10° and − 15°C. (+ 15° and + 5°F.). Work by Peppler[4], Dessens[5], and Lafargue[6] confirms this result.

During the past two years a large number of cloud flights have been made by the Meteorological Research Flight, and during the preliminary analysis 37 flights have been examined in which it was improbable that the cloud level investigated was seeded from above by an ice-crystal cloud. The frequency of occurrence of water droplets and ice crystals at various temperatures in these flights is shown in histogram form in Fig. 1. It will be noted that the result is weighted in favour of the higher temperatures. This is a consequence of the limitation imposed by the effective ceiling of the aircraft for work of this type.

It does appear, however, that water droplets become much less probable at temperatures below about − 20°C. (− 5°F.), and this may be the level at which aircraft icing becomes infrequent save where there are unusually strong up-draughts as in convective clouds before maturity. This accords well with the observation of Pettit[7].

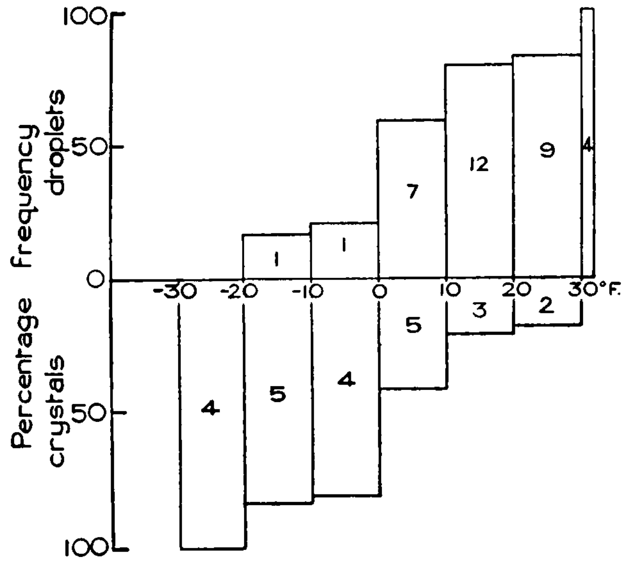

FIG. I—FREQUENCY OF OCCURRENCE OF ICE CRYSTALS AND WATER DROPLETS IN NATURAL CLOUDS AS A FUNCTION OF TEMPERATURE

Figures in the blocks are the number of cases

It also appears that ice crystals have a small probability of occurrence at temperatures between freezing and − 12°C. (+ 10°F.).

Further, there is an approximately equal probability that cloud tops having temperatures between − 18° and − 12°C. (0° and + 10°F.) contain crystals or supercooled droplets. Thus, on about 50 per cent. of occasions a cloud which has a top at a temperature within this range and its lower portions at a higher temperature will be in a suitable condition for the Bergeron process to operate. As cloud-top temperature decreases the probability that the solid phase will appear increases.

The range − 18° to − 12°C. then is the highest cloud-top temperature range for which precipitation by the Bergeron process would normally be expected. For higher temperatures coalescence processes would have to predominate in the production of any rainfall. Similarly any initiation of the Bergeron process by artificial nucleation would normally only be worth-while when the cloud-top temperatures are above about − 12°C. (+10°F.), as below this temperature the change of phase occurs naturally on at least 50 per cent. of occasions.

REFERENCES

1. FINDEISEN, W., and SCHULZ, G.; Experimentelle Untersuchungen über die atmosphärische Eisteilchenbildung I. *Forsch.-u. ErfahrBer. Reichamt Wetterdienst, Berlin,* A, Nr. 27, 1944.
2. BIGG, E. K.; The supercooling of water. *Proc. phys. Soc., London,* **66,** B, 1953, p. 688.
3. MASON, B. J. and HOWORTH, B.P.; Some characteristics of stratiform clouds over North Ireland in relation to their precipitation. *Quart. J. R. met. Soc., London,* **78,** 1952, p. 226.
4. PEPPLER, W.; Uber Glorien und Halos. *Z. angew. Met., Leipzig,* **56,** 1939, p. 173.
5. DESSENS, H.; Some remarks on the study of the microphysics of natural clouds. Centenary Proceedings of the Royal Meteorological Society, 1950, p. 59.
6. LAFARGUE, C.; Quelques remarques concernant la microphysique des nuages surfondus et les noyaux de congélation atmosphériques. *Bull. Obs. Puy de Dôme,* Ser. 2, No. 1, 1953, p. 12.
7. PETTIT, K. G.; "The Rockliffe Ice Wagon" and its role in Canadian icing research. *Publ. R. met. Soc. Canad. Branch, Toronto,* **2,** No. 5, 1951.

AN INSTRUMENT FOR RECORDING THE FREQUENCY DISTRIBUTION OF MEAN HOURLY WIND SPEEDS

By B. G. COLLINS, B.Sc.

Programmes of ventilation research carried out in experimental houses at the Building Research Station, Garston, Hertfordshire, have shown that the air-change rate in a house is closely related to, amongst other factors, the external wind speed[1]. In order to use the information obtained from these experiments for prediction purposes in other locations, it is necessary to have a knowledge of the structure of wind-speed variations to be expected in various types of locality ranging from freely exposed sites to built-up areas. The most convenient form in which to obtain this is the frequency distribution of the mean hourly wind speed.

The wind-run analyser, described elsewhere[2], provides a record from which the desired information can be obtained, but to eliminate tedious arithmetic it was decided to develop an instrument from which the frequency distribution could be read directly. In view of the fact that the ventilation requirements for some particular types of building may be critical for only a limited period each day, it was thought that it would be desirable to break the frequency distribution down into smaller periods than the whole day. For example, offices have a definite ventilation requirement only during the period of day occupancy, say 9 a.m. to 5 p.m., whereas in a hospital ward ventilation is required at all times, and the critical period will probably be during the early hours of the morning when wind speed is normally at its lowest level. Accordingly an instrument was designed to register the distribution of the mean hourly wind speed in three separate 8-hr. periods of the day, namely midnight to 8 a.m., 8 a.m. to 4 p.m., and 4 p.m. to midnight. It is, of course, a simple matter to adjust the recorder to operate over any other desired 8-hr. period.

The wind-speed-frequency recorder described in this article, of which a circuit diagram is given in Fig. 1, works in conjunction with a standard Meteorological Office cup contact anemometer, and records the distribution of the mean hourly wind speed on Post Office message registers. With the exception of a time switch operating once an hour, all the parts used are standard Post Office components. They comprise telephone selector switches (known as uniselectors), and type 3,000 relays, in addition to the message registers. The operating details of the recorder are given below.

The making contact of the anemometer closes 20 times for every mile of wind run, and is used to operate relay A/1, thus closing contact A1 and energizing the operating coil of uniselector U. The latter is arranged as a scale-of-20 counting-down device, and its output, one pulse for every mile of wind run, is used to operate a second uniselector V, which therefore steps round with the increasing wind count. This selector is connected to a bank of Post Office message registers, one representing each wind-speed interval, so that, as it steps round, the register appropriate to the total counted is selected.

At the end of each hour the time switch operates, and relay D/4 is energized. This is a slugged relay and its operating time is considerably longer than that of the message registers. Hence a pulse from the time switch is passed to the message register which is then in circuit, via contact D2, increasing its count by one. Then relay D/4 operates, returning the second uniselector V to zero by contact D1, and at the same time breaking the anemometer and message-register circuits by contacts D4 and D2. Contact D3 is also closed and energizes uniselector W which thus steps round one contact. Three identical banks of message registers are provided, for use in the three 8-hr. periods of the day already mentioned. The operation of uniselector W is used to change to the next bank on every 8th, 16th and 24th hourly pulse received from the time switch.

It is found that ten message registers in each bank are sufficient to obtain the distribution, and these are arranged to count the number of hours with wind speeds of 0·5, 1, 2, 3–4, 5–7, 8–10, 11–15, 16–20, 21–30, and 31–50 m.p.h., these intervals being selected to permit the most accurate drawing of the curve of the distribution. It is thought improbable that a mean hourly wind speed greater than 50 m.p.h. will be encountered save in the most exposed coastal sites, with which the present investigation is not concerned.

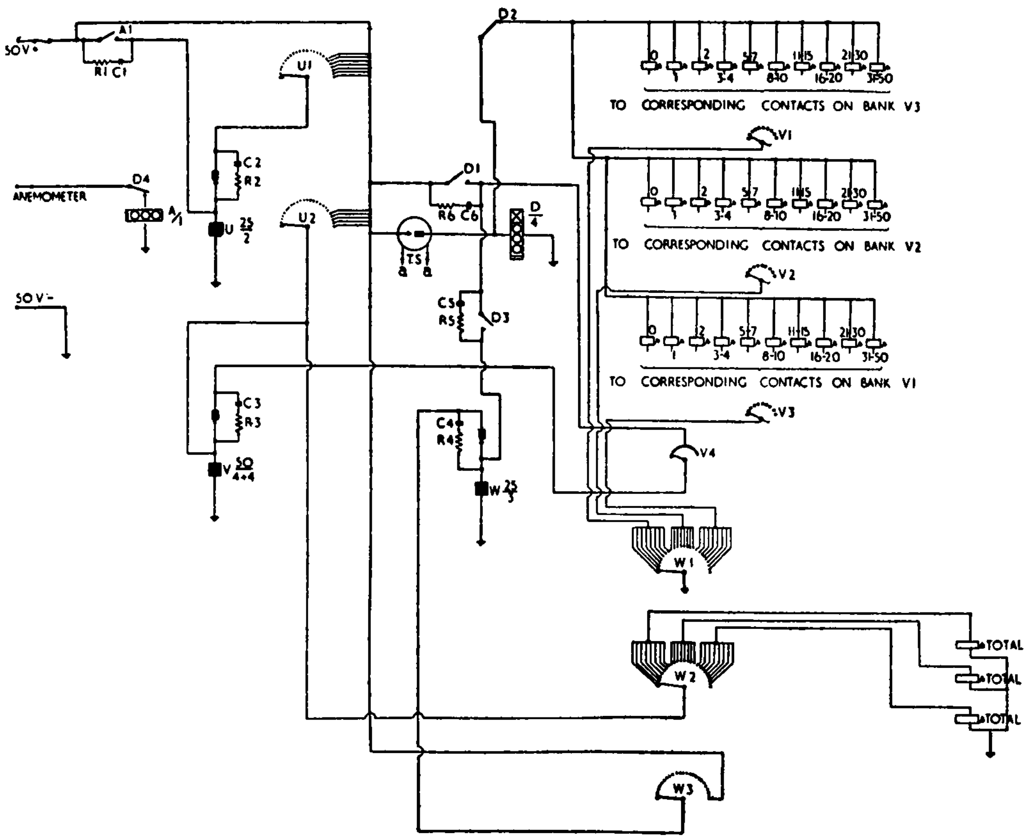

FIG. 1—CIRCUIT DIAGRAM, WIND-SPEED FREQUENCY RECORDER

In order to obtain also the value of the mean wind speed over each 8-hr. period, three additional message registers are provided which indicate the total number of miles of wind run occurring during the period. These registers are operated directly from uniselector U, receiving one pulse for every 20 pulses from the anemometer.

The uniselectors, message registers and relays used all operate from a 50-v. d.c. supply. A mains-operated unit delivering 50 v., 2 amp. d.c. is incorporated in the instrument, and since the time switch is also mains operated, a 230 v. 50 c. supply is all that is needed for the recorder. The equipment fits into a standard 19-in. Post Office rack for convenience of mounting, and all connexions are

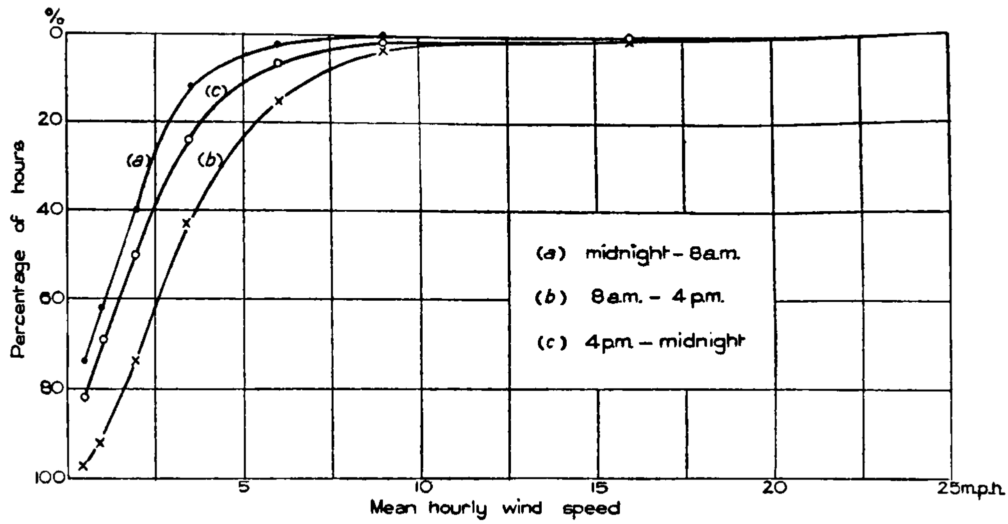

FIG. 2—CUMULATIVE PERCENTAGE FREQUENCY OF WIND SPEED EXCEEDING GIVEN VALUES

(one month's record)

brought into detachable plugs and sockets. The photograph (facing p. 256) shows a front view of the complete instrument.

Fig. 2 shows an example of the curves obtained for the cumulative-frequency distribution of the mean hourly wind speed on a fairly exposed site for the month of September 1952. If a ventilation system is required to be so designed that sufficient fresh air is admitted to maintain a given rate of air change for a certain minimum percentage of the hours, the graph will give the wind speed on which the design should be based for each of the three 8-hr. periods. For example, suppose that in a hospital it is essential that a stipulated rate of air change be maintained for at least 75 per cent. of the hours. The graph (*a*) shows that during the period midnight to 8 a.m., when the mean wind speeds are lowest, for 75 per cent. of the hours the mean hourly wind speed does not fall below 0·5 m.p.h., and hence, if the ventilation system admits sufficient fresh air to give the desired air-change rate with a wind speed of 0·5 m.p.h. it will be satisfactory. If, however, the ventilation rate needs to be maintained only during the period 8 a.m.–4 p.m., the graph (*b*) shows that for 75 per cent. of the hours the mean hourly wind speed does not fall below 2·0 m.p.h., and a ventilation system designed to admit enough fresh air at this speed will be satisfactory. These wind speeds of 0·5 m.p.h. and 2·0 m.p.h. are then known as the design wind speeds.

In a case where it is acceptable for the air-change rate to be maintained for only 50 per cent. of the hours, the design wind speeds for the two periods mentioned are seen from the graph to be 3 m.p.h. and 1·5 m.p.h. respectively.

This paper is published by permission of the Director of Building Research, and the work described forms part of the programme of the Building Research Board of the Department of Scientific and Industrial Research.

REFERENCES

1. DICK, J. B.; Experimental studies in natural ventilation of houses. *J. Instn Heat. Vent. Engrs, London*, **17**, 1949, p. 420.
2. PRATT, A. W., COLLINS, B. G., LACY, R. E., and SPINK, E. W.; Some meteorological instruments used in building research. *Proc. Instn elect. Engrs, London*, **98**, Part II, 1951, p. 474.

SINGULARITIES IN THE ANNUAL VARIATION OF AIR, GRASS AND SOIL TEMPERATURES

By E. N. LAWRENCE, B.Sc.

Before proceeding to the subject of air minimum, grass minimum and soil temperatures, and frost frequencies, it is helpful to bear in mind the main processes involved in the heat exchange at night near the surface of the ground. Heat is lost mainly in accordance with the Stefan-Boltzmann law of radiation, that every body radiates with an intensity proportional to the fourth power of its absolute temperature, and heat is lost also by evaporation. Heat is gained primarily by the counter radiation of the atmosphere and by conduction from the lower soil, but also by convection and to a smaller degree by radiative pseudo-conduction, by thermal conduction and in the formation of dew. Under clear night skies and generally calm conditions, evaporation and convection are restricted, and the main processes affecting the temperature near the ground are the radiation and counter radiation of the earth and atmosphere respectively (i.e. effective outgoing radiation) and the supply of heat from the lower soil. Now, the effective outgoing radiation (R cal./cm.^{2}/min.), using Raman's values for the constants, is given by

$$R = 8{\cdot}26 \times 10^{-11} [T^4 (0{\cdot}23 + 0{\cdot}28 \times 10^{-0{\cdot}074e})] \qquad \ldots . (1)$$

where T is the absolute temperature of the ground surface and e is the vapour pressure measured near the ground in millimetres of mercury. According to Ångström[1], R may be replaced by $R/(1 - c)$ on cloudy nights, c being a constant depending on the height of base and type of cloud and the temperature at this height. Also, it has been shown[2] that, to a high degree of approximation, the fall of surface temperature δT is given by

$$\delta T = 2R\,(t/\pi ks)^{\frac{1}{2}} \qquad \ldots . (2)$$

where t is the number of hours after sunset, k is the coefficient of conductivity and s the thermal capacity of the soil. Combining equations (1) and (2) and using Ångström's relationship for cloud,

$$\delta T = 16{\cdot}52 \times 10^{-11} [T^4(0{\cdot}23 + 0{\cdot}28 \times 10^{-0{\cdot}074e})(t/\pi ks)^{\frac{1}{2}} (1 - c)] \ldots . (3)$$

Variations in absolute temperature and vapour pressure are often insufficient to explain nocturnal minimum temperatures on clear calm nights and a satisfactory explanation must include a consideration of the properties of the soil. The values of conductivity and thermal capacity can be greatly altered by changes in soil moisture. Increased moisture content (percentage of water in wet weight) causes increased heat conductivity because the water film between the grains leads to better "thermal" contact. Another effect of increased soil moisture is increased specific heat. Both these factors may help to check the fall of temperature at or near the ground surface, though, with air movement, loss of heat by evaporation may neutralize this. However, the net result of all operating factors is shown by the following presentation of data from Rothamsted (height 420 ft.), a site on clay soil (with flints) over chalk, near the top of a rise on slightly sloping ground with a north-eastern aspect. The data used applies to the period 1921–50 inclusive and mainly to the season January 1 to June 3, stated in terms of Shaw weeks, which are measured from November 6, week 1 being November 6–12 (inclusive). Thus January 1–7 is Shaw week 9. In leap years, week 17 is February 26–March 3 (instead of February 26–March 4) and the year ends on November 3 (instead of November 4).

The graph (Fig. 1) of the frequency of the number of occasions when the grass minimum temperature T_g is at or below freezing point shows a rapid decrease during March, but during early April there is an increase, and not until the end of April is the rapid decrease resumed. The corresponding curve (not shown) for screen minima T_n, shows a similar though less marked singularity. The curves for other examined meteorological sites in the northern part of eastern England show similar singularities.

The graph of the mean daily minimum grass temperature for each week (right-hand scale of Fig. 1) shows a sharp rise during late March, but during April there is a slight decrease until late in the month when minimum temperatures continue to increase rapidly. The corresponding curve (not shown) for screen temperatures shows a similar form, though the singularities are less marked.

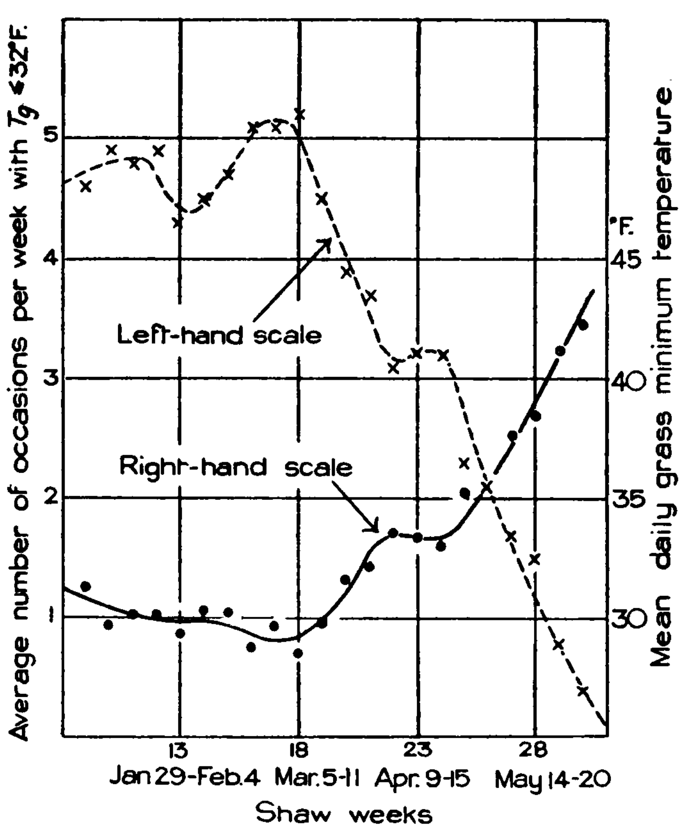

FIG. 1—AVERAGE WEEKLY FREQUENCY OF GRASS MINIMUM TEMPERATURES AT OR BELOW FREEZING POINT AND MEAN DAILY GRASS MINIMUM TEMPERATURE AT ROTHAMSTED

The graph in Fig. 2 of weekly mean values of soil temperature at 0900 at a depth of 4 in., T_4, shows little or no change during January, February and early March, but thenceforth temperature rises steadily. The corresponding curve for a depth of 8 in. shows a similar discontinuity.

The graph of monthly moisture deficit, as calculated at Rothamsted, is roughly as shown in Fig. 3 (right-hand scale). This curve suggests that after about the middle of March, the rate of loss of soil moisture begins to increase rapidly.

During early March, a period of maximum anticyclonic activity[3], the value of $(T_4 - T_g)$ commences to increase rapidly (Fig. 3, left-hand scale), for soil temperature is increasing while grass minimum temperature is decreasing. After early March, the value of $(T_4 - T_g)$ continues to increase steadily, for on the relaxation of anticyclonic conditions it appears that the rise in T_g is checked while T_4 increases steadily.

It may at first seem surprising that frost frequencies increase, or decrease less rapidly, and that mean daily air minimum and grass minimum temperatures decrease, or increase less rapidly, in spite of the high and steadily increasing soil temperature at 4 in. and 8 in. below the surface. The warming of the surface-soil layer during afternoons following "dry-out" is considerably greater than before, and this heat is transferred downwards to the 4-in. and 8-in. levels. At night, some heat is conducted upwards but this does not appear to counteract

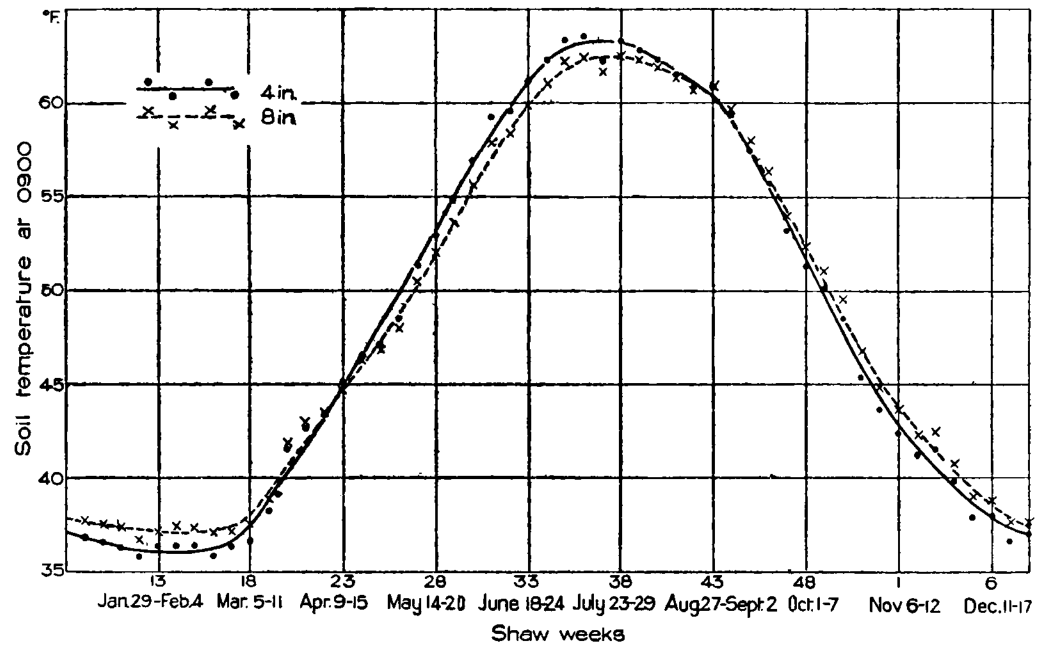

FIG. 2—WEEKLY SOIL TEMPERATURES AT DEPTHS OF 4 IN. AND 8 IN. AT 0900 G.M.T. AT ROTHAMSTED

the rapid loss of heat by radiation from the dry surface layer. If heat can be transferred downwards by day, it might be expected to be conducted upwards sufficiently by night to check the increased frost frequency. It is suggested that the explanation lies in the fact that both the change in frost liability and the increase in soil temperature are associated with the drying-out of the soil; that, after drying-out, heat is transferred downwards to a large extent by water percolation and that this process must more than compensate for the reduced soil conductivity. Whatever the mechanism, it is clear that soil drainage must be considered as an important means of influencing soil temperature in the zone of plant growth.

Thus, the graphs described above show the following:—

(i) Well marked discontinuities associated with the anticyclonic maximum during early March. These take the form of:—

a gradual decrease followed by a sharp rise in mean air minimum and grass minimum temperatures;

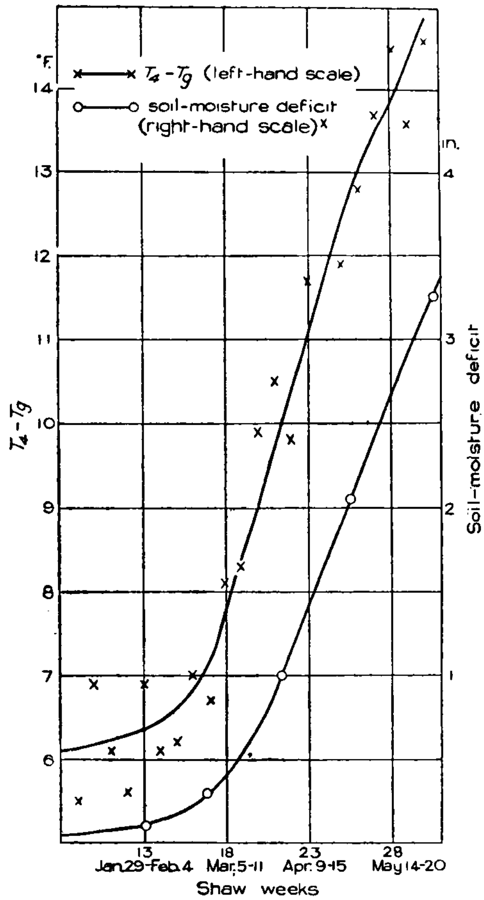

FIG. 3—DIFFERENCE BETWEEN WEEKLY MEAN TEMPERATURE AT A DEPTH OF 4 IN. AT 0900 AND GRASS MINIMUM TEMPERATURE $(T_4 - T_g)$, AND MONTHLY SOIL MOISTURE DEFICIT AT ROTHAMSTED

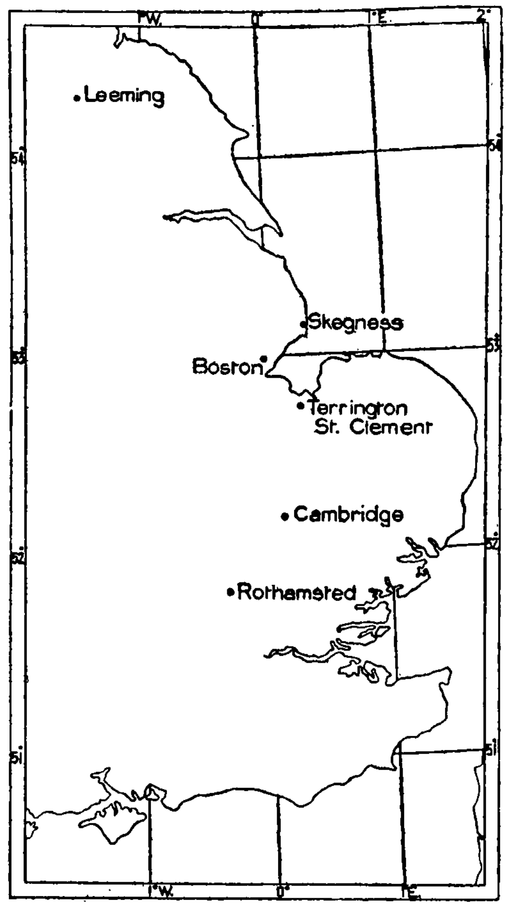

FIG. 4—POSITIONS OF STATIONS

a corresponding increase followed by a sharp decrease in frost frequencies; almost constant soil temperatures at 0900 at depths of 4 in. and 8 in. followed by a sharp rise.

(ii) Lesser marked singularities associated with the drying out of the top soil in the early spring. These take the form of:—

a decrease or check in the rate of increase of air minimum and grass minimum temperatures;

a corresponding increase or check in the rate of decrease of frost frequencies;

a maximum rate of increase in soil temperatures around the beginning of spring.

Mean maximum nocturnal inversion of temperature gradient near the ground.—As an application of the relationship between air minimum and grass minimum temperatures and soil moisture and to obtain further evidence of their connexion, an investigation was made into the relationship between types of soil of various water-holding capacities and the mean maximum nocturnal inversion l in the surface air layer between the ground and a height of 4 ft., as defined by $l = \overline{T_n - T_g}$ or $l = \overline{T_n} - \overline{T_g}$.

The data used applied to the period January 1 to June 3, for the years 1921–50 where these were available. Cases of snow-covered ground (more than half-covered at 0900) were excluded. The places examined together with the details of the sites are given in Table I and their positions shown in Fig. 4. All the sites are in flat terrain, except that of Skegness, which is situated in a slight depression, and Rothamsted.

TABLE I

	Period	Number of years	Distance from sea	Type of soil
			miles	
Rothamsted	1921–50	30	53	Clay with flints over chalk
Cambridge	1921–50	30	42	Chalk and sand
Leeming	1945–52	8	28	Clay
Terrington St. Clement	1935–46, 1951–53	15	3	Silt and loam
Boston	1939–53	15	3	Alluvial loam
Skegness	1933–41	9	0	Sand

In calculating the value of l, a slight error was introduced by the fact that normally T_n refers to a 24-hr. period (0900 to 0900) while T_g (except at Leeming) applies to the night period only. Normally, both screen and grass temperatures will reach minimum values around dawn, and when this happens, the error will not exist. A further small error is produced by the fact that readings are made at 0900 and a single large value of l on one night may give rise to a further large value for the subsequent day if the former value for l persists to some extent after 0900.

The results are shown in the graphs in Fig. 5 and may be summarized briefly as follows:—

With one exception (Boston) the curves have a characteristic form. In January and early February, the value of l is low and decreasing slightly. In March and April, l is high but gradually decreasing until by the end of May, the values are comparable with those for January. The high values of March and April are presumably caused by the drying-out of the top soil and initially aided by the effect of the "anticyclonic-calm" period. The subsequent gradual decrease may be a result of the increase in atmospheric water vapour or of shortening nights.

Apart from orography, the main factors influencing the value of l appear to be soil type and distance from sea. Cambridge and Rothamsted (places furthest from the sea) have the highest values of l but the value at Rothamsted is less than at Cambridge although further from the sea. This is probably because at Rothamsted, cold air is able to drain off so that a strong inversion is not built up, but soil differences may be partly responsible in that the water-holding Rothamsted clay is less conducive to the build-up of inversions than the Cambridge soil.

The value of l at Leeming is far below those at Terrington St. Clement and Boston, probably owing to soil differences, moisture-retaining clays tending to give much lower values than the lighter sandy soils or loams, especially in winter, when a light soil may often develop a dry top layer. Skegness, on the coast, has, as might have been expected, a low value of l but soil type and orography help to produce a value which, in spring, exceeds that at Leeming.

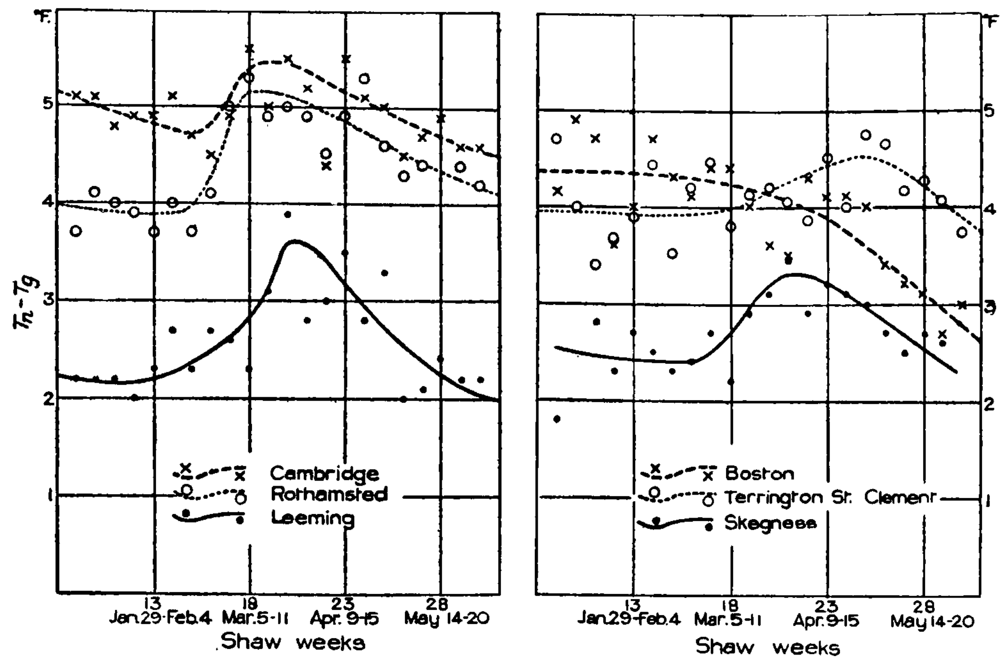

FIG. 5—DIFFERENCE BETWEEN WEEKLY MEAN DAILY MINIMUM SCREEN TEMPERATURE AND GRASS MINIMUM TEMPERATURE

Further singularities.—It has been shown[4] that during the autumns of 1948 and 1949 there occurred in early October, a sudden change in the time of the evening discontinuity in the rate of cooling under clear skies; it is suggested that this phenomenon is associated with very humid top-soil after this date. It may be expected that at about this date there will be other singularities. That the early October phenomenon just mentioned occurred well before the main autumn rain suggests that other discontinuities, associated with soil moisture, occur before the main autumn rain and are determined primarily by solar intensity rather than weather changes. This would mean that the "critical" dates for, say, frost frequency are less variable from year to year than the dates of the main weather changes.

September or early October is a period of maximum anticyclonic activity[3,5,6] and this phenomenon is normally followed by the very wet period of late October. This probably makes it difficult to distinguish the various autumn singularities. The September anticyclonic period occurs with much drier soil than the February–March anticyclone so that any water percolation aided by declining insolation produces a rapid decrease in soil temperatures at depths of 4 in. and 8 in. This decrease follows a very slow decrease from the mid-July maximum and the average soil-temperature curves present an unsymmetrical appearance. In late October, with the relaxation of anticyclonic conditions, the frequent onset of wet weather and decrease in insolation, the top soil becomes permanently moist, and it may be expected that changes in temperature (of screen minima, grass minima, soil temperature, etc.) caused by declining insolation would be checked. The Rothamsted soil-temperature curves do not show any discontinuity until the beginning of November, and then only a weak one. This may be because the Rothamsted site is well drained. A "flat" clay site would presumably show an earlier (latter part of October) and more marked discontinuity.

The mean dates of the spring and autumn temperature discontinuities would provide important demarcations in any division of the year into natural seasons of soil climate or microclimate. Lamb[3] gives March 30 as a seasonal demarcation based on pressure patterns, and although there is not a one-to-one correspondence between pressure pattern and weather, the change after March 30 to a period when "long spells . . . are clearly at their rarest" and therefore to a decrease in prolonged wet weather, may lead to better drying-out conditions. Similarly, during October, the change from anticyclonic to a wetter cyclonic type of weather helps to maintain a moist top-soil layer. Thus in both early spring and early autumn soil climate, microclimate and macroclimate show a seasonal demarcation, though it is probable that at both times the soil climate and microclimatic discontinuities are primarily controlled by solar intensity rather than by weather changes, and consequently less variable from year to year but with considerable local variation due to topography.

The close relationship between frost frequency and past weather has been demonstrated in an analysis[7] which used the long-term records for Greenwich and Kew, contained in "A century of London weather"[8]. It is concluded that the odds against May frosts increase if the weather has been wet during the previous March and April and decrease if the previous March and April have been dry.

Conclusions.—Soil moisture is a factor of paramount importance in the determination of frost frequency, screen-minimum, grass-minimum and soil temperatures. In particular, soil type and drainage have a considerable influence on soil temperatures.

As a result of a decrease in soil moisture in the spring, data from Rothamsted, supported by data from other stations, indicate that, at this time,

Frost frequency either increases or its rate of decrease is sharply checked;

Mean daily minimum temperatures either decrease or their rate of rise is sharply checked;

Soil temperatures rise considerably.

The mean maximum inversion of temperature gradient at night l is dependent on the type of soil, distance from sea and orography. The influence of soil type is due to its water-holding capacity, the better drained lighter soils giving rise to higher values of l. This type of data could be used as a guide to estimate or forecast grass minimum temperatures. Maps may be drawn for flat terrain, showing, for a particular date, the variation of l with location (distance from sea) and soil. Similar maps could probably be drawn for the mean dates of the various singularities.

REFERENCES

1. ANGSTRÖM, A.; On the radiation and temperature of snow and the convection of the air at its surface. *Ark. Mat. Astr. Fys., Uppsala*, **13**, No. 21, 1918.
2. BRUNT, D.; Notes on radiation in the atmosphere. I. *Quart. J. R. met. Soc., London*, **58**, 1932, p. 389.
3. LAMB, H. H.; Types and spells of weather around the year in the British Isles: Annual trends, seasonal structure of the year, singularities. *Quart. J. R. met. Soc., London*, **76**, 1950, p. 402.
4. SAUNDERS, W. E.; Some further aspects of night cooling under clear skies. *Met. Res. Pap., London*, No. 687, 1951.
5. BELASCO, J. E.; The incidence of anticyclonic days and spells over the British Isles. *Weather, London*, **3**, 1948, p. 233.
6. BROOKS, C. E. P.; Annual recurrences of weather: "Singularities". Part I and Part II. *Weather, London*, **1**, 1946, p. 107 and p. 130.
7. SMITH, L. P.; Pray for a really wet April. *Grower, London*, **39**, 1953, p. 674.
8. MARSHALL, W. A. L.; A century of London weather. London, 1953.

METEOROLOGICAL RESEARCH COMMITTEE

The 29th meeting of the Physical Sub-Committee of the Meteorological Research Committee was held on April 2 to discuss the problem of the artificial production of rainfall. After a keen and stimulating discussion it was agreed that whilst at present there was no reliable evidence to show that rainfall had ever been increased on an economically useful scale by any methods, nevertheless, in view of the potential economic value of artificial production, trials to obtain a knowledge of large-scale diffusion of airborne particles should be initiated, analyses of natural nuclei concentrations should be extended, and the design of large-scale field trials to test the effectiveness of any suggested methods of seeding for increasing rainfall on an economic scale should be fully explored.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:

PROFESSIONAL NOTES

No. 110—On the accuracy of contour charts in forecasting upper winds. By R. Murray, M.A.

The practical importance of the various errors associated with forecasting winds by means of contour and forecast contour charts is assessed for the 700-, 500-, 300-, and 200-mb. levels.

Isobaric charts contain errors in terms of wind arising from the following factors:

(i) errors caused by inaccuracy of contour height observations,
(ii) errors caused by inaccurate estimation of geostrophic wind,
(iii) errors owing to the personal element in chart construction,
(iv) wind-measurement errors,
(v) small-scale wind fluctuations,
(vi) geostrophic departures.

Most of these errors are acceptably small, but (i) increases in importance with height and becomes the largest individual error at 200 mb. These errors are inherent in the contour method of wind representation and cannot be substantially reduced except at high levels where an increase in the accuracy of contour height observations is required.

In forecasts there is an additional error because of erroneous forecasting of contour patterns. In 24-hr. forecasts of wind at a point this is the main cause of forecast errors up to 300 mb., but at 200 mb. it is about equal to the combined effect of errors inherent in the contour method.

No. 111—Nocturnal winds. By E. N. Lawrence, B.Sc.

The relationship of katabatic winds and land-breezes to topography, soil and ground cover is examined, and the speed, depth, frequency, temperature, conditions of flow and other characteristics of these winds are discussed in the light of results of the present investigation and in relation to the results of other surveys and experiments. An empirical formula for the speed of the katabatic wind in terms of the slope and distance from the sea is obtained for extensive flat slopes. The magnitude of the land-breeze (and hence the nocturnal wind) over England is assessed.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society on April 28, 1954, the main event was the delivery of Dr. O. G. Sutton's presidential address.

Presidential Address—Development of meteorology as an exact science

Dr. Sutton stated that his aim was to attempt a critical examination of the part played by mathematics in meteorology. One of the main uses of mathematics in applied science was to provide an objective method of summarizing experience and another was to make predictions. However only certain ideal problems, which had affinities with the real problem, could be solved. In meteorology the gap between the real situation and the ideal problem was much greater than in laboratory physics, and we were usually well satisfied with a meteorological "theory" in which the difference between the observed and calculated values was not more than, say, 10 per cent.

Nature of the meteorological problem.—The picture of the atmosphere as a shallow gaseous fluid, heated from below, was complicated by the fact that the system was based on a spinning earth and that the water vapour in the atmosphere was an effective means of taking up and releasing heat in enormous quantities. The system could not be isolated from the universe as a whole, and the state of the lower boundary influenced, and was also influenced by, the condition of the gaseous fluid resting upon it; almost every element of the system reacted significantly with every other. There was a strong temptation to propound soluble problems in physics which had some relation to atmospheric processes, but the essential step lay in discovering the framework of the real problem.

Two classes of problems could be distinguished. Problems like evaporation had nearly everything in common with laboratory problems except the possibility of complete control, but in the second class were problems which had little or nothing in common with laboratory experience such as those which appertained to the development and movements of large-scale pressure systems. Mathematics could be applied with profit in both classes but with different criteria of success.

Evaporation.—Evaporation was a typical problem of the first class, which could be approached in two ways, (i) by an examination of the mechanics of the process disregarding the economics, and (ii) by evaluating the energy balance disregarding the mechanics.

The earliest treatment was that of Jeffreys, in which the total evaporation from an area extending a known finite distance down wind was given by an expression involving the wind speed, dimension of the area and the eddy conductivity K; this solution could not be used to make numerical predictions because of the uncertainty regarding the value of K. Dr. Sutton in 1934 published an extended treatment of the semi-infinite area problem, taking into account the variability of wind speed with height and expressing the effect of turbulence in terms of measurable quantities; Dr. F. Pasquill used this solution and showed that the measured total of evaporation from small saturated surfaces agreed with the mathematical forecast to within 10 per cent. Subsequently there had been an attempt, in America, to extend the investigation to the meteorological scale at Lake Hefner; it was concluded that two of the theoretical formulae tested "gave good results" in predicting the rate of evaporation from measurements of wind, temperature and humidity.

As more was discovered about the mechanics of turbulence we should get better agreement. All observations of physical quantities contained random fluctuations which limited the precision with which the result could be stated. Meteorologists must accept, as satisfactory, agreement between quantities which were, to the laboratory physicist, rather crude averages.

The energy-balance method of attacking the problem consisted in estimating all the terms in the transformation of energy, except the one which represented the heat used up in evaporation, which was finally determined as a difference. This method gave good results.

Evaporation was typical of a large class of meteorological problems in which one might look forward to ultimate success. It was otherwise with problems arising in the phenomenon of weather.

Mathematics in the synoptic problem.—The central problem of meteorology was that of forecasting weather. Attempts to solve this mathematically had been mainly by the study of "model" atmospheric disturbances, by statistics and by the equations of hydrodynamics.

The three-dimensional character of the middle-latitude disturbance began to emerge in the Norwegian concept of the evolution of a depression, but we know now that the true Bjerknes depression was somewhat rare, and that the events described in the earlier papers represented on over-idealization of what actually occurred; nevertheless, we had reason to be grateful to the Bergen school for showing the value of air-mass analysis in routine forecasting.

The results obtained by the statistical approach were not commensurate with the effort expended. The search for empirical periodicities and correlations was unsound, because it tended to create a state of mind of the "true believer" who saw examples to support his creed in every case he examined. The application of statistical theory to pressure-time series for forecasting weather was considered to be a misuse of a mathematical tool. The main purpose of statistical theory was to examine data for internal consistency and weigh the evidence for a previously formulated hypothesis. In meteorology it was essential that the research had a sound physical basis before a statistical approach was attempted.

The direct attack on the problem by means of the equations of hydrodynamics held out considerable hope but the limitations were very serious. It seemed at times that the initial conditions might be insufficient to determine a unique solution. Disturbances, which were below the threshold of observation at one time, could grow exponentially and affect the distribution significantly at some later time. Also it was not yet known how far unpredictable astronomical events might affect the macro-processes of the atmosphere.

In routine forecasting the weather prognosis was built around the time extrapolation of the existing pressure fields, a process which was highly subjective. Whatever method was adopted by the forecaster, it was evident that good judgement and long practice were essentials in this difficult art. The mathematical method should be regarded as a means of indicating the most probable line of development.

In practice for a 24-hr. forecast, calculations were restricted to the movements of air masses over a rectangle covering part of the eastern Atlantic and part of western Europe. The distribution of air pressure at the surface and at some considerable height in the troposphere was known tolerably well within this rectangle at any one time. With a conventional "lid" at the tropopause and the assumption that conditions did not change (or changed according to some prescribed law) at the boundaries, the problem amounted to tracing the movements of the air inside the box formed by the rectangle, the vertical walls and the "lid" in a period of, say, 24 hr. We set up a model atmosphere which obeyed certain simplified forms of the laws of nature but we were not restricted to a rigid model of an anticyclone or depression.

This model was a compromise. Meteorologists must be prepared to accept models which were not strictly logical, in that there was an arbitrary selection of certain features to be retained, while others were rejected, not necessarily because they were small but because their retention would make the model unworkable. Such models were idealizations not easily justified on mathematical grounds. Attention was limited to an examination of the pressure and motion fields over a relatively small part of one hemisphere in the middle latitudes. The services of the meteorologist, as distinct from the mathematician, would still be required to "put in the weather", which might well be the most difficult part of the whole process of forecasting. The forecaster must recognize that the subjective element had not been eliminated by the mathematics but removed a stage further back, to the initial postulates of the model.

The results of the numerical method, tried by the Meteorological Office on a few occasions only, were encouraging. The charts produced by the machine have reproduced the main kinematical features of the real situation and were about as good as those which were drawn by experienced forecasters on the date in question. Though it was far too early to claim that the value of the method was established there were good grounds for continuing the research.

Conclusion.—The fact that a weather forecast was essentially a statement of chances, was not fully appreciated by the non-meteorologist, and some of the distrust with which the forecasts were regarded could be attributed to this misunderstanding.

The task of the meteorologist did not finish with the composition of the forecast—there was still the important problem of conveying the results of the analysis to the public in simple and straightforward terms; this part of the problem was almost as important as the examination of the physical processes at work.

LETTERS TO THE EDITOR

Monthly temperature characteristics at Kew Observatory

When I looked at Table IV of Mr. Marshall's interesting article about temperatures at Kew Observatory* I was struck by the large number of 9's in May and the small number in September. In 25 yr. there were 12 changeable Mays and only 3 changeable Septembers. This led me to make a table of frequency of occurrence of the ten different categories in each of the twelve months. The three groupings of the categories correspond broadly with "changeable", "above average" and "below average". Several points of interest emerge from it.

It is, I think, surprising that October should be the month most frequently "average". The preponderance of 7's in the autumn and of 8's in the spring

* MARSHALL, W. A. L.; Mean maximum and mean minimum temperatures as criteria of temperature characteristics of a month. *Met. Mag., London,* **83,** 1954, p. 100.

Index number	Description	Number of occasions in 25 yr. Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0	Average	0	0	1	0	0	0	0	1	2	6	3	0
1	Rather warm ...	4	0	1	1	1	0	0	0	1	1	1	2
2	Rather cold ...	0	2	0	0	1	2	3	3	1	4	1	1
3	Warm	0	4	5	4	0	2	3	4	3	0	1	1
4	Cold	5	2	0	0	2	0	0	2	1	0	0	2
5	Brief cold periods	3	2	1	4	2	4	3	2	2	1	4	4
6	Brief warm periods	1	4	2	7	4	3	5	2	3	1	5	8
7	Warm then colder	3	4	1	0	0	2	1	1	8	7	3	2
8	Cold then warmer	3	3	8	3	3	3	3	3	1	1	0	1
9	Changeable ...	6	4	6	6	12	9	7	7	3	4	7	4
Total of 5, 6, 9, ...		10	10	9	17	18	16	15	11	8	6	16	16
Total of 1, 3, 5		7	6	7	9	3	6	6	6	6	2	6	7
Total of 2, 4, 6		6	8	2	7	7	5	8	7	5	5	6	11

might have been expected as these are the seasons of falling and rising temperatures, but there is no such obvious reason for the lop-sidedness disclosed by the totals for 3 and 4—27 warm months and only 14 cold months. Another unexpected result is that while May has the greatest and October the least number of changeable months, they both stand out as having the least number of months above average.

The period July–September 1953 was exceptional in having a mean maximum temperature well below the average in spite of the fact that it had 111 hr. of sunshine more than the average. There is a substantial positive correlation in summer between duration of sunshine and mean temperature (+0·76 for Oxford) and one would expect a higher correlation with mean maximum temperature. It was the very unusual character of July as shown by the graph of maximum temperature in the *Monthly Supplement to the Daily Weather Report* which led to my letter last August* suggesting the investigation so effectively completed by Mr. Marshall. It now leads me to suggest a computation of the correlation between duration of sunshine and maximum temperature, and, if the horticultural data exist, the correlation between the keeping properties of the apple crop and the sunshine and mean maximum temperature in the months July, August and September†. My apples have had a greater proportion than usual of bad ones in the past four months.

E. GOLD

8, Hurst Close, London, N.W.11, May 2, 1954.

[From my previous studies of the weather in London it was no surprise to me to see in Mr. Gold's most informative table and groupings of my index numbers that day-time temperature at Kew Observatory was about average more frequently in October than in any other month of the year. On the contrary, they confirm Figs. 6 and 7 of "A century of London weather" ‡ which show that October has been the month with fewest warm spells from 1841 onwards, and, for the first half of the month, fairly free from cold spells also, except during the late 1880's and early 1890's, which were very cold years generally.

The much larger number of consistently warm months than consistently cold months is due mainly to the warm springs which have been so noticeable in London's weather from 1933 onwards. If the original investigation had been carried out over the same period as that on which the average temperature value was based, i.e. 1906–35, the lop-sidedness in this respect would not have

* GOLD, E.; Unusual temperatures recorded during fog. *Met. Mag., London,* **82,** 1953, p. 246.

† The Food Investigation Laboratory, Ditton, of the Department of Scientific and Industrial Research is understood to be examining this problem.—Ed., *M.M.*

‡ MARSHALL, W. A. L.; A century of London weather. London, 1952.

been expected to occur. When the figures for March (5 warm, none cold) and April (4 to 0) are taken out of lines 3 and 4 of Mr. Gold's table there are 18 warm months compared with 14 cold months; an unexceptionable proportion. It is interesting to note that if the months with index number 5 are added to those with index number 3, i.e. the consistently warm and mostly warm months, the total is the same as the combination of consistently cold and mostly cold months given by index numbers 4 and 6, but this is probably accidental.

As Mr. Gold points out, May was the most changeable and October the least changeable month, yet these two otherwise contrasting months had one feature in common: they rarely came into the "above average" temperature grouping. The majority of Mays and Octobers classified in Table IV as changeable—index number 9—had mean maxima below average. This would, I think, hold good for typically changeable spring and autumn months in any 25-yr. period, when experience suggests and records confirm that the cold periods are usually longer and/or more pronounced than the warmer periods. But the small number of Mays and Octobers with temperature above average to which Mr. Gold draws attention is doubtless related to the period covered by the investigation.—W. A. L. MARSHALL]

"Very rare" rainfall at Wyton, Huntingdonshire

On June 5, 1954, 3·32 in. of rainfall occurred in 2¼ hr., of which 3·15 in. is estimated to have fallen in 105 min. The rainfall during this spell was extremely heavy, and the intensity can only be described as tropical. The rate of fall was approximately 1·80 in./hr., and during the hour and three quarters, 14 per cent. of the annual average rainfall was experienced. Damage done on the station was extensive. The R.A.F. Station headquarters building, which lies centrally in the camp in a slight depression, became an island with water nearly 2 ft. above floor level. The boiler houses of both the Officers' and Airmens' Messes and several of the old-type married quarters were flooded to depths of up to 5 ft.; the sewage ejector pump was also flooded and the mass of water flowing through the drain-pipes was such that sewage was being forced out of the manholes in places. The meteorological office itself, on the first floor of a hangar building, was under a few inches of water as the verandah outside was filling from the hangar roof more quickly than the drains out could clear, with the consequence that the water made its way through the communicating door from the office. With the flooding of the headquarters, land-line connexions were disrupted, and both the teleprinter and telephone lines became unserviceable before the end of the storm.

Other damage in the district was extensive; notable was that at Broughton, a low-lying village in a rather narrow valley about two miles north of Wyton, where part of one street was under 5 ft. of water for about 8 hr., and there was a report from a chicken farm to the south of Ramsey of the drowning of 90 birds. The area of torrential rainfall appears from reports to be approximately that defined by Abbots Ripton and Somersham to the west and east (about 9 miles) and by Bury (just south of Ramsey) and Houghton to the north and south (about 7 miles); probably falls of 3 in. were confined to a considerably smaller area. Wyton appeared to be near the southern limit of heavy rain, and a report by Mr. J. S. Smith who happened to be in Hemingford two miles to the south of Wyton was of heavy but in no way exceptional rain.

At 1200 G.M.T. there was a shallow depression centred south of Newbury; the 0300 G.M.T. radio-sonde ascents for both Crawley and Hemsby had suggested a thundery prospect if surface temperatures reached about 70°F. (as seemed likely) though neither ascent appeared outstandingly unstable. At 1500 G.M.T. the depression was centred about 20 miles south of Wyton (having moved north-east at 15–20 kt.). Temperatures at this time were about 70°F. to the west and south of the area with fairly high dew points (Mildenhall air temperature 72°F. dew point 53°F., and Stansted air temperature 69°F. dew point 56°F.) whilst the Wyton air temperature rose between 1200 and 1500 from 59° to 67°F. and the dew point from 54° to 60°F.

Upper winds between 5,000 and 15,000 ft. were generally 140–180°, 10–15 kt. over the Midlands and south-east England, but the wind at 2,000 ft. above Hemsby at 1500 G.M.T. was easterly 15–20 kt. At just before 1500 conditions were quite clear to the west, but an extremely threatening cumulonimbus was observed to the east of the station, and the lower cloud which was visible was moving towards the west; the storm, as a body of course, travelled north-westwards with the medium-level winds. The surface wind was 360° 16 kt.; the wind over the previous hour or two had been 30° 10 kt. At 1500 moderate rain began, and within 5 min. it had become extremely heavy and remained so until 1645; much lighter rain continued until 1715. The temperature fell abruptly by 12°F. between 1500 and 1520, and the barometer which had been falling fairly rapidly (2·4 mb. in 3 hr.) slackened off to little change at 1500. At 1553 there was a sudden kick up of about 1 mb. and there was a gust of 30 kt. from 210°. The wind remained over 20 kt. from 210–230° until 1700, but by 1800 the speed fell to 10 kt., and by 1900 it had backed again to 10°. Thunder was heard intermittently during the whole period of the storm, and distant lightning was still being reported at 1800. Raindrop size was very large, and there was heavy hail mixed with the rain at times; the hailstones were large enough to bruise a cyclist's hands at Somersham. The character of the rain was such that at 1600 the visibility was reduced to 350 yd., and no assessment of the cloud base was possible. Cars in the roads nearby were either parked, or were proceeding with lights switched on. The rainfall was specially measured at 1800, and the total of 3·32 in. must be credited to the period 1500–1715 as no rain was observed outside these hours. It is worth noting that the rainfall for the conventional 24-hr. period ending 0900 G.M.T. on the 6th was 3 .56 in., which represents just over 16 per cent. of the annual rainfall for the district.

G. W. HURST

Wyton, June 11, 1954

NOTES AND NEWS

Voyage of the O.W.S. *Weather Recorder*

The following is an extract from the report of the Master, *Weather Recorder*, for Voyage 52, May 5–30, 1954:

"A voyage that started off with a violent westerly gale which was of short duration and henceforth a voyage which was the best that we have had for several years. The men were in swimming and the Mark D rubber dinghies were used for recreational purposes. The weather was so good that it was even reflected in the quality of the cooking; the cook excelled himself. Model makers, amateur landscape painters and rug makers were able to further their hobbies under ideal conditions. The films which were of good quality were very much enjoyed whilst the midweek shows of films from the Central Office of Information, mostly travelogues, were very acceptable. The Naval film documentary of the war in north Africa was enlightening and duly appreciated. Altogether a rare trip after what we have suffered in the past couple of years.

"The voyage commenced rather dramatically with an 'Urgent' message from the British steamer *Sir James* who was being blown ashore off the Ayrshire coast. We went to her assistance along with the *Lairds Ben*, and, after the *Lairds Ben* had failed to pass a line in the very full gale, we closed the *Sir James* ready to take the crew of four men and a boy off or pass the towing wire; however, it was found that the *Sir James* was slowly clawing off the shore and we got to windward of her and tried to provide a lee. We escorted the *Sir James* over to the coast of Arran accompanied by the Troon lifeboat; close to Arran we left the *Sir James* in the hands of the lifeboat."

The Meteorological Officer, *Weather Recorder*, reports as follows:—

"The wind veered to north-westerly and increased to 50–55 kt., a short steep sea rose in a matter of minutes and the flying spume gave the effect of low-lying fog on the sea surface, this occurred even when we were more-or-less sheltered by the shore. The ship was diverted to stand by a vessel which found itself in difficulties being caught in the extraordinary weather conditions."

C. E. N. FRANKCOM

Loan of rain-gauges

The Council of the Royal Meteorological Society recently agreed that up to six rain-gauges could be purchased annually for loan to suitable observers in remote districts, who would be prepared to send their daily readings to the Meteorological Office on forms which would be supplied. The object of the loan is to secure records from areas at present unrepresented by rainfall observers. With the growing demand for water for domestic purposes, industry, agriculture and hydroelectric schemes it is becoming increasingly important to have more complete details of the amount of rainfall in all parts of the country. Moreover, observations from a closer network of stations are needed to define more precisely the distribution of rain in intense and widespread heavy rains which often cause extensive flooding.

Whilst the collection of reliable rainfall reports is one of the functions of the Meteorological Office the actual observations have always been obtained mainly from voluntary observers who provide their own rain-gauges and forward copies of their daily observations to the Meteorological Office at the end of every year, or at more frequent intervals where required. The number of such observers now exceeds 5,000. There is a great advantage in this system in that the records are maintained by observers who are interested in finding out the amount of rain falling in their gardens or farms, which results in the records attaining considerably reliability. Meteorologists from other countries often comment most favourably on the reliability of the data obtained here by the co-operation of interested observers.

The reading of the rain-gauge occupies but a few minutes each morning. It consists of pouring the collected rain-water into a glass measure and reading the amount on the graduated scale. Readings are required to be made regularly each morning usually at 0900 G.M.T., but regular readings at a fixed time between 0700 and 1000 G.M.T. are acceptable provided the time of measurement is noted on the register. The need for regularity usually entails that there should be a deputy observer available in the absence of the observer. The gauge has to be set up with the rim 1 ft. above ground in a site which is neither too sheltered nor too wind-swept. The ideal exposure to aim at is the centre of a lawn in a fairly large garden, but guidance on siting the gauge can be given if details of the available positions are provided. Detailed instructions are set out in "Rules for rainfall observers" obtainable on application from the Meteorological Office.

Most of the stations which report rainfall are situated in the towns and well populated parts of the country, but there are relatively few in the mountainous districts, which are generally the wettest parts. The offer to lend a rain-gauge and measure is therefore available to those living in remote districts, where there is no existing representative record and where there is a reasonable probability of measurements being maintained for at least five years. It may be that some readers of the *Meteorological Magazine* know of people living in such districts who would be willing to maintain a record if the necessary instruments were supplied. Additional rainfall reports are especially required in parts of the north and north-west of Scotland, Wales and in the north of England. These areas include, in Scotland, parts of the Outer and Inner Hebrides and large areas in the Highlands. The largest gaps in Wales are near St. David's (Pembrokeshire) and Aberayron (Cardiganshire). In England the largest remaining gaps are in northern Cumberland around Bewcastle; in the Cheviot Hills to the west of Wooler; the North Yorkshire Moors, e.g. Pickering Moor, Fylingdales Moor and the valley of the River Rye; in the Stainmore Forest area to the west of Barnard Castle; in Derbyshire between Tideswell, Matlock, Sudbury and Leek including Dovedale; in Lincolnshire a 15-mile band from the outskirts of Lincoln through Wragby and south to Mablethorpe and in the north-eastern quarter of Suffolk.

Applications for the loan of instruments under this scheme should be made to the Director, Meteorological Office, Headstone Drive, Harrow, Middlesex, in the case of places in England, Wales and Northern Ireland; and for places in Scotland to the Superintendent, Meteorological Office, 26 Palmerston Place, Edinburgh 12. The Meteorological Office will then advise the Royal Meteorological Society of those observers recommended for the loan.

J. GLASSPOOLE

REVIEWS

Mathematics in action. By O. G. Sutton. 8½ in. × 5½ in., pp. viii+226, *Illus.*, G. Bell & Sons Ltd, London, 1954. Price: 16*s.*

The interpretation of physical science for non-physicists dates from the middle of the last century and received a tremendous impetus from the new ideas developed in physics after the turn of the century; indeed it would be difficult to list the popular books on modern physics. The exposition of mathematical ideas for non-mathematicians has never enjoyed such a vogue and it is only in comparatively recent times that popular books on mathematics have begun to appear. Most of these books have dealt with the pure mathematical aspect of the ideas of mathematics; in this book Dr. Sutton is concerned with how the applied mathematician uses these ideas in "solving" physical problems.

In the first chapter the author explains how the applied mathematician builds up a simply related skeleton world whose main features have something in common with the world in which a physical event occurs, and so is able to treat the more amenable problem of the mathematical world which is the abstraction of the real physical problem. He is very careful to point out that there is considerable idealization and simplification before the translation into mathematical language, and that the real problem is usually quite insoluble by mathematics. There has been a regrettable tendency in popular books, especially those on relativity, to identify the real and mathematical worlds but the author avoids the trap.

The second chapter is entitled "The tools of the trade" and perhaps it was the most difficult to write, since any account in a few pages must be a miracle of compression (the latest American book which might well have had the same title is advertised as in two volumes, each of 1,000 pages!). Dr. Sutton cannot achieve the impossible task of keeping the mathematics at the same level—all the tools are not equally sharp or of equal importance—so that there is a variation from the elements of the infinitesimal calculus to partial differential equations. The general reader may be alarmed at the number of definitions and equations in this chapter, but if read judiciously, skipping the actual equations as verifiable later (which is what mathematicians do in a first reading of a paper) there is a lot to be learned here about the general applied mathematical method, and the author is particularly happy in showing how the initial and boundary conditions determine the form of the solution of a differential equation. For some of the later work the reader will have to refer back to this chapter.

The five following chapters apply the methods to a very varied fare in mathematical physics. The short chapter on ballistics develops the notion of viscous drag and shows how this complicates the equations of motion so much that an analytical solution becomes impossible. Step-by-step integration leads naturally to a discussion of methods of calculation and so to analogue machines and digital calculators.

The chapter on waves (where a wave is the noun corresponding to the verb "to propagate" and not "to undulate") is very good indeed. There is a customary treatment of Fourier series and integrals, and the integrals are used to find a relation between a radio signal and its band-width, thus preparing the way for relationships of the type of the uncertainty principle. Waves and particles follow naturally and here the author is very clear in stating that they are the applied mathematicians' inventions designed to give a coherent theory which can be tested against experiment. Most experimental observations deal either with a length or an angle, not with a wave or a particle. This section is especially recommended as an antidote against metaphysical writings that are still widely read. The chapter ends with an account of the method of characteristics in the solution of partial differential equations—which is the mathematical high-water mark of the book—and the application to fluid flow round a corner and the formation of shock waves.

The chapter on the mathematics of flight gives a simple account of how an aircraft which is heavier than air can sustain flight, bringing home to the reader that what may be neglected in one aspect of a problem may well be the crux of another aspect. Simple hydrodynamical theory and conformal transformation are dealt with, without much mathematics. How Bernoulli's theorem enables the mathematician to deal quantitatively with the dynamics of flight is well brought out, and the schematic solution of the problem is given. The Joukowski transformation is introduced showing how a circle may be transformed into a shape similar to that of an aerofoil, and this together with the previous schematic solution for the lift on a long cylinder, completes in outline the calculation of the lift. The chapter ends with a short account of high-speed flight and more about shock waves, of interest to everyone today.

A very short account of the use to which statistics can be put is then given. The four typical problems—distribution, correlation, sampling and significance—are dealt with and examples of each given; what is more important, there are many warnings as to the free interpretation of statistical results as meaningful in the physical world, and the example on p. 183 should be especially noted as an awful warning of how not to interpret. The final conclusion—to call in the expert—will be agreed by all.

To meteorologists the last chapter will in many ways be the most interesting. Why is it not possible to produce a book of weather forecasts for a long time ahead? The answers are sketched here—the complexity of the problem, instability, the failure to find a reasonably simple abstraction and so on. Richardson's work is discussed and contrasted with present routine forecasting methods. Finally the author gives his views on the possibility of forecasting by mathematical methods and mentions some of the numerical work which is going on now.

Since the author cannot allow himself to use too much technical mathematics he has in many cases to illustrate by analogy. The analogies are simple and appealing and, what is more important, not pushed too far—a common failing of popular accounts. The book is very modern in content, very readable and with humour in the pages. The professional will enjoy this book as much as the amateur; it is a book to be recommended and a book to own.

The publisher's name guarantees good printing and I did not notice any errors in the mathematical display.

E. KNIGHTING

Centenary of the Royal Netherlands Meteorological Institute

Koninklijk Nederlands Meteorologisch Instituut 1854–1954. 10¼ in. × 5¼ in., pp. 472, *Illus.*, Staatsdrukkerij-en Uitgeverijbedrijf, 's-Gravenhage, 1954.

The Royal Netherlands Meteorological Institute was founded on February 1, 1854, and the magnificent volume under review has been published in celebration of the centenary. The royal decree establishing the Institute, signed by King William III on January 31, 1854, is reproduced in the book.

The volume is in three main parts. The first part describes the history of the Institute, the second is a detailed description of the current work, and the third consists of a number of scientific papers written by members of the staff. The volume concludes with lists of past and present members of the governing body (College of Curators), of the Directors-in-Chief and other senior staff, and a list of publications.

The first Director-in-Chief was Prof. C. H. D. Buys Ballot known to all who have ever studied meteorology at all seriously for the law he enunciated in 1857.

Buys Ballot was a lecturer in chemistry and mineralogy, later Professor of Experimental Physics, at the University of Utrecht. He had established a meteorological observatory at the bulwark of Sonnenbergh on the town wall of Utrecht in 1848 and did much to stimulate and organize meteorological observing in Holland before 1854. Buys Ballot remained Director-in-Chief until his death in 1890 at the age of 72. A reproduction, in colours, of his portrait appropriately faces the title page.

The collection of weather reports by telegraph was soon organized and the issue of storm warnings began on June 1, 1860. Holland was the first country in Europe to have a storm-warning organization.

Since these early days the work of the Institute grew steadily until after the end of the Second World War when it became very rapid indeed. The Institute now provides the national service of meteorology, climatology, oceanography, terrestrial magnetism and the observation of the ionosphere. Maritime meteorology has naturally always been prominent in the Institute's work from the earliest days and port meteorological offices were opened at Rotterdam and Amsterdam in the 1880's.

The Dutch Institute has always played a large part in international meteorological work. Buys Ballot was one of the early instigators of international collaboration, and the first President, in 1874, of the International Committee. In 1928 the first permanent office of the International Meteorological Organization was established in the Institute building.

The Institute moved from Utrecht to De Bilt in 1897 and is now housed in an imposing building, of which several photographs are included, standing in large grounds. A high tower for anemometer development is a prominent feature.

The ten scientific papers deal with a wide variety of subjects from improved electrical methods of obtaining continuous records of wind speed and direction from Dines and contact anemometers, the theory of the general circulation, statistical methods in climatology, an apparatus for continuously recording sea temperature and salinity, to the application of microseismic observations in forecasting and the theory of the ionosphere.

All British meteorologists will wish the Royal Netherlands Meteorological Institute every success during its second hundred years of existence.

G. A. BULL

ADDENDUM

To the article, in the March 1954 number of the *Meteorological Magazine*, "Estimation of meteorological averages for other months given average values for January, April, July and October" by A. F. Jenkinson, the following paragraphs should be added.

Dr. C. E. P. Brooks points out that by the omission of the sin $(60t)^\circ$ term in the expansion (1) the assumption is made that the maxima or minima of the semi-annual term occur at the mid-season months. It is, of course, not possible to complete the full four-term harmonic expansion from only four equally spaced values. The reasonableness of this assumption is shown by Tables III and V. It would not, however, apply generally for tropical regions.

"Nearly" with reference to the use of mid-month values in place of monthly means gives a difference of about 1 per cent.

METEOROLOGICAL OFFICE NEWS

Academic success.—We congratulate Mr. C. E. Wallington, Experimental Officer, on passing the London M.Sc. examination in mathematics.

Sports and athletics.—The Harrow Meteorological Office Social and Sports Club held their fifth Annual Sports meeting at Headstone Manor Sports Ground on July 1, 1954. A full programme of events was held and there was a good entry for all. The following records were set up:—

I. McDonald ran the mile in 4 min. 50·4 sec.

Miss K. Newman ran the ladies' 100 yd. in 12·6 sec.

L. P. Farrant jumped 18 ft. 0¾ in. in the long jump.

R. Cowen set up a time of 24·4 sec. for the 220 yd., an event not previously held at Harrow.

There were several novelty races during the evening. Commander Frankcom won the veterans 80 yd. and Messrs. B. C. V. Oddie, J. K. Bannon and G. J. Evans won the Meeting Officials' four-legged race. During the evening there was an excellent display of archery by Dr. and Mrs. R. Frith and at the end of the evening Mrs. R. G. Veryard presented the prizes.

Cricket.—The annual match between the Central Forecasting Office cricket team and a team selected from the meteorological offices in the London area was played on the ground of the Dunstable Town Cricket Club at Bull Pond Lane on June 16. Winning the toss, the visitors elected to bat first and, by tea-time, were able to declare at 126 for 8 wickets. This total proved too difficult a target for the home side despite a forceful contribution of 29 from H. Snow and they were all out for a total of 58 runs. The outstanding performance of the afternoon was the batting and bowling of J. B. Shaw for the visitors, who scored an undefeated 81 and took six wickets for 18 runs. The inclusion of a lady player, Miss Audrey Winterbottom, in the Dunstable side appeared well justified by her very competent performance. The Dunstable ladies provided an excellent tea for the occasion.

Swimming.—Miss C. W. Fleming, Scientific Assistant at Renfrew, has been selected to swim for the Civil Service against the Royal Air Force on July 1, and against the Army and the Navy on September 1 and 2. Miss Fleming was third in this year's Scottish Ladies' Breaststroke Championship which was held recently.

WEATHER OF JUNE 1954

Mean pressure was 2–4 mb. above normal from the Bay of Biscay south-westwards to the Azores and westwards to Newfoundland; and slightly below normal over northern Europe, the Mediterranean and the eastern United States.

Mean temperature was slightly above normal over most of Europe and the Mediterranean.

In the British Isles, generally speaking, the weather was dull and cool, with heavy rain and thunderstorms at times.

In the first few days of the month an anticyclone to northward of Scotland gave rise to dry weather almost everywhere; it was dull and cool in eastern districts with morning drizzle, but in the west it was sunny and warm. At

Prestwick Airport temperature reached 77°F. on the 4th and over 15 hr. of sunshine was recorded daily at some places in the Hebrides and west Scotland. Brighter weather occurred in parts of eastern England on the 3rd and 4th but on the latter day there were isolated thunderstorms in the south Midlands. On the 5th a trough of low pressure moved over the British Isles from the Atlantic and it was preceded by an extensive outbreak of thunderstorms, particularly in the Midlands and the south-east. A depression formed in this trough and became slow moving over England giving rise to widespread rain, heavy in places, over the Whitsun holiday (3·46 in. at Long Newnton, Gloucestershire and 3·56 in. at Wyton, Huntingdonshire, of which 3·15 in. fell in about 105 min., on the 5th, and 2·21 in. at Treherbert, Glamorgan and 2·06 in. at Swansea Waterworks, Brecknockshire on the 6th). During the ensuing week further depressions moved from the Atlantic into the south of the British Isles bringing much rain, particularly in southern and western England, but there were sunny periods especially in east England and north-west Scotland. Strong winds occurred in the English Channel on the 9th. From the 6th to the 12th London had its wettest June week since 1905. Following an outbreak of thunderstorms during the night of the 12th–13th (1·98 in. of rain in the 36 min. ending at 0130 on the 13th at Hertford Sewage Works) the 13th was a cold, rather wet day in east and south-east England and at Dunstable the temperature fell to 46°F. during the early afternoon. From the 14th to the 24th a sequence of small but active depressions moving east brought cloudy rainy weather with only brief intermissions to parts of Scotland and rain at times to northern England and Northern Ireland; on the 15th the rainfall was heavy in north-west England and west Scotland (4·37 in. at Grasmere, 4·33 in. at Langdale, Westmorland and 3·81 in. at Borrowdale, Cumberland. In the south the fronts associated with these depressions were very weak and in the intervening ridges of high pressure fine, rather warm weather occurred in many places especially from the 22nd to the 24th. A depression formed south of Iceland on the 25th and moved slowly to Scandinavia; cool northerly winds spread to all areas on the 26th and 27th and lasted until the 29th, with some rain or showers in places. Long sunny periods were recorded on the 26th and 27th, but it was mainly cloudy on the 28th and 29th though there were bright periods in the west. On the 29th a warm front moved into Scotland from the north-west and later moved south-east over England; winds backed to W. or SW. and temperature rose somewhat, particularly in eastern districts (maximum 72°F. at Dyce, near Aberdeen on the 30th). Rain fell in Scotland on the 29th and spread south but it did not reach the south-east until the night of the 30th.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	77	30	−1·4	142	+3	70
Scotland	79	28	−0·6	143	+2	78
Northern Ireland ...	70	37	−1·3	111	+2	71

RAINFALL OF JUNE 1954

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square	3·42	169	*Glam.*	Cardiff, Penylan	4·51	180
Kent	Dover	1·91	99	*Pemb.*	Tenby, The Priory	2·52	105
,,	Edenbridge, Falconhurst	3·94	179	*Radnor*	Tyrmynydd	6·43	197
Sussex	Compton, Compton Ho.	3·82	153	*Mont.*	Lake Vyrnwy	5·52	171
,,	Worthing, Beach Ho. Pk.	2·45	140	*Mer.*	Blaenau Festiniog	9·03	139
Hants.	Ventnor Cemetery	2·94	156	,,	Aberdovey	6·10	224
,,	Southampton, East Pk.	3·54	176	*Carn.*	Llandudno	2·75	145
,,	South Farnborough	2·87	149	*Angl.*	Llanerchymedd	3·41	144
Herts.	Royston, Therfield Rec.	1·91	85	*I. Man*	Douglas, Borough Cem.	2·22	92
Bucks.	Slough, Upton	4·04	196	*Wigtown*	Newton Stewart	5·04	191
Oxford	Oxford, Radcliffe	3·63	162	*Dumf.*	Dumfries, Crichton R.I.	3·33	132
N'hants.	Wellingboro' Swanspool	2·60	124	,,	Eskdalemuir Obsy.	6·21	197
Essex	Shoeburyness	2·59	147	*Roxb.*	Crailing	1·72	78
,,	Dovercourt	...	...	*Peebles*	Stobo Castle	2·58	110
Suffolk	Lowestoft Sec. School	2·13	118	*Berwick*	Marchmont House	2·48	107
,,	Bury St. Ed., Westley H.	2·22	106	*E. Loth.*	North Berwick Res.	2·72	164
Norfolk	Sandringham Ho. Gdns.	2·10	97	*Midl'n.*	Edinburgh, Blackf'd. H.	2·29	115
Wilts.	Aldbourne	5·52	238	*Lanark*	Hamilton W. W., T'nhill	2·45	111
Dorset	Creech Grange	2·59	113	*Ayr*	Colmonell, Knockdolian	4·07	161
,,	Beaminster, East St.	2·94	130	,,	Glen Afton, Ayr San.	3·89	123
Devon	Teignmouth, Den Gdns.	2·76	144	*Renfrew*	Greenock, Prospect Hill	4·02	129
,,	Ilfracombe	3·77	174	*Bute*	Rothesay, Ardencraig	4·52	147
,,	Princetown	8·17	203	*Argyll*	Morven, Drimnin	4·59	148
Cornwall	Bude, School House	2·73	136	,,	Poltalloch	5·19	170
,,	Penzance, Morrab Gdns.	3·22	145	,,	Inveraray Castle	6·15	155
,,	St. Austell	4·24	163	,,	Islay, Eallabus	4·19	160
,,	Scilly, Tresco Abbey	2·87	166	,,	Tiree	3·48	136
Somerset	Taunton	2·59	147	*Kinross*	Loch Leven Sluice	2·97	136
Glos.	Cirencester	5·58	233	*Fife*	Leuchars Airfield	2·13	128
Salop	Church Stretton	3·76	148	*Perth*	Loch Dhu	4·16	100
,,	Shrewsbury, Monkmore	2·55	123	,,	Crieff, Strathearn Hyd.	2·57	97
Worcs.	Malvern, Free Library	3·70	159	,,	Pitlochry, Fincastle	2·10	100
Warwick	Birmingham, Edgbaston	3·21	138	*Angus*	Montrose, Sunnyside	2·03	122
Leics.	Thornton Reservoir	3·45	160	*Aberd.*	Braemar	1·96	100
Lincs.	Boston, Skirbeck	2·84	156	,,	Dyce, Craibstone	2·39	128
,,	Skegness, Marine Gdns.	2·62	146	,,	New Deer School House	3·26	164
Notts.	Mansfield, Carr Bank	3·09	137	*Moray*	Gordon Castle	2·86	140
Derby	Buxton, Terrace Slopes	3·77	117	*Nairn*	Nairn, Achareidh	2·18	123
Ches.	Bidston Observatory	3·32	151	*Inverness*	Loch Ness, Garthbeg	2·09	92
,,	Manchester, Ringway	2·85	118	,,	Glenquoich	7·94	162
Lancs.	Stonyhurst College	4·07	133	,,	Fort William, Teviot	5·22	147
,,	Squires Gate	2·49	120	,,	Skye, Broadford	4·16	106
Yorks.	Wakefield, Clarence Pk.	1·03	48	,,	Skye, Duntuilm	5·86	225
,,	Hull, Pearson Park	1·52	74	*R. & C.*	Tain, Mayfield	2·56	135
,,	Felixkirk, Mt. St. John	2·53	116	,,	Inverbroom, Glackour	3·25	115
,,	York Museum	1·96	95	,,	Achnashellach	5·70	152
,,	Scarborough	1·24	67	*Suth.*	Lochinver, Bank Ho.	5·56	260
,,	Middlesbrough	2·61	138	*Caith.*	Wick Airfield	3·41	189
,,	Baldersdale, Hury Res.	2·67	122	*Shetland*	Lerwick Observatory	4·69	262
Norl'd.	Newcastle, Leazes Pk.	2·06	98	*Ferm.*	Crom Castle	2·00	74
,,	Bellingham, High Green	1·98	86	*Armagh*	Armagh Observatory	2·29	91
,,	Lilburn Tower Gdns.	1·30	63	*Down*	Seaforde	2·56	93
Cumb.	Geltsdale	4·16	154	*Antrim*	Aldergrove Airfield	2·83	117
,,	Keswick, High Hill	5·29	182	,,	Ballymena, Harryville	3·50	120
,,	Ravenglass, The Grove	3·81	146	*L'derry*	Garvagh, Moneydig	3·28	129
Mon.	A'gavenny, Plâs Derwen	5·97	223	,,	Londonderry, Creggan	3·63	129
Glam.	Ystalyfera, Wern House	8·33	221	*Tyrone*	Omagh, Edenfel	3·71	132

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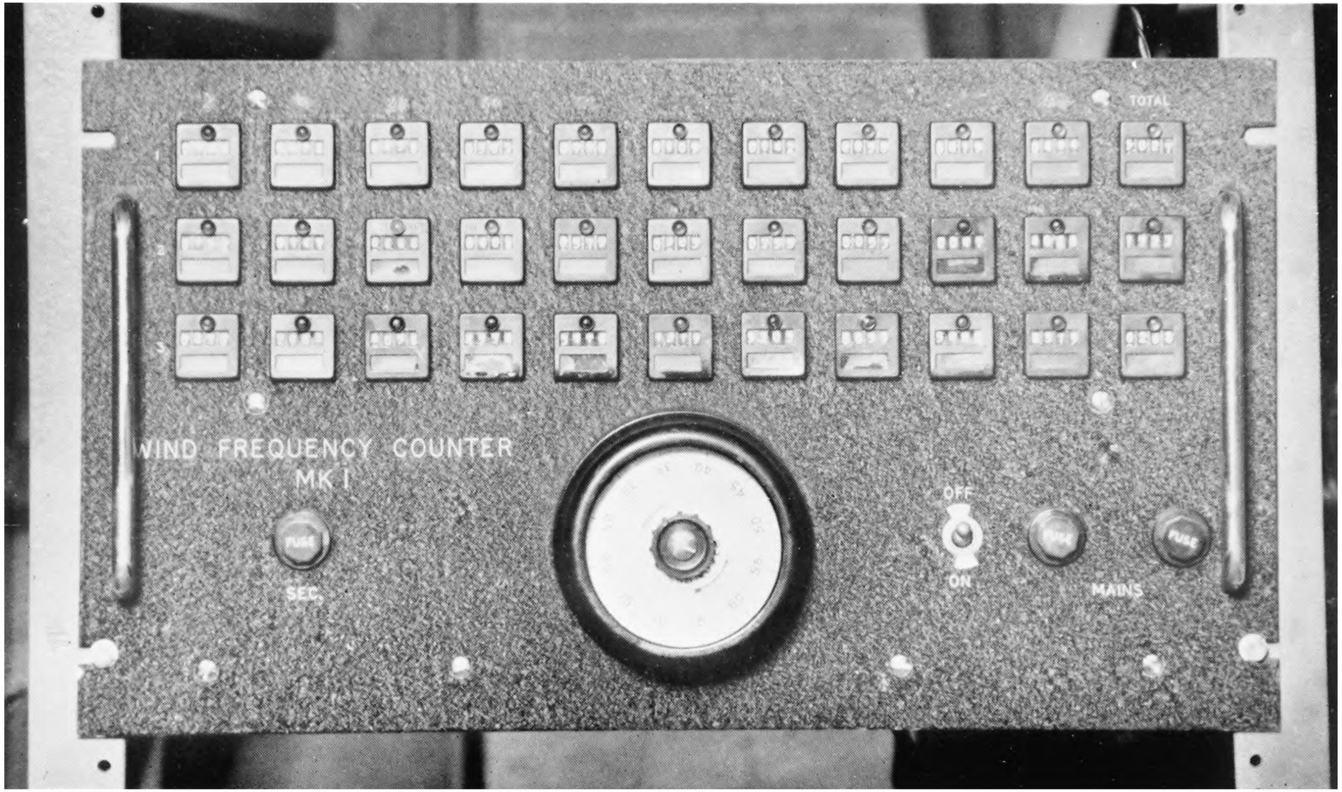
[To face p. 256



WIND-SPEED FREQUENCY RECORDER
(see p. 232)

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PHOTOGRAPHS OF LIGHTNING TAKEN AT ACTON, MIDDLESEX, DURING THE STORMS OF THE NIGHT OF JUNE 12–13, 1954

M.O. 581 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 83, No. 987, SEPTEMBER 1954

NOTE ON THE SUBTROPICAL JET STREAM IN JANUARY AND APRIL 1951

By J. K. BANNON, B.A.

Introduction.—A zone of strong westerly winds is known to occur in the upper troposphere just outside the tropics in many longitudes, as found, for example, by Namias and Clapp[1] in their study of mean temperature distribution in the upper air, showing the position of the mean strong streams or mean jet streams in the northern hemisphere in winter and summer. This subtropical jet stream is strongest in winter and spring. It has been studied over the United States where it is often combined with the strong upper current associated with the polar front[2,3]. Studies for other longitudes, for which sufficient high-level observations are available, have been made for the northern hemisphere over Iraq[3-7] (45°E.), India[8] (80°E.), China[9] (120°E.), and Japan[3,10] (140°E.). For the southern hemisphere studies have been made of the westerly flow over Australia[11,12] and New Zealand[13] (170°E.). For the most part analyses have been confined to an examination of the mean flow for periods of 1–3 months. Apart from that for longitude 170°E. in the southern hemisphere, these studies have related to land areas. Further it should be noted that, except in summer, there is a trough in the mean upper flow over North America and over the neighbourhood of east China and Japan[14]. The flow over southern Asia in winter and spring is influenced by the polar front which on the average is much nearer the equator over Asia than in other longitudes except over North America. Most information about the subtropical jet stream in the northern hemisphere is thus available from studies over land and in regions where the polar front is on the average further south than over the oceans. The paper by Namias and Clapp[1] extends the study over the oceans, but it is based on the few upper air temperatures observed before the year 1944.

It is clear that further information concerning the subtropical jet stream over the oceans is needed. More information about the structure of the stream is also required for all longitudes. The following note describes a study of wind observations in the upper troposphere over the region of the Hawaiian Islands and over the West Indies in January and April 1951, and over Dakar (14° 40'N. 17° 26'W.) in January 1951, which may throw some light on the nature of the subtropical jet stream over the eastern Pacific Ocean, on its structure over the West Indies and on its existence over west Africa.

Method of analysis.—Wind observations for levels of 300 mb. and above are less frequent than for lower levels, especially on occasions when winds are strong. The following analysis, using incomplete data, is therefore crude; it attempts merely to show that strong winds do exist in the upper troposphere and to describe their general character. The source of data is the tabulations in the *Daily series synoptic weather maps* of the United States Weather Bureau.

Several stations in the neighbourhood of the Hawaiian Islands report winds to high altitudes, namely Johnston Island, Midway Island, Lihue (or Mokuleia), Hilo and ocean weather station U (see Fig. 1). On some days perhaps none of these stations will have observed winds at 300 mb. or above; on others there will be several such observations. The criterion adopted here for the existence of the subtropical jet stream is the occurrence of a wind speed of 50 kt. or more at any of these stations at the level of 300 mb. or above; exceptions are those cases where the wind is between NW. and NNE. at 200 mb. which are (arbitrarily) not considered as examples of the subtropical jet stream. (The subtropical jet stream is usually thought of as a zonal current and for this reason cases of marked meridional flow are omitted from the analysis.) In the two months analysed, January and April 1951, the occurrence of strong winds in the upper troposphere over the Hawaiian area was not associated with the penetration of the main polar front to these latitudes as far as could be discovered from the charts published with the data.

Near the West Indies there are several stations reporting wind, namely Burrwood (28° 58'N. 89° 22'W.), Brownsville (25° 54'N. 97° 26'W.), Miami (25° 49'N. 80° 17'W.), Havana (23° 08'N. 82° 21'W.), San Juan (18° 28'N. 66° 06'W.), and Albrook Field (8° 58'N. 79° 33'W.). In January 1951, the wind exceeded 50 kt. in the upper troposphere over southern parts of the United States on every day for which there were sufficient observations to show whether this was so or not. In April 1951, a strong stream existed over the southern United States or the West Indies on all days except one when the polar-front jet stream was displaced northwards. In the analysis those occasions were picked out in which the wind observations showed a second wind maximum at about the 200-mb. level occurring over the West Indies and to the south of the main core of strongest winds over the southern United States. It is this secondary current which is called the subtropical jet stream, to which Gilchrist[3] has drawn attention. There were many occasions when, as far as could be determined from the available wind observations, the strong stream did not have this double structure. There were also many days, particularly when winds were strong, when observations were lacking for 200 mb. and it was impossible to say whether the subtropical jet stream existed separately or not.

The observations at Dakar were examined. Data were available for January 1951 but not for April 1951. From a study of unpublished charts in the Meteorological Office of the distribution of mean heights of constant-pressure surfaces in that area (admittedly vague over west Africa as temperature observations are few), the mean position of the axis of strongest winds would be expected to be 10° further north. For this reason the lower threshold of 45 kt. for the wind speed at 35,000 or 40,000 ft. above Dakar was taken as evidence for the existence of the subtropical jet stream in the neighbourhood of that station.

The next step was to list those days on which the subtropical jet stream, on the above definition, existed in the three regions. Table I gives a summary of

TABLE I—NUMBER OF DAYS WITH STRONG WINDS IN THE UPPER TROPOSPHERE

SS = Winds from SSW. to NW. 50 kt. or more (45 kt. or more at Dakar), occurring at or above the 300-mb. level and not associated with the polar front.

SN = Strong winds in the upper troposphere from between NW. and NNE.

IK = Insufficient observations to determine the wind structure in the upper troposphere.

CS = Strong winds in the upper troposphere but not having a definite maximum separate from the polar-front jet stream.

None = No strong stream in the upper troposphere.

	SS	SN	IK	CS	None
			number of days		
January 1951					
Hawaiian area ...	18	5	8	0	0
West Indies ...	21	0	7	3	0
Dakar	12	0	12	0	7
April 1951					
Hawaiian area ...	28	2	0	0	0
West Indies ...	13	0	0	16	1

details. When the subtropical strong stream was present the following data were extracted from the sounding judged to be nearest to the axis of the stream:

(i) maximum wind speed

(ii) height of axis

(iii) the base of strong vertical shear in the upper troposphere (i.e. shear greater than 2 kt./1,000 ft.).

The figures were necessarily crude estimates of these parameters as so few observations were available for analysis. The mean values of (i), (ii) and (iii) are given in Table II. Winds are tabulated in the *Daily series synoptic weather maps* for the standard levels 500, 300, 200 and 100 mb.; often, but not invariably, they are also given at the fixed heights 20,000, 25,000, 30,000, 35,000 ft., etc. The height of the maximum wind could thus often be determined to the nearest 5,000 ft. There were occasions, however, when the height of the maximum reported wind was also the limit of the ascent; the wind may have been stronger at greater heights. The mean height of the maximum wind given in Table II is therefore probably an underestimate. Similarly, the mean maximum wind speed is also likely to be too low.

TABLE II—MEAN CHARACTERISTICS OF THE STRONG STREAM IN THE UPPER TROPOSPHERE

	Mean maximum wind speed	Mean height of maximum wind	Mean height of base of strong shear*	No. of observations
	kt.	ft.†	ft.†	
January 1951				
Hawaiian area	75	42,000	25,000	16
West Indies	83	40,000	25,000	20
Dakar ...	66	40,000	22,500	12
April 1951				
Hawaiian area	83	41,000	28,000	26
West Indies	73	40,000	28,000‡	12

* Strong shear defined as 2 kt./1,000 ft. or more.
† In I.C.A.N. atmosphere.
‡ From 11 observations.

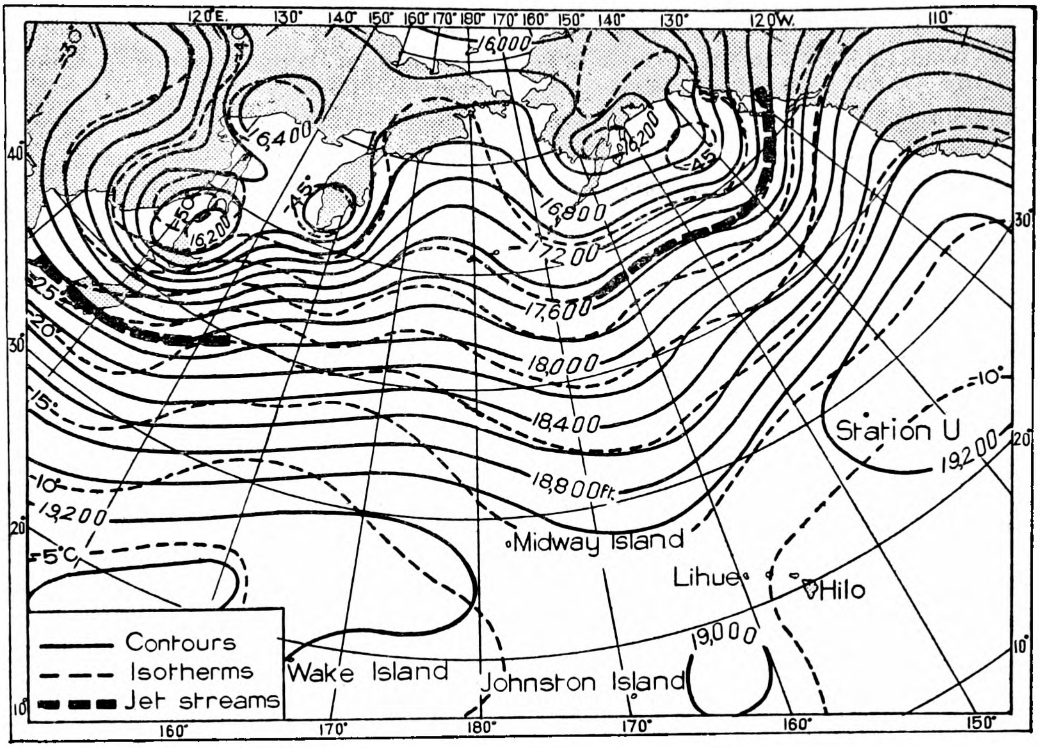

FIG. 1—500-MB. CONTOURS AND ISOTHERMS, 1500 G.M.T., JANUARY 13, 1951

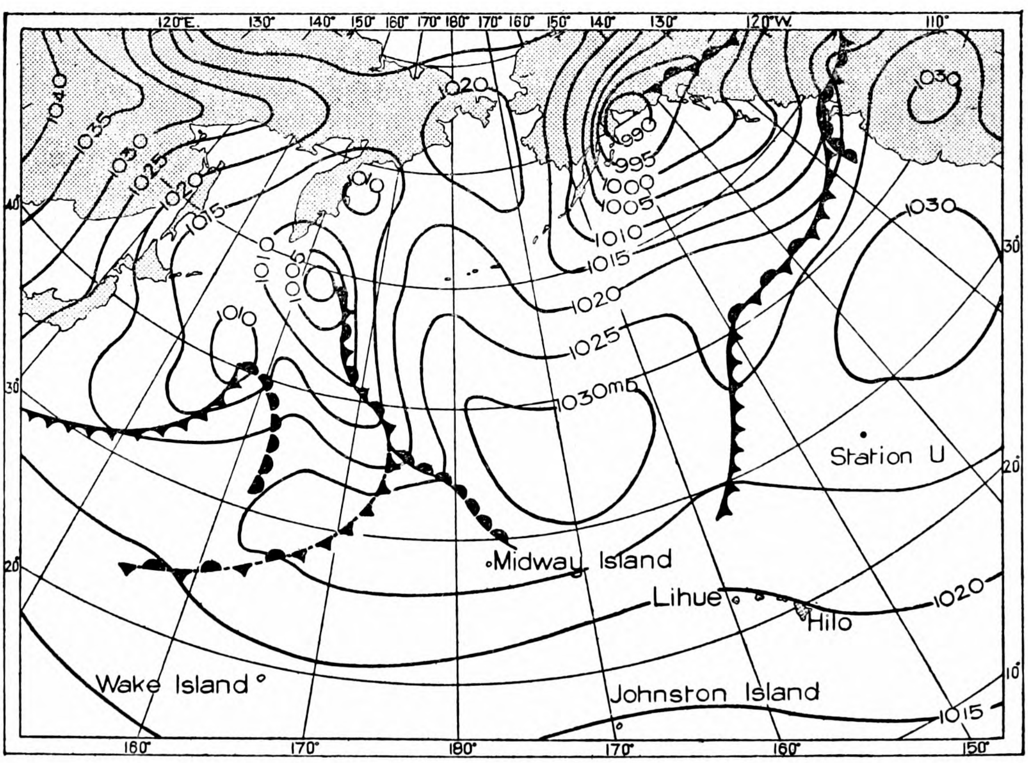

FIG. 2—SURFACE CHART, 1200 G.M.T., JANUARY 13, 1951

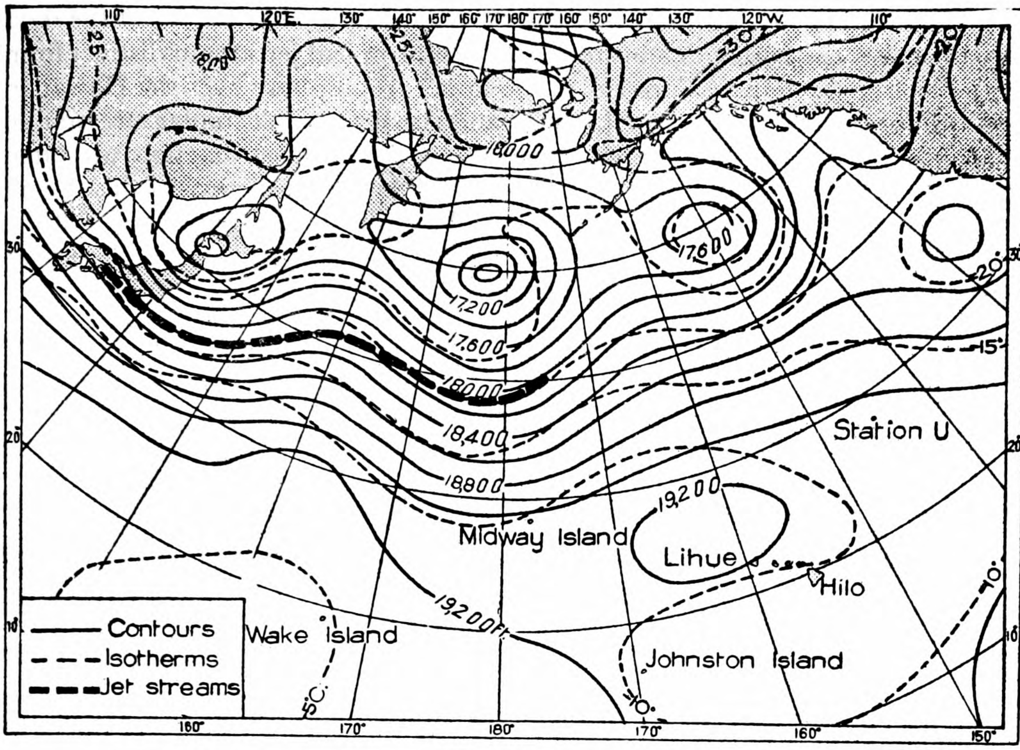

FIG. 3—500-MB. CONTOURS AND ISOTHERMS, 1500 G.M.T., APRIL 23, 1951

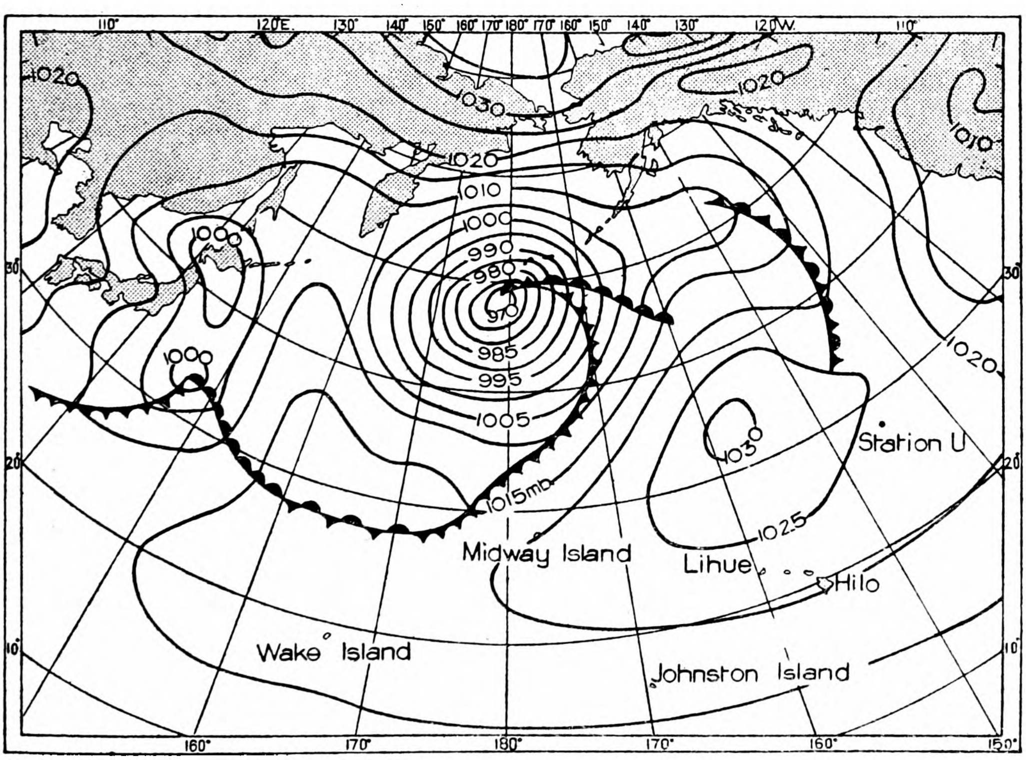

FIG. 4—SURFACE CHART, 1200 G.M.T., APRIL 23, 1951

Discussion.—The statistics in Table I, in spite of the limitations of the data on which they are based, demonstrate that a subtropical jet stream distinct from the polar-front system was present in the upper troposphere over the Hawaiian area on the majority of days of January and April 1951. A similar stream also occurred over the West Indies but, especially in April, the strong flow was often a part of the strong stream associated with the polar front, the axis of this stream being over the United States. It may also be deduced that on about half the days of January 1951 a strong stream existed in the upper troposphere near Dakar.

TABLE III—UPPER WINDS, 0300 G.M.T., JANUARY 13, 1951

Pressure level	Lihue Direction	Lihue Speed	Hilo Direction	Hilo Speed	Wake Island Direction	Wake Island Speed
mb.	°	kt.	°	kt.	°	kt.
100	240	61	...	...	...	...
150	260	88	...	...	...	...
200	250	86	270	110	330	58
240	260	58	270	96	...	...
300	250	28	280	65	320	49
375	220	23	280	10	...	...
500	230	6	170	2	30	9

To demonstrate that the Hawaiian stream was distinct from that of the polar front, Figs. 1–4 were prepared giving surface and 500-mb. charts for two typical cases, January 13, 1951 and April 23, 1951. These charts are tracings of the isopleths on the charts published in the *Daily series synoptic weather maps*. The axes of the polar-front jet streams have been added in Figs. 1 and 3. Table III gives details of the winds 12 hr. before the time of the chart in Fig. 2. Observations for Midway Island at the time of the chart gave a maximum wind of 56 kt. from 315° at 150 mb. (45,000 ft. approximately), and at the same time the wind at 250 mb. (34,000 ft.), the greatest height reached at ocean weather station U, was 270° 24 kt. Table IV gives wind data for 0300 G.M.T. April 23, 1951.

TABLE IV—UPPER WINDS, 0300 G.M.T., APRIL 23, 1951

Pressure level	Lihue Direction	Lihue Speed	Hilo Direction	Hilo Speed	Johnston Island Direction	Johnston Island Speed	Wake Island Direction	Wake Island Speed
mb.	°	kt.	°	kt.	°	kt.	°	kt.
100	...	...	290	33	...	...	330	30
116	260	62	270	43	...	...	...	...
150	270	68	270	71	...	...	...	...
200	270	39	270	66	270	82	270	60
240	250	14	280	35	...	...	...	...
300	180	18	240	15	...	...	270	15
375	90	14	170	8	...	...	...	...
500	60	19	110	9	...	...	160	16

Tables III and IV are examples of the type of data from which the values for the Hawaiian area in Table II were prepared, and show that the height of the axis of strongest winds was at or above 40,000 ft. (200 mb.) and also that the strong winds were a phenomenon of the upper troposphere only. Table II shows that a similar stream occurred over the West Indies also, as Gilchrist[3] and others have shown previously. When a strong stream occurred near Dakar in January 1951, it was also confined to the upper troposphere.

Table II shows that the subtropical jet stream near Hawaii was stronger in April than in January 1951. Mean winds over the Hawaiian Islands in 1950 and 1952 were also stronger in April than in January.

The strong northerly winds which occurred on a few days in the upper troposphere in the Hawaiian area are both interesting and surprising.

Conclusions.—This brief study has established that there was often a strong westerly wind stream in the upper troposphere in January and April 1951 at about 20°N. in the neighbourhood of the Hawaiian Islands and that this stream was quite distinct from the strong flow associated with the polar front which was 10° or more further north. The stream was confined to the upper troposphere. A similar stream was also found to exist over the West Indies (20–25°N.) on many occasions in the same months, confirming previous ideas[3]; the observations from Dakar suggest that a similar type of stream is often found over west Africa in winter.

This strong flow in the upper troposphere in certain seasons in tropical or subtropical latitudes must be linked with the temperature field at these levels. It will be necessary to study wind and temperature observations together to find out more of the structure of the stream, and it would seem that the observations from the mid-Pacific Islands are probably best suited to such a study as the polar front is usually well to the north of this area. As stated in the introduction, other areas with good networks of upper air observing stations are in regions where the polar front is comparatively far south.

REFERENCES

1. NAMIAS, J. and CLAPP, P. F.; Confluence theory of the high tropospheric jet stream. *J. Met., Lancaster Pa*, **6**, 1949, p. 330.
2. PHILLIPS, N. A.; The behaviour of jet streams over eastern North America during January and February 1948. *Tellus, Stockholm*, **2**, 1950, p. 116.
3. GILCHRIST, A.; Upper winds in the tropics and subtropics. *Met. Res. Pap., London*, No. 795, 1953.
4. FROST, R.; Upper air circulation in low latitudes in relation to certain climatological discontinuities. *Prof. Notes met. Off., London*, **7**, No. 107, 1953.
5. BANNON, J. K.; Note on the structure of the high-altitude strong-wind belt in the Middle East in winter. *Met. Res. Pap., London*, No. 821, 1953.
6. London, Meteorological Office. *Upper air data 1946–50*. Part 3. Habbaniya. London, 1953.
7. AUSTIN, E. E. and DEWAR, D.; Upper winds over the Mediterranean and Middle East. *Met. Res. Pap., London*, No. 811, 1953.
8. KOTESWARAM, P., RAMAN, C. R. V. and PARTHASARATHY, S.; The mean jet stream over India and Burma in winter. *Indian J. Met. Geophys., Delhi*, **4**, 1953, p. 111.
9. YEH, T.-C.; The circulation of the high troposphere over China in the winter of 1945–46. *Tellus, Stockholm*, **2**, 1950, p. 173.
10. OOI, S., MATSUMOTO, S., ITOO, H. and ARAKAWA, A.; A study of westerly troughs near Japan (II). *Pap. Met. Geophys., Tokyo*, **3**, 1952, p. 1.
11. LOEWE, F. and RADOK, U.; A meridional aerological cross section in the southwest Pacific. *J. Met., Lancaster Pa*, **7**, 1950, p. 58.
12. GIBBS, W. J.; Notes on the mean jet-stream over Australia. *J. Met., Lancaster Pa*, **9**, 1952, p. 279.
13. HUTCHINGS, J. W.; A meridional atmospheric cross section for an oceanic region. *J. Met., Lancaster Pa*, **7**, 1950, p. 94.
14. 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.

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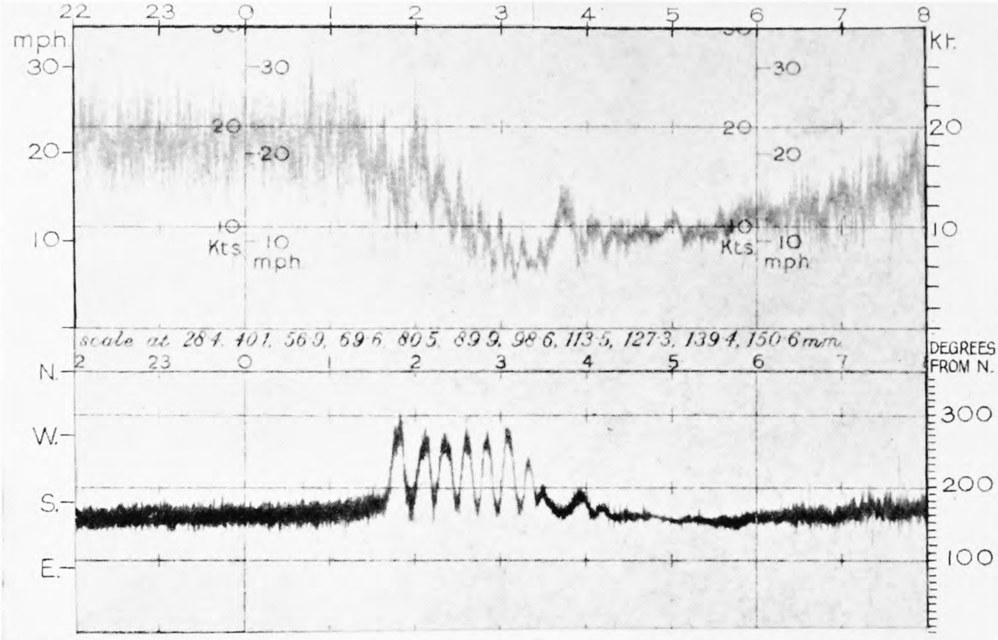
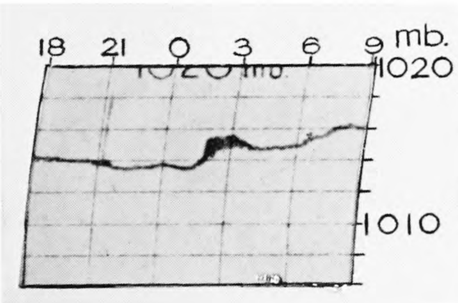
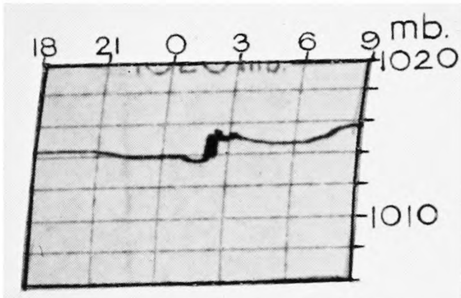
Three separate international meetings were held at the Central Meteorological Office, Zurich in May 1954 under arrangements made by the Director of the Swiss Meteorological Service, Prof. Dr. Lugeon.



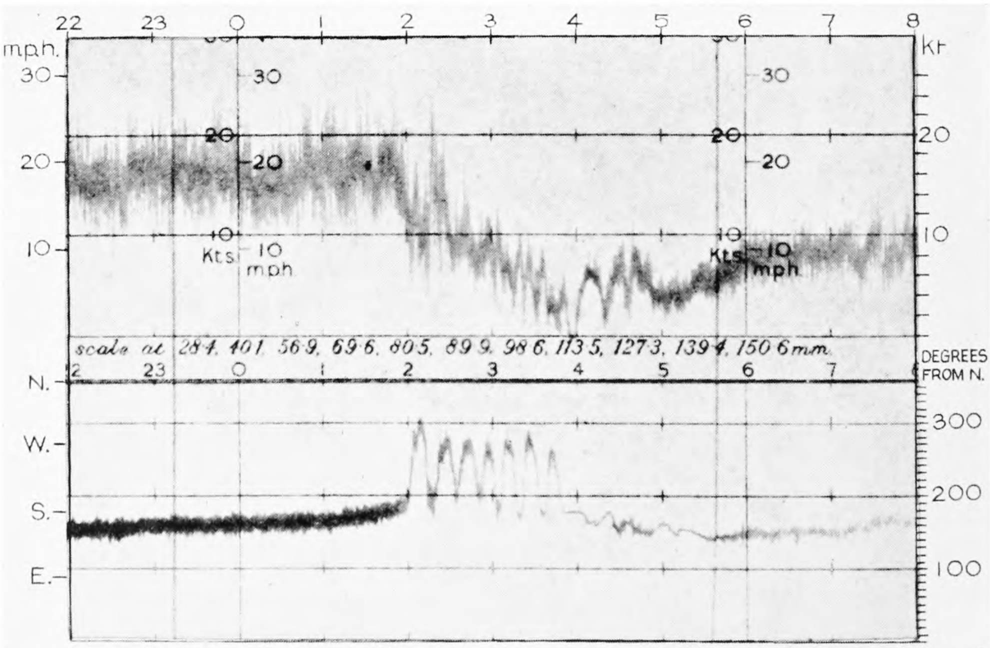
ANEMOGRAM, LUQA, MALTA, 2200 G.M.T., OCTOBER 15 to 0800 G.M.T., OCTOBER 16, 1953



BAROGRAM, LUQA, MALTA, 1800 G.M.T., OCTOBER 15 TO 0900 G.M.T., OCTOBER 16, 1953



BAROGRAM, QRENDI, MALTA, 1800 G.M.T., OCTOBER 15 to 0900 G.M.T., OCTOBER 16, 1953



ANEMOGRAM, HAL FAR, MALTA, 2200 G.M.T., OCTOBER 15 TO 0800 G.M.T., OCTOBER 16, 1953
Clock believed to be 9–10 min. fast

intervals of about 15 min. Two more swings of less amplitude but similar period occurred after 0315. Thereafter the wind settled down in about the same direction as before the occurrence. The wind fell from a mean speed of about 20 kt. before to about 10 kt. after the occurrence. There were no very strong squalls, the motion approximating more to a smooth oscillation. It is noticeable that the strongest gusts occurred in conjunction with the troughs in the direction trace, i.e. each time the wind reverted to its original southerly direction. The westerly puffs were less strong.

The barometer rose rather more than 2 mb. when the occurrence began, and the barogram (left-hand centre photograph) showed oscillations of about 1-mb. amplitude for as long as the wind continued swinging. Actually the amplitude of the pressure oscillations gradually decreased from nearly 2 mb. to perhaps 0·7 mb. The barograph record is not clear enough for precise measurement, particularly as regards separation and timing of the individual oscillations. It seems, however, that the westerly wind puffs brought a pressure maximum (or maxima) as there was a drop of nearly 1 mb. at the end of the oscillations, suggesting that waves on the pressure and wind-velocity traces were out of phase all the time.

None of the autographic records from the other instruments shows anything of interest. The sky was partly covered with altostratus, altocumulus, cirrus and cirrostratus, and there was a trace of rain about 0200 G.M.T. There was no low cloud.

Similar, and doubtless related, behaviour of the surface wind and pressure was briefly noted at Qrendi radio-sonde station, 3 miles south-west of Luqa, where however fewer swings of the surface wind were observed, and the Qrendi barogram (right-hand centre photograph) shows only two full oscillations, corresponding in time to about the first two of the eight swings at Luqa. The observer noted the surface wind at Qrendi as 170° 17 kt. at 0150, but when the radio-sonde balloon was released at about 0155 it was 270° 20 kt. By 0200 the surface wind was again southerly.

The winds obtained from the radio-sonde balloon are given in Table I. The rate of rise was plainly affected by vertical air currents. The figures in Table II are derived from the observations.

TABLE I—WINDS FROM RADIO-SONDE ASCENT, QRENDI, 0155, OCTOBER 16, 1953

	Height (ft.)					
	0	2,000	3,450	5,070	6,690	10,350
Direction	270°	221°	198°	202°	206°	202°
Speed (kt.)	20	17	45	40	39	28

TABLE II—VERTICAL AIR MOVEMENT OVER QRENDI, 0155, OCTOBER 16, 1953

	Time after release (min.)							
		1·65		2·75		5·00		10·00
Pressure level (mb.)		933		911		896		771
Height above station (ft.)		1,900		2,550		3,150		7,300
Mean actual rate of rise (ft./min.)...	1,150		590		266		830	
Mean deduced upward motion of air (ft./min.)	−180		−740		−1,070		−500	

The station height at Qrendi is 445 ft. above M.S.L. There was an inversion of temperature from 911 to 896 mb.—3,000 to 3,600 ft. above M.S.L. (see Fig. 1).

The balloon attained a steady rate of rise from about 7,500 ft. above sea level, averaging 1,333 ft./min. from the eleventh to the thirtieth minute. This figure has been used to get the figures in the bottom row of Table II. From these figures it can be deduced that the balloon became involved in air with a rapid downward motion (approximately 1,000 ft./min.) at a point not far behind the advancing front of the surface westerly breeze, especially near and underneath the inversion layer.

The Fleet Meteorological Officer Malta has kindly made available for examination the autographic records from the Royal Navy meteorological office at Hal Far, Malta, about 3 miles south-east by south (150°) from Luqa. Chief interest attaches to the anemogram (facing p. 265) which shows seven wind oscillations corresponding, with remarkable identity of form and period, to the first seven of the eight swings recorded at Luqa. The wind appears to have been 3 or 4 kt. lighter at Hal Far throughout, whereas the direction swings are in close agreement. Corresponding to the eighth (last) swing of the breeze at Luqa towards the westerly direction, Hal Far shows 5 min. of flat calm.

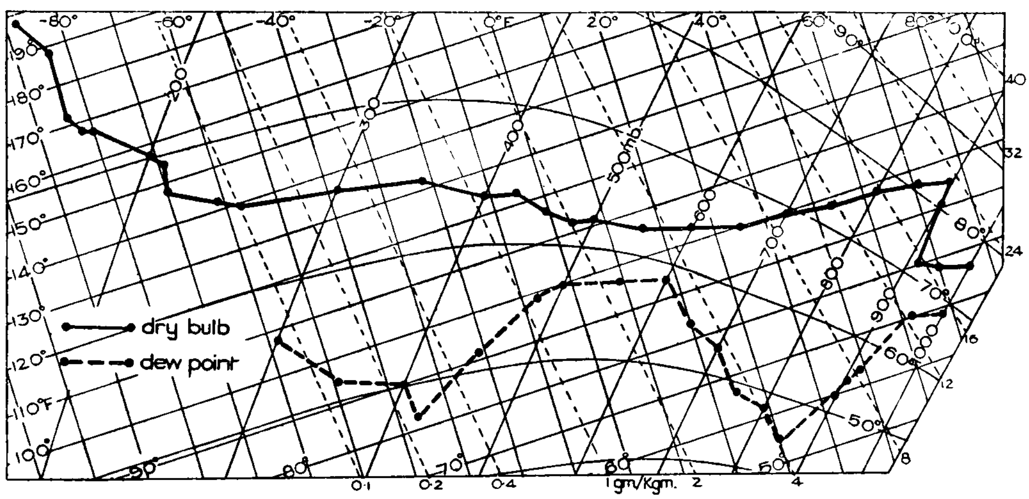


FIG. 1—TEPHIGRAM, QRENDI, MALTA, 0200 G.M.T., OCTOBER 16, 1953

Careful comparison of the Hal Far anemogram with the small-scale barogram for the same station and with the fixed-time observations in the register, suggests that the anemograph clock was 9–10 min. fast. Allowing for this, the westerly wind puffs registered by the anemometer at Hal Far must have come something like 7 min. after the corresponding features on the Luqa record. If this were a straight north–south frontal line of the westerly wind displacing the southerly stream, the time lag from Luqa to Hal Far would have been 15–20 min. From these figures it seems permissible to deduce that the front was of wavy form and that the tip of each wavelet (maximum eastward penetration of the surface westerly wind) was travelling northwards from abreast of Hal Far to abreast of Luqa in 8–13 min., a wave speed of the order of 12 kt. This is in the direction of the general southerly wind stream and of the same order of speed as this wind at the surface, but certainly slower than the southerly winds at 3,000–4,000 ft. (above the inversion). The wave-length would be of the order of 3–4 miles. Probably the amplitude was of the same order, because not all the waves recorded at Luqa reached Hal Far in the east or Qrendi in the west.

The weather map analysis showed a broad southerly air stream (the scirocco) between a ridge of high pressure from Russia and the Balkans to Cyrenaica and depressions centred in the western Mediterranean. The main cold front at the western boundary of the southerly wind stream lay along the coast of Tunisia and was accompanied by thunderstorms. There was also an old, degenerate cold front trailing north and south near (perhaps over) Malta. This front was marked chiefly by a discontinuity of wind speed and isobar spacing; west of the degenerate frontal line the winds, although still generally southerly, were much lighter and more erratic in direction.

The simplest and most plausible explanation is to suppose that the wind oscillations noted in Malta corresponded to ripplets on the degenerate front, the surface of which aloft is represented by the inversion in the Qrendi tephigrams. If so, this surface oscillated up and down with an amplitude of 3,000–4,000 ft. The Qrendi balloon encountered maximum downward air motion at about 3,000 ft.; there was some movement in the same sense up to twice this height.

The case may be held as an example of the general experience in the Mediterranean and north Africa, as elsewhere in suitable circumstances, that when a front is dying out the last characteristic of all to disappear is the discontinuity of wind, often still noticeable long after the main features of associated weather and cloud structure have gone (frontolysed).

Wind-direction oscillations of the kind here described are luckily infrequent; the situation was decidedly awkward for aircraft coming in and taking off from the busy Luqa airport.

The author's attention has since been drawn to published accounts of several similar occurrences observed in Great Britain together with some theoretical discussion of wide applicability[1–3]. Although no relevant upper air temperatures were available, it seemed reasonable in each instance to deduce the existence of a nearly horizontal discontinuity surface aloft. In one case—southern England August 14, 1914—this surface may have been as high as 13,000 ft.; in the other cases, e.g. Abbotsinch, Glasgow, November 16, 1936, it was probably much lower, say 4,000 ft. or below, though again associated air motions in the vertical plane were detected up to 12,000 ft. Goldie[1] also mentions having noticed one case where a steeply sloping frontal boundary was involved. The details of the present case in Malta indicate a frontal surface with a slope of roughly 1 in 7, say 8–10°, from the ground up to 3,000–4,000 ft.

The dimensions arrived at or suggested in these various cases are probably trustworthy as regards order of magnitude and are in fair agreement (see

TABLE III—COMPARISON OF OCCURRENCES OVER SOUTHERN ENGLAND, ABBOTSINCH AND MALTA

	Wave-length	Amplitude (horizontal)	Amplitude (vertical)	Period	Wave speed	Surface wind speed*	Maximum vertical air current
	miles	miles	ft.	min.	kt.	kt.	ft./min.
Southern England, 1914 ...	4½	...	1,500	10	25	10–20	...
Abbotsinch, 1936 ...	3	...	4,000	60 decreasing to 20	5	4–12	900 downwards
Malta, 1953	3–4	c. 4	3,000–4,000	15	12	6–16	1,070 downwards

* Approximate extremes of mean wind over several minutes.

Table III). In all cases the pressure fluctuations were of the same order, amplitude about 1 mb. or rather less. The waves travelled in the general direction of the upper wind at the height of the discontinuity surface but at differing speeds. Goldie examined several other cases for which less data were forthcoming; in these and the cases here discussed the associated discontinuity surface generally had a height of 3,000–6,000 ft. above the ground.

It seems probable that a fairly sharp temperature inversion is required, though there is nothing exceptional about the inversion of 11°F. observed at Qrendi on October 16, 1953. Such wave motion is theoretically likely at the boundary surface between two air streams marked by a discontinuity of velocity, and the problem of why the effects are so seldom observed in our instrumental records at the ground remains unsolved. The air motions must be in some respects not unlike those in rolls of stratocumulus cloud, for example. If these smooth oscillations are normally damped out near the ground by surface friction, perhaps the exceptional cases are attributable to some freak conformity of ground relief to the patterns of air circulation occurring. The phenomenon may well be commoner at sea and near windward coasts than elsewhere. Once set up, however, the English and Scottish cases show that the waves may continue for up to 12 hr. or more in the one area, and may travel 200 miles or more without notably changing their dimensions.

REFERENCES

1. GOLDIE, A. H. R.; Waves at an approximately horizontal surface of discontinuity in the atmosphere. *Quart. J. R. met. Soc., London,* **51**, 1925, p. 239.

2. ANDREWS, R. T.; Wave motion in the upper air. *Met. Mag., London,* **72**, 1937, p. 156.

3. BULL, G. A.; Wave motion in the upper air. *Met. Mag., London,* **73**, 1938, p. 231.

4. SHAW, SIR NAPIER, and AUSTIN, E. E.; Manual of meteorology. Vol. III. The physical processes of weather. London, 1930.

A SUCCESSFUL TRANSATLANTIC CROSSING IN A JET STREAM

By N. E. DAVIS, M.A.

British Overseas Airways Corporation stratocruiser G-ALSA, Captain L. V. Messenger, Navigating Officer M. H. Sutcliff, left New York at 2114 G.M.T. on August 2, 1953 and arrived at London Airport at 0828 G.M.T. on August 3 after a flight in which a tailwind approaching 100 kt. was experienced for over 3 hr. (over 1,000 nautical miles) at an altitude of 21,000 ft.

The general synoptic situation showed a deepening depression south-east of Greenland moving north-east and an anticyclone over the Azores with a ridge of high pressure over the United Kingdom. The cold air had advanced well round the southern side of the depression with the main cold front trailing back towards Bermuda. The warm air was advancing rather slowly towards Scotland and Iceland—the ridge over the United Kingdom being in cold air. The associated thermal pattern (1000–500-mb. thickness) was south-westerly over the greater part of the Atlantic becoming north-westerly ahead of the warm fronts. Hence the upper air contour charts showed a south-westerly air stream over most of the Atlantic becoming north-westerly over the British Isles. The 500-mb. and 300-mb. contour charts for 0300 G.M.T. on August 3, 1953 are shown in Figs. 1 and 2. They indicate a belt of strong south-westerly winds extending from south-east of Newfoundland to about 20°W. The centre of

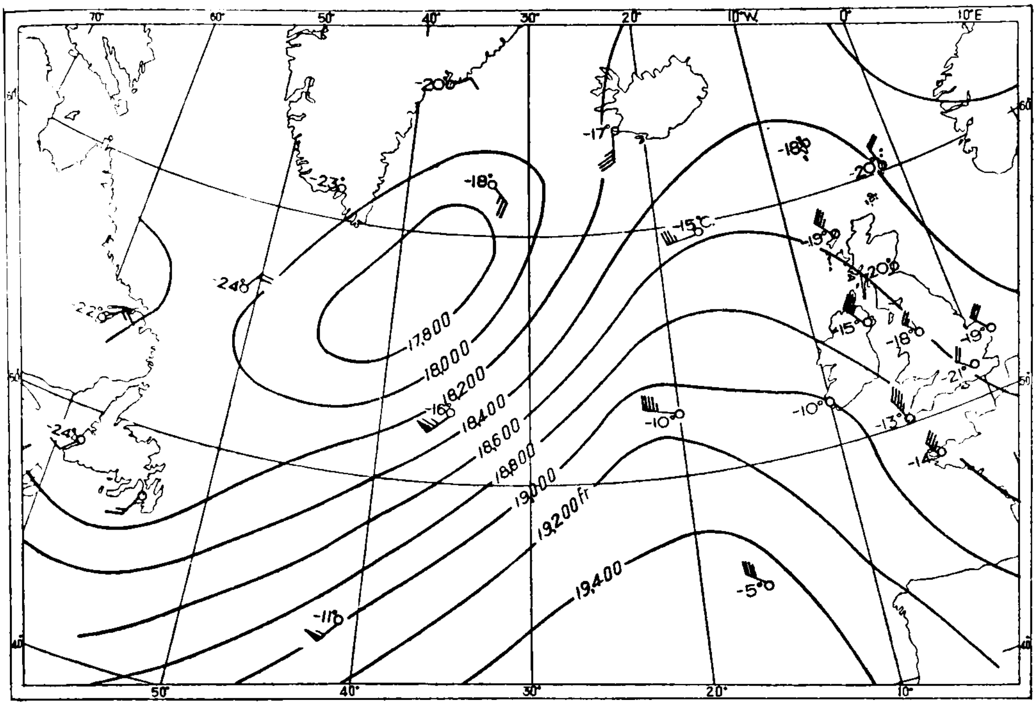


FIG. 1—500-MB. CONTOUR CHART, 0300 G.M.T., AUGUST 3, 1953

Wind speed—one full feather represents 10 kt., one half feather 5 kt. and one solid pennant 50 kt.

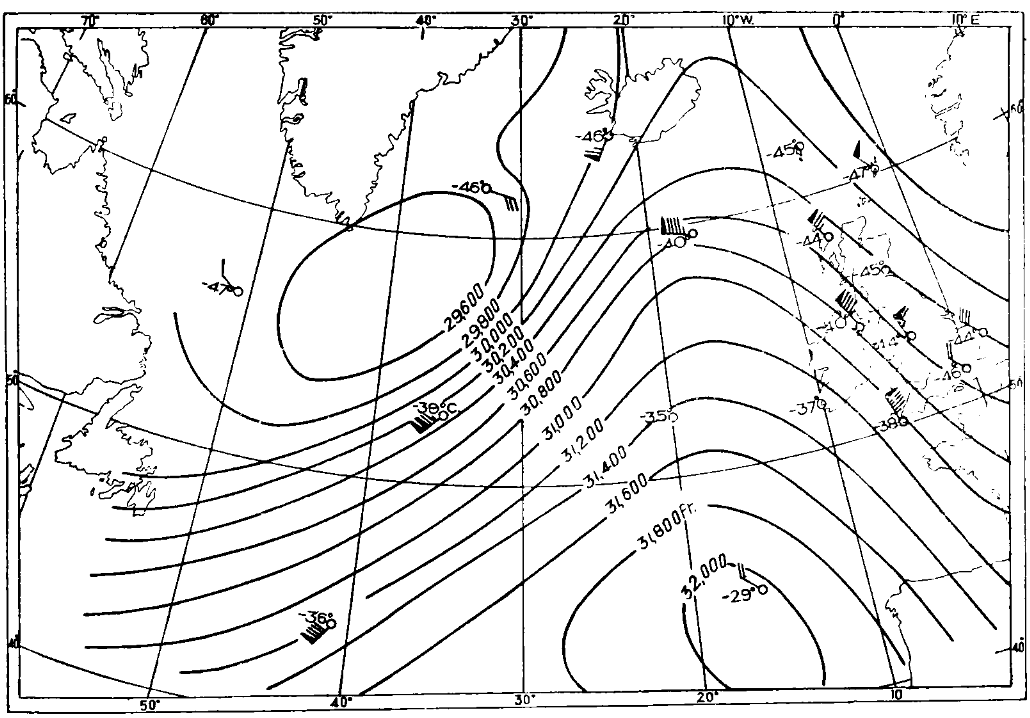


FIG. 2—300-MB. CONTOUR CHART, 0300 G.M.T., AUGUST 3, 1953

Wind speed—one full feather represents 10 kt., one half feather 5 kt. and one solid pennant 50 kt.

the belt at 500 mb. was along the line 45°N. 45°W. to 55°N. 25°W., and at 300 mb. somewhat farther north-west. The upper wind and temperature ascent made from the ocean weather ship at station C at 53°N. 35°W. was located on the north-west edge of the strong-wind belt though it gave the highest winds. The maximum speed of the belt at 500 mb. was about 80 kt. and at 300 mb. 140 kt. or more, so that at the level at which the aircraft flew (namely 21,000 ft.) the maximum speed was about 100 kt.

The aircraft left Idlewild, New York, on a rhumb-line track to 45°N. 50°W. and the flight plan was to fly thence on a great circle to Malin Head. The course of the flight may be best described by quoting the navigator's own words:

The 500-mb. forecast chart, provided by the meteorological office at Idlewild, indicated, as is usual with their charts, the forecast position of the upper front. Using this as a datum and noting that the forecast winds were to be strongest in the vicinity of this frontal surface, we altered our course to approach the jet somewhat sooner than planned, and, making use of the cross-section diagrams in the *Meteorological Magazine* for May 1953[1], made frequent observations of the outside air temperature, and, when this rose at an increasing rate, made more frequent observations of the wind velocity (by Loran fixes). When the wind speed approached 100 kt., we altered course to make this a tailwind and continued to take frequent fixes and temperature readings. The wind speed was maintained for over 3 hr. (over 1,000 nautical miles), the average component at the flight altitude of 21,000 ft. being +94 kt.—most of the time at this altitude was in the jet stream.

We also made some observations of the cloud forms (see *Meteorological Magazine* for October 1951[2]) but not too conclusively. The cloud to start with was small cumulus low down—the anticipated high stratus appeared to starboard (south-east) and crossed over our track at an oblique angle. There was light occasional turbulence, but no noticeable increase in wind speed.

When it eventually became necessary to alter course for Malin Head, the next fix after the alteration produced a wind velocity of 106 kt. The "quality" of fixes at that time was good, so it might be that we were not right in the centre of the stream.

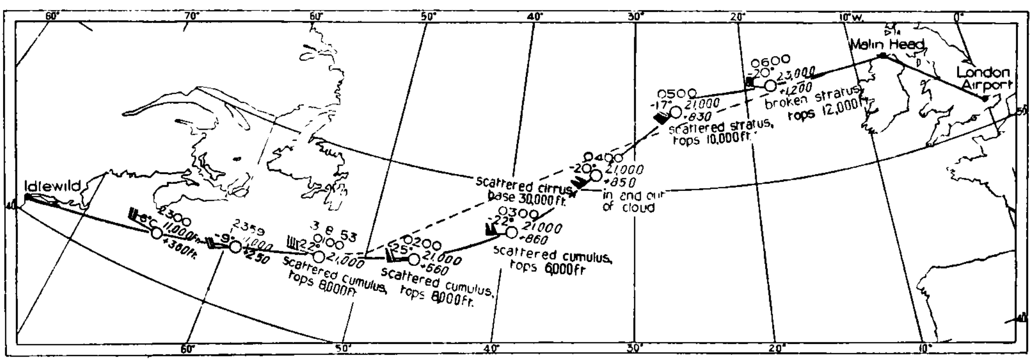


FIG. 3—TRACK OF AIRCRAFT AND HOURLY POSITION REPORTS

———————— Aircraft track   — — — — — — Planned route

Wind speed—one full feather represents 10 kt., one half feather 5 kt. and one solid pennant 50 kt.

Below the average height is given the D value, i.e. the difference between the radio altimeter and pressure altimeter readings

The track of the aircraft and its hourly position and weather reports are plotted in Fig. 3. The high cloud reported at 0300 and through which the aircraft flew at 0400 was evidently associated with a secondary cold front which crossed the track at 31°W. on the 0600 synoptic chart. No change of wind speed in the stream would be expected on passage through the cloud associated with such a secondary cold front. The D value (the difference between the radio altimeter and the pressure altimeter) showed a slight decrease along the jet stream between 0200 and 0500, and this, in conjunction with the reported wind speed of 106 kt. just after the change of course at about 25°W., would seem to indicate that the aircraft had edged towards the polar side while flying down the jet stream.

The navigator concluded his remarks on the flight by saying that the most helpful item in the forecast folder issued by New York, apart from the tabulated winds which could be seen to increase in mid ocean, was the indication of the upper air front on the 500-mb. chart. While this undoubtedly assisted the captain and navigator in deciding where to look for the jet stream, an indication on the 500-mb. chart of the probable position of the jet stream would have sufficed. The success of this flight depended to a very great extent on the frequent observations of outside air temperature—a rapid increase of which is generally associated with an approach to a jet from the polar side—coupled with the accurate and frequent determinations of wind speed and direction.

REFERENCES

1. MURRAY, R.; Jet stream over the British Isles during June 14–18, 1951. *Met. Mag., London*, **82**, 1953, p. 129.
2. SAWYER, J. S., and ILETT, B.; The distribution of medium and high cloud near the jet streams. *Met. Mag., London*, **80**, 1951, p. 277.

HUMIDITIES ASSOCIATED WITH MAXIMUM AND MINIMUM TEMPERATURES IN SOUTH-EAST ASIA

By G. A. TUNNELL, B.Sc.

Introduction.—During recent years British meteorological offices in south-east Asia have been examining and analysing their thermograms and hygrograms in order to collect data concerning maximum and minimum temperatures, the associated relative humidities, and their times of occurrence. This information is being analysed in the World Climatological Branch of the Meteorological Office, and, as the information is frequently requested by industrialists and scientists, a preliminary report has been made in which some 40 tables give the results of the analysis of the first two years of data. A summary of these tables for the five stations listed in Table I are given in Table II. Data for three years have now been collected and a more thorough analysis will be carried out on these at a later date.

TABLE I—STATIONS

	Latitude	Longitude	Height	Period of data
	N.	E.	ft.	
MALAYA				
Changi ...	1°22′	103°59′	34	January 1951–January 1953
Tengah ...	1°23′	103°42′	34	January 1951–January 1953
Butterworth ...	5°28′	100°23′	8	April 1951–February 1953
CEYLON				
Trincomalee ...	8°32′	81°11′	32	August 1950–November 1951
Negombo ...	7°10′	79°53′	28	August 1950–January 1953

The five stations examined (Changi and Tengah on Singapore Island, Butterworth near the west coast of Malaya, and Trincomalee on the east coast and Negombo on the west coast of Ceylon) are all in the paths of the NE. and SW. trade winds during the appropriate seasons. The data have been divided into three seasons: the NE. trade-wind season (NE. monsoon), the SW. trade-wind season (SW. monsoon) and the transitional months. Data are given for the last season, but only the seasons in which the trade-wind régime is definitely established are discussed here.

TABLE II—MAXIMUM AND MINIMUM TEMPERATURES AND ASSOCIATED RELATIVE HUMIDITIES IN SOUTH-EAST ASIA

U_1 = range of associated relative humidity U_2 = range of most frequent associated relative humidity U_3 = Mean associated relative humidity

	Highest					Lowest					Most frequent							Time of occurrence†		
	Value	Frequency*	U_1	U_2	Frequency* of U_2	Value	Frequency*	U_1	U_2	Frequency* of U_2	Value	Frequency*	U_1	U_2	Frequency* of U_2	Mean	U_3	Mean	Most frequent	Frequency*
	°F.	%	%	%	%	°F.	%	%	%	%	°F.	%	%	%	%	°F.	%			%
Maximum temperature																				
NE.-MONSOON SEASON (December–March)																				
Changi	92–93	7·1	55–69	55–59	3·3	76–77	0·5	95–99	95–99	0·5	90–91	26·0	45–74	60–64	8·0	87	66	13·8h.	13h.–14h.	26·9
Tengah	92–93	2·3	45–54	50–54	1·4	74–75	0·5	95–99	95–99	0·5	88–89	35·4	50–74	60–64	15·2	87	65	13·2h.	12h.–13h.	26·4
Butterworth	96–97	1·6	35–39	35–39	1·6	82–83	0·8	75–79	75–79	0·8	90–91	38·5	45–69	60–64	17·2	91	58	14·1h.	14h.–15h.	33·6
Trincomalee	92–93	0·8	55–59	55–59	0·8	76–77	0·8	90–94	90–94	0·8	82–83	39·8	60–94	75–79	13·2	84	75	12·8h.	13h.–14h.	28·1
Negombo	98–99	0·4	40–44	40–44	0·4	76–77	0·4	85–89	85–89	0·4	88–89	36·5	35–74	55–59	9·5	88	58	13·3h.	14h.–15h.	27·8
SW.-MONSOON SEASON (June–September)																				
Changi	94–95	3·3	55–64	60–64	2·2	78–79	0·5	90–94	90–94	0·5	90–91	32·7	45–84	60–64	14·2	89	64	13·6h.	14h.–15h.	27·9
Tengah	92–93	2·1	50–64	50–54	1·1	78–79	0·5	85–89	85–89	0·5	88–89	34·4	45–74	60–64	12·0	88	65	13·0h.	13h.–14h.	24·0
Butterworth	94–95	1·0	35–54	35–54	1·0	76–77	0·5	85–89	85–89	0·5	90–91	45·3	45–69	60–64	18·6	89	62	14·2h.	14h.–15h.	30·1
Trincomalee	100–101	1·1	35–39	35–39	1·1	82–83	0·6	70–74	70–74	0·6	96–97	25·6	30–54	40–44	14·4	95	45	13·3h.	13h.–14h.	36·9
Negombo	88–89	3·3	60–74	65–69	2·2	80–81	1·8	75–89	75–84	1·4	84–85	53·9	65–84	70–74	25·1	85	74	12·8h.	12h.–13h.	31·3
TRANSITIONAL MONTHS (April, May, October, November)																				
Changi	94–95	7·0	45–69	55–59	3·8	80–81	0·5	85–89	85–89	0·5	90–91	34·9	45–79	60–64	14·2	90	63	13·4h.	13h.–14h.	23·5
Tengah	92–93	3·8	50–59	55–59	2·2	80–81	1·0	75–89	75–89	1·0	88–89	40·9	50–74	65–69	16·4	89	64	12·7h.	12h.–13h.	27·3
Butterworth	94–95	0·5	35–39	35–39	0·5	80–81	0·5	80–84	80–84	0·5	88–89	42·6	55–79	65–69	20·8	89	65	13·7h.	13h.–14h.	29·0
Trincomalee	98–99	1·6	45–49	45–49	1·6	74–75	1·1	95–99	95–99	1·1	94–95	16·3	30–59	50–54	7·1	90	60	13·1h.	13h.–14h.	25·0
Negombo	90–91	4·9	35–74	65–69	2·5	78–79	0·8	75–84	75·84	0–8	88–89	35·3	40–79	70–74	14·8	87	71	13·0h.	12h.–13h.	26·8
Minimum temperature																				
NE.-MONSOON SEASON (December–March)																				
Changi	78–79	3·6	90–99	90–94	2·9	68–69	0·8	90–99	90–99	0·8	74–75	49·3	80–100	95–99	28·8	75	94	4·2h.	6h.–7h.	29·2
Tengah	76–77	3·3	90–99	95–99	2·2	68–69	1·1	95–99	95–99	1·1	72–73	53·4	90–100	95–99	44·2	73	97	4·9h.	6h.–7h.	31·8
Butterworth	76–77	4·7	85–99	95–99	4·2	68–69	5·7	85–99	90–99	4·8	72–73	37·3	85–100	95–99	25·5	73	95	6·7h.	7h.–8h.	60·4
Trincomalee	78–79	0·8	85–89	85–89	0·8	64–65	1·7	90–94	90–94	1·7	74–75	34·9	75–100	90–94	20·7	73	92	0·7h.	0h.–1h.	21·5
Negombo	76–77	4·6	85–99	95–99	2·3	62–63	0·3	95–99	95–99	0·3	72–73	35·1	80–100	95–99	16·1	72	93	5·6h.	6h.–7h.	67·2
SW.-MONSOON SEASON (June–September)																				
Changi	82–83	1·2	80–89	80–84	0·8	70–71	3·3	95–99	95–99	3·3	76–77	31·6	80–99	90–94	17·2	76	92	4·4h.	6h.–7h.	35·2
Tengah	78–79	0·4	95–99	95–99	0·4	68–69	0·8	95–99	95–99	0·8	74–75	48·7	75–100	95–99	38·1	74	96	4·7h.	6h.–7h.	30·3
Butterworth	78–79	0·8	90–99	90–99	0·8	70–71	1·6	95–100	95–100	1·6	74–75	56·1	85–99	95–99	53·7	74	97	6·4h.	6h.–7h.	50·0
Trincomalee	82–83	0·6	80–84	80–84	0·6	70–71	0·6	85–89	85–89	0·6	78–79	43·0	70–84	75–79	21·8	77	80	3·1h.	5h.–6h.	31·1
Negombo	80–81	8·2	70–94	80–84	3·9	72–73	1·9	90–100	95–100	1·6	78–79	47·2	75–99	85–89	25·6	77	90	4·0h.	6h.–7h.	32·9
TRANSITIONAL MONTHS (April, May, October, November)																				
Changi	80–81	2·4	85–99	85–89	1·2	70–71	1·2	95–99	95–99	1·2	76–77	43·0	80–99	90–94	20·1	76	94	4·4h.	6h.–7h.	36·9
Tengah	76–77	15·1	85–99	95–99	13·9	70–71	0·8	95–99	95–99	0·8	74–75	54·9	85–99	95–99	49·2	74	97	4·9h.	5h.–6h.	36·9
Butterworth	78–79	2·0	90–99	95–99	1·6	70–71	1·2	95–100	95–100	1·2	74–75	54·1	85–100	95–99	50·0	75	97	6·1h.	6h.–7h.	51·6
Trincomalee	78–79	8·6	75–94	85–89	6·0	68–69	0·5	90–94	90–94	0·5	74–75	35·0	75–94	90–94	23·0	75	89	2·6h.	5h.–6h.	23·7
Negombo	82–83	1·3	75–94	80–84	0·7	68–69	1·0	95–99	95–99	1·0	74–75	38·7	85–100	95–99	31·8	75	95	4·0h.	6h.–7h.	34·8

*Frequency expressed as a percentage of all observations

† 82½° E. meridian time for stations in Ceylon; 112½° E. meridian time for stations in **Malaya**

Season of the NE. trade wind (NE. monsoon).—During the NE. monsoon, Singapore is exposed almost directly to the general air stream from the South China Sea, although both Changi and Tengah are to some extent sheltered. These two stations are on different sides of the island and this work shows that there are distinct climatic differences between them. The NE.-monsoon air reaches Butterworth after its passage across the Malay Peninsula but this does not seem to have a great influence upon the characteristics of the air.

The air of the NE. monsoon reaches Ceylon from the Bay of Bengal. Trincomalee is directly exposed while Negombo is sheltered. The effect of the passage across Ceylon is considerable.

Maximum temperature and associated relative humidity.—Malaya.—The main differences between the three Malayan stations are due to their varying degrees of shelter from air arriving directly off the sea. Tengah, which appears to be the most exposed of the three stations, has a number of occasions of lower maxima associated with higher humidities than any experienced at the other two stations. The flow round the southern end of Malaya is probably complicated and it may not be easy to trace the cause of this difference between Changi and Tengah. Butterworth, which is completely sheltered, has a compact frequency distribution. The frequency "tails" towards lower maxima and higher humidities experienced at Changi and Tengah are not evident. Maxima occur most frequently between 13h. and 14h. ($112\frac{1}{2}°$ E. meridian time) at Changi, 12h. and 13h. at Tengah, and 14h. and 15h. at Butterworth. Over 60 per cent. occur between 12h. and 15h. There is a distinct difference in the times of occurrence of maxima at Changi and Tengah. This is almost certainly due to differences of exposure.

Ceylon.—Air passing over Ceylon is considerably modified; maxima at Trincomalee are about 4°F. lower than those at Negombo and associated relative humidities are about 17 per cent. higher. Trincomalee experiences the NE. monsoon directly from the Bay of Bengal. This air is colder and wetter than that which reaches Singapore Island; this may be partly due to the influences of shelter although these cannot be very great. Even with this air direct from the sea there is a definite significant negative correlation between maximum temperature and associated relative humidity. Where there is considerable modification, as in this case, the range of temperature and humidity is likely to be greater after the air has passed across the island. The tables for Trincomalee and Negombo confirm this. At Trincomalee the sea-breeze is augmented by the trade winds. This influences the time of the maxima. In Ceylon there is a wide range of times of maxima from 11h. to 15h. ($82\frac{1}{2}°$ E. meridian time); 90 per cent. of maxima occur here during these hours. The sea-breeze usually gives an early maximum but it can delay it for an hour or so. There is a similar effect at Negombo but the trade wind is against the sea-breeze and the effect is not so large.

Minimum temperature and associated relative humidity.—Malaya.—Malayan night minima are very uniform. They are within 4°F. of 74°F. on more than 90 per cent. of occasions and the relative humidity is above 90 per cent. on over 90 per cent. of occasions. Changi has a high frequency of 90–95 per cent. relative humidity which is possibly associated with subsiding air. This is supported by slightly higher minima. The minimum may occur at any time of the day or night depending upon numerous causes. It most often occurs towards dawn. When it frequently occurs well before dawn, it points to the existence of some form of heating which is probably katabatic subsidence. This occurs at Changi and Tengah and to a lesser extent at Butterworth. There is not a high degree of negative correlation between minimum temperature and relative humidity.

Ceylon.—Minimum temperatures are not highly correlated with associated relative humidity in Ceylon during this season. The most striking feature is that the majority of minima at Trincomalee occur within about an hour after midnight; in addition the air is less frequently near saturation during the night than that at Negombo. The number of occasions of 95–100 per cent. relative humidity is less than half as many at Trincomalee as at Negombo. This clearly points to the existence of a flow of air off the higher land inland strong enough to reverse the trade wind at Trincomalee. Negombo is normal in having a high preponderance of night minima near sunrise. The range of minimum temperature is less than that of the maximum. This is also true for associated relative humidity but the humidity at Negombo is less variable than that at Trincomalee. Conditions at night in Ceylon are more variable than they are in Malaya although the general levels of temperature and associated relative humidity are very similar.

Season of the SW. trade wind (SW. monsoon).—During this season the SW. trade winds reach Malaya after they have passed across Sumatra and the Strait of Malacca.

Trincomalee and Negombo during this season have exactly opposite situations with regard to the SW. monsoon as they had to the NE. monsoon. Negombo is almost directly exposed to the air coming from the Indian Ocean while Trincomalee is sheltered by the island.

Maximum temperature and associated relative humidity.—Malaya.—The frequency distributions for the three places in Malaya are very similar. This is probably due to the air reaching them having very similar histories. The effect of Sumatra upon conditions at Malayan stations seems to be fairly uniform. The lower temperatures and higher humidities noted in the NE. monsoon are not experienced at the Singapore stations during this season. Butterworth does not differ greatly from the Singapore stations but it is slightly cooler and wetter than it was during the NE. monsoon. All the above facts are consistent with the change in wind direction and show that the NE. and SW. monsoons bring air to Malaya whose characteristics are very similar. The maxima occur at similar times to those in the NE. monsoon but there is a tendency for them to occur earlier.

Ceylon.—As in Malaya, there is clear negative correlation between maximum temperature and associated relative humidity at both stations in Ceylon during this season. Negombo, where the monsoon air arrives unmodified, has a very small variation of maxima and associated relative humidity. On almost 80 per cent. of occasions the associated relative humidity is between 70 and 80 per cent., and on over 90 per cent. of occasions the maxima are between 82° and 88°F. The monsoon air must be very homogeneous. Trincomalee, where the monsoon air is modified, experiences maxima about 10°F. higher than those at Negombo with associated relative humidities about 30 per cent. lower. There is in addition a greater variability. The maxima occur mainly between 13h. and 14h. at Trincomalee and between 12h. and 13h. at Negombo.

The difference is again probably due to an augmented sea-breeze at Negombo. At both places the maxima have a relatively high probability of occurrence over several hours about noon.

Minimum temperatures and associated relative humidity.—Malaya.—There is evidence that during this season Changi frequently experiences subsiding air. The frequencies of relative humidities of 95–100 per cent. are lower than those of 90–94 per cent. and the most frequent night minimum is higher than the corresponding temperature during the NE. monsoon. Tengah also is slightly drier and warmer. Butterworth is slightly more humid but its minimum temperatures are similar. Night minima occur mainly towards sunrise, but at Changi minima occur very frequently before dawn (on almost 50 per cent. of occasions). This is consistent with frequent subsidence.

Ceylon.—Night minima at Negombo are less variable during this season than during the NE. monsoon. They are higher and associated with lower relative humidities; again there is evidence here of subsidence. Trincomalee is also warmer and drier at night in this season; minimum temperature is more negatively correlated with associated relative humidity and conditions are less variable. All this confirms that the air during this season is more homogeneous than that of the NE. monsoon. Night minima in Ceylon occur mainly towards sunrise but they are also frequent before dawn, particularly within an hour after midnight at Trincomalee. Again subsidence or katabatic winds are indicated.

Conclusion.—This preliminary examination has brought to light features of climate in south-east Asia of which forecasters are probably aware. However statistical evidence is very useful to confirm ideas. The strong katabatic effects at Changi and Trincomalee, for example, must have a great influence on the prediction of night visibility. These stations should have good visibility at night.

The results obtained from the automatic records seem to carry a wealth of information and are quite reliable. It is not possible, however, to come to any striking conclusions until there are sufficient data to justify them.

LOWERING OF FREEZING LEVEL OVER A MOUNTAIN RANGE

By S. M. ROSS

A direct observation of freezing level during a mountain climb demonstrates the danger of slavishly taking the freezing level over mountain country from adjacent upper air ascents, and bears out, to some extent, one of the considerations discussed in a recent inquiry into the cause of an aircraft crash[1].

On Sunday, December 13, 1953, a moist homogeneous southerly air stream, conditionally unstable but with no marked fronts, covered the British Isles. The ascents for 0200 G.M.T. suggested that a freezing level in the region of 6,500–7,000 ft. would exist in the Cairngorm area of Inverness-shire.

A party set out with the intention of climbing Ben Macdhui by the north face of Cairn Gorm (Fig. 1), and about 3 miles south of Glenmore Lodge they climbed into patches of cloud at a height of 2,000 ft. The cloud became 8 oktas some 300 ft. higher and the visibility fell to 40 yd. remaining of that order throughout the climb. On the plateau, at a height of 3,700 ft., conditions became uncomfortably wet and cold as the party climbed up out of shelter into a strong southerly wind.

At midday, while sheltering behind some rocks near the summit of Cairn Gorm (4,084 ft.), it was noticed that small amounts of ice had been forming on woollen garments during the last 100 ft. or so of the climb, though not on smooth "wind-cheaters" which were quite wet. On examining the windward side of the rocks ice was found, in clear nodules, on every projection, while moisture was being blown back over the rock. The growth was very slow and difficult to observe owing to the moisture over the ice, but the average thickness was quarter of an inch with occasional half-inch projections. No actual precipitation was encountered and no ice was found on any but the windward faces of the rocks. The wind speed was estimated at 30 kt., blowing from 170°.

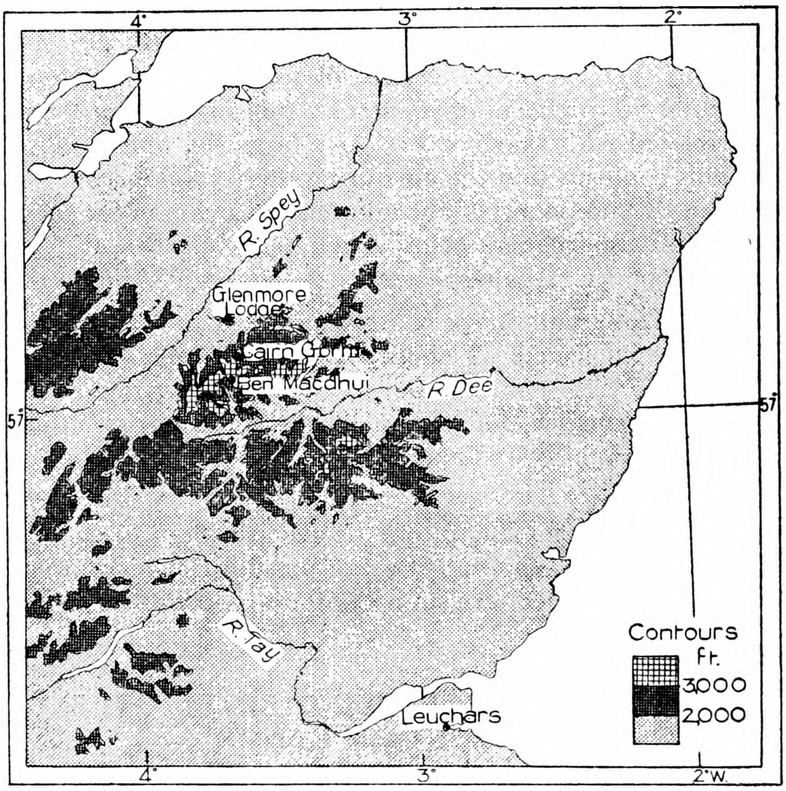


FIG. 1—THE GRAMPIANS, SHOWING THE POSITION OF CAIRN GORM, GLENMORE LODGE AND LEUCHARS

The Leuchars 1400 G.M.T. ascent (see Fig. 2) is taken as being representative of the air over the area during the period (Leuchars bears 150° 50 nautical miles from Cairn Gorm). This gave a freezing level of 6,400 ft. and 42°F. at 4,000 ft. The wind at 4,000 ft. from the ascent was 180° 20 kt. and increased by 10–15 kt. westwards, as shown by the Aldergrove and Stornoway ascents at that time. The freezing levels at 0200, as shown by the Liverpool, Aldergrove, and Leuchars ascents, were 6,800 ft., 7,000 ft., and 6,900 ft. respectively. The gradient wind measured on the 1200 surface chart was 170° 30 kt., while the surface wind at Glenmore Lodge was SE. force 1 and that found in the valley, 3 miles to the south, variable or N. force 1–2.

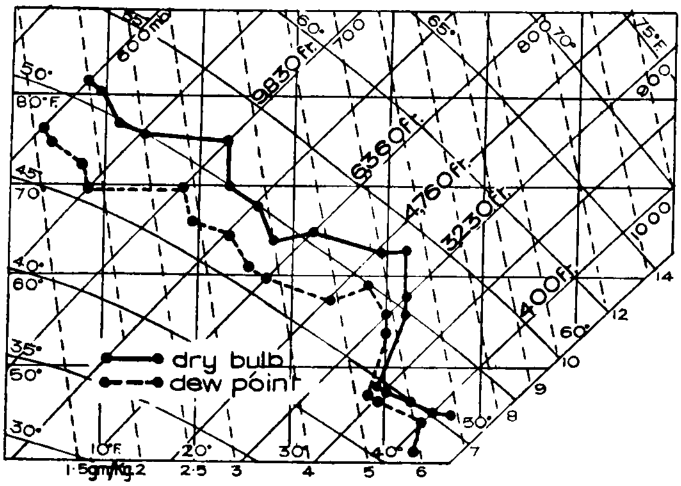


FIG. 2—TEPHIGRAM OF UPPER AIR ASCENT AT LEUCHARS, 1400 G.M.T., DECEMBER 13, 1953

From the above observations it would appear that the freezing level had fallen by some 2,500 ft., owing to the forced uplift of air over the Cairngorm Mountains which form a barrier at approximately right angles to the wind. Forced uplift between 1000 and 940 mb. of any air represented by the 1400 Leuchars ascent, would give condensation some 10 mb. higher and a freezing level between 873 and 865 mb. (4,000–4,250 ft.). The effects of forced uplift over the Highlands on cloud formation have already been discussed by Virgo[2].

The drying out by deposition of moisture in cloud on mountains is demonstrated by the 1200 observation at Glenmore Lodge, taken at a point 1,100 ft. above sea level (975 mb.) and 3 miles to the north, which gave a dry-bulb temperature of 43°F. and a dew point of 39°F. with 6 oktas cloud at 1,800 ft. This air, if forced to rise, would give condensation at 950 mb. (2,000 ft.) and a freezing level of 880 mb. (3,800 ft.).

REFERENCES

1. London, Ministry of Civil Aviation. Report of the court investigation on the accident to Dakota EI-AFL on 10th January, 1952. *M.C.A.P.*, No. 102, 1952, p. 17.
2. VIRGO, S. E.; Conditional instability over the Highlands of Scotland. *Met. Mag., London*, **80**, 1951, p. 88.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

METEOROLOGICAL REPORTS

No. 14—Sea-breezes at North Front, Gibraltar. By A. Ward.

The southerly sea-breeze at Gibraltar is occasionally a considerable hazard to the safe landing of aircraft at the airfield at North Front since it blows at almost right angles to the only runway and, during the summer months, often reaches a mean speed of over 15 kt. with gusts to 30 kt.

This report is based on observations during 1947–49 and indicates a close relationship between the wind structure and temperature distribution from the surface to 3,000 ft. and the incidence of the sea-breeze. The sea-breeze occurs mainly when the air is stable and the wind at 2,000–3,000 ft. is westerly; it is comparatively rare when the upper wind is easterly.

No. 112—Classification of upper air temperature according to tropopause pressure. By J. K. Bannon, B.A.

Upper air temperatures in the neighbourhood of the tropopause are best classified for some purposes according to tropopause pressure. Resulting from such a classification for 20-mb. ranges of tropopause pressure, mean temperatures at Larkhill are presented for standard pressure levels from 500 to 100 mb. for four months for a period of three years. The use of these mean temperatures for obtaining statistics of lapse rates and for the study of year-to-year temperature variations is discussed.

ROYAL METEOROLOGICAL SOCIETY

At a meeting of the Society on May 19, 1954, with Prof. P. A. Sheppard, Vice-President, in the Chair, the following papers were read:—

*Mordy, W. A. and Eber, L. E.—Observations of rainfall from warm clouds**

This paper, which was presented by Mr. Mordy, gives detailed observations of rain from cloud in the trade-wind belt as it crossed the south-eastern corner of the island of Oahu in the Hawaiian group during 10 days of June–July 1952. In addition to special aircraft flights, pilot-balloon observations, etc., a continuous record of cloud conditions and movements were made by lapse-time cinematography supplemented by aerial photography; extracts from the film were shown.

The observations showed that appreciable rain, often of intensity 0·4 in./hr. and on one occasion totalling 2·10 in. within 24 hr., fell from comparatively shallow warm clouds of no more than 7,000 ft. vertical extent, the tops of which were never higher than 8,500 ft. The freezing level was about 14,000 ft. so that the Bergeron process of rain formation could not occur. The thicker the cloud the more the rain was likely to occur and it was noticed that an orographic lenticular-shaped cloud only a few hundred feet thick just above the cumuliform cloud was often associated with the rainfall. Droplets of diameter 300μ were occasionally observed falling from this cloud canopy but the precise mechanism was not understood. Seeding of the underlying cumulus clouds from the canopy was not observed on radar.

East, T. W. R., and Marshall, J. S.—Turbulence in clouds as a factor in precipitation†

It has been found difficult to explain the formation of raindrops in moderate-sized cumulus clouds that did not reach freezing levels because of the comparatively long time calculated as necessary for a cloud droplet of small initial size to grow to raindrop size by natural collision and coalescence with smaller droplets. This paper, which was presented for the authors by Prof. Sheppard, was a mathematical attempt to show how turbulence could increase the rate of collision—sufficient in all except small cumulus to cause rainfall without recourse to the Bergeron process.

If by some means, in this case turbulence, the gravitational field could be effectively doubled the range of diameters of the droplets collected by a drop of, say, 15μ diameter would be more than doubled, the efficiency of collection would be increased ten times to 30 per cent. at the most suitable size of droplet, and

* *Quart. J. R. met. Soc., London,* **80,** 1954, p. 48.
† *Quart. J. R. met. Soc., London,* **80,** 1954, p. 26.

the time required for growth would be reduced to a thirteenth. Attempts were then made to show that this order of acceleration could be effected by turbulence and to calculate the resulting growth rates. Discussion of the paper revolved mainly around the existence of such turbulent accelerations; Mr. Mason and Dr. Scorer pointed out that the suggested order of 1-dimensional turbulence, if it existed, would be audible at the frequencies claimed. Mr. Mordy said that in his experience turbulence did shorten the lifetime of a cloud droplet.

*Langleben, M. P.—The terminal velocity of snowflakes**

Mr. Langleben described some experiments by cinematography to measure the terminal velocity of snow-flakes. The size of the snow-flake was measured by subsequent melting on filter paper dusted with powdered dye and by measuring the melted diameter.

It was found that the terminal speed was approximately proportional to the one-tenth power of the mass of the snow-flake, provided the snow-flakes were all of the same type; dry dendrites were slower than plates and columns, but the speed of fall was increased by rime deposits or slight melting. The results were applied to observations of snow-fall by a zenith-pointing radar, and it was concluded, since the observed rate of fall near the generating region was two or three times higher than it would be for single crystals and no riming could be detected at ground level, that snow aggregates do exist at high levels, including those at extremely low temperatures.

Mr. Gold and Mr. Bonacina were both curious as to the difficulty of measurement of dancing or bouncing snow-flakes. Mr. Langleben said there had been no difficulty; stereoscopic photographs were taken but they were tedious to work out and it had been simpler to use the camera pointing cross-wind. The vertical speed was independent of wind strength.

LETTERS TO THE EDITOR

Distortion of condensation trail at a frontal surface

The photograph (facing p. 280) of an unusual distortion in a condensation trail was taken at Wick by Mr. W. Glander who has supplied the following details: Time of observation, 1030 G.M.T., March 2, 1954. Cloud—3 oktas altocumulus at 9,000 ft. with 3 oktas cirrus at 23,000 ft. (both heights estimated). Camera facing 170° true and elevated at 25°. The aircraft flew approximately from north to south, not quite overhead. When first formed the trail was quite straight, the distortion photographed occurring in some 6–8 min. as nearly as could be assessed afterwards.

At the time north-east Scotland was just coming under the influence of S.–SW. winds in cold air ahead of a warm front which, at 0600 G.M.T., was oriented north-north-west to south-south-east about 200 miles to the west-south-west of Stornoway. The winds were 290–300° in the warm air aloft.

It is thought that the aircraft may have climbed gently into the upper westerlies for a short time and descended again, or alternatively that there was a slight corrugation in the zone of separation between the lower southerlies and upper westerlies.

The Mintra height† at the time was about 17,000 ft. and the contrail would probably be quite near the cirrus, estimated at 23,000 ft. The length of the

* *Quart J. R. met. Soc., London,* **80,** 1954, p. 174.

† Theoretical minimum height at which condensation trails can form.

distortion on the photographic plate was about 0·4 in. so that the distance of displacement of the trail would be about

$$\frac{23000 \text{ cosec } 25 \times 2\cdot54 \times 12}{10\cdot5} \times \frac{0\cdot4}{12 \times 6080} \text{ nautical miles,}$$

that is about 1 nautical mile in 6–8 min. Thus the vector wind change was at least 8–10 kt. from some westerly direction.

A similar type of effect is shown by the Stornoway 0800 PILAR report which gives: at 14,000 ft. 204° 16 kt., at 16,000 ft. 240° 11 kt., at 18,000 ft. 265° 15 kt. That is a vector change between 14,000 and 18,000 ft. of 325° 16 kt. probably concentrated around 14,000 ft. Assuming an even slope in the frontal surface of about 7,000 ft. in 100 miles, the height of the frontal surface at Wick would be about 21,000 ft. at 0600, thus supporting, to some extent, the theory put forward above.

P. E. PHILLIPS

Pitreavie Castle, Dunfermline, April 28, 1954

Aircraft icing at very low temperatures

A rather interesting case of clear-air icing above the tropopause was experienced recently by Flt-Lt J. Gingell. It occurred during a flight on January 18, 1954 at an indicated height of 40,000 ft. (and a true height of 100–300 ft. below this in the area concerned). The flight had been from the Midlands to the Prestwick area and back, and the icing was first noticed just south of Stranraer at 1345 G.M.T. on the return flight. It was in the form of a thin layer of hoar frost on the leading edge which glistened in the sunshine and did not disperse until the aircraft descended into the lower levels over the Midlands. Flt-Lt Gingell observed that the top of all cirrus and cirrostratus on the ascent had been at 39,000 ft., and there was no cirrus as high as 40,000 ft. during the entire flight. He saw no condensation trails at the flight level, and at least over south Scotland any trails which his aircraft might have been making were non-persistent as none was visible when he turned to fly south; there were persistent trails at 2,000–3,000 ft. below flight level however.

There was a deep depression south-west of Iceland at 1200 G.M.T. on January 18, and a warm front from Stornoway to Anglesey and Devon was moving east at 25 kt. in the north, slowly in the south. There were breaks in the cloud cover over the east Midlands, but from the Mersey northwards there was 8 oktas multilayered frontal cloud over the route. The tropopause height was 40,000 ft. in the vicinity of the Isle of Man, and 37,000 ft. near Prestwick. Winds were 280° 45–55 kt. at the level of flight. Considerable variation existed in the temperature at 200 mb. (38,200–38,500 ft.) and at 170 mb. (41,700–41,800 ft.) as the following data for 1500 G.M.T. show:–

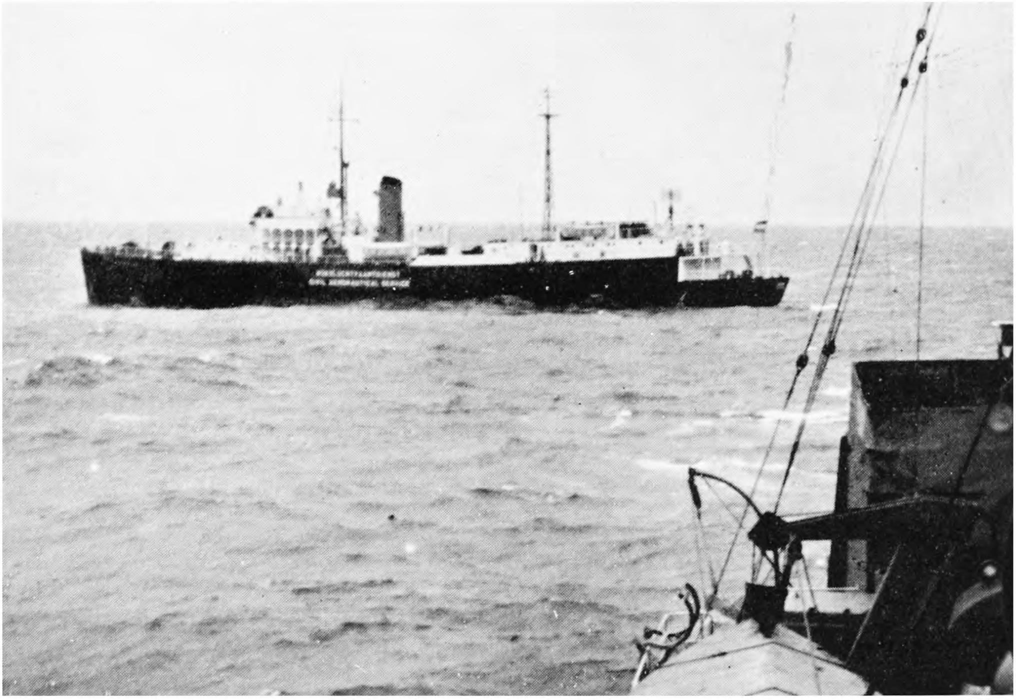
	Liverpool	Aldergrove	Leuchars	Stornaway
		degrees Centigrade		
At 170 mb. ...	−67	−58	−54	−59
At 200 mb.	−68	−63	−53	−63

It is seen that at flight level appreciable differences of temperature existed in places not far separated in distance, and in the neighbourhood of the north Irish Sea and southern Scotland a difference of at least 6°C. could be expected

[To face p. 280

Reproduced by courtesy of Mr. W. Glander

DISTORTION IN A CONDENSATION TRAIL, WICK, 1030 G.M.T., MARCH 2, 1954
(see p. 279)



O.S.V. *Cumulus* AS SEEN FROM O.W.S. *Weather Watcher*
Photograph taken when relieving at station J

CAPT. FORD OF *Weather Recorder* AND CAPT. GROEN OF *Cumulus* WITH SOME OF THEIR STAFFS ABOARD *Cumulus* AT STATION J within the compass of about 50 miles, which could be covered easily in less than 10 min. As the aircraft would take longer than this to attain environmental temperature, part of the flight would be in conditions where the ambient temperature was distinctly warmer than the aircraft, with consequent hoar-ice formation if the frost point were sufficiently high.

G. W. HURST

Wyton, February 22, 1954

Two other instances of aircraft icing at very low temperatures have been reported. On the first occasion, the aircraft was flying from Lyneham to Doncaster at about 1500 G.M.T. on December 1, 1953. Icing, described as hoar or light rime forming at a low rate on the canopy and leading edge of the wings, was encountered for 30 min. at an indicated height of 40,000 ft. while in cirrus cloud. On leaving the cloud the ice formation ceased. The corrected temperature in the cirrus cloud during the encounter and the clear-air temperature on leaving cloud were reported as $-61°$C. and $-65°$C. respectively. Another aircraft from the same station reported icing in clear air in "similar circumstances" on the same day. Precise details of this encounter are not available.

On the second occasion, the aircraft was flying over Bristol between 1000 G.M.T. and 1100 G.M.T. on December 28, 1953. Icing, described as opaque rime forming at a low rate on the canopy, was encountered at an indicated height of 40,000 ft. while in clear air and continued in a climb to 45,000 ft. which was probably the maximum height reached. The corrected air temperatures at 40,000 ft. and 45,000 ft. were reported as $-61°$ and $-52°$C. respectively.

These reports lead to the rather surprising conclusion that water exists in the liquid phase in the free atmosphere at temperatures as low as about $-65°$C. It has been stated by Ludlam[1] that the limit of supercooling, at which crystals grow spontaneously in liquid water without the aid of foreign nuclei, has been roughly estimated theoretically at about $-70°$C. or below, and that Rau appeared to have found this limit experimentally at $-72°$C. As far as is known to the writer, however, the lowest temperature at which aircraft icing in the free atmosphere has been reported previously[2] is $-54°$C. although aircraft-wing icing has been observed at an ambient air temperature of between $-44°$C. and $-58°$C. in a condensation trail formed at the airscrew[3].

J. B. SHAW

London, March 11, 1954

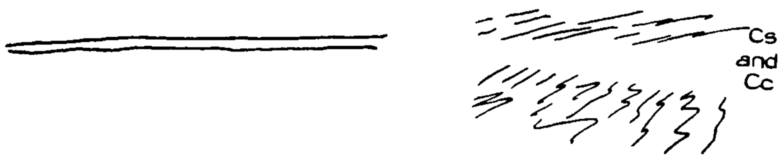
REFERENCES

1. LUDLAM, F. H.; The physics of ice clouds and mixed clouds. Compendium of meteorology. Boston, Mass., 1951, p. 192.
2. BEST, A. C.; Ice accretion in cirrus cloud. *Met. Res. Pap., London*, No. 730, 1952.
3. AANENSEN, C. J. M.; Unusual condensation trails. *Met. Mag., London*, **77**, 1948, p. 17.

Circular condensation trails

Around 1140 G.M.T. on Friday, April 11, 1954, a line of white rings, some incomplete, were seen high in the sky for a short time over Mildenhall and might have been very puzzling had the observer not seen the sequence of events which had led to their formation.

An aircraft, barely visible and estimated to be above 40,000 ft. and still climbing, had cut a wide swathe through a diffuse layer of cirrostratus and cirrocumulus and had then made a very dense double contrail against a background of blue sky:—



The double contrail soon began to expand and after about half a minute began to disperse except for regularly spaced patches:—

Several of the patches were then seen to form into circles, whilst others formed into rough ellipses and other shapes:—

At this stage it was seen that whilst the more diffuse shapes were dispersing the cloud constituting the better-formed circles was actually thickening and forming into hard and nearly annular shapes with clean-cut edges, each one writhing like a smoke ring. The size of each ring would be about a tenth that of the original contrail.

A possible explanation is that the double contrails were formed as counter-rotating vortices which were being broken down by the regular wave motion of the ambient air into dimensions best suited for forming annular vortices.

N. F. HORMBREY

Mildenhall, April 28, 1954

NOTES AND NEWS

"Half-century" of voyages by each of the British ocean weather ships

With the arrival at Greenock of o.w.s. *Weather Explorer* on March 30, 1954, each of the four British ocean weather ships has completed at least 50 voyages to either station I or station J.

During this period several members of the meteorological staff have rendered long service in ocean weather ships. The record is held by Mr. P. G. O. Felton who completed 38 voyages in o.w.s. *Weather Observer*; on leaving the ship he was presented with a suitably inscribed gold pencil. Two other meteorologists have completed 33 voyages and are still serving in the ships; others have completed 28, 27, 25 and 23 voyages, whilst no fewer than 14 of the remainder have completed two tours of duty (18 voyages). Thus a nucleus of seagoing meteorologists is being gradually built up. The Masters of all the ships have served in them continuously and so have 1 Engineer Officer, 3 Radio Overseers, 2 Chief Radio Technicians, 1 Chief Steward, 1 Radio Technician, 1 Radio Operator and 2 Boatswains.

Meteorological observations have been carried out in all weathers and only on rare occasions has a radio-sonde ascent been abandoned. Some of the meteorological teams have released a full-rig radio-sonde in a force 10 wind. Radio-sonde ascents very seldom fail to reach 100 mb. and wind measurements by radar are usually obtained to approximately 50,000 ft. The following meteorological statistics may be of interest:—

	Air temperature Extreme maximum	Air temperature Extreme minimum	Sea temperature Extreme maximum	Sea temperature Extreme minimum	Average number of days of gales	Maximum mean wind speed
	°F.	°F.	°F.	°F.	days/yr.	kt.
Station I ...	61·3	28·0	59·6	45·3	89	68
Station J ...	65·5	35·0	64·0	46·0	89	68

Some of the meteorological staff have become very proficient as voluntary members of the ship's dinghy's crew.

Credit is due to the Chief Engineers and their staffs for their successful endeavours to economize in oil fuel. An average of 8·4 tons/day was used during the first voyage of each ship, whereas the average for each ship's 50th voyage is 6·9 tons/day. At over £7 a ton this means a considerable saving in cost.

A highlight of events during these 200 or more voyages was the attendance of o.w.s. *Weather Explorer* at the Review of the Fleet by Her Majesty the Queen at Spithead in June of Coronation Year.

The periodical air/sea rescue exercises, METHOP, carried out with aircraft of the Royal Air Force Coastal Command, during which mail and newspapers, in Lindholme containers, are dropped to the ship, and, more recently, the weekly MAILDROP by aircraft from the Royal Air Force station, Topcliffe, have not only provided valuable practice in air/sea rescue technique, but have also been a very welcome diversion to the ships' companies. In addition to the personal contacts which have been made at station J with individuals serving aboard Netherlands vessels during the last three summers, opportunity has occurred for an exchange of visits with officers of United States weather ships when, on two occasions, one of these vessels visited Glasgow. These personal exchanges of visits have been valuable both technically and socially.

o.w.s. *Weather Recorder* has been concerned in two search and rescue operations and *Weather Explorer* and *Weather Observer* in one each. On one occasion *Weather Recorder* navigated by radar through the islands off the west coast of Scotland and rescued the crew of a Norwegian ship. On the occasion of the loss of a United States Air Force aircraft over the North Atlantic, *Weather Recorder* was appointed to control the search vessels in the area, and herself recovered the body of the pilot which was subsequently transferred to a United States' ship. During this operation *Weather Recorder* and *Weather Observer*, who relieved her, between them steamed 806 miles. *Weather Explorer* steamed 1,700 miles on her search operation.

Passengers aboard the ships for complete voyages or parts of voyages have included the Deputy Director of the Naval Weather Service, the Marine Superintendent and other members of the Meteorological Office, as well as scientists from universities and other institutes, ornithologists and journalists.

Spare-time activities aboard the ships have included boat sailing and rowing in rubber dinghies, swimming, ornithology, darts, educational classes, model making and shark fishing. The weekly film show is very popular, also reading and card playing.

C. E. N. FRANKCOM

REVIEW

The climates of the continents. 4th edition. By W. G. Kendrew. 8½ in. × 5¼ in., pp. 607, *Illus.*, Geoffrey Cumberlege, Clarendon Press, Oxford, 1953. Price 50*s*. net.

This is a standard textbook, well established among both meteorologists and geographers, in which the principles, set out in Kendrew's equally well known "Climatology", are applied to the climates of the world on a regional basis. The book was first published in 1922 but was soon out of print. A second edition appeared in 1927 and this was reprinted in 1930. A considerably improved third edition was produced in 1937 and this was also reprinted—in 1941, 1944 and 1948. Now we have an even better and bigger fourth edition which, as the preface is dated 1950, might well have appeared earlier than 1953!

For this fourth edition there has been extensive revision to bring the various sections up to date. A discussion of air masses and fronts has been introduced, some specimen synoptic charts have been added, and there are indications of an approach to synoptic climatology. Many new diagrams are given and the climatic data have been improved and expanded, including the addition of new tables of wind direction, diurnal temperature, sunshine, visibility and other elements. However, the framework remains unaltered. This consists essentially of an introductory section giving some general remarks on temperature, precipitation and wind together with an outline of the main features of the distribution of atmospheric pressure and the prevailing winds. Then follow sections dealing with each of the continents. At the beginning of each section there is a chapter relating to the general features (now including the predominant air masses) of the continent or subcontinent, and at the end of each section, divorced from the text, are tables of climatic means. Finally, there are some useful conversion tables, a six-page bibliography and an index of place names and names of local winds.

Throughout the book the author brings out the effect of geographical features and oceanic conditions in conjunction with physical factors in determining local climate. As indicated above, there are now paragraphs describing the predominant air masses, their movement and boundaries and mention is made here and there of the effect of vertical air motion. No attempt is made, however, to depict three-dimensional air flow or to explain the variations of climatic régimes in terms of modern theories of the general circulation of the atmosphere. This is not surprising as, to do this, the climatologist needs the results of meteorological research and, as yet, the field of dynamic climatology has not been fully explored. Although the broad-scale patterns of atmospheric circulation are becoming fairly well established, their precise variation in time and place has still to be determined and explained.

The text is well written and the inclusion of apt quotations and anecdotes—some a bit dated—enables the reader to give local colour to his mental picture of the effect of climate on human activity. In this connexion it would be of current interest to know whether the white community in east Africa would agree with the paragraph discussing the suitability of the climate in that region for white settlement! To assess the accuracy of all the facts which are presented would require a detailed and world-wide knowledge of local climate, a knowledge which the reviewer does not claim to possess. One or two statements would doubtless be disputed by meteorologists in the light of current knowledge of the physics of precipitation and of upper air flow patterns, but, maybe, this points to the need for the geographer and the meteorologist to think in each other's terms.

There are now nearly 200 helpful illustrations but, without being unduly critical as the book is concerned with continental climates, one cannot help noting the lack of a diagram of the main ocean currents to which frequent reference is made. The collection of tables is one of the most useful available. Indeed, the whole book is a gold-mine of information; but it would have been useful, in view of secular changes, if the periods for which the data had been extracted were given. As the author says himself, "no mean, however long the period on which it is based, has absolute validity except for that actual period." The bibliography is quite comprehensive but one notices the omission of some important studies in the field of synoptic climatology. Now that the author has introduced his reader to the conception of air masses and fronts these omissions, it is suggested, ought to be made good in the next edition. The printing and reproduction of the diagrams are of the high standard which one has become accustomed to expect from the Clarendon Press. Students, teachers, travellers, economists and many others will find this a most valuable book to have in their library.

R. G. VERYARD

HONOUR

The following award was also announced in the Birthday Honours List, 1954, in addition to those mentioned in the July 1954 *Meteorological Magazine*:—

Queen's Commendation for Valuable Service in the Air

Flt-Sgt G. N. Franklin, Air Meteorological Observer Leader, Aldergrove.

OBITUARY

Mr. Osmond Bernard O'Sullivan.—It is with regret that we have to record the death of Mr. O. B. O'Sullivan, Senior Experimental Officer, last serving at Lyneham. This occurred on July 9, 1954, his 53rd birthday, as a result of a bicycle accident on July 3 from which he never recovered consciousness.

Mr. O'Sullivan joined the Office in 1921 and served at a number of outstations at home and overseas. His Irish temperament made him a noteworthy character at whichever outstation he served. "OBOS" was universally liked and his many friends will be saddened by the tragic manner of his passing.

METEOROLOGICAL OFFICE NEWS

University Degrees.—We offer our congratulations to Mr. A. C. Best, O.B.E., Assistant Director (Special Investigations), who has been admitted to the degree of D.Sc. in the University of Wales, and to Mr. R. G. Lloyd, Scientific Officer, who has been admitted to the degree of Ph.D. also in the University of Wales.

Horticultural Show.—The Air Ministry Horticultural Society held their Annual Show at Adastral House on July 16. The staff of the Office were represented in all three sections—flowers, fruit and vegetables. Prizes were won by Mr. B. G. Brame (flowers, fruit and vegetables), Miss H. G. Chivers (flowers and fruit) and Mr. H. A. Scotney, Miss D. J. Wordsworth and Miss A. F. Mickleburgh (flowers).

Sports activities.—*Netball.*—The Air Ministry Ladies' Netball Competition for 1954 was won by the Harrow Meteorological Office Ladies' team for the sixth consecutive year. This is a fine achievement particularly as the game is popular in the Air Ministry and competition is keen. The winning team is to be presented with spoons to mark the occasion.

Athletics.—The Air Ministry Annual Sports were held at the White City Stadium on July 14 and marked the end of the year for the competition for the Bishop Shield. The Meteorological Office retained the Shield by a considerable margin of points for the sixth consecutive year—an achievement due entirely to team work. The main contributions to the total number of points were successes in football, netball, athletics and swimming. On Sports Day, Miss K. Newman retained the Ladies' Sprint Championship for the fourth time, Miss M. Jones won the 70 yards and 100 yards Ladies' Handicap, Mr. R. Cohen was second in both the 100 yards and 220 yards Championships, Mr. B. J. Flatley was third in the 440 yards Championship and Mr. J. P. McDonald was third in the One Mile Championship. Mr. McDonald also won the Mile Sealed Handicap. The Office won the Men's Inter-Divisional Relay Championship for the third consecutive year, but the Ladies' Inter-Divisional Relay Championship was lost by a very narrow margin. The Office failed to retain the W. S. Jones Memorial Cup by two points only.

WEATHER OF JULY 1954

Mean pressure was below normal, generally between 1 and 6 mb., in the region extending from Iceland eastward to Scandinavia and south-eastward to central Europe. It was above normal in the Iberian peninsula and in the region of the Atlantic extending westward to the Azores and north-westward to Greenland. The mean pressure over most of the United States was below normal.

The mean temperature was generally 3–5°F. below normal over much of Europe; this is consistent with mean north-westerly winds associated with the mean pressure distribution over Europe.

In the British Isles the weather was notably cool and dull; it was wet in some southern and western areas but in large areas in north-east England and the Midlands and in parts of east and central Scotland rainfall was less than average. Throughout the month an anticyclone was situated near the Azores but at no time did it spread over the British Isles sufficiently to establish fine, warm weather; on almost every day some part of the country at least was under the influence of a low-pressure system. As far as can be estimated at present it was the coolest July since 1922; in particular the days were very cool, at Kew, for example, the mean daily maximum temperature was 6·1°F. below the average, while at Ross-on-Wye the absolute maximum, 70°F., was the lowest on record for July. The duration of bright sunshine was much below average but over the country generally the month was less dull than July 1944.

From the 1st to the 7th the whole country experienced a north-westerly to northerly type of weather beginning with frontal systems moving south-eastward and followed by a depression from Iceland, which became slow moving over the North Sea and Denmark. Cool weather was general throughout this period; the temperature was 10°F. below the average at times locally during the day while during the nights of the 5th and 6th temperature on the ground fell below freezing point in parts of Hampshire and south-west Scotland. Rain or showers occurred each day in many districts and thunderstorms were reported from the 4th to the 6th in widely scattered areas but chiefly in eastern England. There was, however, some sunshine on most days and daily totals rose to more than 12 hr. at a few places from the 4th to the 7th. From the 7th to the 24th pressure was low near Iceland and a number of small but often active depressions moved in some easterly direction across the British Isles. The intervening ridges of high pressure were weak and transitory but they gave some fine, rather warm days, particularly in the south and east; on the 20th temperature rose to 78°F. locally on the east coast. Throughout this period the weather was changeable with some rain or showers in many districts on most days; thunderstorms occurred locally in East Anglia on the 15th. The 16th and 17th were wet days; during the 24 hr. ending at 1700 on the 17th more than an inch of rain was recorded at a number of places in south and south-east England, while 2·14 in. fell at Llangurig, Montgomeryshire and 2·20 in. at Maesteg, Glamorgan in the 24 hr. ending at 0900 on the 17th. On the 23rd heavy rain fell in northern England and southern Scotland, for example, 3·10 in. at Ribblehead in the West Riding of Yorkshire, 2·24 in. at Stonyhurst, Lancashire and 2·22 in. at Blaenau Festiniog, Merionethshire. On the 25th and 26th a deepening depression moved south-east from the south of Iceland and after moving irregularly over Scotland on the 27th moved into the North Sea on the 28th. It was preceded on the 25th and 26th by small disturbances moving eastward across southern England, giving heavy rain in southern counties; more than 2 in. was registered locally in Devon, Dorset, the Isle of Wight and Sussex on the 25th (2·88 in. at Princetown, 2·47 in. at Creech Grange, Dorset and 2·07 in. at Heathfield, Sussex). From the 26th to the 28th there was widespread rain at times in northern England and parts of Scotland and showers in the south, but there were also sunny periods (2·85 in. of rain fell at Watendlath Farm, Cumberland on the 27th). Thunderstorms occurred in places on the 27th and 28th and strong winds, reaching gale force at times, occurred in many parts of England and Wales on the 27th and 28th, western and southern coastal districts being particularly affected. From the 29th onwards weather continued generally cool, with some rain, mainly slight, in Scotland, but also sunny periods especially in the east.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	78	33	−3·5	126	+3	75
Scotland	76	29	−2·3	105	+2	80
Northern Ireland ...	69	41	−2·7	129	+6	66

RAINFALL OF JULY 1954

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	3·01	126	*Glam.*	Cardiff, Penylan ...	4·41	143
Kent	Dover	4·39	208	*Pemb.*	Tenby, The Priory ...	4·22	143
”	Edenbridge, Falconhurst	2·85	124	*Radnor*	Tyrmynydd	4·74	115
Sussex	Compton, Compton Ho.	4·13	146	*Mont.*	Lake Vyrnwy	6·77	190
”	Worthing, Beach Ho. Pk.	4·06	199	*Mer.*	Blaenau Festiniog ...	15·64	184
Hants.	Ventnor Cemetery ...	5·13	249	”	Aberdovey	5·12	146
”	Southampton, East Pk.	2·60	114	*Carn.*	Llandudno	2·54	113
”	South Farnborough ...	2·32	114	*Angl.*	Llanerchymedd ...	3·95	138
Herts.	Royston, Therfield Rec.	3·10	123	*I. Man*	Douglas, Borough Cem.	3·51	115
Bucks.	Slough, Upton	2·69	140	*Wigtown*	Newton Stewart ...	4·94	157
Oxford	Oxford, Radcliffe ...	2·18	92	*Dumf.*	Dumfries, Crichton R.I.	2·95	90
N'hants.	Wellingboro' Swanspool	2·76	121	”	Eskdalemuir Obsy. ...	5·30	129
Essex	Shoeburyness	2·34	128	*Roxb.*	Crailing	2·64	91
”	Dovercourt	1·98	99	*Peebles*	Stobo Castle	3·91	135
Suffolk	Lowestoft Sec. School ...	1·75	77	*Berwick*	Marchmont House ...	2·36	77
”	Bury St. Ed., Westley H.	3·32	133	*E. Loth.*	North Berwick Res. ...	2·22	86
Norfolk	Sandringham Ho. Gdns.	2·98	116	*Midl'n.*	Edinburgh, Blackf'd. H.	1·69	60
Wilts.	Aldbourne	2·28	96	*Lanark*	Hamilton W. W., T'nhill	2·90	101
Dorset	Creech Grange... ...	4·43	181	*Ayr*	Colmonell, Knockdolian	4·31	137
”	Beaminster, East St. ...	2·61	100	”	Glen Afton, Ayr San. ...	4·79	114
Devon	Teignmouth, Den Gdns.	2·13	91	*Renfrew*	Greenock, Prospect Hill	3·38	91
”	Ilfracombe	4·77	188	*Bute*	Rothesay, Ardencraig ...	5·09	129
”	Princetown	8·91	166	*Argyll*	Morven, Drimnin ...	3·90	88
Cornwall	Bude, School House ...	4·73	193	”	Poltalloch	5·66	137
”	Penzance, Morrab Gdns.	3·86	142	”	Inveraray Castle ...	5·05	101
”	St. Austell	4·40	131	”	Islay, Eallabus	5·66	166
”	Scilly, Tresco Abbey ...	3·35	151	”	Tiree	3·02	83
Somerset	Taunton	2·01	95	*Kinross*	Loch Leven Sluice ...	2·92	101
Glos.	Cirencester	2·68	104	*Fife*	Leuchars Airfield ...	1·55	60
Salop	Church Stretton ...	2·98	113	*Perth*	Loch Dhu	3·61	75
”	Shrewsbury, Monkmore	2·41	115	”	Crieff, Strathearn Hyd.	2·48	84
Worcs.	Malvern, Free Library...	2·60	114	”	Pitlochry, Fincastle ...	2·57	96
Warwick	Birmingham, Edgbaston	4·10	177	*Angus*	Montrose, Sunnyside ...	2·19	83
Leics.	Thornton Reservoir ...	2·21	89	*Aberd.*	Braemar	2·30	89
Lincs.	Boston, Skirbeck ...	1·99	90	”	Dyce, Craibstone ...	2·74	90
”	Skegness, Marine Gdns.	1·54	71	”	New Deer School House	3·17	104
Notts.	Mansfield, Carr Bank ...	1·79	68	*Moray*	Gordon Castle	3·07	96
Derby	Buxton, Terrace Slopes	6·43	164	*Nairn*	Nairn, Achareidh ...	3·00	118
Ches.	Bidston Observatory ...	2·61	101	*Inverness*	Loch Ness, Garthbeg ...	3·01	95
”	Manchester, Ringway...	3·79	136	”	Glenquoich	5·45	86
Lancs.	Stonyhurst College ...	8·07	209	”	Fort William, Teviot ...	3·51	72
”	Squires Gate	4·41	159	”	Skye, Broadford ...	4·18	76
Yorks.	Wakefield, Clarence Pk.	1·63	64	”	Skye, Duntuilm ...	3·41	91
”	Hull, Pearson Park ...	1·94	83	*R. & C.*	Tain, Mayfield ...	4·23	155
”	Felixkirk, Mt. St. John...	2·78	102	”	Inverbroom, Glackour...	5·76	155
”	York Museum	2·05	81	”	Achnashellach	5·21	107
”	Scarborough	1·55	64	*Suth.*	Lochinver, Bank Ho. ...	5·45	180
”	Middlesbrough... ...	1·65	64	*Caith.*	Wick Airfield	3·11	118
”	Baldersdale, Hury Res.	2·32	79	*Shetland*	Lerwick Observatory ...	3·16	138
Norl'd.	Newcastle, Leazes Pk....	1·99	78	*Ferm.*	Crom Castle	4·27	123
”	Bellingham, High Green	3·52	107	*Armagh*	Armagh Observatory ...	4·61	160
”	Lilburn Tower Gdns. ...	2·17	88	*Down*	Seaforde	3·59	113
Cumb.	Geltsdale	5·09	148	*Antrim*	Aldergrove Airfield ...	3·60	129
”	Keswick, High Hill ...	5·45	142	”	Ballymena, Harryville...	3·99	116
”	Ravenglass, The Grove	5·46	145	*L'derry*	Garvagh, Moneydig ...	3·42	106
Mon.	A'gavenny, Plâs Derwen	1·32	49	”	Londonderry, Creggan	4·12	112
Glam.	Ystalyfera, Wern House	6·76	147	*Tyrone*	Omagh, Edenfel ...	5·93	174

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

Wt-34. K16

M.O. 581 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 83, No. 988, OCTOBER 1954

A KATA-FRONT OF NOTABLE STRUCTURE

By M. K. MILES, M.Sc.

A cold front which crossed England on July 6, 1953, seems worthy of attention on account of the way in which warm and very dry air came in at medium levels ahead of the surface front.

At 0200 G.M.T., when the surface front was near the Isle of Man lying approximately north-east to south-west, the Liverpool radio-sonde observation showed very dry air above a weak inversion at 650 mb. Below, the air was fairly moist with a very steep humidity lapse near 650 mb. The Hemsby 0200 observation showed fairly moist air at all levels, with a slight increase of humidity above 700 mb. (see Figs. 1 and 2).

At 1400 when the surface front was lying from the Wash to Pembroke (see Fig. 3) the Crawley radio-sonde observation showed a similar structure, moist air to 750 mb. and then a very rapid decrease of humidity. The temperature of the very dry air was in both cases the same or a little higher than that of the moist air at Hemsby.

The rear edge of the rain belt (about 100 miles wide) was at least 100 miles ahead of the surface front at 0200, and, later, clearances occurred as much as 150 miles ahead. At some places rain began again, but at no time was there rain nearer than 100 miles to the front.

The vertical structure of the atmosphere near the front may be represented schematically as in Fig. 4. The boundary of the dry air must be supposed to slope upwards nearly vertically just east of Liverpool since Hemsby showed no sign of it, and in the moderate rain reported at Manchester at 0100 saturated air must have reached to 500 mb. at least. This nearly vertical boundary appears to have been nearly parallel to the surface front since it can be assumed almost coincident with the back edge of the rain area. The wind field at 600 mb. is consistent with this inference. The fluctuation of the edge of the rain belt may indicate that there was some oscillation of this boundary.

The components of the winds normal to the surface front indicate relative forward motions of about 7 kt. at 600 mb. and 19 kt. at 500 mb. at Liverpool, but at Hemsby the air was moving slower than the front up to 400 mb. Over-running is shown at Aldergrove, beginning at 700 mb. and increasing with height. It is also noteworthy that a wind veer occurred at 700 mb. and above before the passage of the surface front at Liverpool, Hemsby and Crawley.

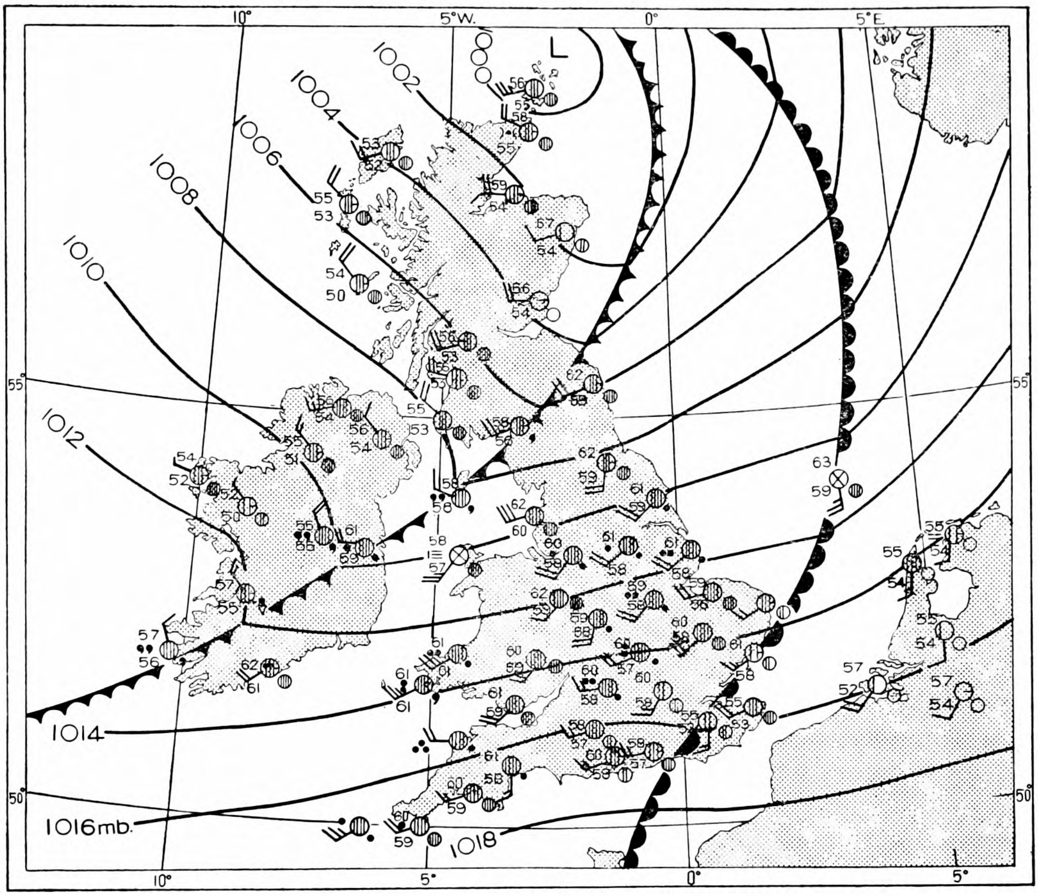


FIG. 1—SYNOPTIC CHART, 0200 G.M.T., JULY 6, 1953

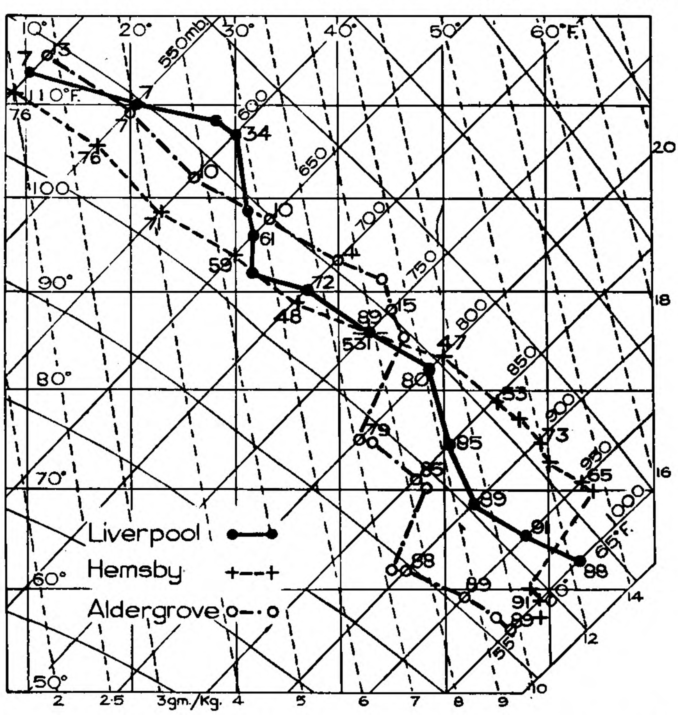


FIG. 2—TEPHIGRAM OF RADIO-SONDE ASCENTS, 0200 G.M.T., JULY 6, 1953
The figures at the side of the curves give the observed relative humidity.

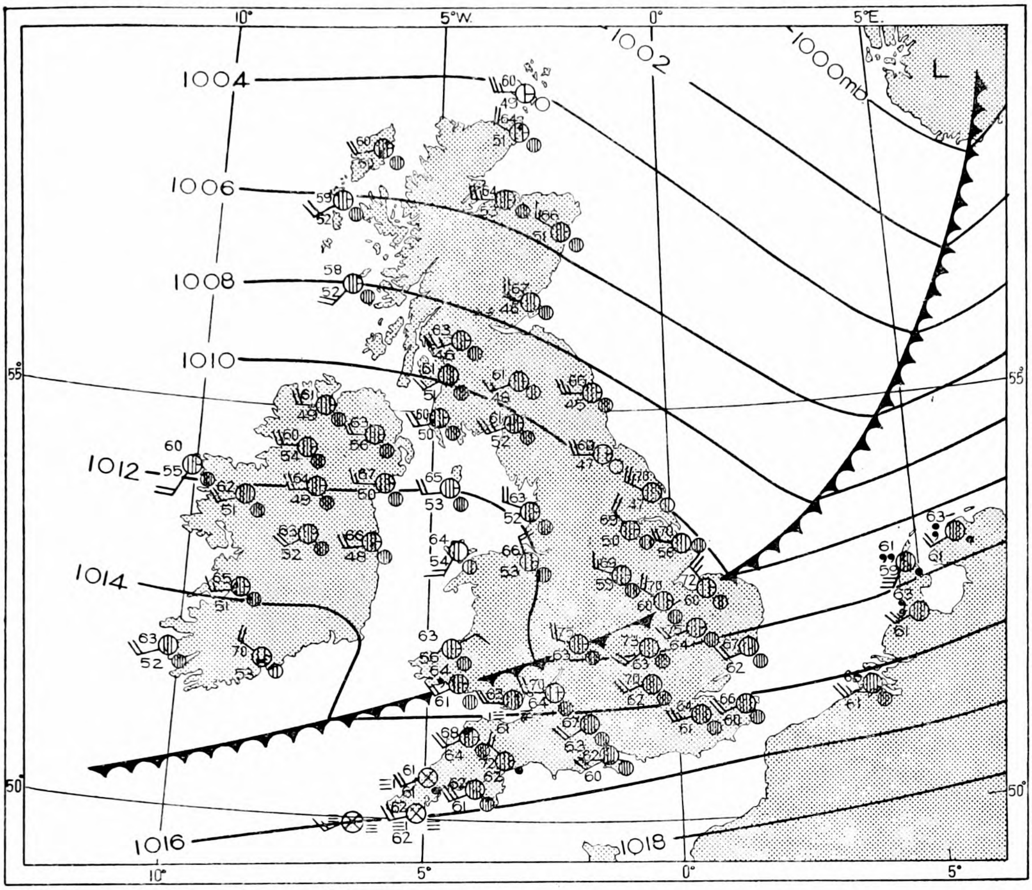


FIG. 3—SYNOPTIC CHART, 1400 G.M.T., JULY 6, 1953

The wind and temperature distributions at Aldergrove are typical of those behind kata-fronts as found by Sansom[1]. The Liverpool sounding was not typical for places 100 miles ahead, where Sansom usually found moist air. However, it is quite common for rain to cease for distances of up to 50 miles ahead of kata-fronts, and in these cases it may be presumed that drier air is coming in aloft ahead of the surface cold air. This case, then, may be thought of as an extreme example of this forward over-running.

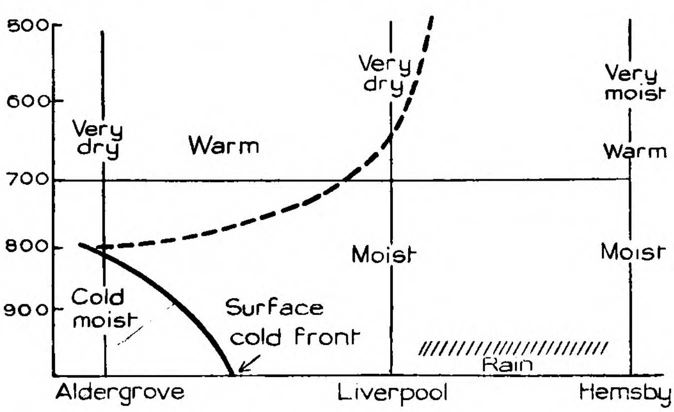


FIG. 4—SCHEMATIC STRUCTURE OF THE COLD FRONT
0200 G.M.T., July 6, 1953

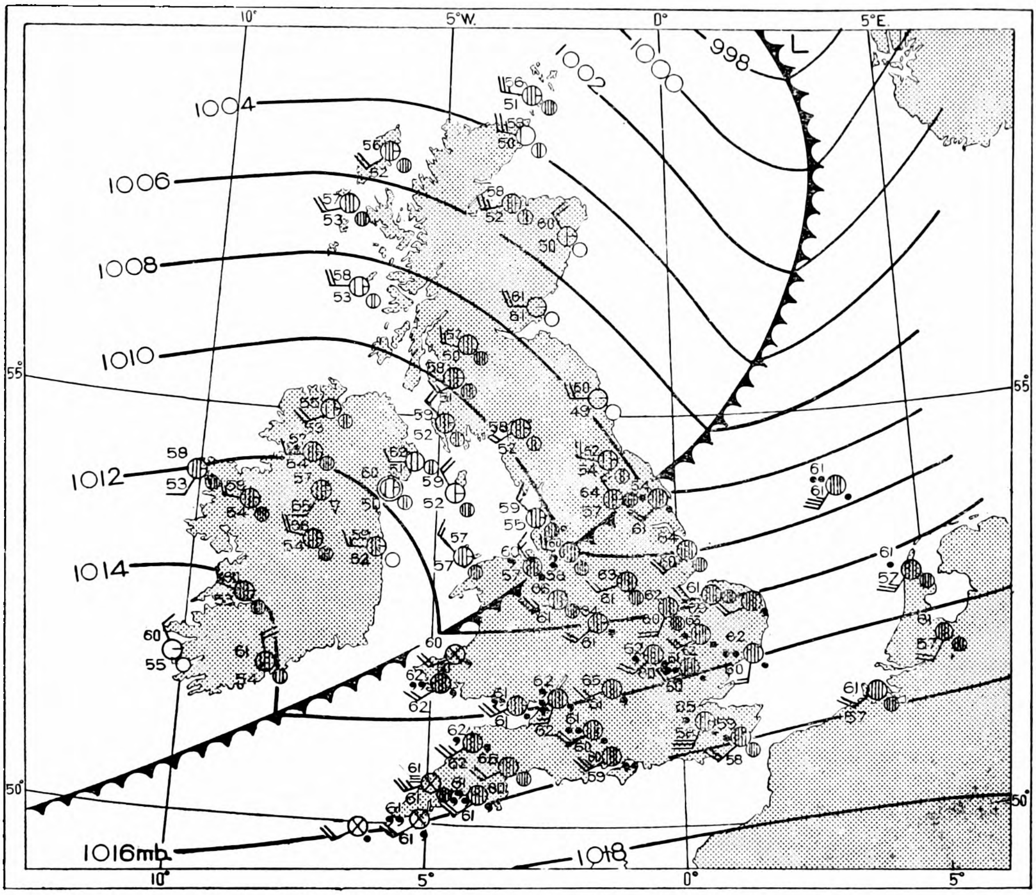


FIG. 5—SYNOPTIC CHART, 0800 G.M.T., JULY 6, 1953

It is interesting to notice that this front was very well defined at the surface. The dew points on the two sides differed by 8–10°F., wind veers of about 90° occurred and there was a sharp isobaric trough (see Fig. 5). This has enabled the estimates of wind normal to the front to be made with some confidence, but the chief interest of the situation lies in the apparent dissociation of this well marked surface front from events in the upper air. All the dynamical activity occurred about 100 miles ahead of it, i.e. the change in the field of vertical motion indicated by the cessation of rain and the humidity change, and this was approximately associated with the wind veer above 700 mb. noted above. The isobaric structure at the surface can be accounted for by the hydrostatic effect of a wedge of air about 5°F. colder and reaching a maximum depth of about 6,000 ft., and this the upper air ascents show to have actually existed.

Two interesting questions then remain. What controls the dynamical aspect of the front as opposed to the hydrostatic? How are we to classify this warm but dry air that lies above, and goes forward more or less independently of, the shallow cold wedge?

It is suggested that here it was the advance of an intensifying trough, little more than 30° of longitude to the west, that affected the dynamics of the front. The relevant flow pattern can be seen clearly on the 300-mb. chart for 0200 G.M.T. (Fig. 6). The contour ridge up wind from this frontal trough over the British Isles is little more than 15° of longitude away. With the prevailing flow

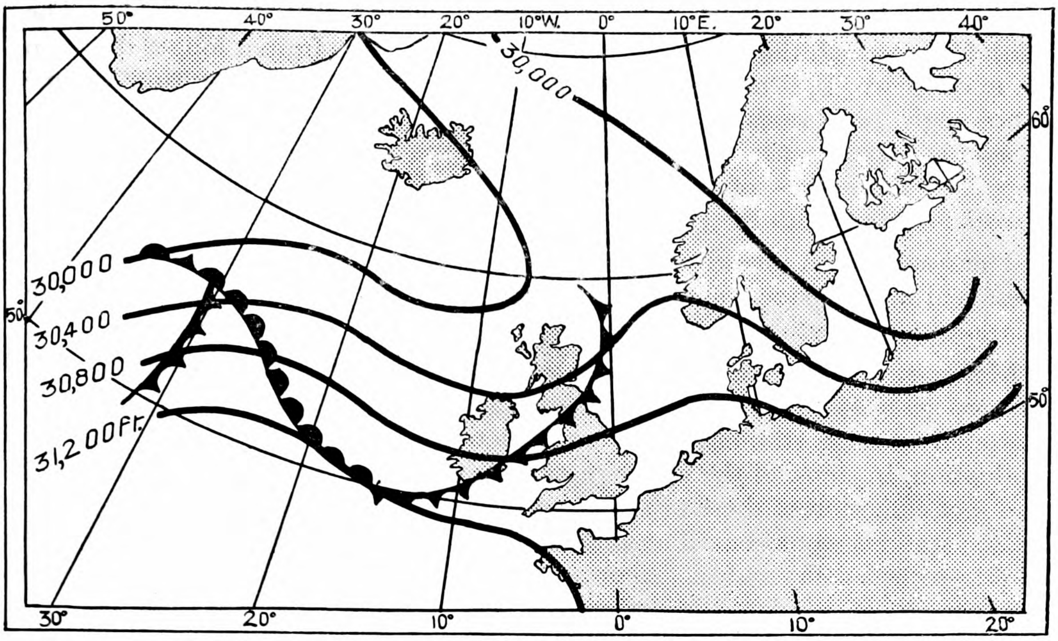


FIG. 6—300-MB. CONTOURS, 0200 G.M.T., JULY 6, 1953

The surface frontal system is indicated by the usual symbols.

(106 kt. at 300 mb. at ocean weather station J) this short wave-length implies considerable ageostrophic motion causing an acceleration and perhaps a weakening of the down-wind trough. At lower levels where the zonal flow is less there would be less or even no acceleration and the upper trough would thus get ahead of the surface front. The acceleration (and weakening) of the upper trough would probably be accompanied by dynamical warming of the southern and western parts of the associated thermal trough[2]. This would lead to the existence behind the upper trough line of dry subsided air, and this, it is suggested, is the air encountered above 650 mb. at Liverpool at 0200 and above 700 mb. at Crawley at 1400. The dry air should on this hypothesis be classified as subsided cold air—a description consistent with the low wet-bulb potential temperatures observed.

REFERENCE

1. SANSOM, H.; A study of cold fronts over the British Isles. *Quart. J. R. met. Soc., London*, **77**, 1951, p. 96.
2. MILES, M. K.; Influence of a quasi-stationary long-wave pattern on small-scale thermal features (in the press).

ONE ASPECT OF THE PATTERN OF RAINFALL

By A. B. THOMSON, M.A.

A glance at the appropriate tables in the annual volumes of *British Rainfall* shows that, if a reasonably long period is taken, rain anywhere in the British Isles falls at a mean rate (i.e. total amount divided by its duration) which is very nearly constant, a fact which is not as well known amongst meteorologists as it deserves to be. To give one example; in 1951, 66·74 in. of rain fell during the 12 months at Eskdalemuir (Dumfriesshire) in 1,380 hr. The corresponding figures for Mildenhall (Suffolk) were 26·63 in. in 581 hr. The respective mean rates of rainfall were 0·048 and 0·046 in./hr. The popular belief that rainfall is more intense in the western Highlands of Scotland, say, than in the drier areas of the east is not supported by the mean-intensity records available. The truth is that much the greater part of the excess results from a longer duration or, in other words, it merely rains longer in the Highlands. From time to time exceedingly high rates of rainfall do, of course, occur and, being of great economic importance, receive considerable space in the volumes of *British Rainfall.* They are infrequent, however, and will not appreciably affect statistics dealing with the general distribution pattern of rainfall.

The results of an investigation into one aspect of the question of "pattern" is presented in this paper, namely the incidence of amount of rain in an hour in relation to locality, season and total rainfall.

Method.—Tables in an article on the distribution of rainfall in the *Meteorological Magazine*[1] showed the constancy of distribution over four widely scattered coastal stations. The construction of these tables involved the evaluation, in steps, of the duration of rates of rainfall greater than r mm./hr., and any extension of these tables to cover a period of several years at suitably chosen stations would entail an immense expenditure of time in the evaluation of rain-recorder charts. In the present investigation the more easily obtained number, N, of tabulated hours with r mm. or more has been used. Within limits, a statistical relationship between N, r and R (the total rainfall) can be found.

Data.—For each of the stations listed in Table I the number, N, was ascertained for various values of r, and the ratio R/N calculated, R being the total monthly or annual rainfall recorded in millimetres. It was not felt justifiable to evaluate monthly values of R/N for a period of less than 5 yr. except for $r \geqslant 0\cdot1$ mm./hr. The results are set out in Tables II and III.

Conclusions.—For periods of 5–6 yr. there is good agreement in the monthly ratios up to $r \geqslant 2$ mm./hr. or $r \geqslant 3$ mm./hr., and in the annual ratios up to $r \geqslant 4$ mm./hr. At Leuchars and Valentia the annual ratios for $r \geqslant 5$, 6,

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

Station	Period	r or more millimetres of rain 0·1	1·0	2·0	3·0	4·0	5·0	6·0	7·0	Total recorded rainfall
		number of hours								mm.
Wick	1948–52	6,644	1,274	368	130	50	28	14	10	4,039·5
Leuchars	1936–40, 1945–52	13,085	2,818	971	407	202	105	56	38	9,074·8
Glasgow, Renfrew	1948–52	6,914	1,726	582	235	107	51	36	19	5,157·6*
Prestwick	1947–52	7,467	1,765	607	242	120	54	27	11	5,403·3†
Valentia	1922–37	29,004	7,226	2,912	1,334	630	337	175	101	22,726·0
Orkney, Grimsetter	1951	1,675	326	84	27	10	5	4	0	1,023·1
Aberdeen, Dyce	1951	1,292	314	114	53	27	18	10	7	977·2
Edinburgh, Turnhouse	1951	1,063	270	95	32	19	11	6	4	797·4
West Freugh	1951	1,276	351	122	52	22	6	4	0	997·9
Eskdalemuir	1935	1,826	520	192	81	39	22	9	5	1,523·6
Kew	1935	870	204	85	34	15	7	4	1	651·9

* Excluding January and February 1948.

† Excluding February and March 1947 and December 1950.

TABLE II—MONTHLY VALUES OF R/N

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
						$r \geqslant 0{\cdot}1$ mm./hr.							
Wick	0·6	0·5	0·7	0·5	0·5	0·6	0·7	0·9	0·6	0·6	0·6	0·6	0·6
Leuchars	0·6	0·6	0·6	0·5	0·7	0·6	0·9	0·9	0·9	0·7	0·7	0·6	0·7
Renfrew	0·7	0·7	0·6	0·7	0·7	0·7	0·8	0·9	0·9	0·8	0·7	0·7	0·7
Prestwick	0·6	0·6	0·6	0·7	0·7	0·7	0·8	1·0	0·9	0·8	0·7	0·6	0·7
Valentia	0·9	0·7	0·7	0·7	0·7	0·8	0·8	0·8	0·8	0·7	0·8	0·8	0·8
Grimsetter	0·6	0·5	0·6	0·6	0·3	0·5	0·7	0·7	0·4	0·6	0·7	0·6	0·6
Dyce...	0·7	0·7	0·5	0·5	0·5	0·7	1·2	0·8	0·6	0·8	1·2	0·8	0·8
Turnhouse	0·8	0·6	0·6	0·6	1·0	0·9	1·0	1·1	0·4	0·4	0·8	0·6	0·8
West Freugh ...	0·7	0·5	0·7	0·6	0·9	0·7	0·7	0·9	0·8	0·6	1·0	0·9	0·8
Eskdalemuir ...	0·6	0·9	0·6	1·0	1·0	0·8	0·6	1·1	1·1	0·9	0·8	0·5	0·8
Kew	0·4	0·7	0·4	0·7	0·6	0·8	2·1*	1·3	0·8	0·7	0·8	0·5	0·7
						$r \geqslant 1{\cdot}0$ mm./hr.							
Wick	3·1	2·5	2·9	3·7	3·3	3·2	3·3	3·3	3·4	3·4	3·0	3·6	3·2
Leuchars	3·1	3·4	3·3	3·6	2·9	3·6	3·2	3·2	3·5	3·2	2·9	3·4	3·2
Renfrew	2·7	3·1	2·7	3·7	2·8	3·2	3·1	3·2	3·2	2·8	2·9	2·9	3·0
Prestwick	3·0	3·2	2·8	3·0	3·0	3·1	3·3	3·5	2·9	3·3	2·8	3·1	3·1
Valentia	3·1	3·0	3·1	3·1	3·0	3·3	3·2	3·3	3·2	3·1	3·2	3·2	3·1
						$r \geqslant 2{\cdot}0$ mm./hr.							
Wick	11·8	16·1	12·5	8·4	15·2	10·6	10·2	8·1	11·5	11·8	14·2	11·8	11·0
Leuchars	10·9	19·5	12·6	13·5	8·3	10·1	7·4	7·2	9·0	7·9	8·1	13·3	9·3
Renfrew	9·8	10·0	11·6	12·9	10·0	9·1	7·1	8·3	7·5	7·7	9·4	8·8	8·9
Prestwick	10·2	11·4	13·8	12·6	9·2	8·1	8·1	7·3	6·8	8·8	7·7	10·5	8·9
Valentia	7·5	8·1	8·3	8·6	8·4	8·4	6·8	7·9	7·7	8·3	7·7	7·3	7·8
						$r \geqslant 3{\cdot}0$ mm./hr.							
Leuchars	35·7	71·6	29·9	30·3	25·3	22·8	14·2	11·6	14·3	16·1	29·0	58·2	22·3
Valentia	16·6	18·3	20·1	20·9	24·5	15·5	14·6	14·5	18·2	18·5	15·1	16·0	17·0
						$r \geqslant 4{\cdot}0$ mm./hr.							
Leuchars	99·1	214·8	209·4	72·8	44·6	61·5	25·1	22·6	23·9	39·1	73·7	106·8	44·9
Valentia	31·7	46·4	43·4	60·0	55·0	32·8	27·4	26·2	36·2	40·6	33·6	36·7	36·1

* A fall of 21·4 mm. in one hour accounted for more than half the month's total rainfall.

7 mm./hr. compare not unsatisfactorily. The monthly figures indicate a seasonal variation at some of the stations, but whether this and the high values of $r \geqslant 2, 3, 4$ mm./hr. at Wick and Grimsetter are real is not certain.

The formula (by least squares),

$$\frac{R}{N} = 0{\cdot}291 \times 10^{1{\cdot}063\sqrt{r}}$$

or

$$\log \frac{R}{N} = 1{\cdot}063\sqrt{(r)} - 0{\cdot}536,$$

where R and r are in millimetres, gives a reasonably good fit to the observed Valentia data up to $r \geqslant 5$ mm./hr. or $r \geqslant 6$ mm./hr. (see Table III). The

TABLE III—ANNUAL VALUES OF R/N

	r or more millimetres of rain							
	0·1	1·0	2·0	3·0	4·0	5·0	6·0	7·0
Wick	0·6	3·2	11·0	31·1	80·8	...	...	...
Leuchars ...	0·7	3·2	9·3	22·3	44·9	86·4	162·1	238·8
Renfrew ...	0·7	3·0	8·9	22·1	48·2	...	...	...
Prestwick ...	0·7	3·1	8·9	22·3	45·0	...	...	...
Valentia ...	0·8	3·1	7·8	17·0	36·1	67·4	130·0	227·0
Grimsetter ...	0·6	3·1	12·2	36·9	102·3	...	...	...
Dyce	0·8	3·1	8·7	18·4	36·2	...	...	...
Turnhouse ...	0·8	3·0	8·4	24·9	42·0	...	...	...
West Freugh ...	0·8	2·8	8·2	19·2	45·4	...	...	...
Eskdalemuir ...	0·8	2·9	7·9	18·8	39·1	...	...	...
Kew	0·7	3·2	7·7	19·2	43·5	...	...	...
Theoretical R/N, Valentia	0·6	3·4	8·9	20·2	38·9	69·3	116·7	189·1

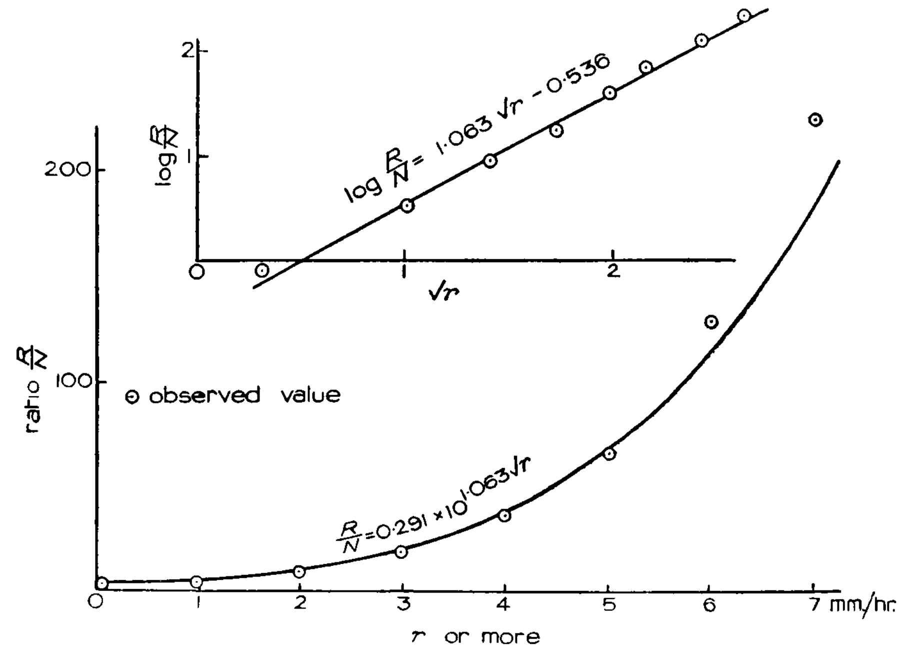


FIG. I—HOURLY RAINFALL AT VALENTIA, 1922–37

theoretical curves for Valentia are shown on Fig. 1. If this formula holds for all stations in the British Isles, then the total rainfall, *R*, will determine the number of tabular hours, *N*, on which not less than *r* mm. of rain will fall.

Reference was made above to the small variation over the British Isles of the mean rate of rainfall, i.e. the ratio of total rainfall to the actual time during which it rains is nearly constant. Table II shows that at all the stations the number of tabular hours in which rain falls (0·1 mm. or more) is very nearly $1\frac{1}{3}$ times the total rainfall measured in millimetres.

A similar relationship between *R*/*N* and $\sqrt{r}$ seems to hold at Poona. Table IV was compiled from data published by Narasimhan and Zafar[2] for the 10-yr. period 1930–39.

TABLE IV—MEAN NUMBER OF HOURS, *N*, A YEAR WITH *r* IN. (OR MM.) OR MORE RAIN AT POONA, 1930–39

Mean annual rainfall 27·7 in. (703·6 mm.)

r in. or more	0·01	0·06	0·11	0·16	0·21	0·26	0·31	0·36	0·41	0·46	0·51
r mm. or more	0·25	1·52	2·79	4·06	5·33	6·60	7·87	9·14	10·41	11·68	12·95
N (hr.)	443·5	109·5	59·8	40·1	28·4	22·1	17·7	14·0	10·3	8·5	6·9
Observed *R*/*N*	1·6	6·4	11·8	17·6	24·9	31·9	39·9	51·0	68·3	83·0	102·3
Theoretical *R*/*N*	2·0	5·3	9·5	14·8	21·8	30·7	41·9	55·7	72·5	93·3	118·3

The observed values of *R*/*N*, and the theoretical values calculated from the formula (by least squares) connecting *N*, *R* and *r* (*R* and *r* in millimetres),

namely $$\frac{R}{N} = 1\cdot05 \times 10^{0\cdot57\sqrt{r}}$$

or $$\log\frac{R}{N} = 0\cdot02 + 0\cdot57\sqrt{r},$$

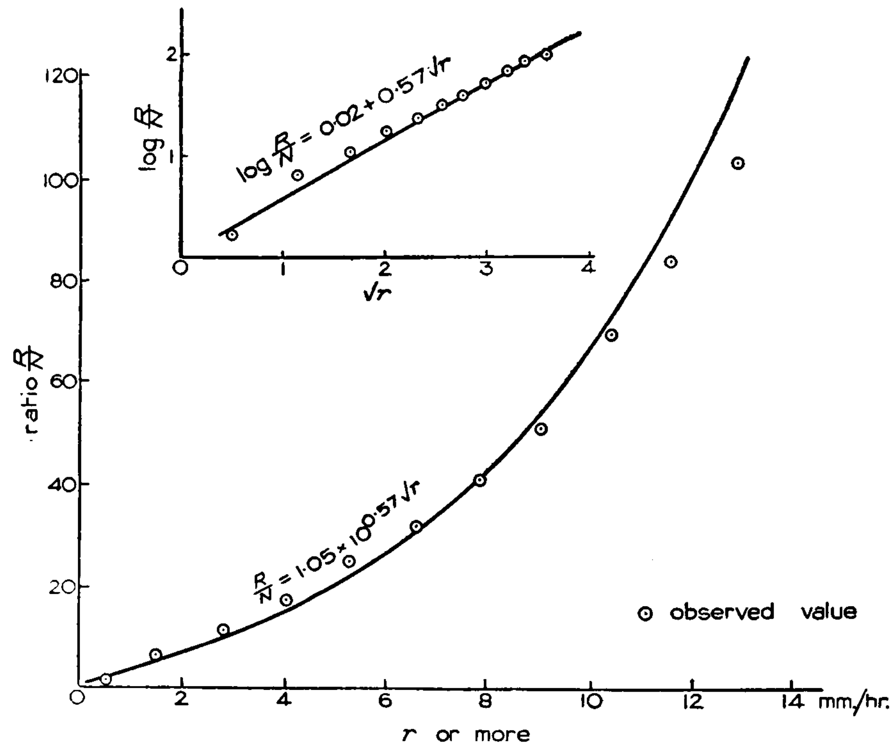


FIG. 2—HOURLY RAINFALL AT POONA, 1930–39

are appended to Table IV and the theoretical curves for Poona are shown in Fig. 2.

REFERENCES

1. MCCONALOGUE, D. J.; On the distribution of rainfall rates at some coastal stations in the British Isles. *Met. Mag., London*, **82**, 1953, p. 304.

2. NARASIMHAN, V. L., and ZAFAR, M.; An analysis of the hourly rainfall records at Poona. *Sci. Notes met. Dep. India, Simla*, **9**, No. 110, 1947, p. 93.

SURFACE TEMPERATURE AND VAPOUR PRESSURE AT LONDON AIRPORT

By N. E. DAVIS, M.A.

Surface temperature.—Statistics relating to the mean daily maximum and minimum temperature for each month are available for most weather observing stations together with the highest and lowest recorded. In addition, values may be given of the mean monthly maximum and minimum, i.e. the highest (or lowest) in any particular month averaged for that month over a number of years. At observatories values of the means for each hour for each month are also published. However such statistics in no way fully describe the variation of temperature at a place. Curves showing the diurnal variation of hourly mean temperature and the diurnal variation of standard deviation about the hourly means give a much better representation of the temperature régime at a place, a representation which, although not entirely complete, is sufficient for most purposes and allows adequate comparison of the temperature at different places.

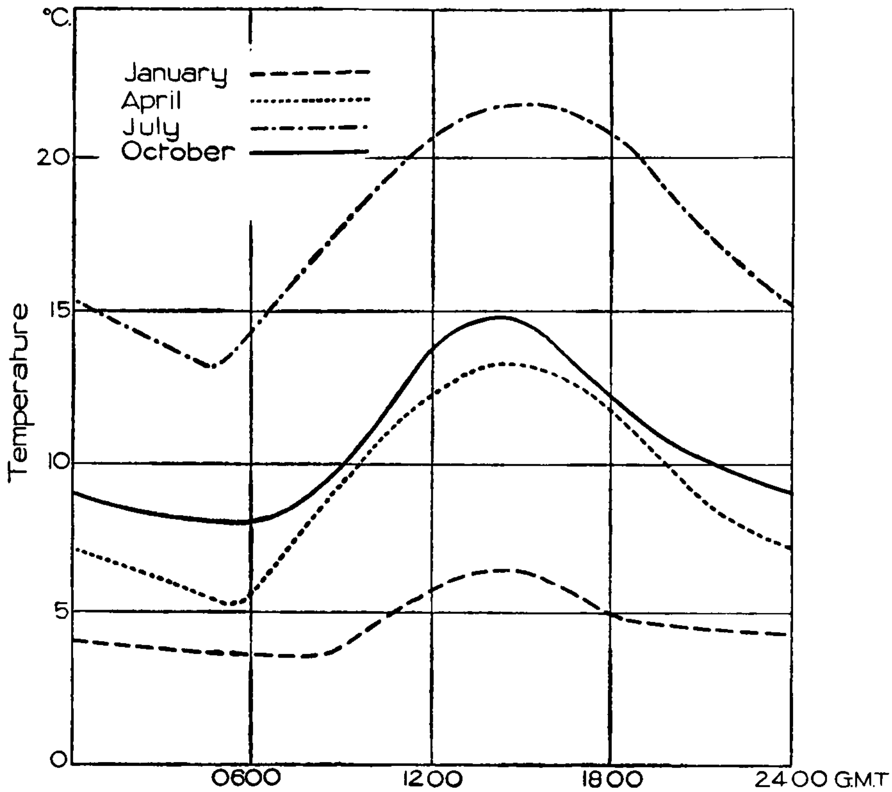


FIG. 1—DIURNAL VARIATION OF TEMPERATURE AT LONDON AIRPORT

A curve showing the diurnal variation of hourly mean temperature may be constructed by taking the mean for each hour or as many hours as are available over a particular month for a number of years and drawing a smooth curve through the values so obtained. The temperature at any particular time of day however varies from day to day, and this may be shown by calculation of the standard deviation of the temperature about its mean for a particular hour for a particular month. The values thus calculated vary from hour to hour and may be presented by means of a curve drawn through the values.

At London Airport the diurnal curves of mean temperature for the four months January, April, July and October are given in Fig. 1 and the diurnal curves of standard deviation for the same months are given in Fig. 2. These curves are derived from observations of temperature at the main observing hours, 0000, 0300, 0600, 0900, 1200, 1500, 1800 and 2100 G.M.T. over the five years 1947–51, inclusive. Means and standard deviations for each of these hours for each month were calculated separately and smooth curves were drawn through the calculated values.

The most remarkable feature of these two sets of curves is that although the diurnal curve of mean temperature is at a much higher average level in July than it is in January, the standard deviation curves show little annual variation in general level. The prime reason for this is that the polar front is active over Great Britain throughout the year—in no month does one air mass predominate to the exclusion of the others. The reason for the standard deviation at night

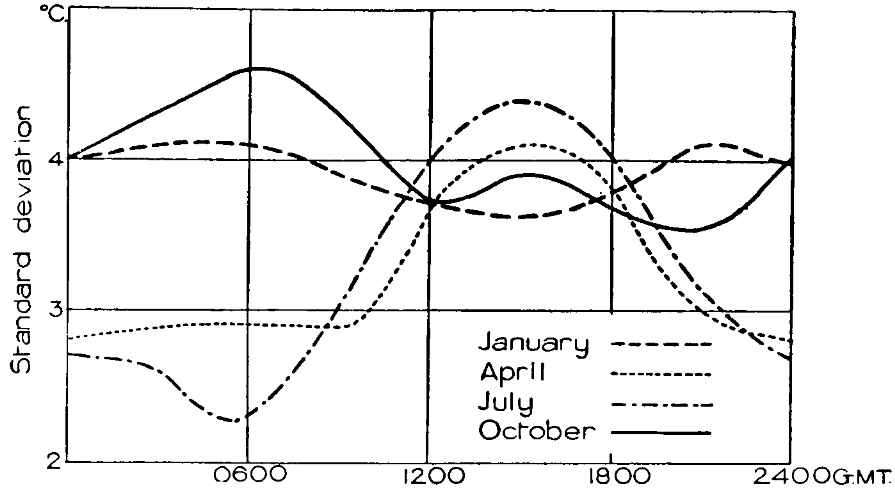


FIG. 2—DIURNAL VARIATION OF THE STANDARD DEVIATION OF TEMPERATURE AT LONDON AIRPORT

being greater in January and October than in April and July will become apparent after discussion of the shapes of the individual curves.

The significant features of the individual curves are as follows:—

In January:

(*a*) the small diurnal range of temperature

(*b*) the maximum standard deviation at about the time of minimum temperature and a minimum standard deviation at about the time of maximum temperature

(*c*) the small fall of temperature during the night hours.

In April:

(*a*) a greater diurnal range of temperature compared with January

(*b*) a maximum standard deviation at the time of maximum temperature.

In July:

(*a*) a maximum diurnal range

(*b*) a maximum standard deviation at about the time of maximum temperature and a minimum at about the time of minimum temperature

(*c*) the time of maximum temperature delayed until 1500 or 1600.

In October:

(*a*) a smaller diurnal variation of temperature than in April but still more than in January

(*b*) a maximum standard deviation at the time of minimum temperature and a secondary maximum at the time of maximum temperature

(*c*) a slow rise of temperature after sunrise.

These features are to be explained in the main by consideration of the amounts of cloud or fog normally associated with each type of air mass, the velocity of the wind and the amount of insolation. Average day-time cloud cover does not vary much from month to month, averaging about 6 oktas throughout the year. Hence the diurnal range of temperature which depends on the amount of incoming radiation should be greatest in July and least in January, while that of April should be greater than that of October. Over the period under consideration 1947–51, however, April was probably rather less cloudy than usual so that the diurnal variation was rather larger than one would expect.

In any type of air mass except with E. and SE. winds the temperature at London Airport tends to approach the temperature of the surrounding seas by day or night whenever there is sufficient cloud cover to keep incoming or outgoing radiation to a minimum or sufficient surface wind, and consequent turbulence, near the ground to minimize the effects of radiation. With E. or SE. winds, owing to the shorter sea track, the air tends to retain the temperature characteristic of its continental source. Hence at London Airport the larger departures of temperature from the sea temperature will normally occur when skies are clear, so that the diurnal variation of the standard deviation of temperature for the most part depends on the relative frequency at various times of day of such clear skies.

In January the least cloudy skies are associated for the most part with polar westerlies and north-westerlies in which the sky tends to clear at night, the wind tends to drop and consequently low temperatures occur. During the day, however, the increased surface wind and cloudiness normally associated with polar westerlies and north-westerlies tends to raise the temperature towards the sea temperature. Hence the spread of temperature, and consequently the standard deviation will be a maximum during the latter part of the night.

In April, clear skies tend to be associated with warm S. and SE. types of weather by day resulting in the occurrence of some high day temperatures whilst the cool W. and NW. types tend to be cloudy so that the greatest spread of temperature and consequently the maximum standard deviation occurs at the time of maximum temperature.

In July cool air masses are cloudy while warm air masses have clearer skies so that insolation results in the greatest spread of temperature and consequently the maximum standard deviation occurs at about the time of maximum temperature.

October shows the characteristics of both July and January. There is still sufficient heating in the afternoon to cause a maximum of standard deviation to occur then. On the other hand warm air masses are very cloudy or foggy at night so that as in January there is a maximum of standard deviation at the time of minimum temperature.

From the foregoing it will be seen that the reason why the standard deviation of temperature at London Airport at night in January and October is greater than in April and July is that the cool air masses in January and October tend to have clearer skies resulting in radiational cooling spreading the difference in temperature between the air masses. In April and July, however, the cool air masses tend to be cloudy so that radiational cooling reduces the difference in temperature between the air masses.

The above paragraphs give only a broad outline of the weather at London Airport in so far as it is necessary to explain the general features of the standard-deviation curves. A discussion of the more detailed shape of the curves would require a much closer description of the weather at London Airport.

The remaining significant features of the diurnal variation of mean temperature curves are explained briefly in the following. The small fall of temperature during the night hours in January is due to the greater frequency of cloudy warm air masses in which temperature at night falls less quickly than on clear nights, and may even rise slightly. In the mean this largely compensates for the more rapid fall of temperature on the clear nights. In July the time of maximum is delayed until well into the afternoon by reason of the length of day and the small difference in the sun's elevation between noon and 1600. In October the mornings are frequently foggy so that there is a slow rise of temperature after sunrise until the fog clears.

The two sets of curves are typical of a maritime temperate climate in which an occasional continental type of climate does occur—but infrequently. Similar curves apply to most places in north-west Europe but with increasing diurnal range of temperature and increasing standard deviation as the frequency of the continental type increases.

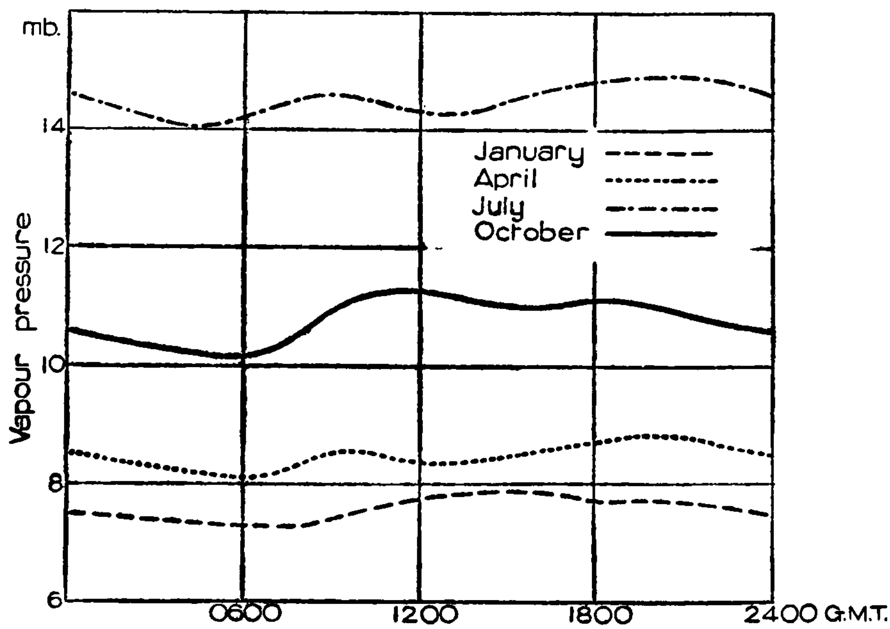


FIG. 3—DIURNAL VARIATION OF VAPOUR PRESSURE AT LONDON AIRPORT

Vapour pressure.—Fig. 3 shows the diurnal variation of vapour pressure at London Airport obtained in a similar manner to the diurnal curve of mean temperature. As would be expected in a place not far from the sea in any direction, the vapour pressure shows very little diurnal variation. All four months show a minimum around sunrise. January shows a maximum in the middle of the afternoon while the other months show maxima some time in the morning and some time after sunset with a secondary minimum in the afternoon.

The minimum at sunrise (the time of minimum temperature) is due to stabilization of the lowest layers by cooling and the deposition of moisture as dew. When the sun rises the dew is re-evaporated into the air and mixing takes place with the layers immediately above causing a rise in vapour pressure. As the morning progresses temperature rises further and convection sets in causing a fall in vapour pressure as moisture is carried upwards until a balance is struck between fresh moist air arriving from the sea and the ability of convection to carry it up. Convection dies down towards sunset but moist air is still arriving from the sea so that vapour pressure rises again as the moisture is concentrated in the lowest layers. This process continues after sunset until falling temperature produces an inversion in the lowest layers with a consequent dropping off of wind speed and the deposition of moisture as dew.

In January, however, the diurnal rise of temperature is insufficient to start convection, and there is frequently an increase of absolute humidity upwards from the surface. Furthermore the ground is frequently saturated so that, all in all, the air near the ground tends to remain saturated in spite of the diurnal rise of temperature, and consequently the vapour-pressure curve has a single maximum in the late afternoon.

In October the mornings are frequently foggy with a consequent inversion of absolute humidity so that the rise in vapour pressure in the morning is greater than in the other months.

The curves for April and July in Fig. 3 are typical of most maritime temperate situations, but the range of diurnal variation tends to increase with increasing distance from the sea provided the climate still remains to some extent maritime.

Application.—The curves in Figs. 1, 2 and 3 are of considerable use to the planners of aircraft operations. In general, the higher the temperature and to a less extent the higher the absolute humidity the greater the length of runway required by an aircraft to take off with a given weight or alternatively the less weight that can be lifted with a given length of runway. With the diurnal curves of temperature and standard deviation it is possible, assuming that the temperature distribution for a particular hour is normal, to calculate the frequency with which a certain temperature is exceeded at any particular time of day, and consequently the frequency with which a given weight cannot be lifted. While this question is only of academic interest at London Airport because of the length of the runways, at some overseas airfields the economic operation of an aircraft may be severely restricted, and, however inconvenient it may be, it may be essential to plan operations so that take-offs occur only in the early morning at the coolest time of day.

The assumption that the temperature distribution for a particular hour is normal may not be true for certain places at certain times of the year and certain hours of the day. The distribution may exhibit a skewness due to the presence of a long tail of high or low values or to the suppression of the normal tail of high or low values. A skew distribution due to the presence of a long tail of high or low values is most probable at those hours at which the standard deviation is a maximum, and a skewness due to the suppression of the normal tail of high or low values is most probable at those hours at which the standard deviation is a minimum. The general climatic features of a place indicate which way the distribution is skew, whether it is the high or low values which are affected, so that allowance can be made when using the curves in the manner described above. At London Airport slight skewness occurs in the early hours in January owing to a long tail of low values, and rather more skewness in the afternoon in January owing to the suppression of high values. In other months the skewness is insignificant.

USE OF "FACSIMILE" FOR METEOROLOGICAL TRANSMISSIONS

By C. V. OCKENDEN, B.Sc.

A recent survey showed that about 400,000 five-figure groups are handled daily by the meteorological communications centre at Dunstable, and the great volume of traffic continues to grow. The demand by forecasters is for more data to be received more speedily to meet the requirements of aviation in these days of aircraft flying at ever increasing heights and speeds. The problem of transmitting from Dunstable all the basic and derived information which is required by the many meteorological stations in the British Isles becomes more acute with the passage of time. Basically there are only two land-line teleprinter channels over which information can be broadcast from Dunstable; one of these can only operate for 45 minutes in each hour because it has to be used for the collection of hourly reports, and the other only serves a relatively small number of main centres. Whilst the volume of data has increased, the channels available for their rapid dissemination have remained as they were at the end of the last war. The provision of another meteorological teleprinter channel to all stations would solve one problem, but create another in that more personnel would be required at stations to plot the additional data so that they can be used by the forecasters. Over the past 18 months tests have been in progress in the Meteorological Office on the development of transmissions by "facsimile" apparatus since it appears possible that this technique might be extended to provide an answer to the problem of supplying the needed additional data without the necessity for employing additional personnel.

At a meeting in April 1953 of the World Meteorological Organization Commission for Synoptic Meteorology it was agreed that "facsimile is an extremely effective means of communication for meteorology, permitting, even in its present stage of development, improvement in meteorological services, complete accuracy of material transmitted, and a certain amount of economy". The purpose of this article is to give the reader a general background without entering into detailed technicalities.

The possibilities of making use of the technique of photo-telegraphy or facsimile transmissions for meteorological purposes have been realized for the last quarter of a century. In 1929 the Commission for Synoptic Weather Information of the International Meteorological Organization examined pictures of charts, plain-language forecasts and messages in figure codes which had been received by picture telegraphy, and set up a Sub-Commission to "consider the best method of utilizing wireless pictures in synoptic meteorology and of keeping the Commission informed of the progress made in different countries in the development of this system".

At about the same time, the Meteorological Office made trials of transmitting simple weather charts by radio from Cardington to an airship in flight by using the Fultograph process. The same system was also used by the British Broadcasting Corporation which included weather charts in its broadcasts from Daventry. Judged by today's standards the picture was crude and small and took a relatively long time to send. Reproductions of material actually transmitted are contained in Watson Watt's Symons Memorial Lecture[1] delivered to the Royal Meteorological Society on March 20, 1929. With the disbandment of the Airship Section of the Meteorological Office transmissions ceased, and meteorologists waited for better apparatus to be produced giving larger pictures, better definition and greater speed. The wait was to be a long one. On the one hand, manufacturers naturally concentrated their energies towards the development of apparatus best suited to the financially more important needs of radio and cable companies and newspaper concerns where large size was not as necessary as quality. On the other hand meteorologists did not press for equipment, probably because the teleprinter was being introduced on a large scale and largely satisfied the requirement for greater speed in the exchange of meteorological information as compared with hand-morse transmissions necessitating the employment of wireless operators. So it was that, until the Second World War 1939–1945, there was no progress to report on the application of facsimile to meteorology. During the war, however, large numbers of facsimile "transceivers" were used by American weather services, and several long-distance circuits were successfully operated. The apparatus enabled pictures 12 in. × 18 in. to be transmitted in about 20 min.

After the war, the Meteorological Office arranged for five United States "transceivers" to be lent for trials which were made by land-line between Dunstable, Transport Command, Lyneham and Victory House. The experiments had to be curtailed because the period of loan was terminated before expectation, but the general feeling was that the Meteorological Office would be well advised to wait a little longer for further technical improvements to be made before embarking on any large-scale scheme of facsimile working. Attention was therefore directed to producing a specification for a recorder which would satisfy the requirements of the average outstation and at the same time be capable of being developed without too long a delay. Up to this time all facsimile recorders used in meteorological offices had been of the drum type, requiring an operator to unload and load the machine after the receipt of each individual picture. The new specification called for a continuous-paper recorder so that the received chart could be seen as it was produced inch-by-inch, and could be simply torn off after completion just as one tears off data from a teleprinter for the forecaster's use. It was also demanded that the recorder should be compact, easy to maintain by unskilled personnel, quiet in operation, operate at more than one speed, give good definition and be capable of handling charts up to 18 in. × 22 in. in size. It was realized that there was a most important international aspect—for example, stations in the United Kingdom would wish to be able to intercept meteorological charts broadcast by radio from transmitters in the United States and from any which might be set up in European countries in the future. The matter was therefore brought up at the meeting of the European Sub-Commission for Weather Transmissions held in Stockholm in 1949, and an agreed list of desiderata was prepared, taking into consideration the opinions of technicians in the field of facsimile. It will be realized that many compromises have to be made in designing a recorder best suited to any particular purpose. If the meteorologist wants apparatus which will enable a very small symbol on a detailed working chart to be clearly recognizable in all circumstances he must be prepared to accept a longer time for the transmission of the chart, because of limitations of "band width" of communications channels. If he wants to be able to send a very large chart, the manufacturer's costs may rise out of all proportion so that few services would be able to purchase the apparatus in large quantity. The best compromise seemed to call for a definition of about 100 lines/in. and a picture width of about 18 in. The product of the diameter of the drum and the number of lines scanned per

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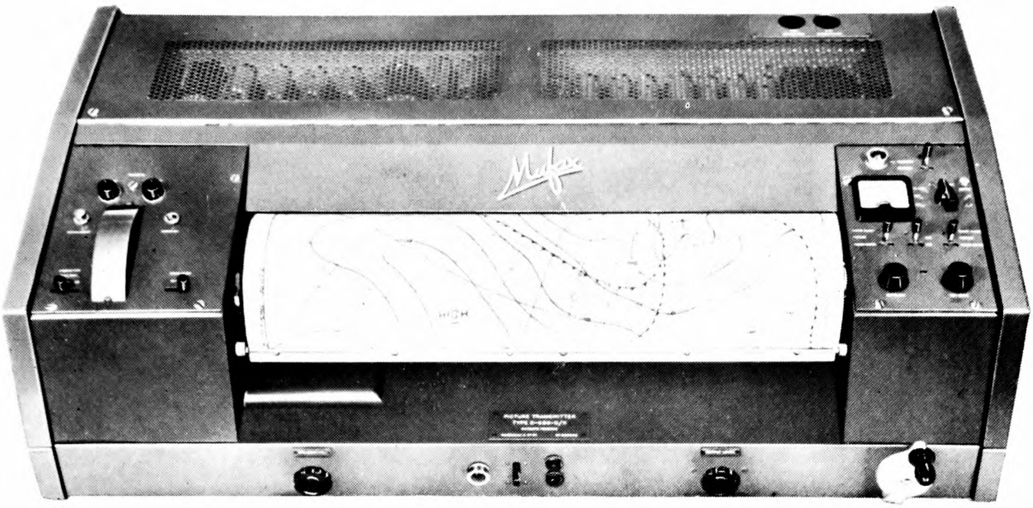
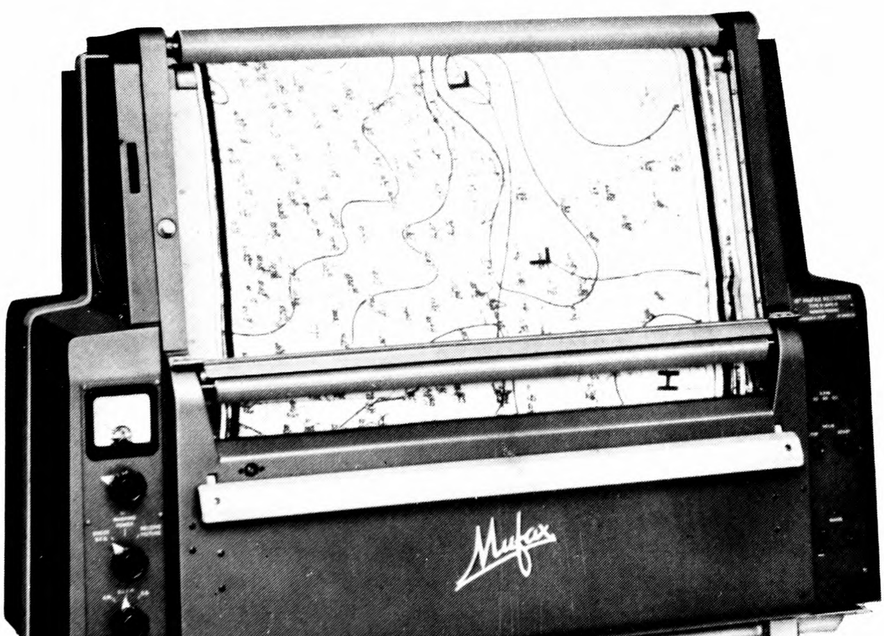


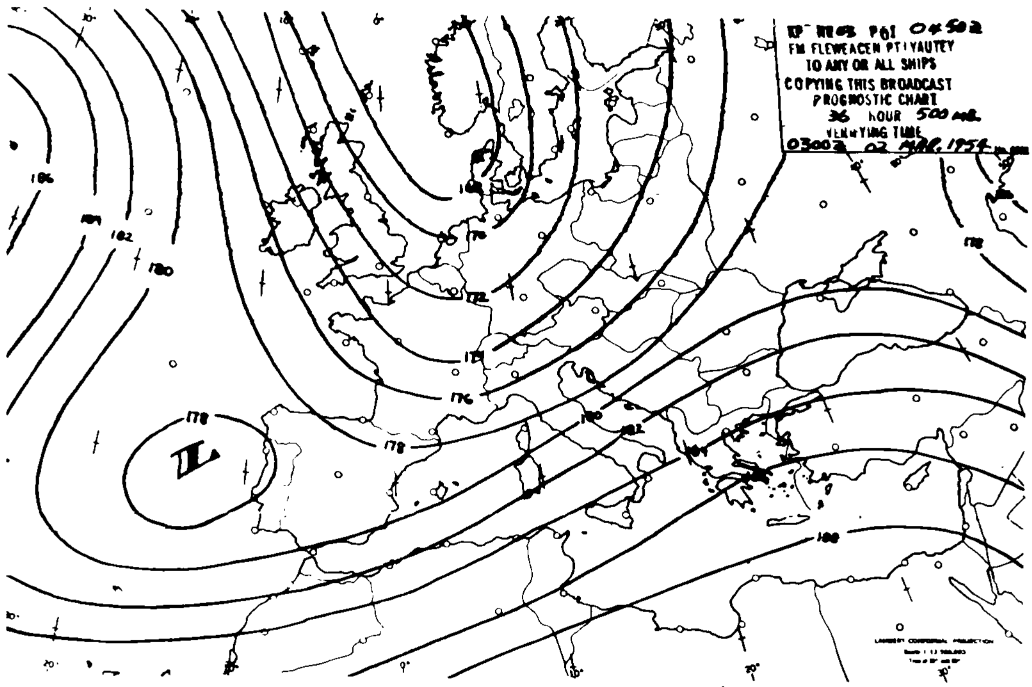
18-IN. CHART TRANSMITTER



18-IN. CHART RECORDER

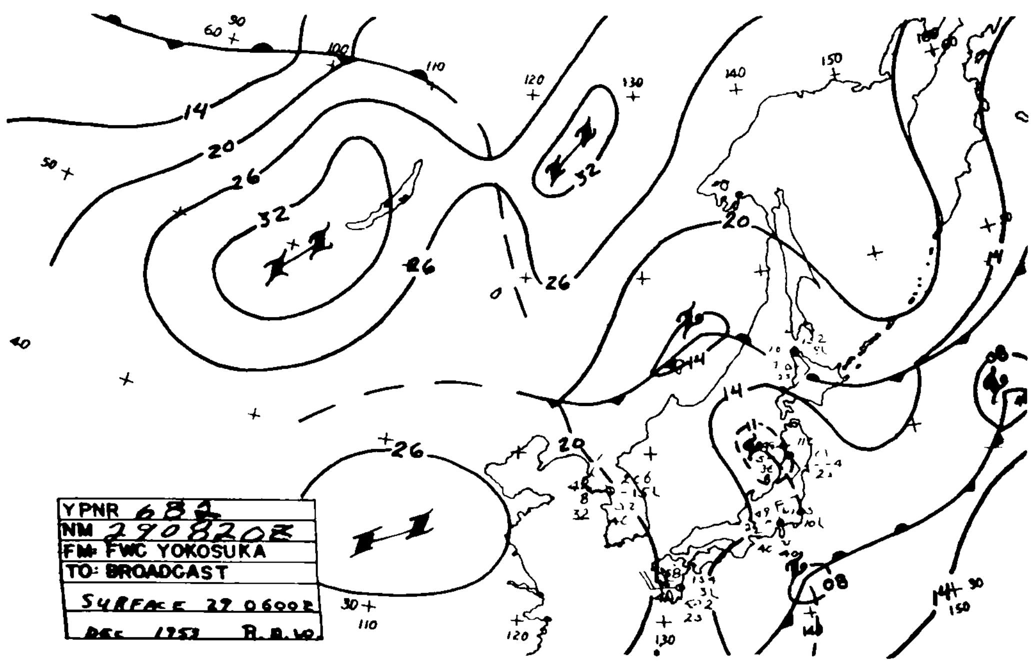
Photographs reproduced by courtesy of Muirhead & Co., Ltd.

FACSIMILE APPARATUS FOR TRANSMITTING CHARTS
BY RADIO OR LAND-LINE
(see p. 303)



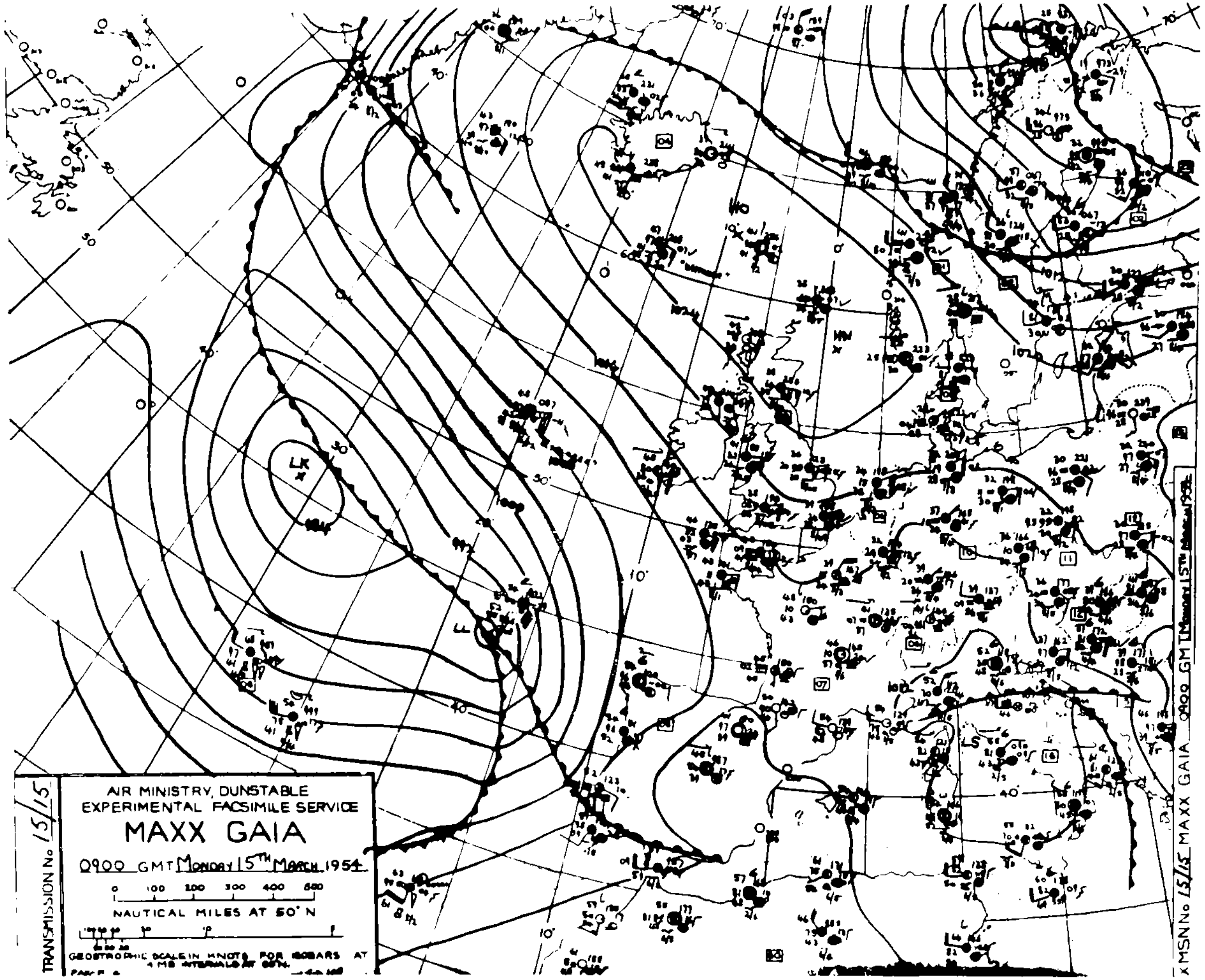
FORECAST UPPER AIR CHART AT 500 MB., 0300 G.M.T., MARCH 2, 1954

This is a quarter-scale reproduction of a chart received at Dunstable, 0505 G.M.T., March 1, 1954, by direct interception of Port Lyautey (U.S. Navy) radio-facsimile broadcast



SURFACE CHART, 0600 G.M.T., DECEMBER 29, 1953

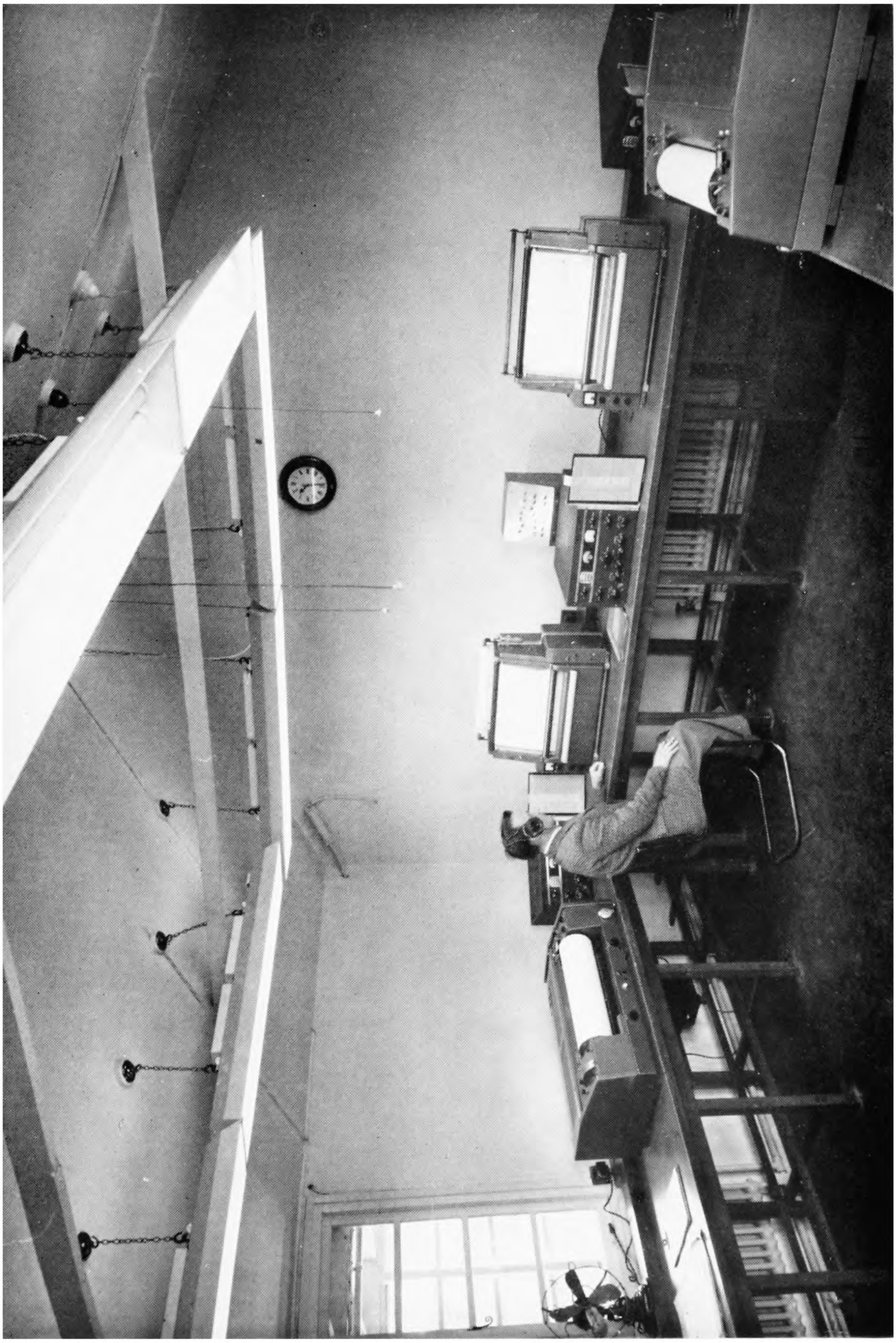
This is a quarter-scale reproduction of a chart received at Dunstable, 0955 G.M.T., December 29, 1953, by direct interception of Yokosuka (U.S. Navy) radio-facsimile broadcast on 9,427 Kc./sec.



SURFACE CHART, 0900 G.M.T., MARCH 15, 1954

This chart was received at Dunstable on a recorder monitoring the radio-facsimile broadcast

To face p. 305]



FACSIMILE TRANSMITTING AND RECORDING ROOM,
CENTRAL FORECASTING OFFICE, DUNSTABLE

unit length is known as the index of co-operation, and in the case of most facsimile apparatus used for meteorological transmissions at the present time this index has the value 576 (96 lines/in. and 6 in. drum diameter). In order to secure successful inter-working without distortion it is necessary that the index of co-operation, the direction of scan and the speed of rotation of the transmitter drum and the drum (or other scanning device such as a helix) of the receiver shall be identical.

The latest type of meteorological facsimile transmitter as installed in the Central Forecasting Office at Dunstable is illustrated in the photograph facing the top of p. 304. The chart to be transmitted is wrapped round a horizontal drum 22 in. long and 6 in. diameter which is rotated by a synchronous hysteresis motor supplied with 1,000 c./sec. by a valve-maintained tuning fork. At the same time a spot of light is caused to traverse the surface of the drum parallel to the drum spindle. Thus the chart is scanned in the form of a spiral. The image of the illuminated portion of the chart is arranged to fall on to a photo-multiplier cell which passes a current proportional to the illumination. This current is amplified and converted to either an amplitude-modulated signal or a frequency-modulated subcarrier, according to the transmission system used. Provision is made for transmitting a phasing signal to start the chart recorder in the correct relative position. The drum can be caused to rotate at speeds of either 30, 60, or 120 rev./min. selected by a switch.

The 18-in. continuously operating recorder is illustrated in the photograph facing the bottom of p. 304. For the past year recorders have been in operation at four selected outstations whilst two are available at Dunstable for monitoring transmissions and for receiving foreign facsimile broadcasts. The recorder produces a continuous record 18·75 in. wide on electro-sensitive paper which is supplied in 100-ft. rolls, sufficient for operation at normal speed for over 30 hr. The roll is contained in a substantially air-tight compartment in the bottom front part of the machine. The paper is drawn at constant speed between a stainless steel writing-edge and a rotating helix. A current, controlled by the received signal, passing through the paper at the point of contact causes the dissociation of the electrolyte and a ferric salt reacts with a colour-forming substance in the paper to give a black colouration. The record is permanent if dried thoroughly before storing, though the paper itself may deteriorate over a period of years. The rotation of the helix and movement of the paper together cause the point of contact to traverse the paper in a series of horizontal lines. The paper advances at 96 lines/in., each line taking 1 sec. to trace at normal speed (corresponding to the rotational speed of the drum at the transmitting station). The helix and paper-feed rollers are driven by a hysteresis motor supplied with 1,000 c./sec. derived from a high-stability valve-maintained tuning fork and power amplifier. The paper passes up over the "lectern" in front of the recorder and the forecaster therefore sees the chart as it is built up. A chart 18 in. × 22 in. can be transmitted in about 17 min. at the higher speed available, or a chart 18 in. × 11 in. can be sent in 8½ min. The system can be operated either over a radio link or a good-quality land-line. Radio interference causes dark lines across a chart which spoil its appearance but do not cause a great loss in intelligibility unless very severe; in fact, a chart received by radio may still be perfectly usable to the meteorologist in propagation conditions which would cause so much "garbling" on a radio-teleprinter channel that no map could be plotted. Looking to the future it seems highly probable that the meteorological services of many countries will make simultaneous facsimile broadcasts by land-line to many subsidiary stations which can be conveniently and economically served in this way, and by radio for reception by the more remote stations and ships at sea. A photograph of the facsimile room at the Central Forecasting Office, Dunstable is shown facing p. 305.

The exchange of meteorological information by facsimile is most useful in the case of "processed" information such as baratic, prebaratic, contour and prontour charts for widely separated regions. The present method involves selecting points on curves, coding the positions of the selected points, sending lengthy messages by teleprinter or wireless telegraphy, decoding and plotting and joining the points by lines. Not only is this laborious, but the chart prepared by the recipient is liable to differ from the original to such an extent that derived information, e.g. upper wind speed and direction may be in error to a dangerous degree. The day is probably not far distant when charts prepared by analysts at main centres in different regions of the world will be exchanged by radio point-to-point or broadcast facsimile transmissions, to facilitate the preparation of charts covering a whole hemisphere. The individual regional analyses would of course be based on considerably more detailed information than could be transmitted or used by other regions in the limited time available. At the present time about a dozen radio-facsimile meteorological broadcasts are made from widely scattered centres in the northern hemisphere, including, for example, Dunstable, New York, Washington and Tokyo. A very extensive land-line facsimile network exists in the United States, and within recent months a coast-to-coast Weatherfax network has been established in Canada using apparatus manufactured in the United Kingdom. The network involves the employment of a score or so of transmitters (at regional stations) and over 100 recorders which are fully automatic. A description of the way in which stations will receive facsimile transmissions of weather information from the Central Analysis Office at Dorval, Quebec and from the District Aviation Forecast Offices is given in Circular 2337 of the Canadian Department of Transport, Meteorological Division[2].

Apart from the role which meteorological facsimile broadcasts will undoubtedly play in the world-wide exchange of basic charts, it will be readily appreciated that the technique might well be employed at a main airport where many operating companies could be served with a local broadcast of meteorological information comprising a selection of simplified actual and prognostic charts to keep aircrews and operations staff in touch with the development of the synoptic situation. Where several companies operate a frequent service over the same air route, pictorial flight forecasts could be transmitted on a routine basis. Such local broadcasts would reduce the number of telephone calls and personal inquiries which tend to disrupt the work of a forecasting office. It would also be practicable for one office at a main airport to prepare cross-section charts for a particular route or routes, and issue them by facsimile to other departure airfields. In the future there might be a requirement for a special broadcast service from the Central Forecasting Office, the contents and schedule being designed to benefit small airfields without meteorological offices, gliding clubs, yachting clubs, port organizations, etc. Such a broadcast might be of value to universities and various industrial concerns and public utilities whose activities are directly affected by the weather.

Facsimile transmission programme

Frequencies: 2655, 3143 and 4780 Kc./sec. *Items broadcast:* Monday–Friday 1–26
Saturday 1–15 Winter
1–16 Summer

	Transmission time	Transmission speed		Fax chart
	G.M.T.	rev./min.		
1	0100	120	Prontours 700 mb.	F3
2	0115	120	Prontours 500 mb.	F3
3	0130	120	Pre-thickness chart	F3
4	0145	120	Prontours 300 mb.	F3
5	0200	120	Prontours 200 mb.	F3
6	0215	120	Prontours 100 mb.	F3
7	0430	120	Prebaratic 2400	F3
8	0445	60	British winds } Upper air stations* ...	F6
9	0510	60	British tephigrams } Upper air stations* ...	F2
10	0550	60	0300 1/10,000,000 chart, plotted and analysed ...	F4
11	0650	60	0600 1/2,000,000 chart, plotted only	F1
12	0750	60	0700 1/2,000,000 chart, plotted only	F1
13	0850	60	0800 1/2,000,000 chart, plotted only	F1
14	0950	60	0900 1/2,000,000 chart, plotted only	F1
15	1045	120	Prebaratic 0600	F3
16	1145	60	0900 1/10,000,000 chart, plotted and analysed ...	F4
17	1230	120	Prontours 700 mb.	F3
18	1245	120	Prontours 500 mb.	F3
19	1300	120	Pre-thickness chart	F3
20	1315	120	Prontours 300 mb.	F3
21	1330	120	Prontours 200 mb.	F3
22	1345	120	Prontours 100 mb.	F3
23	1400	60	1300 1/2,000,000 chart, plotted only	F1
24	1630	120	Prebaratic 1200	F3
25	1645	60	British winds } Upper air stations* ...	F6
26	1710	60	British tephigrams } Upper air stations* ...	F2

* *List of upper air stations:* Lerwick, Stornoway, Leuchars, Fazakerley, Hemsby, Crawley, Camborne, Aldergrove, Valentia, ocean weather stations I and J.

Details of the radio transmission which is at present being made from Dunstable on a frequency of 4780 Kc./sec. are given above and some examples of charts intercepted at and transmitted from Dunstable in recent months are reproduced in the photographs in the centre of this Magazine.

REFERENCES

1. WATSON WATT, R. A.; Weather and wireless. *Quart. J. R. met. Soc., London,* **55,** 1929, p. 273.
2. Toronto, Department of Transport, Meteorological Division. Faxpro: Procedure manual of the Canadian Weatherfax system. *Circ. met. Div. Dep. Transp., Toronto,* No. 2337, 1953.

LOCAL DEGREE-DAY VARIATIONS IN THE READING AREA

By M. PARRY, M.Sc.

It is well established that the heat requirement of a building depends partly on the outside temperature, and Dufton[1] has prepared a map showing the variation of mean daily temperature conditions over Great Britain in terms of accumulated temperatures, in degree-days below a base of 60°F. (the outside temperature below which indoor heating is considered necessary). Although it has been recognized that quite local variations in degree-day values occur and may be significant[2], there can as yet be little precise information as to the magnitude of these local differences, as few investigations of local climates have been undertaken in this country.

A study of this kind has been carried out recently in and around Reading, and the data obtained include values of degree-days (base 60°F.) over a 12-month period at 10 stations sited so as to yield temperature records representative of different facets of the area. The values were calculated day by day (60° minus the mean temperature) and summed for the whole period. These annual degree-day totals are mapped against a background of the relief of the district and the built-up area (Fig. 1); the height of each station, the kind of exposure, and the degree-day totals, expressed as percentages of that at the University station, are given in Table I.

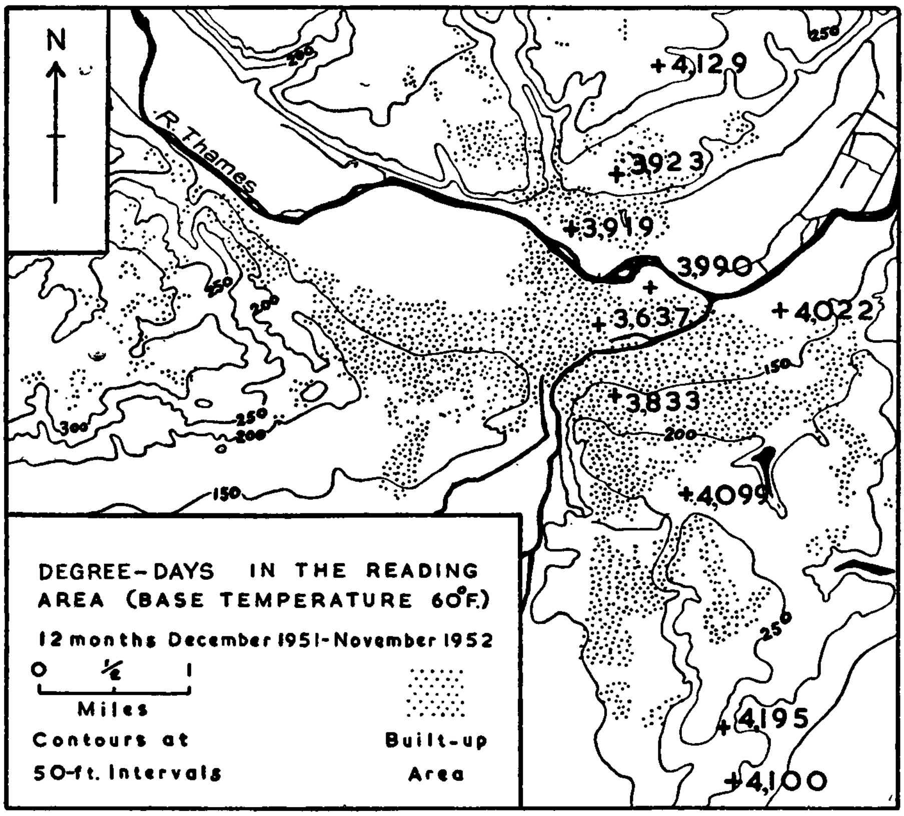


FIG. 1

The records at two stations, Forbury Gardens and Queen Anne's School, include a few interpolated values; elsewhere, the records are continuous over the period. The Forbury Gardens station is over-sheltered in some directions, and its annual degree-day total may be considered too low in comparison with those at the other stations, where conditions of exposure, while varying, nevertheless conform to official requirements.

TABLE I—DEGREE-DAYS IN THE READING AREA

12-month period, December 1951-November 1952
Base of 60°F.

	University	Shinfield	Seed Trial Grounds	Caversham Park	St. Patrick's Hall	Lower Caversham	King's Meadow	Forbury Gardens	Shinfield Green	Queen Anne's School
Height above M.S.L. (ft.)	152	200	141	274	230	125	120	143	248	178
Exposure	Urban	Open	Open	Open	Suburban	Urban	Open	Urban	Open	Suburban
Degree-days ...	3,833	4,100	4,022	4,129	4,099	3,919	3,990	3,637	4,195	3,923
Degree-days as percentage of University values	100	107	105	108	107	102	104	95	109	102

If the Forbury Gardens value is increased to, say, 98 per cent. of the University value, then the magnitude of local variation of degree-days in the Reading area is of the order of 10 per cent. Of this about 5 per cent. seems due to difference in elevation (compare King's Meadow and Caversham Park or Shinfield Green), and the other 5 per cent. to the difference between sheltered (urban) and open exposures (compare University and Seed Trial Grounds). A favourable exposure on a south-facing terrace seems responsible for the relatively low value at Queen Anne's School.

Of the stations used in the investigation, three are permanent auxiliary climatological stations. Table II shows the mean annual degree-day totals—calculated by the simplest method[2]—for a 12-yr. period during which contemporaneous records are available from all three stations. The differences are of the same order as those obtained for the 12-month period.

TABLE II—MEAN DEGREE-DAY TOTALS

12-yr. period, 1940–51

	University	Shinfield	Seed Trial Grounds
Degree-days	3,588	3,789	3,771
Degree-days as percentage of University values	100	106	105

From a comparison of totals for the 12-month period at stations of similar exposures but at different heights, it seems that the effect of increasing altitude is to augment the annual degree-day values, on the average, by 100 units in about 90 ft. Over a long period, assuming the mean daily temperature to be below the base of 60°F. for 10 months of the year, and the usual average fall of temperature of 1° in 300 ft., the expected increase of annual degree-day values with increasing elevation would be about 100 units every 100 ft. This was, in fact, broadly the conclusion reached by Dufton[1], after examining degree-day variations on the macroclimatic scale over the period 1881–1915.

The range of elevation between highest and lowest stations in the Reading area is relatively small (154 ft.), and the urban warmth due to a mainly residential and light-industrial town of moderate size (some 120,000 people), a fairly clean atmosphere, and a relatively open pattern away from the centre, is not strongly marked. Local variations of degree-day totals of more than 10 per cent. are clearly to be expected with more closely built-up towns and in sites of more pronounced relief contrasts.

REFERENCES

1. DUFTON, A. F.; Degree-days. *J. Instn Heat. Vent. Engrs, London,* **2,** 1934, p. 83.

2. London, Ministry of Works. Post-war building studies No. 19. Heating and ventilation of dwellings. By the Building Research Board, Department of Scientific and Industrial Research. London, 1945.

METEOROLOGICAL RESEARCH COMMITTEE

The 31st meeting of the Synoptic and Dynamical Sub-Committee of the Meteorological Research Committee was held on June 24, 1954.

Numerical forecasting was the subject of two reports both by Mr. F. H. Bushby and Miss M. K. Hinds[1,2]. The Committee also discussed future development and research in the application of numerical methods. Two other papers dealt with high-level turbulence. The first by Mr. G. A. Corby[3] dealt with the air flow over mountains, the second by Mr. D. C. E. Jones[4] discussed the exceptionally severe high-level clear-air turbulence on April 14, 1954. Other papers considered by the Committee included one by Mr. J. K. Bannon[5] on the variation of temperature in the lower stratosphere above Larkhill and Lerwick and one by Mr. D. H. Johnson[6] on the diurnal and semi-diurnal oscillations of the lower stratosphere.

ABSTRACTS

1. BUSHBY, F. H. and HINDS, M. K.; The electronic computation of two series of 1000-mb., 500-mb., and 1000–500-mb.-thickness forecast charts by application of the Sawyer-Bushby two-parameter baroclinic model. *Met. Res. Pap., London,* No. 841, S.C.II/162, 1953.

2. BUSHBY, F. H. and HINDS, M. K.; A preliminary report on ten computed sets of forecasts based on the Sawyer and Bushby two-parameter atmospheric model. *Met. Res. Pap., London,* No. 863, S.C.II/169, 1954.

The Sawyer-Bushby model of the atmosphere is set out in a form suitable for machine computation of the height and thickness of pressure levels. The technique of computation is described and the results of two trials are shown in numerous charts. They gave a fair representation of the motion of the real atmosphere for a 24-hr. period. In the second paper ten 12-hr. and 24-hr. forecasts of 1000-mb. and 500-mb. contours and 1000–500-mb. thickness over the North Atlantic and western Europe were computed on the Sawyer-Bushby model using 1-hr. steps. Machine time was 8½ min./step. Actual and forecast charts are shown, and each case is discussed and compared with conventional forecasts. Correlation coefficients between actual and forecast 24-hr. changes are tabulated. Correlation is good; on the whole the conventional forecasts showed up better, but this was mainly due to neglect of heating of cold air over Atlantic in winter, over-estimation of contour heights in anticyclones, and small area of grid.

3. CORBY, G. A.; The air flow over mountains: a report on the state of current knowledge. *Met. Res. Pap., London,* No. 842, S.C.II/163, 1953.

In Part I of this exhaustive report the observational evidence of air flow over mountains, notably lee waves, is summarized. It includes mountain clouds, especially stationary lenticular clouds and rotors, and experiences of pilots of gliders and powered aircraft. Part II summarizes (with standardized notation), discusses and generalizes the theoretical studies of Queney, Lyra and Scorer; fundamental importance is attributed to the magnitude l^2. The various assumptions involved in the theories are reviewed. In Part III model experiments by Abe, Long and others, including the Gibraltar investigation, are critically discussed. Part IV takes up the gliding studies of Förchgott in mountain regions and his consistent theories of types of flow. Finally applications to aviation forecasting and criteria of safety heights are considered.

4. JONES, D. C. E.; Note on exceptionally severe clear-air turbulence and other phenomena on April 14, 1954. *Met. Res. Pap., London,* No. 868, S.C.II/172, 1954.

Turbulence, severe enough to turn aircraft upside down, was met at 40,000 ft. in a strong NW. current near Edinburgh; it ceased below 38,000 ft. It was in the upper troposphere in pronounced vertical and horizontal wind shear on the warm side of the jet stream above the axis. On the same day many standing waves were reported at 4,500–18,000 ft. over England.

5. BANNON, J. K.; Variation of temperature in the lower stratosphere above Larkhill and Lerwick. *Met. Res. Pap., London,* No. 860, S.C.II/167, 1954.

Correlation coefficients of temperature at 150 mb., 100 mb. and 60 mb. with height of 300-mb. surface and with tropopause pressure, based on all available data, are tabulated separately for day and night. Those with H_{300} are negative, those with P_T positive; in both cases magnitude decreases to less than a half between 150 mb. and 60 mb. The decrease is greatest in January and April and least in October, and may be related to annual variation of ozone.

6. JOHNSON, D. H.; Diurnal and semi-diurnal oscillations of the lower stratosphere. *Met. Res. Pap., London,* No. 861, S.C.II/168, 1954.

Changes of wind in 6 hr. at 100 mb. over Great Britain in 1950–51 show significant variations which are similar in each month. These are analysed harmonically; the mean amplitude of the diurnal component is 0·54 kt. from S. and 0·51 kt. from E.; semi-diurnal 0·67 kt. from S. and 0·51 kt. from E.; both give elliptical paths (diurnal NW. at 0000; semi-diurnal NE. at 0900 and 2100). The variations are attributed to solar tides.

ROYAL METEOROLOGICAL SOCIETY

Visit to the National Institute of Oceanography

This year, the summer meeting of the Royal Meteorological Society was held on July 7 in the very pleasant surroundings of the National Institute of Oceanography at Wormley near Godalming in Surrey. The Society was invited by the Director, Dr. G. E. R. Deacon, to walk freely through the building, inspecting the instruments and specimens displayed.

The instruments and appliances included plankton nets, water-sampling bottles, a reversing thermometer (to measure the temperature of the sea at various depths), a sensitive resistance thermometer and a float salinity meter.

Ocean currents are reported from many light-vessels round the British Isles but experiments are also being made with drift cards—prepaid postcards in double plastic envelopes which are dropped by aircraft about every ten miles along a course some 500 miles west of the British Isles. After two or three months the cards reach the sea-shore and many are found and forwarded to the Institute. During May and June this year winds have been sufficiently often from W. and N. for some of these cards, despite the North Atlantic Drift, to travel east-south-eastwards towards Ireland.

Much of oceanography has to do with waves and several wave recorders were displayed including one like that installed in O.W.S. *Weather Explorer*. Owing to her size waves exceeding 50 ft. in height cannot be recorded on this ship (traces were shown of such waves) but comparison with a similar recorder aboard R.R.S. *Discovery II* showed the records to be reliable up to that value.

Much of the mathematical analysis in oceanography is done by machines, of which the outstanding examples were an automatic curve-follower, a harmonic analyser, and a photo-electric correlation meter.

Because it seems to be of particular interest to meteorologists the correlation meter will be described here. Two curves formed by the dividing lines between black areas and white areas are rapidly scanned by similar narrow lines of light. The amount of light reflected from each line by the curves is picked up on the same photo-electric cell; the output from this cell is squared electronically and then smoothed. Therefore the recorded deflexion is proportional to the sums of the squares of the ordinate of each curve plus a component proportional to the correlation coefficient [$\sum (a + b)^2 = \sum a^2 + \sum b^2 + 2\sum ab$]. The mean squares of the ordinates of each curve can be obtained by masking each line of light out in turn and therefore the resulting record can be calibrated. Separation of the two lines of light can be varied at a constant slow rate so that the recorder draws a "cross-correlogram". For autocorrelation the lines of light both scan the same curve and the resulting record is therefore a correlogram of which the initial peak, when the lines are coincident, is equal to unity.

Among the specimens of marine life displayed were plankton, whale food, squid and even two small foetal specimens of whales; especially interesting were small portions of a huge rock of ambergris weighing several hundredweight when it was taken from the inside of a whale.

The final item on the programme before tea in the canteen was the showing of films made on board R.R.S. *Discovery II* before the war.

LETTERS TO THE EDITOR

Dust clouds in the stratosphere

Dust clouds in the stratosphere during July 1953 after a volcanic eruption in Alaska, as reported in the April 1954 issue of the *Meteorological Magazine*[1], may provide the explanation of an abnormal darkness of the earth's shadow observed during the total eclipse of the moon of July 26, 1953.

According to observations made at Mount Stromlo[2] and reported in the French bulletin *Documentation des Observateurs* of January 1954 the optical density in green light near the centre of the shadow was about 6·0 (or 15 magnitudes), as against 4·8 only (12 magnitudes) during the preceding eclipse of January 29, 1953. This latter value is about normal for the phase of the solar cycle last year. Further, dark nuclei were observed in the intermediate parts of the shadow, some 25′ or 30′ from the centre (radius of shadow: 45′), as might be projected by clouds at abnormally high altitude above the equatorial regions of the earth.

Such evidence led to the following conclusions:

The unexpected appearance of a dark eclipse near the end of a (solar) cycle suggests the presence in the atmosphere of an abnormal source of absorption: perhaps the sequel of recent volcanic eruptions in Alaska? If such is the case we should witness a repetition of phenomena such as followed the great eruption of Mount Katmai in 1912 and pyrheliometer records should show it.[2]

The report of a volcanic eruption in Alaska on July 9 and observations of extensive high-altitude dust clouds over Great Britain and western Europe during the last week of July and first week of August would seem to agree with this hypothesis. Since, however, near mid eclipse (July 26, 1220 G.M.T.) the terminator of the earth[3] followed roughly the Asian and American shores of the Pacific (including Alaska), the extreme South Atlantic and the Indian Ocean, the darkness of the eclipsed moon requires extensive pollution of the atmosphere over most of those areas as well.

Thus additional observations of dust clouds in late July 1953 could have been made elsewhere, and a check on solar radiation records in widely separated stations during the same period would also be of interest.

G. DE VAUCOULEURS

Commonwealth Observatory, Mount Stromlo, Canberra,
June 18, 1954

REFERENCES

1. JACOBS, L.; Dust clouds in the stratosphere. *Met. Mag., London,* **83,** 1954, p. 115.
2. VAUCOULEURS G. DE; L'éclipse totale de lune du 26 juillet 1953. *Docum. Observateurs, Paris,* **7,** 1954, Fasc. 3. (where other references are given).
3. BOUSKA, J. and LINK, F.; Ephéméride détaillée des éclipses de lune de 1953. *Bull. astr. Insts. Csl., Praha,* **3,** 1952, p. 79.

[Following the publication of my article, to which G. de Vaucouleurs refers, F. Volz of the Institute of Meteorology and Geophysics, Mainz University, Germany, sent me a copy of his paper, shortly to be published in the *Meteorologische Rundschau,* on the long streaks of thin, high-level dust cloud seen and photographed from the ground at Mainz on July 24–26, 1953. From the observed slight easterly drift of the cloud he estimates the height as 22 Km. or above against the 15 Km. in the observations I described, and he suggests that the high cloud seen over Mainz was possibly a second layer resulting from the Alaskan volcanic eruption. Volz commented on a marked weakening of the sun's radiation by the dust cloud on the morning of July 24.

Because of the thinness of the dust layers it was only possible to see them from the ground at twilight (apart from the morning of July 24 at Mainz) and observers in other parts of the world may not have noticed them at these times. Even observations by high-flying aircraft were difficult as the cloud had to be observed obliquely. It is not therefore surprising that no observations have been received from the areas listed by G. de Vaucouleurs.—L. JACOBS.]

Wet-bulb temperatures in Aden

A note appeared in the *Meteorological Magazine* for February 1954 on high wet-bulb temperatures in Aden. The month of June 1953 was regarded by residents in Aden as the most uncomfortable experienced for 20 years.

The unpleasant conditions were due to the wet-bulb temperature remaining high for long periods. June 1954, although not pleasant, was probably one of the most comfortable on record, and it is of interest to compare the conditions experienced this June with those of June 1953. The mean daily wet-bulb temperature for June 1954 was 79·8°F. which is 2°F. lower than last year. The mean daily relative humidity was 63 per cent. in June 1954 compared with 67 per cent. in June 1953.

The table below shows clearly why June 1954 was more comfortable than June 1953.

TABLE I—FREQUENCY OF OCCASIONS OF HIGH WET-BULB TEMPERATURE AT ADEN

	Occasions of wet-bulb temperature					
	⩾82°F.	⩾83°F.	⩾84°F.	⩾85°F.	⩾86°F.	⩾87°F.
			number of hours			
June 1953 ...	387	249	146	55	10	1
June 1954 ...	164	65	6	1	0	0

C. C. NEWMAN

Aden, July 7, 1954

Forecasting temperature at 6,000 ft. for transatlantic flights

For transatlantic flights forecast values of wind and temperature are supplied for every 5° in longitude of the route for the heights, 6,000, 10,000 and 18,000 ft. They are derived, according to the time of take-off, from the appropriate set, one surface and two upper air, of composite forecast charts. Winds at the higher levels are taken directly from the 700-mb. and 500-mb. charts while the winds at 6,000 ft. are obtained by a vector interpolation between the 700-mb. and surface charts.

Values of the temperature at 10,000 and 18,000 ft. are readily obtained from the forecast upper air charts. But forecast charts for 800 mb. (approximately 6,000 ft. above the surface or 1000-mb. chart) are not normally constructed. Therefore, after some consideration, it was decided that an attempt should be made to relate the temperature at 6,000 ft. to the 1000–700-mb. thickness. Accordingly, a number of standardized curves with a saturated adiabatic lapse rate were constructed between 1000 and 700 mb., and the temperature at 800 mb. was read off the curves in each case. The results are given in Table I.

TABLE I

1,000–700-mb. thickness (ft.)	9,000	9,100	9,200	9,300	9,400	9,500	9,600	9,700	9,800	9,900	10,000
Temperature at 800 mb. (°C.)	−13	−10	−7	−4	−1	+2	+5	+8	+11	+14	+17

The obvious objection to using a table such as this for forecasting is the assumption of a particular lapse rate. As a first approach to estimating how serious this error was likely to be, a comparison was made, for some 200 occasions during March and April 1953, between the actual temperature at 800 mb. and that derived from Table I using the ascents from the Atlantic ocean weather ships. A wide variety of both weather types and actual temperatures was included in this series. The mean algebraic error was found to be less than 0·1°C. It was found that 65 per cent. of the observations were within an error of ±1°C., 92 per cent. within ±2°C., and 99 per cent. within ±3°C.

The distribution showed no obviously irregular features and the root-mean-square error was 1·5°C.

Thus the method can be used in a similar fashion to many other forecasting techniques; it provides a rapid answer which may be adjusted in the light of other information. It substitutes a known random error for one arising from the otherwise inevitable bias towards the latest actual value. The method has been in use at London Airport since June 1953 with satisfactory results.

R. H. ELDRIDGE

London Airport, February 26, 1954

Contrails and distrails

On re-reading the letter on contrails and distrails from Mr. R. A. S. Ratcliffe on p. 152 of the May 1954 issue of the *Meteorological Magazine* I am prompted to remind observers of these phenomena of the great care needed before it is safe to base any theories on the formation of distrails, for the following reason. If an aircraft flying just above cirrus cloud when the sun is fairly high, makes a contrail, the shadow of the contrail appears on the cirrus cloud and obviously the colour of the shadow is approximately the same colour as the sky which illuminates it; if the cirrus is in bands the effect at first glance may resemble contrails and distrails, but this is erroneous.

I was fortunate in observing recently against blue sky a contrail made by an aircraft flying appreciably above a sheet of cirrus cloud, half covering the sky, and seeing at the same time the shadow of the contrail which appeared as a long blue streak across the cloud. Before I could get a camera with an appropriate filter set for taking a photograph, a matter of a minute or so, the shadow had moved off the edge of the cloud sheet and there was nothing to record photographically, although the occurrence indicated an appreciable change of wind between the cirrus cloud and the level of the contrail. A sketch of the contrail and its shadow is illustrated above.

R. M. POULTER

Stanmore, July 29, 1954

REVIEWS

The physics of the stratosphere. By R. M. Goody. *Cambridge monographs on physics.* $8\frac{3}{4}$ in. × $5\frac{1}{4}$ in., pp. 187, *Illus.*, Cambridge University Press, Cambridge, 1954. Price: 25*s*.

So much has been written recently on rival systems of nomenclature for the upper layers of our atmosphere that it is as well to make clear at the outset just what Dr. Goody's book is about. He takes the word "stratosphere", as advocated by Flohn and Penndorf[1], to apply to the layers bounded below by the tropopause and above by the temperature minimum at 70–80 Km., which he designates the stratopause. We may be glad, if only on grounds of euphony, that he has not adopted Chapman's[2] more detailed proposals, but it is a pity that we have now yet another word "stratopause" with two meanings, for in Chapman's scheme it is applied to the ill defined level at the base of the layer heated by ozone absorption.

The interlinked phenomena of temperature, composition, radiation transfer, and air movement in this region form Dr. Goody's subject; in particular he is concerned with the application of "fairly straightforward physical methods" to their measurement and explanation. He claims to write not so much for meteorologists as for physicists, and appears to find much less difficulty than does the reviewer in drawing the distinction between these two classes of reader. It is true that the book contains no treatment of atmospheric dynamics, very little climatology, and less about the weather. But it is concerned with the physics of part of the atmosphere, and atmospheric physics, its methods no less than its results, is meteorology; those who practise it are meteorologists, whether they like the word or not. However, once the professing meteorologist has digested the patronizing remarks on the dust-jacket, which include the information "that he should find it profitable to see how the broad features of part of the atmosphere can be understood in terms of relatively simple physical concepts", he can settle down to enjoy a very good book.

The opening chapter is mainly devoted to a description of the "tools of research"—manned and free balloons and rockets. The second chapter, on temperature, deals with direct measurements by radio-sonde, the use of sound propagation and meteor observations, the several methods using rockets, and the possibilities of spectroscopy and of the observation of scattered light. Composition is next discussed, the topics ranging from frost-point hygrometers to the mass spectrometry of samples collected by rocket. Ozone has a chapter to itself, the longest in the book, and, in accordance with the general plan, the methods of measurement of amount, distribution, and temperature, and the background of photochemical theory, receive much more attention than the correlation with weather and atmospheric movement. Fifteen pages suffice for the discussion of winds and turbulence. The final chapter, on radiation, presents some necessary elements of the theory of molecular spectra and radiative transfer and ends with a discussion of radiative equilibrium temperatures.

Dr. Goody is at pains throughout to ensure that the physical principles underlying the methods he describes are understood, but the calls he makes on his readers in the process vary greatly from chapter to chapter. The superficial description of the determination of temperature structure from sound-ranging observations is easy to read but not very satisfying; the treatment of radiative transfer in the final chapter demands concentration and rewards it. Dr. Goody's own work in this sphere has been on subjects treated in his "Ozone" and "Radiation" sections, and as would be expected these chapters are the best in the book. The latter, especially, must be commended, for no other treatment of the fundamental problems of infra-red radiation in the atmosphere comes to mind which so successfully meets the conflicting claims of clarity, rigour, and conciseness.

The book ends with a four-page bibliography which has clearly been chosen with some care to cover the very early history and the latest work. This is a most valuable feature, but some meteorologists will regret that the selection has excluded such names as W. H. Dines and C. J. P. Cave from both bibliography and index.

It remains to be said that the production of the book conforms to the highest modern standards; so, unfortunately, does its price.

G. D. ROBINSON

REFERENCES

1. FLOHN, H., and PENNDORF, R.; The stratification of the atmosphere. *Bull. Amer. met. Soc., Lancaster Pa.*, **31**, 1950, p. 71 and p. 126.
2. CHAPMAN, S.; Upper atmospheric nomenclature. *J. geophys. Res., Baltimore*, **55**, 1950, p. 395 and *Bull. Amer. met. Soc., Lancaster Pa.*, **31**, 1950, p. 288 and *J. atmos. terr. Phys., London*, **1**, 1951, p. 121.

Meteorological instruments. 3rd edn, revised. By W. E. K. Middleton and A. F. Spilhaus. 10 in. × 6¾ in., xii + 286, *Illus.*, Toronto University Press (London: Geoffrey Cumberlege), 1953. Price: 92*s.* 0*d.* or $11.50.

This, the third edition of *Meteorological instruments*, has been revised by Prof. A. F. Spilhaus, Dean of the Institute of Technology, University of Minnesota. The text of the second edition has been changed into American forms ("endeavour" changed to "endeavor", "metres" to "meters", "apart from" to "aside from", etc.) and a few new sections have been added or existing sections enlarged. Practically no other change was found necessary; this is mainly due to the fact that, on the whole, surface meteorological instruments in use today are very little different from those in use in 1941, when the first edition was published; but it is evidence also of the thoroughness with which Mr. Middleton prepared the original editions. There are a few comparatively recent minor developments which might have been included in the third edition but are not, for example a simple time-marking device developed, I believe, in Germany, and several new types of pen. But lucid accounts are given of the important developments which have taken place in electronic devices for upper air sounding, thunderstorm location, etc., as well as of modern instruments for use on aircraft.

In the earlier editions descriptions of instruments for the measurement of the electrical and optical state of the atmosphere, of radiation instruments, and of instruments for the study of atmospheric pollution were all omitted on the grounds that "only a small minority of meteorologists ever have occasion to operate such instruments". With the exception of the Robitzsch actinograph and of the Eppley pyrheliometer descriptions of all these instruments are still omitted. But most meteorologists nowadays, at some time or other, have occasion to use instruments for the measurement of the optical properties of the atmosphere—or else to use data obtained by the use of these instruments; their continued exclusion can hardly be justified on these grounds. And, in these days of "smog", many would like to see pollution instruments described also.

The only other serious criticism that can be made concerns those sections in which are discussed the desirable performance characteristics of meteorological instruments. In these sections no consideration is given to the use to which the observations are to be put; the authors are influenced only by what present instruments and techniques are capable of. For example, on p. 63, we find in adjacent paragraphs a statement that the soil temperature at a depth greater than 4 ft. should be measured to an accuracy of 0·02°F., and a statement that sea-surface temperatures should be measured to an accuracy of 1·0°F. The first of these is clearly based on the fact that the temperature at a depth of 4 ft. is very steady and could be measured to the accuracy specified; the second on the supposed fact that the difficulty of measuring sea-surface temperature using present techniques is such that the readings can hardly be relied upon to better than 1°F. It is difficult to imagine of what use to a meteorologist would be an accuracy of measurement of soil temperatures, at a depth of greater than 4ft., of 0·02°F.; on the other hand there are many meteorologists who regard an accuracy of 1°F. in the measurement of sea-surface temperature as not good enough.

Another example of rather a different nature arises where the desirable lag coefficient of thermometers used for measuring air temperature are being discussed. The authors present a graph showing temperature measurements made using a rapid thermometer. From this graph it is deduced that the lag of an air-temperature thermometer should be at least 30 sec. The deduction is completely fallacious. If the graph is analysed one finds, as one would expect, that fluctuations of all periods are present; and that the amplitude of fluctuations of period about 30 sec. is roughly 0·8° of period 2 min. about 1·1° and of period 10 min. about 1·0°. It is not possible to analyse for fluctuations longer than 10 min. or shorter than 30 sec., but certainly there is here no evidence on which to select 30 sec. as about the right lag for a thermometer. On the same graph is superimposed what purports to be a record obtained from a thermometer with a lag of 240 sec. It is not. In places the trace is actually going down whilst the air temperature is above the indicated temperature; and a little arithmetic is sufficient to show that a thermometer with a lag of 240 sec. would show very much larger fluctuations than are indicated here.

The desirable accuracy and lag coefficient of meteorological instruments is a matter of some importance; but it is not one which can be decided by a study of the records obtained from one station. The frequency of observations and the distances apart of stations as well as the use which is to be made of the data must also be considered.

The book is well produced and should be studied by all who make or use meteorological observations.

R. FRITH

ERRATUM

August 1954, PAGE 234, line 26; *for* "to be 3 m.p.h. and 1·5 m.p.h. respectively" *read* "to be 1·5 m.p.h. and 3 m.p.h. respectively".

BOOKS RECEIVED

The ice ages. By E. J. Öpik. *Irish astr. J., Armagh,* **2,** 1952, pp. 71–84, *Illus.*

On the causes of palaeoclimatic variations and of the ice ages in particular. By E. J. Öpik. *J. Glaciol., London,* **2,** 1953, pp. 213–218.

A climatological and astronomical interpretation of the ice ages and of the past variations of terrestrial climate. By E. J. Öpik. *Contr. Armagh Obs., Armagh,* No. 9, 1953, pp. 79, *Illus.* Price 10*s.* 6*d.*

Convective transfer in the problem of climate. By E. J. Öpik. *Geophys. Bull., Dublin,* No. 8, pp. 16, 1953. Price 3*s.* 6*d.*

Resumen de Labores, Año 1953. No. 2, 10 in. × 7½ in., pp. 30, *Illus.*, Universidad Mayor de San Andres, Laboratorio de Física Cósmica, La Paz, Bolivia, 1954.

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

Harmonic analysis of the tides at Bakar. By M. Kasumović. *Rad. geofiz. Inst., Zagreb,* Ser. III, Br. 1, pp. 9, University of Zagreb, 1952.

METEOROLOGICAL OFFICE NEWS

Academic successes.—Information has reached us that the following members of the staff have been successful in recent examinations; we offer them our congratulations.

London B.Sc. (General): Second Class Honours in pure and applied mathematics and physics, G. S. Smith.

London B.Sc. (Special): Pass in pure and applied mathematics, Miss J. Portnall.

Intermediate B.Sc.: physics, J. N. Brand.

General Certificate of Education (Advanced Level): pure and applied mathematics and physics, K. Bruley, E. J. Butler, J. W. Davies, D. L. Jones; physics, C. Alderson, Miss P. D. Elcock (with distinction); pure mathematics, C. E. Wood.

Ocean weather ships.—The following extracts from the Master's report, *Weather Observer*, Voyage 56, shows that life aboard a weather ship has its moments of variety:—

July 15. An aircraft from R.A.F. Station Topcliffe circled the ship and dropped mail. The aircrew were unable to see the ship owing to low cloud and fog. We told the pilot to drop the mail as he passed overhead. We were able to see far enough to see the canister hit the water and recover it.

During the voyage a darts and also a cribbage competition was held between the Messes. These were enjoyed by everyone, and other competitions have been arranged for the next voyage. During the lay-up a cricket match was arranged with "our" school, but unfortunately it was cancelled owing to rain; a football match with them is to be arranged later. The highlight of the voyage was when the ship's "dog" gave birth to seven bonnie pups—all are doing well.

WEATHER OF AUGUST 1954

The mean pressure for the month was noteworthy for the fact that it was below normal over an extensive area including Europe, the North Atlantic and most of the United States. The difference from normal was not very great, being generally between 1 and 4 mb. The lowest mean pressure in the region, 1006 mb., occurred just south of Iceland and also over Scandinavia; the highest mean pressure, 1023 mb., was at the Azores. The mean pressure over central and west Europe was very uniform varying only between 1013 and 1015 mb.

Mean temperature in the west and south of Europe was generally 2–4°F. below normal, but over Scandinavia it was 1–2°F. above normal. Over most of the United States, especially the southern half, mean temperature was above normal.

In the British Isles the weather of August was similar to that of the preceding two months and maintained the character of this summer as combining low temperature with a general deficiency of sunshine. Over most of England and Wales and south Scotland there was also more than average rainfall but the distribution was rather variable owing to heavy local falls of rain, associated at times with the rather frequent thunderstorms. The weather in most parts was again dominated by frequent and active depressions.

From the 1st to the 3rd a depression moved from the Atlantic to the northern North Sea and on the 4th a secondary disturbance moved northward to affect southern districts of the British Isles. Troughs to a new Atlantic depression moved across the country on the 5th and subsequently a complex low-pressure system covered the British Isles. On the 9th another small but active depression moved quickly north-east along the English Channel to become slow moving over the North Sea on the 10th. Periods of rain and frequent showers occurred but there were long sunny periods in some places; for example, Leuchars in Fifeshire recorded 13·7 hr. on the 4th and 12·5 hr. on the 7th. Local thunderstorms occurred on most days and rainfall was heavy at times and daily totals of more than 1 in. were recorded at a number of places, notably in Wales on the 1st and in Kent and Sussex on the 9th (3·16 in. at Swansea Waterworks, Brecknockshire and 2·55 in. at Ystalyfera, Glamorgan on the 1st). Strong westerly winds prevailed along the south coast on the 7th. Temperature rose to 70°F. or above in southern England during the first few days; 78°F. was reached in Kent on the 3rd, 80°F. at Camden Square, London, on the 4th, and 78°F. in Dorset on the 5th, but from then until towards the end of the month temperature was for the most part below the August average. A weak ridge of high pressure moved in over the British Isles on the 11th; it was followed on the 12th by a trough of low pressure and on the 15th and 16th by another ridge. Changeable weather occurred over this period, with rain in most areas, heavy at times, with thunderstorms in places but also with sunny periods; Bidston near Liverpool, with 2·36 in. on the 15th, had its heaviest daily rainfall ever recorded in 88 years of observation. On the 17th and 18th a deepening depression from the Atlantic moved eastward across Ireland and northern England giving heavy rain in England and Wales and southern Scotland on the 17th (3·25 in. at Blaenau Festiniog, Merionethshire, 2·12 in. at Uswayford, Northumberland and 2·09 in. at Wet Sleddale, Westmorland). On the 18th an intense ridge of high pressure developed from the Azores towards Scandinavia and maintained fine weather for a few days over much of Scotland, Ireland and parts of western England and Wales. The depression, however, became slow moving in the North Sea on the 19th and then began to move slowly south-west. It was replaced by another system which settled down as a complex depression over the southern North Sea and gave rise to a period of dull rainy weather over eastern districts of England, which gradually extended to much of Scotland, Wales and western England and did not finally clear up until the 25th. During this period there was some very cool weather; on the 19th, Kew, with a maximum of only 57°F., had its coolest August day since 1931. Thunderstorms with heavy local rain were frequent in England (2·08 in. at Halifax Waterworks on the 20th, 3·1 in., most of which fell in 1 hr., at Freshwater, Isle of Wight on the 21st, 2·00 in. at Guisborough, Yorkshire on the 22nd). Morning fog caused some dislocation of road, rail and air traffic in London and the Home Counties on the 22nd. Considerable sunshine occurred in some north-western and western areas during this period; Stornoway recorded 14 hr. on the 16th and over 12 hr. were recorded in parts of south-west England on the 23rd. On the 25th a ridge from the Azores anticyclone spread over the British Isles. It subsequently moved slowly southward into France but southern England had mostly fine weather with considerable sunshine and temperature once more rose into the seventies; on the 31st, 80°F. was reached at a number of places in south-east and east England and locally in the Midlands and 81°F. at Camden Square and Benson, near Oxford. A maximum of 75°F. was registered at Dyce near Aberdeen on the 25th. Scotland, Northern Ireland and, to a less extent, Wales and northern England had mostly cloudy weather with rain or drizzle at times. South-westerly gales occurred in north and west Scotland on the 30th.

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 ...	81	36	−2·3	140	+3	73
Scotland	75	28	−1·5	103	+1	77
Northern Ireland ...	71	38	−1·9	74	−2	87

RAINFALL OF AUGUST 1954

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	3·41	154	*Glam.*	Cardiff, Penylan ...	3·96	94
Kent	Dover	3·37	146	*Pemb.*	Tenby	3·82	101
"	Edenbridge, Falconhurst	3·15	120	*Radnor*	Tyrmynydd	5·91	110
Sussex	Compton, Compton Ho.	3·31	107	*Mont.*	Lake Vyrnwy	4·77	89
"	Worthing, Beach Ho. Pk.	2·73	121	*Mer.*	Blaenau Festiniog ...	13·55	121
Hants.	Ventnor Park	3·99	196	"	Aberdovey	4·79	108
"	Southampton, East Pk.	3·78	144	*Carn.*	Llandudno	3·09	110
"	South Farnborough ...	3·04	137	*Angl.*	Llanerchymedd ...	3·97	110
Herts.	Royston, Therfield Rec.	3·12	121	*I. Man*	Douglas, Borough Cem.	4·64	122
Bucks.	Slough, Upton... ...	3·01	139	*Wigtown*	Newton Stewart ...	4·56	109
Oxford	Oxford, Radcliffe ...	3·16	139	*Dumf.*	Dumfries, Crichton R.I.	4·18	103
N'hants.	Wellingboro' Swanspool	3·48	146	"	Eskdalemuir Obsy. ...	5·84	113
Essex	Shoeburyness	3·97	224	*Roxb.*	Crailing...	6·45	219
"	Dovercourt	3·05	170	*Peebles*	Stobo Castle	5·14	144
Suffolk	Lowestoft Sec. School...	4·88	222	*Berwick*	Marchmont House ...	6·13	185
"	Bury St. Ed., Westley H.	4·37	168	*E. Loth.*	North Berwick Res. ...	5·28	167
Norfolk	Sandringham Ho. Gdns.	4·97	184	*Midl'n.*	Edinburgh, Blackf'd. H.	5·33	166
Wilts.	Aldbourne	3·35	126	*Lanark*	Hamilton W. W., T'nhill	4·67	137
Dorset	Creech Grange... ...	3·47	121	*Ayr*	Colmonell, Knockdolian	4·37	109
"	Beaminster, East St. ...	3·55	113	"	Glen Afton, Ayr San. ...	5·45	101
Devon	Teignmouth, Den Gdns.	2·24	99	*Renfrew.*	Greenock, Prospect Hill	5·14	100
"	Ilfracombe	3·55	99	*Bute*	Rothesay, Ardencraig...	5·79	119
"	Princetown	6·95	102	*Argyll*	Morven, Drimnin ...	4·20	80
Cornwall	Bude, School House ...	2·76	98	"	Poltalloch	4·99	102
"	Penzance, Morrab Gdns.	1·74	55	"	Inveraray Castle ...	6·44	98
"	St. Austell	2·80	77	"	Islay, Eallabus... ...	4·12	94
"	Scilly, Tresco Abbey ...	1·55	56	"	Tiree	3·20	76
Somerset	Taunton	2·31	97	*Kinross*	Loch Leven Sluice ...	3·31	86
Glos.	Cirencester	3·63	121	*Fife*	Leuchars Airfield ...	2·45	80
Salop	Church Stretton ...	5·11	153	*Perth*	Loch Dhu	6·66	99
"	Shrewsbury, Monkmore	3·68	133	"	Crieff, Strathearn Hyd.	4·11	98
Worcs.	Malvern, Free Library...	4·06	140	"	Pitlochry, Fincastle ...	3·12	88
Warwick	Birmingham, Edgbaston	4·15	153	*Angus*	Montrose, Sunnyside ...	2·66	95
Leics.	Thornton Reservoir ...	4·54	162	*Aberd.*	Braemar	2·88	84
Lincs.	Boston, Skirbeck ...	3·58	150	"	Dyce, Craibstone ...	3·06	101
"	Skegness, Marine Gdns.	3·72	152	"	New Deer School House	2·50	84
Notts.	Mansfield, Carr Bank...	4·12	148	*Moray*	Gordon Castle	3·01	95
Derby	Buxton, Terrace Slopes	5·70	130	*Nairn*	Nairn, Achareidh ...	2·22	91
Ches.	Bidston Observatory ...	5·32	173	*Inverness*	Loch Ness, Garthbeg ...	3·03	93
"	Manchester, Ringway...	5·03	153	"	Glenquoich	7·31	89
Lancs.	Stonyhurst College ...	7·51	148	"	Fort William, Teviot ...	5·92	95
"	Squires Gate	4·31	126	"	Skye, Broadford ...	5·68	88
Yorks.	Wakefield, Clarence Pk.	5·88	226	"	Skye, Duntuilm ...	4·33	97
"	Hull, Pearson Park ...	6·20	213	*R. & C.*	Tain, Mayfield... ...	2·22	82
"	Felixkirk, Mt. St. John...	6·05	212	"	Inverbroom, Glackour...	2·31	55
"	York Museum	7·18	285	"	Achnashellach	4·31	68
"	Scarborough	4·38	158	*Suth.*	Lochinver, Bank Ho. ...	3·00	90
"	Middlesbrough... ...	4·55	166	*Caith.*	Wick Airfield	2·35	85
"	Baldersdale, Hury Res.	5·20	157	*Shetland*	Lerwick Observatory ...	2·69	89
Norl'd.	Newcastle, Leazes Pk....	5·62	199	*Ferm.*	Crom Castle	3·36	81
"	Bellingham, High Green	4·53	128	*Armagh*	Armagh Observatory ...	2·26	62
"	Lilburn Tower Gdns. ...	6·21	220	*Down*	Seaforde	2·86	76
Cumb.	Geltsdale	6·08	148	*Antrim*	Aldergrove Airfield ...	2·20	61
"	Keswick, High Hill ...	5·87	112	"	Ballymena, Harryville...	2·38	56
"	Ravenglass, The Grove	5·07	111	*L'derry*	Garvagh, Moneydig ...	3·16	81
Mon.	A'gavenny, Plâs Derwen	3·70	112	"	Londonderry, Creggan	4·45	96
Glam.	Ystalyfera, Wern House	7·49	121	*Tyrone*	Omagh, Edenfel ...	3·40	80

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

Wt-34. K16.

M.O. 581 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 83, No. 989, NOVEMBER 1954

MEMORIAL TABLETS AT KEW OBSERVATORY

In 1950 the late Mr. R. S. Whipple approached Sir Nelson Johnson with the offer to provide at Kew Observatory some memorial to his father and brother and to the other Superintendents of the Observatory with whom his family had been linked. Sir Nelson, in agreeing, suggested that there should also be some separate memento of Mr. Whipple's grandfather, Robert Beckley, mechanical assistant at the Observatory for 20 years.

Preparation of the tablets was entrusted to Mr. Ernest Gillick; he died before the work was complete but it was taken up by Mrs. M. Gillick, known for her design on the new coinage. The tablets are of a Derbyshire marble, the larger one bears the Royal Arms of H.M. King George III, in low relief, gilt, with the wording

His Majesty King George III built this Observatory
primarily to observe the transit of Venus in the year
1769

KING'S OBSERVERS

1769 Stephen Charles Triboudet Demainbray
1782 Stephen George Francis Triboudet Demainbray

SUPERINTENDENTS

1842 Sir Francis Ronalds, F.R.S.
1852 John Welsh, F.R.S.
1859 Balfour Stewart, F.R.S.
1871 Samuel Jeffrey
1876 George Mathews Whipple
1893 Charles Chree, F.R.S.
1925 Francis John Welsh Whipple
1939 James Martin Stagg
1939 Sir George Simpson, F.R.S.

The smaller tablet has the inscription

To Robert Beckley Assistant in this Observatory 1853–72. He invented the recording anemometer and the rain-gauge bearing his name + Dedicated in 1952 by his grandson Robert Stewart Whipple

The tablets are placed in the south octagon room at the Observatory.

The memorials were unveiled by Sir George Simpson on July 21, 1954. Mr. R. S. Whipple died early this year, and the tablets were presented to the

Observatory by his son, Mr. G. A. Whipple, in the presence of Mrs. R. S. Whipple and members of her family, Mrs. Gillick, the Director of the Meteorologial Office, and a few former colleagues of Dr. F. J. W. Whipple. Mr. Whipple gave some details of the family connexion with the Observatory, which is even closer than appears from the wording of the tablets. G. M. Whipple entered as an assistant under his father's close friend John Welsh (at a salary of eight shillings a week) and served under Balfour Stewart and Samuel Jeffrey before becoming Superintendent, and R. S. Whipple, a godson of Balfour Stewart, was himself on the Observatory staff for three years under Charles Chree.

Sir George Simpson then unveiled the memorial, and outlined the history of the Observatory as it came successively under the Royal Household, the British Association, the Royal Society, the National Physical Laboratory and the Meteorological Office. He dwelt on the remarkable foresight of the British Association Committee which in 1842 defined the "Objects of the Observatory" to include the following: complete observations of meteorology, terrestrial magnetism, and atmospheric electricity—eye observations to be replaced by self-recording instruments—balloon observations to be made, in particular "a method to be devised for telegraphing the indications of meteorological instruments carried up in balloons or in kites to an observer at the earth's surface"—new methods and instruments to be studied and developed—scientific instruments to be compared with standards kept by the Observatory. Sir George showed how, through the years, all these subjects had received attention and been notably advanced at Kew, though the radio-sonde, called for in 1842, had to wait almost a century for its realization. Sir George spoke particularly of the work of Welsh and Beckley in the designing and making of instruments, and of Stewart and Beckley in equipping the seven meteorological observatories which began a continuous photographic record in 1869.

Dr. Sutton, accepting the tablets on behalf of the Meteorological Office, spoke of his pleasure in seeing a unique family connexion commemorated.

WORLD METEOROLOGICAL ORGANIZATION

Fifth Session of the Executive Committee

By O. G. SUTTON, D.Sc., F.R.S.

The Executive Committee of the World Meteorological Organization held its fifth session at Geneva from August 25 to September 11, 1954. This meeting differed from the preceding sessions in that it was overshadowed by preparations for the Second Congress, which has now been announced to begin at Geneva on April 14, 1955.

As customary, the Committee divided into two main working groups, dealing with administration and finance and with programme, respectively. It would be inappropriate here to attempt to give a complete summary of the complicated financial and other matters which the first group, under the able chairmanship of Mr. D. A. Davies (President, Regional Association I) sorted out during a very busy three weeks, but it should be mentioned that the Organization has passed through its initial financial period in a very satisfactory manner. Among other things, considerable thought was given to questions of grades, salary scales and structure of the Secretariat for the second financial period which follows Congress. One of the most interesting decisions was that which set up a small working group with a two-fold task: first, to consider plans for the progressive extension of the work of the Technical Division as a "processing centre" for meteorological information, and second, to act as a scientific advisory body on the work of the Technical Division in general. This resolution arose out of the recommendation of a working group on the proposal to set up an international meteorological institute, which was found to be both impracticable and inadvisable at the present time.

The working group on programme, under the chairmanship of Col. Sellick (Rhodesia), had a heavy task, for in addition to the reports of the Regional Associations it had to consider the large and complicated report of the simultaneous session of the Commission for Aeronautical Meteorology (World Meteorological Organization) and the Meteorology Division of the International Civil Aviation Organization. The difficult question of horizontal visibility in meteorological reports occupied much time, and in view of the lack of uniformity which now exists it was decided to ask the various services to carry out, as a matter of urgency, trials on the determination of the so-called "visibility index" in accordance with a procedure laid down by the Executive Committee, and to report results not later than March 1, 1955. At the same time the operational procedure for determining the visibility index was referred to the Commission for Instruments and Methods of Observation for critical examination.

The value of ground radar sets (operated as independent equipment by meteorological services) for weather observations was recognized in another resolution, and it was also decided to instruct the Secretariat to prepare a *Technical Note* giving information about equipment suitable for ground radar weather observations. Members of the Committee felt strongly that unless such equipment was under the complete control of the meteorological officer at an aerodrome its value would be greatly reduced, and in the course of the discussion the interesting point was made that the optimum wave-length for meteorological observations is possibly neither 3 cm. nor 10 cm. but an intermediate length about 5 cm.

For high-level forecasts, a resolution was adopted urging the services to greater efforts in charting the atmosphere above the 200-mb. level, to consider the routine construction of charts showing the height of the tropopause, and to develop techniques for forecasting the vertical extent of cumulonimbus clouds and the extent of cirrus up to the levels required for modern aircraft. After some discussion on ways and means, it was decided to leave it to the Regional Associations to make arrangements for meetings of forecasters from different countries to pool and exchange information on high-level forecasting. Another *Technical Note* planned is one describing progress in research on turbulence and gusts.

The importance of winds over mountains was recognized, and it is gratifying to the Meteorological Office to know that a projected *Technical Note* on this subject will probably be based largely on the excellent report which Mr. Corby made recently to our own Meteorological Research Committee.

The reports of two other Commissions, those for Agricultural Meteorology and for Bibliography and Publications, were also considered. These generally were less controversial, and the Committee expressed its satisfaction with the considerable progress being made in both fields. Arising from the report of the Commission for Bibliography and Publication, the Executive Committee, not unexpectedly, found it difficult to reach a final decision on the International Meteorological Bibliography, and in the end postponed matters by instructing the Secretariat to inquire of members what material they would wish to see included, and how soon after publication a list of such papers could be sent to Geneva. This reflects the general opinion that the value of a bibliography depends very much on its appearing within a relatively short time, say a few months at the most, after the publication of the papers.

Another recommendation which gave rise to much discussion was that dealing with a possible World Climatological Atlas. The difficulty here is two-fold. In the first place, some excellent regional atlases already exist or are in active preparation, and secondly, the preparation of a world atlas *ab initio* by the World Meteorological Organization would be a very long and costly task. It was decided to ask the Commission for Climatology, in consultation with the Regional Associations and the Technical Commissions concerned, to draft specifications for (*a*) a single climatological atlas covering the whole world and based on a strictly uniform plan and (*b*) a series of national, sub-regional and regional atlases which together could be considered as constituting a World Climatological Atlas. The final decision is to be left to the Second Congress.

Among other matters of general interest dealt with by the Committee the following two items may be mentioned. The continuance of the North America Continental Broadcast (WSY) was urged, together with a request that Governments concerned should hasten the change over to radioteletype, a step which is much desired by the United States. *Technical Notes*, which have already gained a high reputation for clarity, reliability and impartiality, are, in future, to have abstracts in all the official languages (English, French, Russian and Spanish) of the Organization. This should go far towards securing a wider circulation of these publications.

Finally, some mention should be made of the resolution on atomic explosions and weather. Not unnaturally, this attracted the attention of the Press of the world, and it is most unfortunate that some of the published accounts were, to say the least, fanciful. No member of the Executive Committee expressed a belief in the reality of a connexion between the explosions and the recent bad summer. The resolution arose from a discussion on a circular letter from the Japanese Meteorological Society which mentioned the possibility of such an effect, and the Executive Committee decided that the World Meteorological Organization, as an international organization, should attempt a proper scientific examination of a belief which apparently is held by many people all over the world. To this end the Secretary-General was instructed to collect what information he could, it being understood that a *Technical Note* would be published if, and only if, the information so obtained justified it. There was not, as some newspapers asserted, any "agreement" to pool knowledge, and anyone acquainted with the constitution and duties of the Executive Committee will realize that it has no powers to resolve, or even discuss, such a momentous question. As meteorologists we may welcome this investigation, not because it is likely to produce an answer which will satisfy the layman, but because it focuses attention on the apparent "abnormalities" of climate which have always existed, and any study which may help to establish their nature and distribution on a world-wide basis is therefore unlikely to be wasted.

The fifth session of the Executive Committee meant three weeks of hard work, with meetings running continuously from 9 a.m. to 6 p.m. and often later. Fortunately, we were favoured with good weather (a somewhat unusual blessing for a gathering of meteorologists) and at the week-ends it was possible to blow away some of the smoke-laden atmosphere of the conference rooms in the clean air of the mountains. For this boon we must express our gratitude to those members of the World Meteorological Organization staff who gave so freely of their scanty leisure to show us some of the beauties of their adopted country.

ESTIMATION OF MEAN WINDS AND STANDARD DEVIATIONS AT HIGH LEVELS

By P. GRAYSTONE, B.A.

Summary.—A method is suggested for estimating upper wind means and standard deviations, when only a restricted summary, possibly with a bias towards lighter winds, is available at high levels. Tests indicate that the method can be used with some confidence even when only a small proportion of ascents reach the required level, and that the corrections necessary are smaller than has generally been supposed.

Introduction.—Upper wind statistics at high levels are frequently based on incomplete data, chiefly owing to a tendency for the balloon to be carried out of radar or visual range by strong winds. There are in fact hardly any complete summaries available above 150 mb., and at some stations, e.g. in the subtropical jet-stream zones, considerable losses occur below 200 mb.

Correlation of wind with height.—Provided that a complete set of observations is available at a lower level, the true vector mean and standard vector deviation at the higher level can be estimated on the assumption that the correlation between winds at the two levels is the same in the case of the missing winds as for the whole set.

Let N be the total number of observations at level 1, of which a are missing at level 2.

Let $\bar{\mathbf{V}}_1$, $\bar{\mathbf{V}}_2$, σ_1, σ_2 and R be the true vector means, standard vector deviations, and the true correlation coefficient between winds at the two levels. Let $\mathbf{u}_1$, $\mathbf{u}_2$, s_1, s_2 and R' be the vector means, standard vector deviations and correlation coefficient based on $N-a$ observations only.

Given a wind $\mathbf{V}_1$ at one level, the most probable wind $\mathbf{V}_2$ at another level is

$$\mathbf{V}_2 - \bar{\mathbf{V}}_2 = R\frac{\sigma_2}{\sigma_1}(\mathbf{V}_1 - \bar{\mathbf{V}}_1)$$

and the mean square vector error is $\sigma_2^2(1 - R^2)$.

These equations, applicable strictly to the whole set of observations, are assumed to be valid for the a missing observations, which are therefore given by

$$\mathbf{V}_2 = \bar{\mathbf{V}}_2 + R\frac{\sigma_2}{\sigma_1}(\mathbf{V}_1 - \bar{\mathbf{V}}_1) + \mathbf{k}$$

where $\sum_1^a \mathbf{k} = 0$ and $\frac{1}{a}\sum_1^a \mathbf{k}^2 = \sigma_2^2(1 - R^2)$.

A further necessary assumption is that there is no correlation between the wind at the lower level, and the departure of the wind from its most probable value at the higher level, i.e.

$$\sum_1^a \mathbf{k}\,\mathbf{V}_1 = 0.$$

The values of $\overline{\mathbf{V}}_2$, σ_2 and R are as yet unknown.

Derivation of formulae.—

Now
$$\overline{\mathbf{V}}_2 = \frac{1}{N}\sum_1^N \mathbf{V}_2$$
$$= \frac{1}{N}\sum_1^{N-a} \mathbf{V}_2 + \frac{1}{N}\sum_1^a \left\{ \overline{\mathbf{V}}_2 + R\frac{\sigma_2}{\sigma_1}(\mathbf{V}_1 - \overline{\mathbf{V}}_1) + \mathbf{k} \right\}$$

whence, on substituting $\sum_1^a \mathbf{k} = 0$,

$$\overline{\mathbf{V}}_2 = \mathbf{u}_2 + R\frac{\sigma_2}{\sigma_1}(\overline{\mathbf{V}}_1 - \mathbf{u}_1).$$

Similarly
$$\sigma_2^2 = \frac{1}{N}\sum_1^N \mathbf{V}_2^2 - \overline{\mathbf{V}}_2^2$$
$$= \frac{1}{N}\sum_1^{N-a} \mathbf{V}_2^2 + \frac{1}{N}\sum_1^a \left\{ \overline{\mathbf{V}}_2 + R\frac{\sigma_2}{\sigma_1}(\mathbf{V}_1 - \overline{\mathbf{V}}_1) + \mathbf{k} \right\}^2 - \overline{\mathbf{V}}_2^2.$$

Inserting the values for $\overline{\mathbf{V}}_2$, $\sum_1^a \mathbf{k}^2$ and $\sum_1^a \mathbf{k}\,\mathbf{V}_1$, we obtain, after simplification,

$$\sigma_2^2 = \frac{s_2^2\sigma_1^2}{\sigma_1^2 - R^2(\sigma_1^2 - s_1^2)}.$$

Finally,
$$R = \frac{1}{N\sigma_1\sigma_2}\left\{ \sum_1^N \mathbf{V}_1\mathbf{V}_2 - N\overline{\mathbf{V}}_1\overline{\mathbf{V}}_2 \right\}$$

and
$$R' = \frac{1}{(N-a)\,s_1 s_2}\left\{ \sum_1^{N-a} \mathbf{V}_1\mathbf{V}_2 - (N-a)\,\mathbf{u}_1\mathbf{u}_2 \right\}.$$

Eliminating $\sum_1^{N-a} \mathbf{V}_1\mathbf{V}_2$ and simplifying,

$$R^2 = \frac{R'^2\sigma_1^2}{s_1^2 + R'^2(\sigma_1^2 - s_1^2)}.$$

We therefore have the formulae:—

$$R = \frac{R'\sigma_1}{[s_1^2 + R'^2(\sigma_1^2 - s_1^2)]^{\frac{1}{2}}} \quad \ldots. (1)$$

$$\sigma_2 = \frac{R'}{R}\frac{s_2}{s_1}\sigma_1 \quad \ldots. (2)$$

$$\overline{\mathbf{V}}_2 = \mathbf{u}_2 + R\frac{\sigma_2}{\sigma_1}(\overline{\mathbf{V}}_1 - \mathbf{u}_1) = \mathbf{u}_2 + R'\frac{s_2}{s_1}(\overline{\mathbf{V}}_1 - \mathbf{u}_1) \quad \ldots. (3)$$

Discussion of formulae.—The formulae are equally applicable to vector and scalar quantities. Equations (2) and (3) are derivable direct from the assumption that the regression equation for the whole set applies also for the partial set a, as this implies that

$$R' \frac{s_2}{s_1} = R \frac{\sigma_2}{\sigma_1}.$$

Equation (1) indicates that a correlation coefficient obtained from an incomplete set will be too low, if, as is usual, $\sigma_1 > s_1$.

The assumptions made in deriving the formulae cannot of course be justified mathematically. Physically they appear reasonable, and are probably the best that can be made. No differentiation is necessary between ascents abandoned owing to the balloon being carried out of range and other causes.

Practical tests.—The method adopted for testing the formulae was to take sets of wind observations which were more or less complete at two levels, and to omit the upper-level observation when the wind speed at the lower level exceeded a certain value. It was not possible to use as tests occasions of very strong wind or to include levels above 150 mb., since in neither case were there any sufficiently complete summaries. On the other hand, the omission of all observations when the wind at the lower level was strong represents a much more rigorous test than occurs in practice.

In the following initial tests in Table I, corrections were made to the wind speed only, the error in direction being small (b = critical speed, at lower level, above which observations at upper level were omitted).

TABLE I

	Levels Lower	Upper	N	a	b	Wind at higher level	R	$\bar{V}$	σ
	Km.	Km.			kt.			kt.	kt.
Tateno	6	9	86	32	80	Uncorrected	0·66	95	38
Dec. 1950–52						Corrected	0·76	111	44
						True	0·68	109	42
Tateno	6	9	242	80	80	Uncorrected	0·60	99	45
Dec.–Feb. 1950–52						Corrected	0·68	112	49
						True	0·66	110	47
	mb.	mb.							
Malta	300	200	112	30	40	Uncorrected	0·47	32	22
July–Aug. 1950						Corrected	0·57	36	23
						True	0·70	36	24

Though upper winds at Tateno (Japan) sometimes show erratic gradients, the results were promising, and further tests were made as in Table II, corrections to wind direction being made as well as to speed.

The corrections to R are frequently erroneous indicating that the correlation in the case of the missing observations does in fact differ from that derived from the lighter winds. That this difference is unimportant is however shown by the high degree of accuracy in the corrected values of **V** and σ. Correlations in the above examples were made below, above and across the tropopause.

In the above tests the value of b was fixed so as to omit about one third of the upper-level winds. To find how the formulae would work with a very restricted summary, three tests were made with a value of b so reduced as to omit three-quarters of the upper-level winds, with the results in Table III. To give an idea of their relative magnitude, all the terms are given for the third example.

TABLE II

	Levels					Wind at higher level				
	Lower	Upper	N	a	b		R	$\bar{\mathbf{V}}$		σ
	mb.	mb.			kt.			°	kt.	kt.
Liverpool Jan.–Feb. 1951	200	150	183	63	40	Uncorrected	0·78	267	15	19
						Corrected	0·88	278	20	25
						True	0·91	280	21	25
Langenhagen July–Aug. 1951	200	150	116	49	48	Uncorrected	0·88	249	18	19
						Corrected	0·93	251	23	25
						True	0·88	252	22	24
Liverpool Apr. 1951–52	300	150	211	69	55	Uncorrected	0·76	280	13	17
						Corrected	0·86	274	17	21
						True	0·82	274	17	20
Habbaniya Apr. 1951–52	300	150	110	37	60	Uncorrected	0·72	267	45	29
						Corrected	0·78	261	52	32
						True	0·70	262	50	31
Downham Market and Hemsby Apr. 1951–52	300	150	223	74	50	Uncorrected	0·70	272	13	16
						Corrected	0·83	274	18	21
						True	0·72	269	17	19

TABLE III

	Levels					Wind at higher level				
	Lower	Upper	N	a	b		R	$\bar{\mathbf{V}}$		σ
	mb.	mb.			kt.			°	kt.	kt.
Liverpool April 1951–52	300	150	211	158	30	Uncorrected	0·58	287	13	13
						Corrected	0·87	280	19	23
						True	0·82	274	17	20
Habbaniya April 1951–52	300	150	110	81	38	Uncorrected	0·67	275	34	25
						Corrected	0·81	262	53	32
						True	0·70	262	50	31
Downham Market and Hemsby April 1951–52	300	150	223	174	20	Uncorrected	0·53	254	8	13
						Corrected	0·88	276	17	22
						True	0·72	269	17	19

At Downham Market and Hemsby $\bar{\mathbf{V}}_1 = 270°$ 23 kt., $\sigma_1 = 40$ kt.
$\mathbf{u}_1 = 258°$ 5 kt., $s_1 = 14$ kt.

The errors in the corrected values of R are now greater, but quite good results, considering the severity of the tests, are obtained for $\bar{\mathbf{V}}$ and σ.

Discussion of results.—The tests indicate that, in general, the formulae can be used with confidence when up to two thirds of the observations are missing, and an approximation can be made when even four-fifths of the ascents fail to reach the higher level. It should be possible therefore to estimate true means and standard deviations up to 100 mb. at most radar stations, and to make a rough approximation for 60 or even 40 mb. in a few cases.

Though the formulae do not specifically require a normal wind distribution, normality is implicit in the idea of correlation. The formulae may therefore be less accurate when the wind distribution at either level is markedly abnormal. This is most likely to occur in jet-stream regions, and in areas experiencing a double wind régime, but even in these cases monthly and seasonal summaries do not often differ seriously from normal.

A noteworthy feature is that the corrections necessary are smaller than has previously been considered likely.[1] At 100 mb. in temperate latitudes, corrections may well be negligible, as balloon losses are primarily caused by strong winds at much lower levels. Table IV gives examples of corrections applied at 100 mb.

TABLE IV

	Wind data at 100 mb.	R	$\overline{\mathbf{V}}$		σ
			°	kt.	kt.
Liverpool, January–February 1951 (118 observations at 100 mb., 183 at 150 mb.)	Uncorrected	0·86	277	15	20
	Corrected	0·88	279	15	22
Downham Market and Hemsby, April 1951–52 (163 observations at 100 mb., 223 at 150 mb.)	Uncorrected	0·89	267	11	14
	Corrected	0·90	270	11	15

The labour required to compute a correlation coefficient is considerable, but if this can be estimated—and a sizable error can be made without materially affecting the result—the corrections can be applied easily in process of computing wind statistics in the usual way. Assuming a correlation coefficient R, the formulae are then:—

$$\overline{\mathbf{V}}_2 = \mathbf{u}_2 + R\frac{\sigma_2}{\sigma_1}(\overline{\mathbf{V}}_1 - \mathbf{u}_1)$$

and

$$\sigma_2 = s_2\sigma_1\,[\sigma_1{}^2 - R^2\,(\sigma_1{}^2 - s_1{}^2)]^{-\frac{1}{2}}$$

where, as before, $\overline{\mathbf{V}}_2$, σ_2, $\overline{\mathbf{V}}_1$ and σ_1 are the true means and standard deviations at upper and lower levels respectively, while $\mathbf{u}_2$, s_2, $\mathbf{u}_1$ and s_1 are corresponding values based on incomplete summaries.

REFERENCE

1. London Meteorological Office. Upper winds on Empire air routes. Unpublished. Copy in Library of the Meteorological Office, London, 1950.
2. DURST, C. S.; Variation of wind with time and distance. *Geophys. Mem., London*, **12**, No. 93 (in the press).

SOME AIRCRAFT AND SURFACE METEOROLOGICAL OBSERVATIONS MADE AT KHARTOUM IN JULY 1952

By P. GOLDSMITH

Summary.—In July 1952, during tropical tests of an aircraft at Khartoum, opportunities occurred of making measurements of temperature and frost point up to 39,000 ft. using an aircraft flat-plate thermometer and a Dobson-Brewer hygrometer. These humidity data are probably the first accurate measurements made at high levels in the tropics and the soundings are described. In conjunction with this work surface observations of solar radiation with a Michelson actinometer were also made, and have been utilized to obtain estimates of the various radiation components in the tropics.

Aircraft measurements of temperature and humidity at high altitudes.—Three ascents were made, two in the day-time and one at night, and the results have been plotted in Figs. 1–3. The instruments used were the Meteorological Office flat-plate thermometer, with readings corrected for airspeed to obtain air temperature, and a pressurized Dobson-Brewer hygrometer to obtain humidity. For comparison purposes the results of the nearest

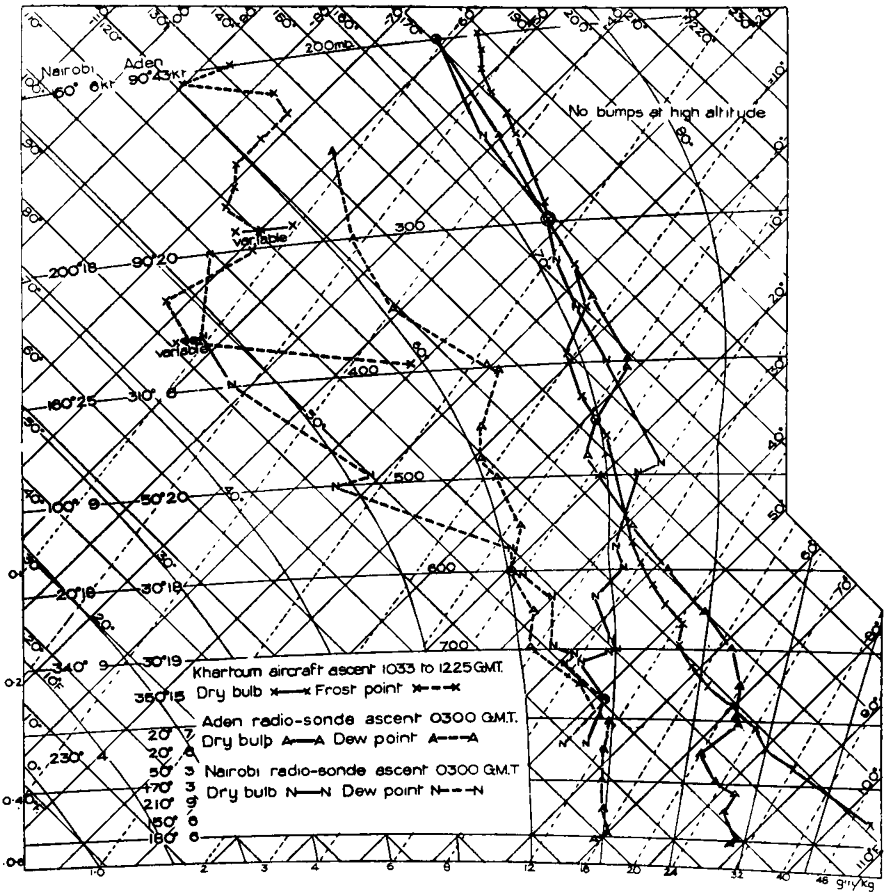


FIG. I—TEPHIGRAM OF RADIO-SONDE ASCENTS FROM NAIROBI AND ADEN TOGETHER WITH AIRCRAFT ASCENT FROM KHARTOUM, JULY 12, 1952

The winds at corresponding heights above Nairobi and Aden are given on the left, aircraft observations at Khartoum on the right.

radio-sonde ascents have also been plotted (Nairobi is about 1,000 miles south-south-east of Khartoum and Aden about 800 miles east-south-east of Khartoum). The main interest of the temperature readings in each case is the general agreement between the form of ascents at Aden and the aircraft ascents at Khartoum. In each case there is a decrease of the lapse rate around or rather above 20,000 ft. at Khartoum, the similar feature at Aden being rather lower. Above 25,000 ft. the Aden, Nairobi and aircraft ascents are broadly similar. The decrease in lapse rate at Aden coincided in each case with a change from a north-easterly to an easterly wind régime.

The frost-point readings are of the same magnitude as those normally found at about the same height by the Meteorological Research Flight in England. However at Khartoum this height is only in the middle troposphere whereas in England it is usually around tropopause level. The humidity usually showed an appreciable decrease above the more stable layer.

Discussion.—It has been shown by E. E. Austin[1] that easterly winds are persistent at Aden in July up to great heights. The vector resultants quoted

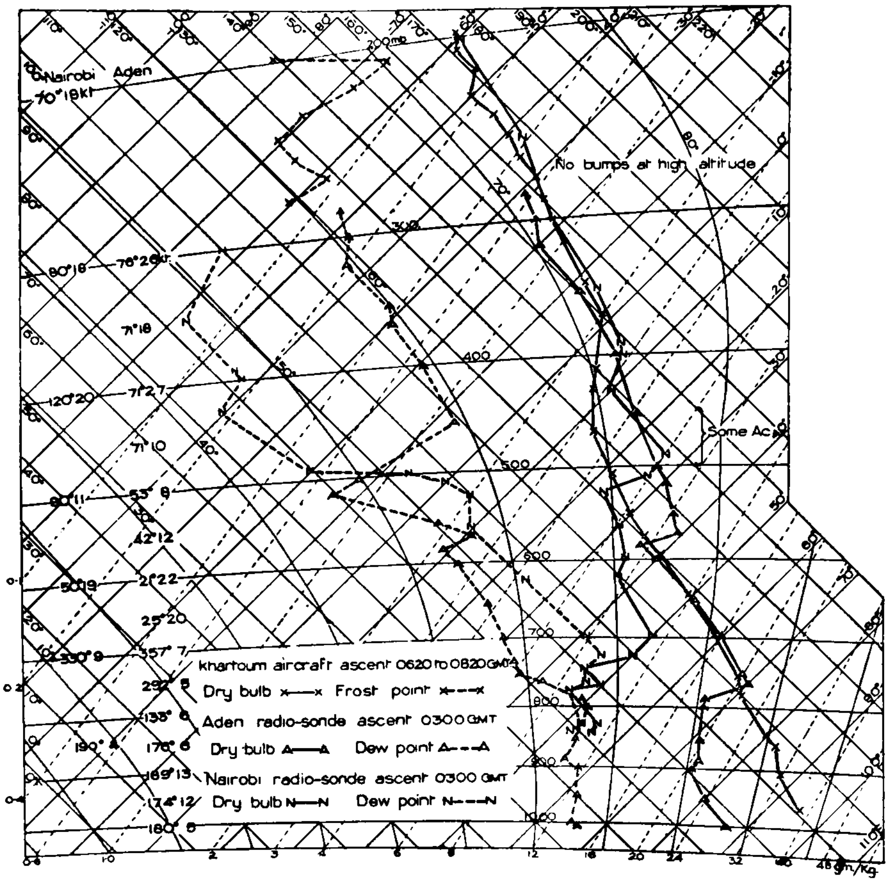


FIG. 2—TEPHIGRAM OF RADIO-SONDE ASCENTS FROM NAIROBI AND ADEN TOGETHER WITH AIRCRAFT ASCENT FROM KHARTOUM, JULY 14, 1952

The winds at corresponding heights above Nairobi and Aden are given on the left, aircraft observations at Khartoum on the right.

in Table I of that paper for July are as follows:—

	Pressure (mb.)						
	850	700	500	300	200	150	100
Vector resultant direction	278°	29°	45°	80°	90°	93°	94°
Speed (kt.)	5	3	13	23	48	71	66

From this it is apparent that the onset of the main easterly stream occurs between 500 and 300 mb., i.e. between 20,000 and 30,000 ft. The Aden soundings discussed above all exhibited this feature and the evidence is that the addendum to E. E. Austin's paper by C. S. Durst, namely that "between 35,000 and 40,000 ft. easterly winds of the same magnitude as at Aden extend over Abyssinia and the Sudan", can probably be extended to include the range 25,000–35,000 ft. in July.

It has been demonstrated that providing the necessary supplies of liquid oxygen can be obtained locally the Dobson-Brewer hygrometer can readily be operated in the tropics. Provided also that attention is given to the effect of the high temperatures (about +130°F.) and humidities in the aircraft on the ground on components such as rubber seals, wiring, etc. there should be

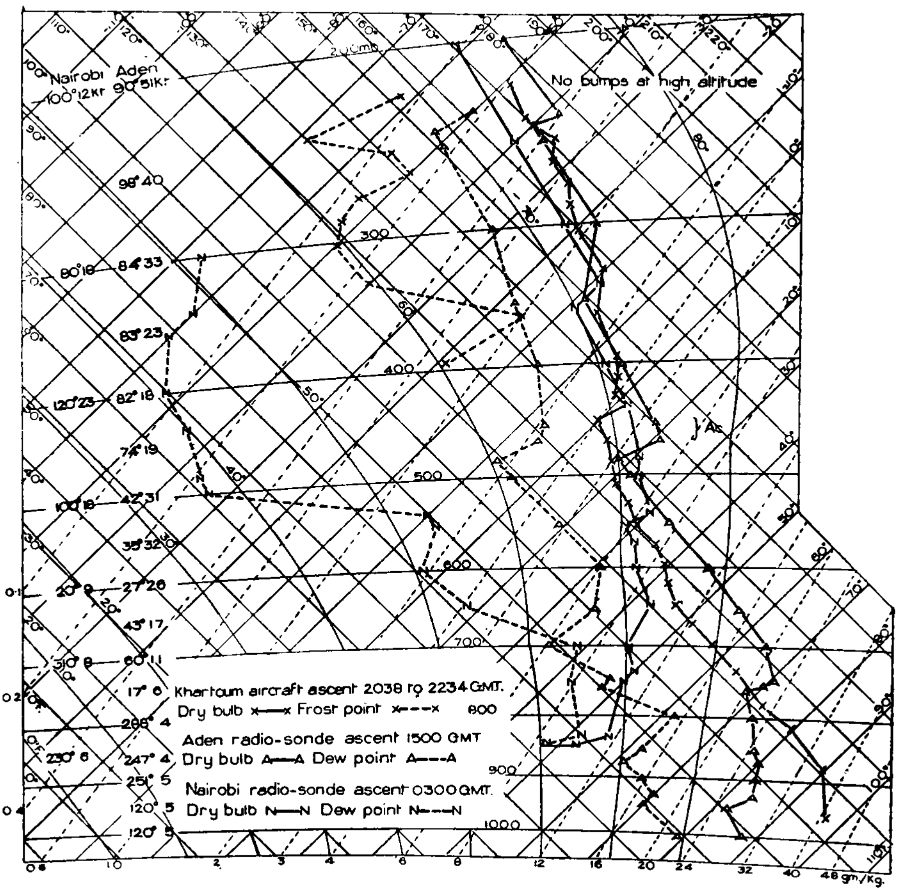


FIG. 3—TEPHIGRAM OF RADIO-SONDE ASCENTS FROM NAIROBI AND ADEN TOGETHER WITH AIRCRAFT ASCENT FROM KHARTOUM, JULY 15, 1952

The winds at corresponding heights above Nairobi and Aden are given on the left, aircraft observations at Khartoum on the right.

no difficulty in extending this work to tropical regions if this should be required. A possible limitation on the use of the instrument is discussed below.

It is known that at frost points of about −120°F. and below, the frost deposit becomes glacial, and so the Dobson-Brewer hygrometer has a lower limit of about −120°F.

It can be seen from Figs. 1–3 that frost points of about −80°F. have been measured at 38,000 ft. in Khartoum with an air temperature of −60°F. The tropopause was at about 57,000 ft. with an air temperature of −110°F. approximately. It seems that, unless the tropopause region in the tropics is always saturated, frost points of −120°F. or lower would be expected there. Although considerable cirrus is found in the tropics, it is not, however, considered likely that saturation will always exist near the tropopause there.

It is interesting incidentally to note that, as temperatures of −130°F. have been reported at moderate altitudes during the polar night[2], this instrument may also fail at high latitudes, and for accurate humidity readings at high altitudes in both tropical and polar regions a new type of instrument will be required.

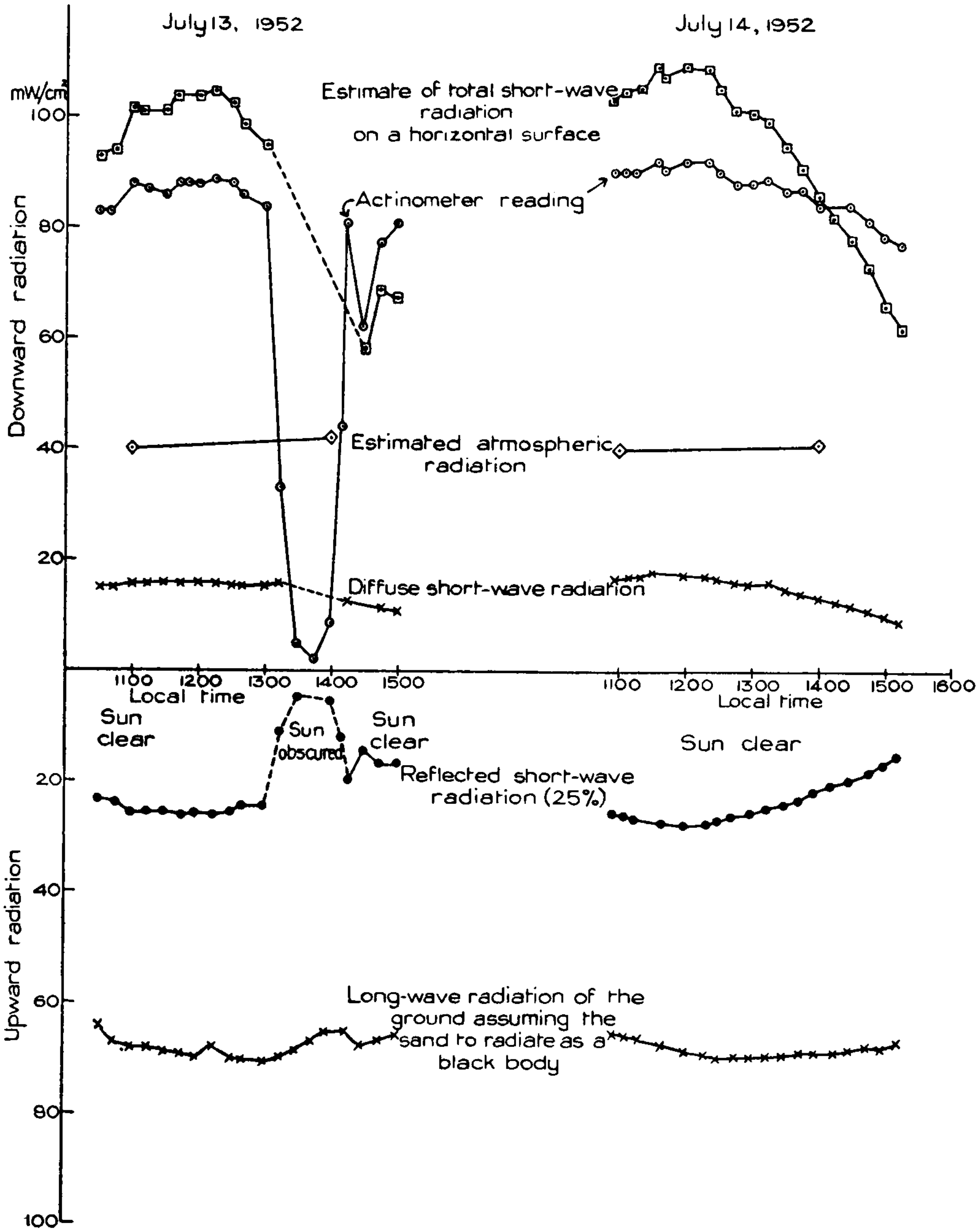


FIG. 4—RECONSTRUCTION OF THE RADIATION FIELD AT KHARTOUM, JULY 13 AND 14, 1952

Surface radiation measurements.—In the estimation of the various radiation components at Khartoum only that from the direct solar beam was measured directly, the others being estimated using other available data. For these extractions and advice on this part of the work I am indebted to Dr. G. D. Robinson and Mr. J. MacDowall of Kew Observatory. The method of obtaining the various components was as follows:—

Direct solar beam.—A Michelson bimetallic actinometer, which had previously been used in Khartoum for other work, was borrowed from Kew Observatory and used for regular measurements of the intensity of the direct solar beam. The sun's zenith angle was also noted at each reading. This instrument was calibrated at Kew before and after use in Khartoum by comparison with a sub-standard Ångström pyrheliometer.

Scattered solar radiation.—This was estimated using an empirical relation between the intensity of the direct solar beam and the intensity of diffuse radiation given by Kimball[3].

Short-wave radiation reflected from the ground.—It was assumed[4] that the sand surface would have a reflectivity of 0·25, i.e. that this component was 0·25 times the sum of the intensities of the direct solar beam received on a horizontal surface and the diffuse radiation.

Atmospheric long-wave radiation.—This component which is dependent mainly on the absorption bands of water vapour and carbon dioxide in the atmosphere is readily estimated by means of a radiation chart when an upper air sounding is available. In view of the general good agreement between the upper air measurements of the three flights and the relevant Aden radio-sonde ascents it was considered that a reasonably accurate value (say ± 15 per cent.) of this component could be obtained by using the Kew radiation chart in conjunction with estimated values of upper air temperature and humidity based on Khartoum surface measurements and Aden radio-sonde measurements on these occasions.

Long-wave radiation from the ground.—Ground temperatures were measured at regular intervals by means of a thermometer with its bulb immersed to a depth of one inch in the sand. This component was then calculated from the sand temperature on the assumption that for the wave-lengths involved the sand radiates as a black body.

Results.—Fig. 4 shows the computed values throughout the day at Khartoum on July 13 and 14, 1952. If we compare the approximate values of these components with representative values at Kew for a cloudless summer day Table I is obtained. This comparison is of course very approximate and for more accurate work direct measurement of the diffuse sky radiation and reflectivity of the soil would be necessary.

TABLE I

	Khartoum mW./cm.^{2}	Kew mW./cm.^{2}
Direct solar beam (local noon)	90	80
Scattered solar radiation	15	15
Reflected short-wave radiation	25	15
Atmospheric long-wave radiation	40	30
Ground long-wave radiation	70	55

REFERENCES

1. AUSTIN, E. E.; Upper winds of Aden. *Met. Res. Pap., London,* No. 729, revised with an addendum by C. S. Durst, 1952.
2. SCHUMACHER, N. J.; The Maudheim expedition 1949–52, Part II. *Weather, London,* **7**, 1952, p. 327.
3. KIMBALL, H. H.; Variations in the total and luminous solar radiation with geographical position in the United States. *Mon. Weath. Rev., Washington D.C.,* **47**, 1919, p. 769.
4. Washington, Smithsonian Institute. Smithsonian meteorological tables. *Smithson. misc. Coll., Washington D.C.,* **114**, 6th revised edn., 1951, Table 154.

AERIAL OBSERVATION OF TOTAL SOLAR ECLIPSE JUNE 30, 1954

By G. W. HURST, B.Sc.

I had the good fortune to be given the opportunity to make a flight over the eclipse area on June 30 in a Canberra; the pilot was the Squadron Commander, Sqdn-Ldr K. Ritchley, and the navigator F.O. Powell. Take-off was from Wyton at 1015 G.M.T., and the aircraft reached the Faeroes area at 1145; 25 min. were spent flying to the west and back (still in the belt of totality) so that the original flight plan of setting a course of 110° from the Faeroes at 1210 could be followed. The aircraft was within the area of totality until about 1250.

The flight north was fairly uneventful; the synoptic situation at 1200 G.M.T. was one of a wide warm sector between a warm front off the Norwegian coast and a cold front east of Iceland to the south-west. The climb had been through multilayered thick cloud in sheets at medium level, and in the flight north there were isolated patches of cirrus at about 35,000 ft. There was the curious effect in the Newcastle area of bands of cirrus orientated west to east apparently above aircraft level, which were difficult to see as they were approached, but proved to be distinctly below flight level (probably owing to the rate of climb of the aircraft). From the Border northwards the aircraft was well above the tropopause, and there was for the most part a complete cloud layer below, with a top at about 5,000–10,000 ft. above sea level. It was, however, of real interest to see the orographic clearances over the east coast of Scotland, where the east of Fife, Dundee and the coast northwards to Rattray Head enjoyed a substantially clear sky. At about 58°N. (1115 G.M.T.) slight clear-air turbulence was felt; this was short-lived—about half a minute. There was a fairly marked discontinuity between Leuchars and Stornoway, winds at 1500 G.M.T. varying from 270° 9 kt. to 246° 44 kt. at 200 mb. with a less marked change from 301° 5 kt. to 238° 27 kt. at 170 mb.

The eclipse was first noticed at 1115 as a small bite out of the right of the sun just above the centre line. As the flight progressed and the eclipsed area of the sun increased the darkened sector moved across to a central position on the right of the sun's disc. Loss of light was not particularly obvious until the sun's surface was three-quarters obscured, although the pilot assured me that the glare from the cloud surface below (still 8 oktas of low cloud) was very much less than normal. From this point onwards however the light fell off noticeably, and by the time totality was near, cockpit lights for both the navigator and pilot had to be switched on. A very interesting point was the sudden onset of totality, which was as sharp as the snap of a switch. The spectacle of the eclipse spreading slowly along the cloud sheet ahead was most impressive, with the foreground darkened and the background comparatively brilliantly illuminated.

Totality lasted from 12h. 22m. 30s. to 12h. 26m. 10s., and during this time the sun was surrounded by the corona, which extended equatorially to a distance about equal to the sun's diameter in each direction; there was slight lack of symmetry early and late in totality. The polar extension was about half the sun's diameter in each direction. Venus, at an elevation of about 40° to the south-east, was quite clearly visible during the darkness (which corresponded almost to that of moonlight, though the sky retained a deep blue rather than a black appearance). Other observers also saw a star to the south-south-west (probably Aldebaran) but the view of a passenger from a Canberra is rather restricted, and I was also engaged in taking photographs with two cameras. Cessation of totality was as sharp as the onset, and light rapidly increased.

There is no doubt, incidentally, that our track was directly along the central line of the belt of totality (which reflected very well on the navigator whose flight from Cape Wrath, an hour earlier, to the north-west was by dead-reckoning) as the sun immediately before and after obscuration showed a vertical arc, and as the time of totality was 3 min. 40 sec., the maximum possible. For a ground observer, the maximum period of totality was 2 min. 35 sec. which, taking into account the speed of movement of the eclipse (approximately 1,800 m.p.h.) and the ground speed of the aircraft (about 460 kt.), gives for the air observer a period of

$$\frac{155 \times 1800}{1800 - 460(38/33)} = 220 \text{ sec.} = 3 \text{ min. } 40 \text{ sec.}$$

The flight was continued down the eclipse line towards Norway, and in the distance could be seen the dark eclipsed horizon with, to the south-east and east, horns of illuminated cloud. These horns gradually closed in, and eventually, the whole horizon was again illuminated. It was difficult to fix the time when this occurred, as the horizon had not the "hard" appearance immediately ahead of the aircraft which it had to the port and starboard, but there was no doubt that by 1242, at the latest, illumination was restored to all the world visible from 45,000 ft. The speed of sweep of the eclipse based on the 15 min. 50 sec. interval between first clearance of the moon overhead and at the horizon was estimated at 1,480 m.p.h. This estimate is based on the assumptions that the ground speed was about 460 kt., and the height of the horizon ahead 3,000 ft. above sea level. The latter is reasonable as Oslo, which would be just north of the horizon ahead, was reporting 3 oktas of stratocumulus at 1,500 ft. at 1200 G.M.T. and high ground just to the west extended to approximately 3,000 ft. The height of the aircraft above the horizon was therefore 45,500 − 3,000 ft., i.e. 8 miles, and the distance of the horizon about 250 miles. The speed of movement of the eclipse is therefore

$$250 \times \frac{60}{15{\cdot}83} + 460 \times \frac{38}{33} = 1{,}480 \text{ m.p.h.}$$

This compares with the actual speed of 1,800 m.p.h. of the speed of passage of the eclipse, so it is clear that totality had ceased on the eastern horizon a few minutes earlier than the last time we recorded.

On the return flight the cloud sheet extended over the whole of the eclipse area to the west coast of Norway in the vicinity of Bergen, but, travelling back, over east Scotland there were again substantial breaks over the coastlines of the Moray Firth, though high ground was in cloud. To the south, the Tay Bridge could be seen, and so could Perth, but the Forth Bridge was covered, and no ground could be seen over England until descent at 1415 G.M.T.

Attempts were made at photography from the start of the eclipse until just after totality had ended. The instruments used were a normal hand-held service camera and a 35-mm. ciné camera. The former was used before the eclipse and during early totality, and the latter during late totality (taken as a

MEMORIAL TABLETS AT KEW OBSERVATORY

(see p. 321)

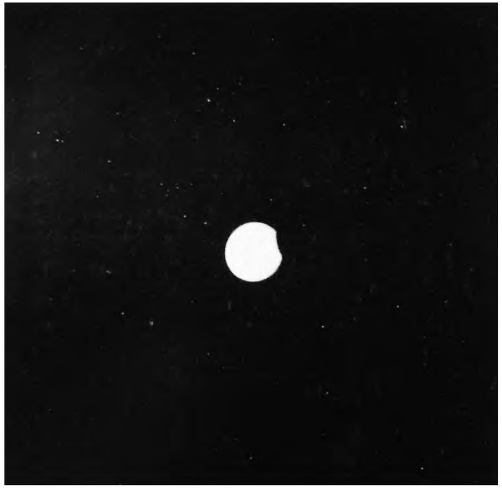


FIG. 1–1115 G.M.T.

FIG. 2–1200 G.M.T.

FIG. 3–1220 G.M.T.

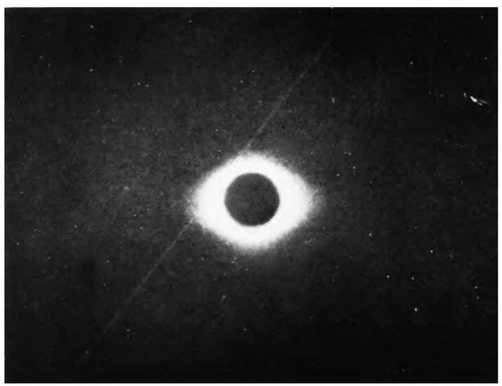


FIG. 4–1225 G.M.T.
(totality)

FIG. 5–1226 G.M.T.

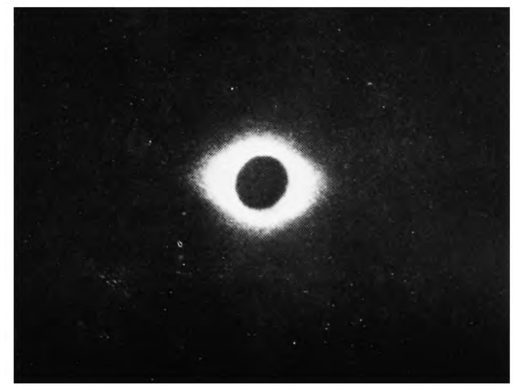


FIG. 6–1226 G.M.T.

FIG. 7–1226 G.M.T.

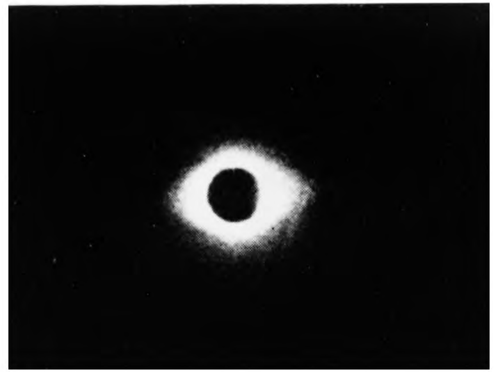


FIG. 8–1226 G.M.T.

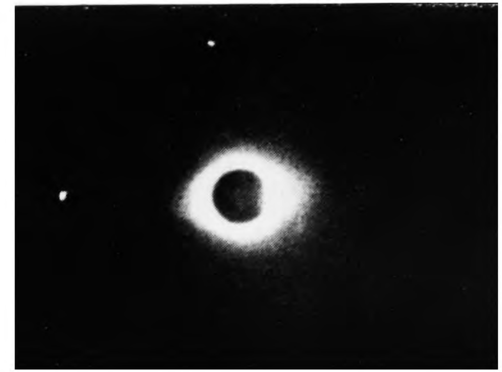


FIG. 9–1226 G.M.T.

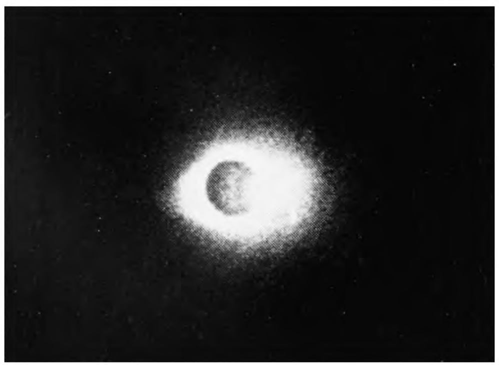


FIG. 10–1226 G.M.T.

FIG. 11–1226 G.M.T.

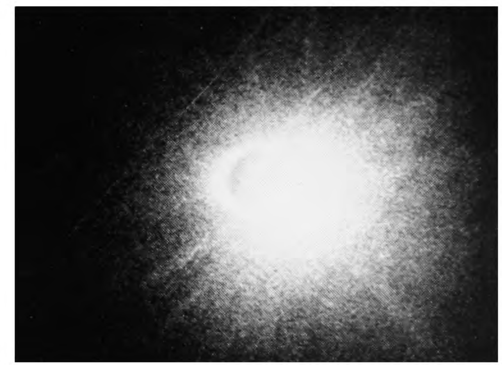


FIG. 12–1226 G.M.T.

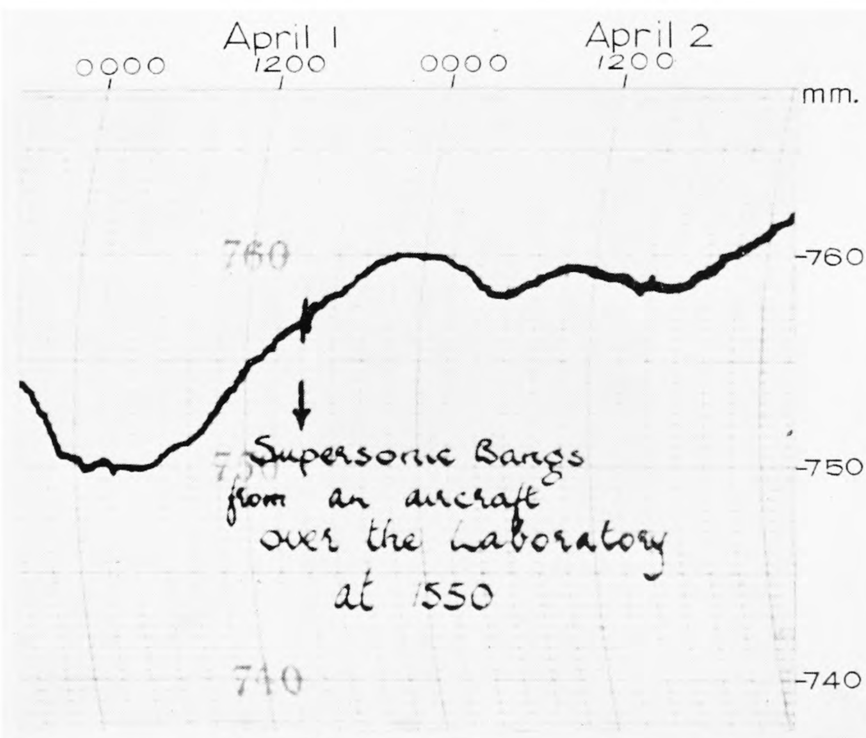
PHOTOGRAPHS OF THE ECLIPSE TAKEN FROM A CANBERRA AIRCRAFT IN THE BELT OF TOTALITY AT ABOUT 45,000 FT.

The first three photographs were taken with a normal hand-held service camera using an infra-red plate, the other nine being taken with a ciné camera using a yellow filter. The last eight photographs near the end of totality were taken at 1-sec. intervals. The aircraft was moving in the direction of motion of the shadows and totality lasted from 12h. 22m. 30s. to 12h. 26m. 10s. (see p. 335).

To face p. 337]

Reproduced by courtesy of the late W. J. Day

ALTOCUMULUS



BAROGRAM FROM THE VETERINARY LABORATORY AT WEYBRIDGE, SURREY, SHOWING THE RECORD OF THE OCCURRENCE OF A SUPERSONIC BANG (see p. 348)

film) and just after. The difficulty of handling these, especially the bulky service camera, in the restricted cockpit of the Canberra was great, and photographs were not in many cases as satisfactory as had been hoped. In particular, no successful shots were obtained of totality with the service camera, though quite good ones emerged using the ciné camera. In general, photographs showing any direct light from the sun were taken through an infra-red filter (which appears almost opaque unless viewed directly against a strong light source), and photographs during totality were taken with a yellow filter and as great an aperture as possible. A selection of the photographs is reproduced in the centre of this Magazine.

It will be seen that the end of totality was indeed very sharp, and Fig. 11 can be regarded as the point of return of the sun's light. The suddenness of the change between Figs. 8 and 12 will be noted.

RADIO-SONDE ASCENTS DURING THE SOLAR ECLIPSE JUNE 30, 1954

By A. P. TAYLOR, B.Sc.

The heating of radio-sonde temperature elements by insolation causes errors in the temperatures reported. Comparisons between day and night soundings fail to determine the magnitude of these errors since diurnal changes of air temperature may account for the whole or part of the observed differences. The eclipse of the sun on June 30, 1954, provided an opportunity of measuring the apparent changes of temperature during a period when the changes of insolation were so rapid that there were unlikely to be any associated changes of true air temperature.

The programme of ascents arranged for all radio-sonde stations in the United Kingdom was:—

(i) one balloon to be released 1 hr. before commencement of the eclipse

(ii) a second balloon to be released 50 min. before the time of maximum phase of the eclipse

(iii) a third balloon (the routine 1500 G.M.T. sounding) to be released approximately 15 min. after the end of the eclipse.

Where possible, stations were asked to duplicate the second ascent by another sounding launched 5 min. later. The soundings were to be followed on both the ascents and descents, and the programme imposed a very rigid time-table on the stations concerned. In spite of adverse weather conditions at the northern stations, and the unfortunate behaviour of some of the special large balloons used, this programme was successfully carried through.

The data obtained from these soundings must be subject to detailed analysis before any final conclusions can be reached, but a preliminary survey shows that the variations of measured temperatures were of the same order as the values calculated by Scrase[1]. In this preliminary survey the thickness from 300 to 100 mb. has been used as a convenient equivalent of mean temperature. The results are given in Table I.

The differences show considerable scatter, the values for Lerwick and Camborne being particularly suspect. The thicknesses were plotted on a chart, together with the shear winds for the same layer, and it seems probable that the value of 23,915 ft. at Camborne is some 200 ft. too great and, though with less certainty, the value of 23,690 ft. at Lerwick is too great by some

TABLE I

	Apparent average thickness 300–100 mb. Before and after the eclipse (1)	At about the time of maximum phase of the eclipse (2)	Difference (1)−(2)
	ft.	ft.	ft.
Lerwick	23,825	23,690	135
Stornoway	23,749	23,530	219
Leuchars	23,364	23,146	218
Aldergrove	23,412	23,170	214
Liverpool	23,567	23,346	221
Hemsby	23,712	23,585	127
Crawley	23,786	23,651	135
Camborne	23,915	23,417	498
		Mean	221

100 ft. If these results are omitted the mean difference becomes 189 ft. Scrase's figures for radiation errors are equivalent to a difference in thickness of the 300–100 mb. layer of 226 ft. The ratio between the computed difference of 226 ft. (for 100 per cent. change in radiation) and the observed value of 189 ft. is 0·83. At the time of maximum phase the eclipse varied from 75 per cent. of totality in the south to almost complete totality at Lerwick. It is reasonable to assume an average of 80–85 per cent. of totality for the six stations used in the mean, and that the insolation was reduced in proportion to the percentage of totality. The figures are in surprisingly good agreement considering the approximations made in this preliminary analysis.

It is interesting to note that in the course of these soundings one radio-sonde carried by a 2,000-gm. balloon released from Camborne reached a height of 100,950 ft. (12 mb.) which is a record height for a normal temperature ascent made by the Meteorological Office. Greater heights have been achieved by balloons carrying only radar targets, modified radio-sondes, or special cosmic-ray equipment, but it is unusual for a radio-sonde to continue to give acceptable readings of both pressure and temperature to such a level.

REFERENCE

1. SCRASE, F. J.; Radiation and lag errors of the Meteorological Office radio-sonde and the diurnal variation of upper air temperature. *Quart. J. R. Met. Soc., London,* **80,** 1954, p. 565.

INFLUENCE OF A QUASI-STATIONARY LONG-WAVE PATTERN ON SMALL-SCALE THERMAL FEATURES

By M. K. MILES, M.Sc.

Abstract.—The behaviour of small-scale (i.e. half wave-length about 20° longitude) cold troughs in the 1000–500-mb. thickness pattern was examined during a period of almost stationary long-wave pattern, and it is suggested that there was a dynamical control exerted by the latter with the following three main features:

(i) The tracks of the cold troughs followed the direction of the mean thickness lines for the period.

(ii) They moved very quickly (30° longitude and more a day) while travelling up to the crest of the large warm ridge.

(iii) Dynamical warming occurred in the southern parts of the troughs during this part of their transit.

The half wave-length up to the warm ridge was significantly greater than the Rossby stationary wave-length, implying horizontal convergence at medium and higher levels to the west of the large ridge. The vertical motion deduced from (iii) is suggested as an indication that this was occurring, and was the principal factor influencing the behaviour of the smaller features in this area.

Data.—During the period February 25 to March 9, 1953 there was a quasi-stationary long-wave thermal pattern over the North Atlantic. The mean thickness lines (1000–500 mb.) during March 3–9 show a flat warm ridge with its axis between 0° and 10°W.; the mean up-stream cold trough was at about 60°W. (see Fig. 1).

Individual small-scale cold troughs moving east from the region of the quasi-stationary cold trough showed some characteristic features which seemed to merit closer study. To enable them to be identified during their progress the movement of the 17,400-ft. thickness line on the 1000–500-mb. chart was selected for examination. Air with a temperature distribution corresponding to this thickness is not very far from equilibrium with the sea surface at this time of the year in the latitudes concerned, and this reduces non-adiabatic effects to a minimum.

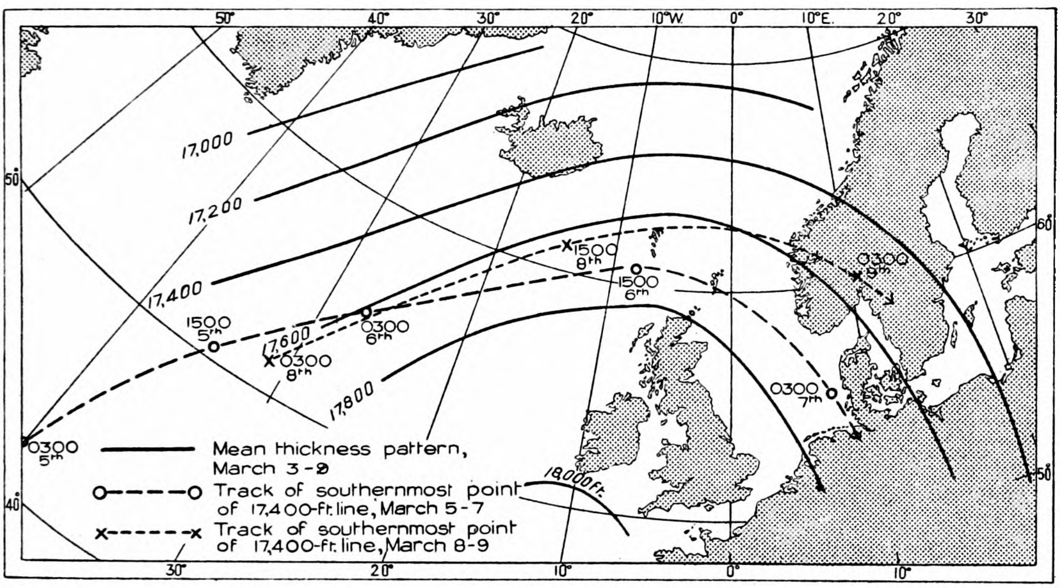


FIG. 1—MEAN 1000–500-MB. THICKNESS PATTERN, MARCH 3–9, 1953

The first example occurred while the quasi-stationary régime was being established. A cold trough with its base, i.e. the most southerly position of the 17,400-ft. line, at 34°W. at 0300 G.M.T. on February 26 had moved to 2°W. 24 hr. later—an unusually rapid motion. Further its base moved from latitude 47° to 60°N. in this period. The large change in the position of the 17,400-ft. line suggests some other warming agency besides the strong southerly winds in mid Atlantic.

The next one on March 1–2 also moved rapidly, going from longitude 30°W. to 0° in 24 hr. The third one on March 5–6 made an almost similar passage (35°W. to 5°W.) in the 24 hr. from 1500 on March 5, while the last one studied travelled from 33°W. to 10°E. between 0300 on March 8 and 0300 on March 9.

Discusssion.—All the tracks could be seen to follow fairly closely the mean total thickness pattern (only two sets are shown on Fig. 1 to avoid confusion), and all moved very fast (over 30° longitude a day) while coming up to the axis of the quasi-stationary warm ridge.

A study of the relevant surface and thickness charts suggests that these features cannot result entirely from advection. In particular the movement of the base of the troughs round the mean pattern appears surprising in view of the westerly surface winds observed behind the cold fronts. These winds, though fairly limited in extent, imply some cold advection towards the mean ridge.

To examine this effect more closely the cases of March 5–6 and 8–9 were selected for more detailed examination. Trajectories based on the geostrophic surface wind were constructed for points on the 17,400-ft. line of the cold trough. This gives a first approximation to the motion of a thickness line, and should enable an estimate to be made of, at least, the sign of any dynamical effect.

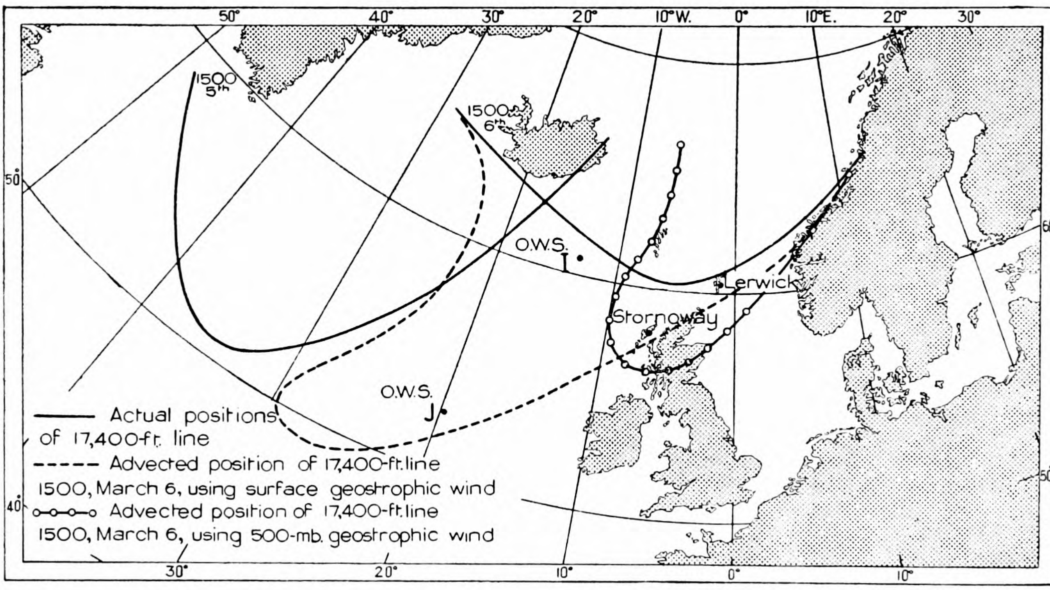


FIG. 2—POSITIONS OF THE 17,400-FT. THICKNESS LINE ON MARCH 5 AND 6, 1953

A comparison of the actual and advected positions on March 6 (see Fig. 2) reveals that a very large area was warmer than might have been expected. The tephigrams for stations in this area were then examined, and at Stornoway and Lerwick there was clear evidence of deep subsidence. At ocean weather stations I and J there was a shallow dry layer with warmer and moister air above. This suggests that the 2,000-ft. trajectories were not giving the true advection at higher levels and approximate trajectories on the 500-mb. surface were drawn. As the map shows, these indicate that warmer air could have been brought to stations I and J at 500 mb. but not to Lerwick and Stornoway. This means that over all the area there was some dynamical warming, and, in a smaller area at the base of the trough, dynamical warming occurred through a deep layer. On March 8–9 the details are quite different but the map (Fig. 3) shows a significant area including station I and Lerwick where warming may have taken place. The ascent at I shows an inversion from 925 to 850 mb. and some evidence of subsidence, but again there is moister air above 600 mb. The

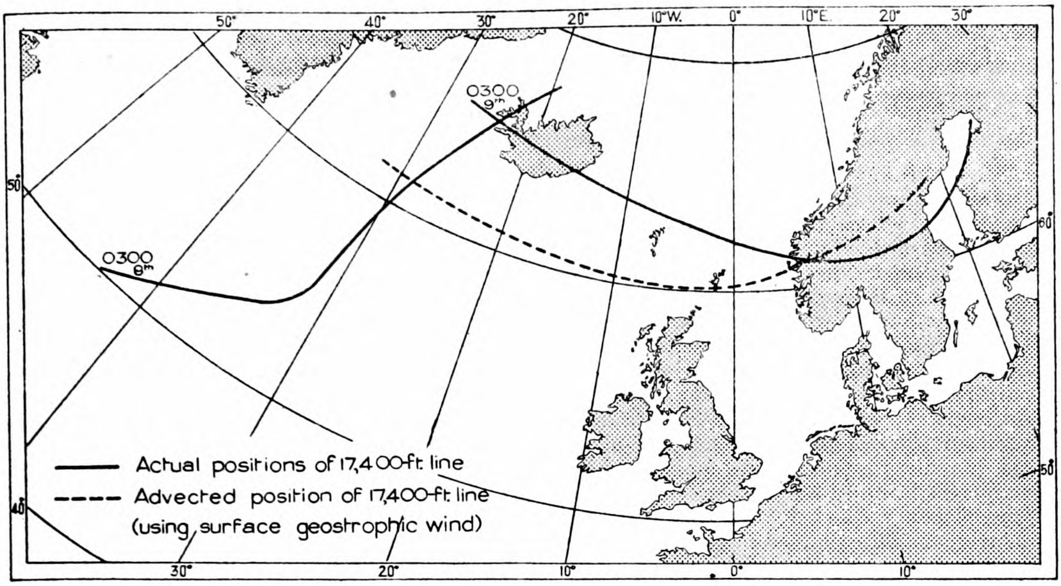


FIG. 3—POSITIONS OF THE 17,400-FT. THICKNESS LINE ON MARCH 8 AND 9, 1953

ascent at Stornoway (outside the area enclosed) shows very dry air above 900 mb. Thus again it seems likely that dynamical warming was occurring. Such dynamical warming of the cold trough, especially of the south-west part, can itself result (see Fig. 4) in an eastward displacement of the axis and a northward movement of a given thickness line.

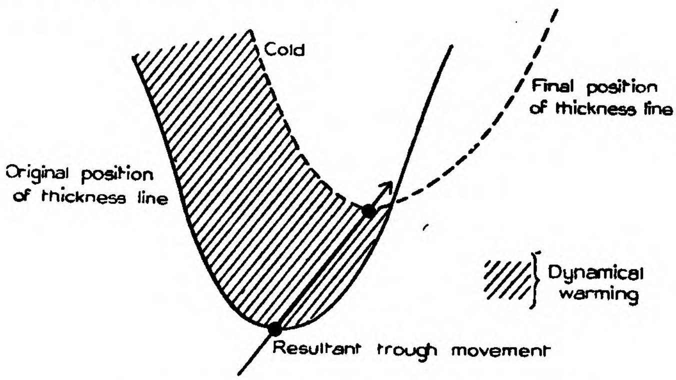


FIG. 4—AREA OF DYNAMICAL WARMING

Conclusion.—There is little doubt that some such process as this played a part in producing the very rapid motion of the cold troughs and their movement along the mean thickness lines. It is interesting to speculate as to whether descending motion to the west of the warm ridge could have been an essential factor in the maintenance of the quasi-stationary pattern. The separation of the ridge from the principal up-wind cold trough was of the order of 60° longitude, and this is greater than required in constant-vorticity flow. There may then have been development of cyclonic vorticity by horizontal convergence to the west of the ridge axis accompanied by descending motion below 500 mb. Thus it is not unreasonable to infer from the observed behaviour of the small-scale thermal troughs that they were influenced by the structure of the quasi-stationary ridge while moving through it.

ROYAL METEOROLOGICAL SOCIETY

Colloquium on the upper atmosphere, Edinburgh, July 16, 1954

A Royal Meteorological Society discussion presided over by Dr. Sutton, President of the Society, took place in Edinburgh on July 16, 1954.

The discussion was opened by Sir Edward Appleton, Principal of Edinburgh University, who began by enumerating some of the many complexities in the study of conditions in the upper atmosphere where the sun daily performs experiments under conditions which cannot be reproduced in the laboratory. Dissociation and ionization of the air are performed at very low pressures and in the presence of the earth's geomagnetic field which profoundly affects the movement of ionized particles; further complications are caused by the solar and lunar air tides, the effects of which are much more marked in the high atmosphere than near the surface of the earth. Sir Edward described briefly some of the research work which he and assistants had carried out in Edinburgh during the past few years. The E and F1 layers behave reasonably well in accordance with theory, though even in these layers there are small but important discrepancies, whereas the F2 layer shows in various ways large departures from theory. An important step in the understanding of these anomalies had been taken when it was found that the distribution of the ionization accorded much better with geomagnetic than with geographic latitude, and subsequent work, notably by Martyn, has shown that other anomalous features such as diurnal variation and ionospheric storminess, which is manifested mainly in the F2 layer, can be explained by geomagnetic distortion, though no complete theory is yet available. Sir Edward ended by discussing means of obtaining accurate values of the recombination coefficient, and explained how the recent solar eclipse had afforded an opportunity of obtaining such values.

The opening speaker had mentioned that rapid movement is a marked feature of conditions in the upper atmosphere, and most of the subsequent speakers concentrated on this aspect of upper air conditions. The emphasis was certainly on the "upper" regions of the atmosphere, for the lowest level considered was 17 Km. (100 mb.)! Mr. D. H. Johnson of the Meteorological Office gave an account of his investigation of solar tides at this level. Systematic effects were revealed by the regular British upper air observations and possible spurious ways in which these effects might have arisen were carefully considered and rejected. The outcome was that there was satisfactory agreement with the tidal theory appropriate to this level; diurnal and semi-diurnal components of about equal amplitude were found in approximate phase with the surface components and little different in magnitude (0·5–1 kt).

Mr. J. Paton, Lecturer in Meteorology at Edinburgh University, spoke of the noctilucent clouds occurring at the second temperature minimum, at about 80 Km. These clouds are probably of much more frequent and wide occurrence than the comparative paucity of reports would lead one to believe. Though the question is still in doubt, the clouds are probably composed of meteoric dust. Twenty-two occurrences have been observed in Scotland since 1939, and wind speeds of the order of 50 m./sec., always from ENE. have been measured. On one occasion, which was illustrated by slides, there was evidence of a rapid growth of turbulence within the cloud. Mr. Paton also gave an account, in the absence of Dr. A. H. Jarrett of St. Andrews University, of the use of multilayer coatings in auroral work. An auroral spectrograph incorporating these coatings enables an estimate to be made of temperature at the levels at which aurora occurs. Such an instrument is to be obtained on loan from America and installed at St. Andrews.

Dr. I. C. Browne of Jodrell Bank described the results of measurements which have been made of winds in the region 80–100 Km. by observing the radar echoes from the ionized trails of air left by meteors. A large semi-diurnal component, of amplitude up to 30 m./sec. and with phase changing with the season, is superimposed on a smaller general wind. The winds increase markedly with height without changing direction. In reply to Dr. Sutton, Dr. Browne said that the large shear was probably maintained by the temperature distribution at these levels; he answered Dr. Wormell's doubts as to whether the measurements reflected real winds, as opposed to movements of ionized particles, by saying that the ions and electrons were produced within the air molecules and could not drift apart.

The old problem as to whether it is possible to deduce the winds in the lower ionosphere directly from geomagnetic records was discussed by Mr. D. H. McIntosh of Eskdalemuir Observatory. The possibility is based on the atmospheric "dynamo" theory which accounts for the solar and lunar daily geomagnetic variations. This theory and the considerable direct evidence which has accumulated in its support were briefly described. In recent years Wulf and Vestine in America have made strenuous efforts to apply the theory to deduce the general ionospheric winds (as opposed to the periodically varying components) from the magnetic records, but with limited success only. There was hope, however, that when direct measurements are made of the mass movement of the air at the height concerned (about 100 Km.) further progress will be possible.

Dr. H. P. Palmer of Jodrell Bank spoke of the inferences that have been drawn from variations in the intensity of the power of radio emissions received from Cassiopeia and Cygnus. Irregularities in the F region of the ionosphere (200–250 Km.) are considered to be the cause of these variations, and from measurements of small time differences in occurrence of the variations on spaced receivers, drift motions of the irregularities are inferred. These drifts are very large (up to some hundreds of metres per second) and sharp reversals are found to occur during the night, when the fluctuations are found mainly to occur. Dr. Palmer mentioned, but did not enlarge upon, the difficult question as to whether measurements of the type described can be interpreted as true air movements as opposed to movements of ionization clouds only.

The fact that the field of study covered during this meeting was relatively unfamiliar to most of the meteorologists present no doubt accounted for the small amount of general discussion that took place. The mass of the air involved at heights above 50 Km. is so small and the direct relationships with solar conditions become, in contrast to conditions in the troposphere, so well marked that it is almost inconceivable that even routine sounding of conditions in these regions would be of direct help with the central problem of meteorology, that of weather forecasting. As was pointed out, however, in the Editorial to the *Quarterly Journal of the Royal Meteorological Society* for January 1953, the indirect benefits of a better knowledge of conditions in the high regions of the atmosphere may well be considerable. It was clear from this meeting that such knowledge is being acquired rapidly and in a variety of ways.

METEOROLOGICAL MEETINGS OF THE FIFTH CONGRESS OF THE ORGANISATION SCIENTIFIQUE ET TECHNIQUE INTERNATIONALE DU VOL À VOILE

The fifth Congress of the Organisation Scientifique et Technique Internationale du Vol à Voile was held in Buxton from July 20 to August 5, 1954, in conjunction with the World Gliding Championships. Delegates attended from many countries to discuss the technical aspects of glider construction and flying as well as the meteorological factors involved. A short account of the meteorological meetings is given below.

Three days were devoted to meteorology on each of which there were morning and afternoon meetings and meteorological films were also shown. In all about 20 papers were read, the majority of which dealt with some aspect of convection or wave motion although many other related subjects were discussed. Most of the papers were in English, but there were several in German, and contributions in French and Italian were also received. The meetings were conducted in an informal atmosphere, and each paper was followed by a discussion and many questions, whilst *ad hoc* translations and previously prepared abstracts removed many of the language difficulties.

The papers on convection included one by R. S. Scorer* describing it as motion of rising bubbles which, although admitted to be only a hypothesis, appears to fit most of the available observations. A recent paper by C. H. B. Priestley, discussing the behaviour of air rising and exchanging heat and momentum with its environment, was presented in which it was shown that depending on the size of the parcel and the lapse rate it will either have absolute buoyancy, asymptotically approach a certain level, or have oscillatory vertical motion about that level. Although this was welcomed as a mathematical advance in the subject it deals at present only with the dry thermal case, and its claim to experimental verification by observation of the motion of cumulus tops received some comment. Synoptic conditions favourable for long-distance thermal flights over France and the associated forecasting aspects were described by N. Gerbier, and another descriptive paper by R. Maletzke of Germany dealt with convection over the ocean and its differences compared with convection over land. Great interest was aroused by a comprehensive review by J. Küttner of cloud streets. These are apparently a very common manifestation of convection in many countries particularly northern Scandinavia, and a description of their general characteristics was given. Radar pictures of typhoon centres and occasionally fronts also show similar orientations of clouds in lines along the wind direction. Cloud streets almost invariably occur in particular synoptic conditions (usually after a cold front) and with given wind profiles, increasing, decreasing and then increasing again with height. They can be simulated in laboratory experiments, and it appears possible to predict theoretically some of their characteristics, e.g. ratio of cloud spacing to cloud depth. Other papers in this section included one by J. S. Malkus and R. S. Scorer on the erosion of cumulus towers and an account of recent laboratory work on Bénard cells by H. Koschmieder and H. v. Tippelskirch. The circulation of Bénard cells is opposite in direction in liquids and gases, and it appears from the latter paper that this can be identified with the characteristics of the viscosity-temperature relation of the substance (liquid sulphur in the experiments described).

Soaring in nature was the subject of two papers: C. G. Johnson discussed measurements of the density of aphides at different heights with reference to seasonal and diurnal variations of

*SCORER, R. S.; Bubble convection. *Met. Mag., London*, **83**, 1954, p. 202.

the lapse rate, and a paper by R. C. Rainey dealt with locusts and convection currents in east Africa. The shape of the locust swarm may be cumuliform or stratiform according to the meteorological conditions, and the latter is considerably easier to attack by spraying. In both these papers it was stated that one of the most difficult tasks of the entomologist is to separate the biological and meteorological factors in the behaviour pattern of these pests. This field of work appears to be one in which the meteorologist can give considerable help in the future.

The papers on waves amply demonstrated how much our understanding of this subject has progressed in recent years. R. Long showed a film of his experiments with a model barrier towed through a tank containing liquids of density varying with height and showed the different wave profiles produced with different values of the Froude number. He examined theoretically the flow in these conditions for the case of a finite obstacle obtaining good agreement with the model results, and also discussed the applicability of this work to atmospheric conditions. The question of the relative importance of gravity and the wind profile in producing rotor phenomena in the lee of mountains was then considered in a paper by P. Queney, and examples were given showing the great importance of the latter. R. S. Scorer outlined further developments in the use of his l^2 parameter for assessing the probability of waves with particular reference to the effect of inversions, and G. A. Corby discussed its routine application in forecasting work. The approximate variation of l^2 with height can be obtained very quickly by means of a celluloid scale and a plotted temperature ascent on a tephigram. The method assumes that the curvature of the wind profile with height is small, a condition which may not always be satisfied, but Mr. Corby was able to demonstrate with several flight examples that good results are being obtained with this method. Finally the conditions for waves in accelerated flow were examined in a paper by J. Zierep. It was shown that in this case the waves move slowly in the direction of the flow, the phase velocity being about one half of the non-stationary velocity increase.

Among the associated subjects discussed were thunderstorm electricity, which included a general review of the subject by B. J. Mason and some critical remarks on present theories by J. Küttner. The latter also gave a survey of recent jet-stream research in the United States where penetrations of jet streams are now being made frequently with aircraft equipped with continuous wind-recording devices and attempts are also being made to measure vertical air motion from its effect on the aircraft's performance.

Finally there were a number of papers principally concerned with instruments. P. Temple described sensitive thermopile instruments which, mounted on the wing tips of a glider, can measure which is the warmer and possibly indicate to the pilot the direction he should turn to fly into a thermal. P. MacCready discussed the application of gliders equipped with hot-wire anemometers and accelerometers to the investigation of gust loads produced by turbulence. A paper by H. Koschmieder and H. Meyer described new photo-theodolites for plotting cloud contours, e.g. the shapes and sizes of cumulus clouds, and gave examples of results obtained.

The films shown included some beautiful time-lapse films of cloud development from the Munitalp Foundation's series and a film of the Sierra Wave Project presented by J. Küttner. The comprehensive observational work and the brilliant flying of the glider pilots who have attained heights of 44,000 ft. unpressurized aroused much admiration and the results of this work are awaited with great interest.

The amount of new data and results presented at this conference were very considerable, and it is hoped that all the papers presented will be published in the near future.

R. J. MURGATROYD

NOTES AND NEWS

Remarkable temperature variations and fog formation over snow at Stornoway, February 8, 1954

On the afternoon of February 8, 1954, Stornoway was on the western side of a weak ridge of high pressure in rather cold polar air. The ground was completely covered with snow to a depth of 5–6 in., the visibility was excellent, the temperature 3°F. below freezing, the wind almost calm and the sun was shining from almost clear skies. Slight snow showers had fallen fairly frequently from the morning of the 7th and intermittent, at times continuous, moderate snow occurred between 0755 and 1144 on the 8th until the depth at 1200 was 5 in. The sun shone almost continuously from 1125 to 1545. The snow was "steaming" from about 1200 onwards; visible condensation was taking place to a height of about 2 ft. above the surface of the snow.

At 1457 G.M.T., a British European Airways Pionair began to taxi, and, when on full power, to turn, throwing small particles of snow in a swirling cloud above the tower and screen enclosure to a height of 40–50 ft. Subsequent events were startling. First the snow particles settled and shallow fog formed in the region where the snow had subsided. After this the fog, which was very clean, rapidly spread in all directions until within a quarter of an hour the whole of the airfield basin was covered with fog to a depth of 13–35 ft. A bank of fog was also seen to move down the main road at Garrabost, 2 miles away. Previous arrivals and departures of the same aircraft had been without incident.

The screen temperature in the fog rapidly dropped until it had reached 13·9°F., the lowest registered at Stornoway since 1945. Shortly afterwards a light breeze cleared the fog and the temperature rose again to near freezing. A thermometer put into the snow to a depth of 1½–2 in. registered 18°F., 2°F. higher than the screen temperature. Throughout the fog, snow continued to melt and drip from roofs at 10 ft. or above. Fuller details are given in Table I.

TABLE I—SURFACE DATA, STORNOWAY, FEBRUARY 8, 1954

Time	Wind		Visibility	Temperature Dry bulb	Wet bulb	Dew point	Vapour pressure	Weather and cloud
	°	kt.	miles	°F.	°F.	°F.	mb.	
0600	170	15	12½	30	...	27	...	Fine after a shower; 1 okta large Cu
1200	260	8	5	33	...	31	...	Cloudy after snow in the past hour; 4 oktas Sc at 1,500 ft., 2 oktas at 800 ft., some Ci
1353	270	7	30	32·6	31·3	29	5·5	1 okta Cu at 2,000 ft.
1451	310	4	30	29·7	28·5	26	4·7	1 okta Cu at 2,500 ft.
			yd.					
1520	Calm		200	26·0	...	...	...	No cloud
1545	Calm		80	20·2	...	...	...	Sky obscured
1556	Calm		80	19·2	19·1	17	3·3	Sky obscured
1640	Calm		200	13·9	...	...	...	2 oktas Sc at 3,000 ft.
			miles					
1654	210	5	2½	18·2	18·0	16	3·1	5 oktas Sc at 3,000 ft.
1710	Calm		15	30·1	...	...	...	No cloud

Depth of snow at 1153: 5 in. Temperature in snow at 1615: 18°F.
Depth of snow at 1757: 4 in. Minimum temperature read at 1800: 14°F.

The above description summarizes information given in two letters by Mr. H. Gillett of the Meteorological Office, Stornoway airport. Dew points, vapour pressures and the 0600 and 1200 observations have been added.

Mr. E. K. Wade, the Air Traffic Control Officer at Stornoway on the day in question, states that during most of the duration of the fog it was possible to look out over the top of the fog from his station in the control tower but that he was occasionally just in it. This confirms a height of 15–20 ft. and occasionally more for the fog.

[The observations reported by Mr. Gillett and Mr. Wade are very remarkable. Without fuller information about the temperature at the surface of the snow and within the snow it is difficult to examine the phenomena quantitatively.

The "steaming" in the lowest 2 ft. over the snow observed from 1200 onwards appears to have been a thin mist forming in relatively warm damp air being cooled over the cold snow analogous to the very low-level mist which may form just over the grass early on calm radiation nights.

Mist formation over snow is well known to be possible with the onset of a warmer damper air mass than the one from which the snow fell, but no record of mist over newly fallen snow was noted in some papers on fog over snow that have been consulted. The snow temperature on this occasion was perhaps unusually low in comparison with the surface air temperature. The upper air temperatures observed over Stornoway by radio-sonde on February 8 are given in Table II.

TABLE II—UPPER AIR TEMPERATURES AT STORNOWAY, FEBRUARY 8, 1954

Pressure	0200 G.M.T. Height	0200 G.M.T. Dry bulb	0200 G.M.T. Dew point	1400 G.M.T. Height	1400 G.M.T. Dry bulb	1400 G.M.T. Dew point
mb.	ft.	°F.	°F.	ft.	°F.	°F.
600	12,560	−12	−28	12,650	−17	−28
700	8,850	−2	−14	8,950	−1	−10
800	5,550	10	2	5,630	12	6
850	4,020	16	9	4,090	18	12
900	2,560	22	17	2,620	25	18
Surface	...	31	24	...	31	28

Isothermal layers.—At 0200: −12°F. from 627 mb. (about 11,500 ft.) to 600 mb. (12,560 ft.)
At 1400: −18°F. from 590 mb. (about 13,000 ft.) to 580 mb. (about 13,400 ft.)

It would be a difficult problem to estimate quantitatively the temperature at the surface in the sunshine supposing the temperature at 2 in. was 18°F., taking account of the net outgoing long-wave radiation, the incoming short-wave sun and sky radiation (which penetrates an appreciable distance into new loose snow), conduction of heat within the snow, and the gains, small in the calm conditions, of heat (including latent heat of condensation from water vapour) diffused down from the atmosphere. It does not, however, seem likely that the surface temperature can have much exceeded the temperature at 2 in. The following calculation of the net outgoing long-wave radiation and the insolation suggests there was little, if any, heating of the surface by radiation even at midday. The net outgoing long-wave radiation from the surface is about a quarter of the black-body radiation appropriate to the surface temperature* which gives, for a temperature of 18°F., a net loss of 0·1 gm. cal./cm.^{2}/min. From the Smithsonian Meteorological Tables† it appears that the total incoming sun and sky radiation on a horizontal surface at midday (sun's elevation 17°) at Stornoway on February 8 was about 0·45 gm. cal./cm.^{2}/min., but, taking the albedo of new snow as at least 80 per cent., less than 0·1 gm. cal./cm.^{2}/min. would be available for absorption by the snow. A higher temperature than 18°F. would make the radiation balance less favourable. It will be seen that the screen temperature fell between 1353 and 1451. If the surface temperature was 18°F. there was, before the onset of the thick fog, a fall of vapour pressure of 1·5–2 mb. from screen level to the snow surface.

The fog which formed when the aircraft violently stirred up much snow at 1457 seems to have been produced by rapid enforced mixing of the cold air near the surface with warmer damper air above and, perhaps, by cooling of the air by the cold snow thrown into it.

The fall of screen temperature to below 14°F. at 1640 is very remarkable. Possibly much of the snow was at a temperature below 18°F. Radiation from the fog may have contributed.

*BRUNT, D.; Physical and dynamical meteorology. 2nd edn, Cambridge, 1939, p. 128.
†Washington D.C., Smithsonian Institution. Smithsonian meteorological tables. *Smithson. misc. coll., Washington D.C.*, **114**, 6th revised edn, 1951, Table 149.

It has been verified that no salt or other freezing-point reducing agents were used. The fact that the snow was melting on roofs at 10 ft. or above does not imply the air temperature at that level was above freezing point.—Ed., *M.M.*]

Atmospheric electricity and jet streams

During fair weather, a positive atmospheric potential gradient averaging about 130 v./m. is normally observed near the surface. Large positive or negative fluctuations are produced by various weather phenomena such as precipitation, fog and duststorms. Fluctuations occur also, however, during fair weather, and a report* based on observations at Albany, New York, suggests that high positive values may be associated with the proximity of jet streams.

To investigate this theory, records and data from Lerwick Observatory were utilized, Lerwick being chosen because of its freedom from smoke pollution and the proximity of a radar-wind station. A correlation coefficient was first obtained between the electrograph readings and the wind speed at 300 mb. measured four times daily. Omitting all occasions of precipitation, fog and very low cloud, the value obtained over a period of five months was −0·06.

A fuller investigation was then made for the period April–September 1953. All the occasions were extracted when, for a period of two hours or more, the electrograph trace had a positive deflexion exceeding 5 mm., this deflexion representing a positive potential gradient of about 225–275 v./m. Occasions when a jet axis was located within 50, 100 and 200 miles of Lerwick were tabulated using the charts at the Central Forecasting Office, a jet stream being defined as a wind maximum of 80 kt. or more at 300 mb. High potential gradient and jet-stream proximity were taken as coinciding if they occurred on the same day. As before, days when the recordings were considered to have been affected by precipitation, etc., were excluded. The following results were obtained:—

Number of days of high potential gradient	33
Number of these days with jet axis within 50 miles ...	4 (3)
Number of these days with jet axis within 100 miles ...	4 (5)
Number of these days with jet axis within 200 miles ...	11 (8)
Total number of days with jet axis within 50 miles ...	14
Total number of days with jet axis within 100 miles ...	20
Total number of days with jet axis within 200 miles ...	35

146 days were considered, and the figures in brackets are the frequencies to be expected with no correlation.

The results may not be exact, owing to the difficulty occasionally of determining the position and velocity of a jet stream, and to the fact that only the 300-mb. level was considered. It would certainly appear, however, that the Lerwick observations show no significant correlation between surface potential gradient and the proximity of jet streams.

P. GRAYSTONE

*FALCONER, R. E.; A correlation between atmospheric electrical activity and the jet stream. *Rep. Gen. Elect. Res. Lab., Schenectady N.Y.*, No. RL-900, 1953.

Pressure changes associated with supersonic bangs

Mr. G. Slavin of the Veterinary Laboratory (Ministry of Agriculture and Fisheries) at Weybridge, Surrey, has drawn attention to the barogram reproduced in the lower photograph facing p. 337 which recorded the occurrence of supersonic bangs at about 1550 on April 1, 1954.

The bangs were very loud but the barograph was not inspected until an hour later when the kicks in the trace were first noticed. The horizontal lines on the barogram are at intervals of pressure of 0·5 mm. of mercury, so that the pressure suddenly rose about 1·3 mm. and fell again about 0·8 mm. of mercury, giving a total amplitude of pressure change equivalent to about 2·8 mb.

The barograms at Kew and London Airport showed no similar traces of sudden changes; even the very sensitive microbarograph at Kew Observatory showed no trace during the afternoon of April 1.

REVIEW

Climatic change: evidence, causes and effects. Edited by Harlow Shapley. $8\frac{1}{2}$ in × $6\frac{1}{2}$ in., pp. xiv + 318, *Illus.*, Harvard University Press, Cambridge Mass., London: Geoffrey Cumberlege, 1953. Price $6 or 48*s*.

This handsome volume brings together 22 papers read at a two-day conference organized by the American Academy of Arts and Sciences in May 1952. The contributions deal with all aspects of the problem, but interest is concentrated mainly on the Quaternary Ice Age and subsequent oscillations of climate. The recurrent theme is that climatic changes, of whatever length, can only be due to changes of solar radiation. The effects of orogeny, continentality and ocean currents are relegated to a minor place, while D. Brouwer dismisses continental drift and pole movements very shortly. Thus H. C. Willett argues that climatic history shows a whole spectrum of cycles of lengths from 10,000 yr. down to the sunspot cycle, all of which are essentially similar, and must therefore result from cycles of solar radiation acting through changes in the atmospheric circulation. Topography only comes in to the extent that mountains may be necessary as gathering grounds for glaciers. Even the Permo-Carboniferous ice sheets of tropical regions are attributed by J. Wohlbach to changes of solar radiation acting on a peculiar topography.

The difficulty that solar changes should theoretically be most effective at the equator while temperature changes are greatest in high latitudes, is overcome in various ways. H. Wexler finds that, owing to their effect on pressure centres, storm tracks and cloudiness, changes of solar radiation are most effective in latitudes 40–50° in winter and 65–70° in summer. D. H. Menzel associates ice ages with irregularities in the ion clouds coming from the sun, causing intense local heating in the auroral zone and increased numbers of condensation nuclei, though he remarks that the latter effect could also be produced by volcanic dust. The most consistent contribution along these lines is that of B. Bell, based on Willett's modification of Simpson's theory. The gradual cooling and desiccation during the Tertiary are attributed to steadily decreasing radiation; this was followed during the Quaternary by a series of oscillations, each glacial period coming during a period of increasing radiation while the seas were still cold and there were floating polar ice caps. Changes in the positions of the centres of glaciation may have been due to shifts of the magnetic pole, through their steering effect on solar corpuscular emissions.

Going back one step further, the cause of the variations of solar radiation is still obscure. The effect of changes in the earth's orbit and its axis of rotation is ruled out by A. J. J. van Woerkom, who gives revised insolation curves bearing little relation to the sequence of glacial periods. There remain the fascinating theory of E. J. Öpik, summarized by P. L. Bhatnagar, which relates variations in the luminosity of a star to a convective cycle of thermonuclear processes involving the conversion of hydrogen into helium, and the ideas of Hoyle and Lyttleton, presented by M. Krook, that ice ages are due to the passage of the sun through clouds of interstellar matter.

The last ten papers deal with various lines of evidence as to climatic changes in geological and recent times. R. F. Flint gives some new material on glacial and post-glacial oscillations of North American ice sheets, to which J. L. Kulp adds the results of radio-carbon dating of deposits in Bermuda. E. Schulman summarizes the dated evidence of tree rings in the Colorado River basin back to 58 B.C., and J. H. Conover discusses the interpretation of instrumental climatic data. E. S. Barghoorn gives some interesting inferences from fossil plants, remarking that the climatic change which culminted in the Pleistocene began twenty million years earlier. E. H. Colbert deals similarly with vertebrates. Finally, E. S. Deevey, Jr. in a long richly documented paper (176 references) brings together the evidence from fossil lakes, especially in western North America and east Africa.

The first three papers (which surely should have been the last three) deal with the effects of climatic changes—H. Shapley on climate and life, C. S. Coon on climate and race, and P. B. Sears on climate and civilization. The last-named, in opposition to Huntington, considers that cultural deterioration and expansion of deserts are due more to pressure of population, causing destruction of forests and soil erosion, than to changes of climate.

The general impression left by the book is one of intense interest and activity in a subject which calls for the co-operation of workers in many different branches of science. The preoccupation with solar cycles is probably only the latest, not the last, of the long succession of "solutions" which began in 1875 with Croll's "Climate and time", but every attempt must bring nearer the real and final solution. The problem is one of real importance; the last half-century has shown that climatic changes are not merely of academic interest as a fertile field for speculation, but will most likely have a practical bearing on the future of man.

C. E. P. BROOKS

SPECIAL PROMOTION ON MERIT

In 1953 Dr. G. D. Robinson, Superintendent of Kew Observatory, became the first member of the Meteorological Office to be awarded promotion on the grounds of special merit. This year it is a pleasure to announce that another member of the Meteorological Office staff, Dr. F. Pasquill, has been promoted to Senior Principal Scientific Officer on the recommendation of the Interdepartmental Scientific Panel, again in recognition of exceptional ability in research.

Dr. Pasquill graduated at Durham in 1935 with first class honours in physics. He spent the next two years in research on the electrification of rain under the direction of Dr. J. A. Chalmers, after which he entered the Meteorological

Office, being posted to the Meteorology Section of the Chemical Defence Experimental Station at Porton. Here he found congenial work in the experimental and instrumental aspects of micrometeorology. Using one of the wind tunnels available in the Meteorology Section, he spent much time in a painstaking study of evaporation from plane free-liquid surfaces into a turbulent air stream, and in 1943 he published in the *Proceedings of the Royal Society* what is now recognized as a major contribution to this problem. By taking full account of the aerodynamic factors and by precise and ingenious experimentation, Dr. Pasquill succeeded, for the first time, in bringing order into this subject, and it is probably fair to say that since the publication of this study it has not been worth while for anyone to repeat the investigation. He also extended the wind-tunnel work to small-scale experiments in the open.

In 1943 he left for Australia to conduct investigations into micrometeorological problems in semitropical conditions, and on his return to the United Kingdom in 1946 he was posted to the School of Agriculture, Cambridge, for studies on the application of meteorology to problems arising in farming. During the next four years he published five notable papers dealing with transfer problems near the ground, and thereby provided a basis for a workable method of estimating the flux of water vapour into the air from natural surfaces. This work again was distinguished by meticulous care in the experimentation. These studies received recognition in 1950 by the double award of the degree of D.Sc. (Durham) and the L. G. Groves Memorial Prize for Meteorology.

From 1949 to 1954 Dr. Pasquill has been stationed at the Atomic Energy Research Establishment, Harwell, where he has extended his work on diffusion to problems relating to the spread of radioactive effluent from an atomic pile. For this purpose he has been attached to the Health Physics Division and has contributed much to the solution of their extremely important problems. He is also a member of the Atmospheric Pollution Research Committee.

Dr. Pasquill will now return to the Chemical Defence Experimental Station, Porton.

METEOROLOGICAL OFFICE NEWS

Academic successes.—To the lists published in the October number should be added:—

General Certificate of Education (Advanced Level).—Pure and applied mathematics and physics, C. D. Kemshall, R. F. Scarsbrook.

City and Guilds.—Mathematics III, J. W. O. Rowe.

Ocean weather ships.—The following extracts from the report of the Meteorological Officer-in-Charge aboard O.W.S. *Weather Recorder*, Voyage 54, at ocean weather station JULIETT illustrate the unusual and interesting natural phenomena which may sometimes be observed aboard an ocean weather ship:—

The aurora, somewhat unexpectedly, was seen on four occasions.

On August 10, a large fish some 4–5 ft. across, in an exhausted condition seen close to the ship was identified as a sun fish. A second fish believed to be of the same species was seen at about 54°N. 13°W. on the homeward passage. A small blue shark about 4–5 ft. long was seen swimming around the ship for about 3 hr. on August 19. Attempts were made to catch it without success. These visitors from tropical waters were unexpected. Sea temperatures were, if anything, lower than normal at about 57°F. although during the time the shark was seen the temperature of the sea surface layer rose by some 3–4°F. to 60–61°F. in calm conditions.

WEATHER OF SEPTEMBER 1954

Mean pressure was below normal over Scandinavia, north France, Belgium, Holland and Germany; the greatest deficit of pressure, 10–11 mb., occurred over Norway and Sweden and the lowest mean pressure, 997 mb., occurred between Norway and Iceland. Mean pressure over the rest of Europe was generally 1–2 mb. above normal and the mean pressure at the Azores, 1025 mb., was 2 mb. above normal. This mean pressure distribution gave a marked gradient for south-westerly winds over much of Europe. The mean pressure over the United States was generally 2 mb. below normal.

The mean temperature was about 2–3°F. above normal over the greater part of Europe except at places in north France, Belgium and north Germany where it was a little below normal. Over most of the United States (south of 45°N.) mean temperature was generally 3–4°F. above normal.

In the British Isles the changeable weather of the preceding three months continued through September. On nearly every day a substantial part of the country was affected by cyclonic systems moving from the Atlantic and the few intervening ridges of high pressure were weak and transitory. Winds were frequently from a westerly point and reached gale force at intervals in association with the more vigorous depressions. Temperature was for the most part below the average but, in marked contrast to the previous three months, sunshine appreciably exceeded the average in many areas. It was very wet in some western districts but drier than usual in eastern England.

The very warm weather of August 31 continued over the following day; Southport, with a maximum temperature of 81°F., had its warmest September day since 1906 and at places in east and south-east England 11–12 hr. sunshine were recorded. In Scotland and Ireland the month opened with mainly cloudy weather and rain in places. This type of weather spread south-east on the 2nd and was accompanied in England and Wales by a fall of temperature amounting to some 10°F. No really warm weather occurred during the rest of the month. On the 3rd a depression moved from south-west Ireland to a position off south-west Norway giving a gale locally in the Irish Sea. On the 9th another depression followed a similar path and on the 10th a wave depression moved quickly across southern England to the North Sea; gales occurred at exposed stations in the west and rainfall was heavy in places, for example 2·61 in. at Borrowdale, and 2·24 in. at Watendlath Farm, Cumberland on the 9th and 1·36 in. at Lake Vyrnwy on the 10th. On the 14th an Atlantic depression moved east-north-east to north-west Scotland and later north-east to west Norway; considerable rain fell in northern districts (2·08 in. at Watendlath Farm on the 15th and 1·85 in. at Lerwick, Shetland Islands on the 16th) and strong westerly winds and local gales were recorded on the 16th. An intense depression moved to north-west of Scotland on the 23rd and thence to the northern North Sea, while troughs of low pressure crossed the British Isles; rain occurred generally and was heavy in places (2·00 in. at Liskeard, Cornwall and at Sheepstor, Devon and 2·04 in. at West Baldwin, Isle of Man) and winds were strong to gale force locally. Though there were periods of continuous rain in many parts of the country much of the rainfall of the month fell as showers and there were considerable sunny intervals in between. Thunderstorms occurred in places on numerous days, chiefly in the second and third weeks. Distinctly colder weather spread southward over Scotland on the 26th and extended to the whole country during the 28th and 29th. Snow fell on the Scottish hills in the last week and sleet locally at lower levels in the north of Scotland on the 28th–30th. Ground frost occurred in widely separated areas in the early morning in the latter part of the month and a screen minimum of 23°F. occurred at Eskdalemuir on the 27th and 28th.

The general character of the weather is given 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 ...	87	24	−1·5	138	+8	119
Scotland	77	23	−2·2	156	+7	105
Northern Ireland ...	71	28	−2·0	162	−9	112

RAINFALL OF SEPTEMBER 1954

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·76	97	*Glam.*	Cardiff, Penylan ...	6·92	227
Kent	Dover	1·51	65	*Pemb.*	Tenby, The Priory ...	3·72	118
,,	Edenbridge, Falconhurst	2·59	114	*Radnor*	Tyrmynydd	6·53	169
Sussex	Compton, Compton Ho.	4·30	154	*Mont.*	Lake Vyrnwy	8·21	227
,,	Worthing, Beach Ho. Pk.	2·51	117	*Mer.*	Blaenau Festiniog ...	12·49	159
Hants.	Ventnor Cemetery ...	3·64	143	,,	Aberdovey	4·74	148
,,	Southampton, East Pk.	3·06	140	*Carn.*	Llandudno	2·48	116
,,	South Farnborough ...	2·17	114	*Angl.*	Llanerchymedd ...	5·45	185
Herts.	Royston, Therfield Rec.	1·29	69	*I. Man*	Douglas, Borough Cem.	6·23	191
Bucks.	Slough, Upton... ...	2·03	115	*Wigtown*	Newton Stewart ...	7·23	212
Oxford	Oxford, Radcliffe ...	2·60	152	*Dumf.*	Dumfries, Crichton R.I.	5·78	213
N'hants.	Wellingboro' Swanspool	2·18	121	,,	Eskdalemuir Obsy. ...	8·77	237
Essex	Shoeburyness	0·98	59	*Roxb.*	Crailing	2·20	108
,,	Dovercourt	1·37	77	*Peebles*	Stobo Castle	4·41	175
Suffolk	Lowestoft Sec. School...	1·29	66	*Berwick*	Marchmont House ...	3·39	141
,,	Bury St. Ed., Westley H.	1·46	73	*E. Loth.*	North Berwick Res. ...	2·61	125
Norfolk	Sandringham Ho. Gdns.	2·63	127	*Midl'n.*	Edinburgh, Blackf'd. H.	3·41	166
Wilts.	Aldbourne	3·35	167	*Lanark*	Hamilton W. W., T'nhill	6·02	225
Dorset	Creech Grange... ...	4·20	153	*Ayr*	Colmonell, Knockdolian	5·35	154
,,	Beaminster, East St. ...	4·86	191	,,	Glen Afton, Ayr San. ...	9·46	243
Devon	Teignmouth, Den Gdns.	2·29	117	*Renfrew*	Greenock, Prospect Hill	8·38	187
,,	Ilfracombe	5·59	208	*Bute*	Rothesay, Ardencraig...	8·85	219
,,	Princetown	9·99	195	*Argyll*	Morven, Drimnin ...	8·58	152
Cornwall	Bude, School House ...	3·40	132	,,	Poltalloch	9·61	210
,,	Penzance, Morrab Gdns.	4·91	168	,,	Inveraray Castle ...	11·16	174
,,	St. Austell	4·83	151	,,	Islay, Eallabus... ...	8·47	203
,,	Scilly, Tresco Abbey ...	3·21	125	,,	Tiree	8·52	230
Somerset	Taunton	2·54	128	*Kinross*	Loch Leven Sluice ...	4·47	174
Glos.	Cirencester	3·88	176	*Fife*	Leuchars Airfield ...	2·09	108
Salop	Church Stretton ...	2·34	111	*Perth*	Loch Dhu	11·54	201
,,	Shrewsbury, Monkmore	1·59	98	,,	Crieff, Strathearn Hyd.	3·93	137
Worcs.	Malvern, Free Library...	1·39	72	,,	Pitlochry, Fincastle ...	3·40	135
Warwick	Birmingham, Edgbaston	1·69	94	*Angus*	Montrose, Sunnyside ...	2·35	118
Leics.	Thornton Reservoir ...	1·90	105	*Aberd.*	Braemar	2·86	114
Lincs.	Boston, Skirbeck ...	2·33	132	,,	Dyce, Craibstone ...	1·31	54
,,	Skegness, Marine Gdns.	2·00	110	,,	New Deer School House	2·63	104
Notts.	Mansfield, Carr Bank...	2·98	162	*Moray*	Gordon Castle	2·08	83
Derby	Buxton, Terrace Slopes	5·84	180	*Nairn*	Nairn, Achareidh ...	2·16	102
Ches.	Bidston Observatory ...	2·22	92	*Inverness*	Loch Ness, Garthbeg ...	3·62	117
,,	Manchester, Ringway...	3·35	148	,,	Glenquoich	12·30	142
Lancs.	Stonyhurst College ...	7·14	187	,,	Fort William, Teviot ...	10·55	165
,,	Squires Gate	5·26	194	,,	Skye, Broadford ...	10·77	156
Yorks.	Wakefield, Clarence Pk.	1·82	114	,,	Skye, Duntuilm ...	5·17	112
,,	Hull, Pearson Park ...	2·30	134	*R. & C.*	Tain, Mayfield ...	2·33	102
,,	Felixkirk, Mt. St. John...	2·01	110	,,	Inverbroom, Glackour...	6·50	147
,,	York Museum	1·82	112	,,	Achnashellach	11·65	169
,,	Scarborough	1·42	79	*Suth.*	Lochinver, Bank Ho. ...	4·49	129
,,	Middlesbrough... ...	1·46	88	*Caith.*	Wick Airfield	2·74	110
,,	Baldersdale, Hury Res.	5·26	205	*Shetland*	Lerwick Observatory ...	6·41	213
Norl'd.	Newcastle, Leazes Pk....	2·84	143	*Ferm.*	Crom Castle	4·90	176
,,	Bellingham, High Green	4·96	207	*Armagh*	Armagh Observatory ...	4·39	178
,,	Lilburn Tower Gdns. ...	3·06	130	*Down*	Seaforde	5·00	182
Cumb.	Geltsdale	5·91	211	*Antrim*	Aldergrove Airfield ...	2·75	111
,,	Keswick, High Hill ...	10·33	244	,,	Ballymena, Harryville...	4·63	149
,,	Ravenglass, The Grove	6·12	182	*L'derry*	Garvagh, Moneydig ...	5·00	168
Mon.	A'gavenny, Plâs Derwen	3·02	118	,,	Londonderry, Creggan	5·55	168
Glam.	Ystalyfera, Wern House	10·14	232	*Tyrone*	Omagh, Edenfel ...	4·95	162

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

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M.O. 581 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 83, No. 990, DECEMBER 1954

SNOW SURVEY OF GREAT BRITAIN
Season 1953–54

An annual report of the Snow Survey of Great Britain has been published by the British Glaciological Society in each of the past seven years in its *Journal of Glaciology*. In 1953 the work of the Survey terminated, and the collection of the records was undertaken by the Meteorological Office. The report for 1953–54 which follows has accordingly been prepared in the British Climatology Branch of the Meteorological Office.

As in previous years the basic material for the report has been derived from the returns made by many enthusiastic voluntary observers who have provided, month by month, daily records of snowfall and of any snow-cover within their range of vision. These records relate to a network of land stations distributed over the country, and are augmented by data extracted from the regular monthly returns from official weather stations and from voluntary climatological stations reporting to the Meteorological Office. In addition, information on snowfall around our coasts has again been provided by the returns from lighthouses and lightships, made available by the courtesy of the Elder Brethren of Trinity House and by the Commissioners of Irish Lights, and also by the returns from a number of ships at sea, supplied through the good offices of various shipping companies. Without the co-operation of all those responsible for these voluntary observations it would not have been possible to have prepared this report in anything approaching its present detail.

In general, measurements of snow depth in this report refer to 0900 G.M.T. or thereabouts.

Summary of the 1953–54 season.—The season may be classed as one of less than average snowfall. Data for the ten representative stations* in Great Britain, at altitudes between 400 and 1,200 ft., which have been used for seasonal comparison since the survey of 1946–47 give a mean of 26 days with snow lying at the hour of morning observation. This compares with an average of 34 such days derived from the past seven seasons. In the preceding seven seasons the mean number of days ranged from 13 in 1948–49 and 1949–50 to 66 in the snowy season of 1946–47, showing the great variability of snowfall in the British Isles. The seasonal distribution of snowfall in 1953–54 was in strong contrast to that of 1952–53, when late autumn and early winter were unusually cold and much

* These stations are:—Dalwhinnie, Braemar, West Linton, Eskdalemuir, Huddersfield (Oakes), Buxton, Whipsnade, Little Rissington, Princetown and Rhayader.

FIG. 1—GREAT BRITAIN AND NORTHERN IRELAND

snow fell in the later half of November and middle of December. In the present season the late autumn and early winter were exceptionally mild[1]. In consequence there was remarkably little snow until early January; even on Ben Nevis the snow in December was described as very light and patchy. The latter part of January and the first part of February 1954 were, however, extremely cold. The heaviest snowfalls occurred over western and southern districts of Great Britain on January 25–26 and in the north and east on February 27–28.

Notes on the months.—*September 1953.*—No reports of snow were received and on Ben Nevis snow completely disappeared about the end of the month.

October 1953.—The weather was again mild for the season in Scotland. There was little snow, though sleet showers occurred at Lerwick on the 3rd, Glenlivet on the 14th and 15th, and at Leverburgh, Isle of Harris, on the 26th–29th; very slight falls of snow were recorded on Ben Nevis on the 14th, 25th and 27th. Snow lay on some of the mountains in central and western Scotland mainly at heights above 2,500 ft. between the 27th and 31st and on Ben Nevis also on the 25th.

November 1953.—The month was unusually mild throughout the country and there was very little snow. Snow or sleet showers occurred at times at a few places, mainly during the first week and on the 30th. Snow lay on the mountains in central and western Scotland on some mornings during the first part of the month and on the 30th; on Ben Nevis it lay throughout the month, generally at a height above 3,000 ft. At Leverburgh, the observer noted that outdoor daffodils were showing.

December 1953 was also exceedingly mild. The extreme mildness of the month can be deduced from the following quotations by observers. Mr. A. F. Airey of Windermere writes: "Prunus trees were in blossom at Ambleside and Grasmere" and Mr. L. H. Lomas of Leverburgh, Isle of Harris, reported: "Daffodils showing five months earlier than usual". Slight snow or sleet fell at times in the later part of the month, chiefly on the 24th and 25th and in the south-east on the 31st. On the 24th drifts of 2 ft. were observed at 2,000 ft. on the eastern faces of the Braes of Balquhidder. Snow lay on some Scottish mountains and on Sca Fell, Westmorland, from the 24th or 25th to the 31st and locally at times during the first part of the month, particularly on the 4th and 5th. On Ben Nevis it lay throughout the month above 3,500 ft. but it was very light and patchy. No snow-cover was reported on the Welsh mountains during the months October to December inclusive.

January 1954.—The first ten days were mainly cold, and a notably cold spell with severe frost occurred from the 23rd to the 31st. Snow or sleet was widespread on the 6th and 7th and rather widespread around the 13th. Heavy snow fell in western districts of Great Britain and much of southern England on the 25th–26th, and mainly small amounts fell daily thereafter until the end of the month. At Clun, Shropshire, the average depth was 13 in. on the 26th–28th and 14 in. on the 29th–31st; at Evancoyd, Radnorshire, 12 in. fell on the night of the 25th–26th and the average depth was 12 in. on the 26th–28th; at Meggernie Castle Gardens in Glen Lyon, Perthshire, the average daily depth after the 26th was 11 in.; at Bwlchgwyn snow lay 12 in. deep on the 26th and there were drifts 6 ft. deep on the 28th; on the Brecon Beacons there were drifts up to 6 ft. on the 29th–31st.

February 1954.—At some places in the south temperature remained at 32°F. or below continuously from the evening of January 29 to the morning of February 7. Thus the snow which fell at the end of January lay on the ground during the first part of February, and mainly slight snow fell at times also during this period. The strong north-easterly winds in southern England caused drifting and some villages were isolated, notably in Kent; on the 1st drifts up to 7 ft. were reported at Throwley, near Faversham, and at Biddenden drifts up to 3 ft. on the 3rd persisted for a week. Considerable snow fell in the north and east from the 6th or 7th to the 10th and, with strong winds, in the northern Pennines on the 12th–13th. On the hills around Balquhidder, Perthshire, snow was 15 in. deep without drifting at 1,200 ft. on the 9th. Drifts up to 5 ft. were recorded at Moor House, Westmorland, and at Alston, Cumberland, on the 10th. Snow fell again during the last few days and was heavy locally at times; it was fairly widespread on the 28th. At Moor House the average depth was 9 in. on the 25th and 12 in. on the 26th–28th.

March 1954.—The weather was unsettled and changeable, with a very cold wintry spell during the first few days. On the 1st snow lay on high ground from the snowfall at the end of February, and more snow fell in some parts during the first three or four days. On the hills in the neighbourhood of Plymouth the snowfall above 400 ft. on the 1st was the heaviest of the winter; depths of 6 in. were reported around Princetown. In north-west England and north Wales heavy snow occurred on the 2nd accompanied by strong winds; the observer at Bwlchgwyn (1,267 ft.) recorded: "the blizzard of the 2nd was the worst of the winter with excessive drifting" and roads were blocked by 2200. At Fairburn (500 ft.), Ross and Cromarty, the average depth on the 4th was 5 in. drifting to 5 ft. and at Glenferness (700 ft.), Nairnshire, there were drifts up to 8 ft. on the 4th. The weather was warm from about the 10th to 12th, but a marked fall of temperature occurred on the 13th and some snow fell locally on the 13th and 14th. Scattered wintry showers occurred at times during the last week.

April 1954.—April was dry generally, and notably sunny. Mean temperature was below the average in England and Wales but somewhat above the average in Scotland. The nights were unusually cold; ground frosts were frequent and air frost was severe locally at times and occurred more often than is usual in April. There was little snow, though snow or sleet showers occurred at times; they were widespread between the 4th and 6th, and occurred locally in western districts of England and Wales on the 1st, at a few scattered places on the 12th and 13th, and in many parts of Scotland on the 30th. There were few days with snow cover even on the hills except on those in the neighbourhood of Glen Lyon during the first half of the month and on the 30th. Ben Nevis was snow-covered throughout the month at heights above 2,500 ft., and down to below 1,500 ft. on the 30th.

May 1954.—The first week and the period 14th–24th were mainly cool, while it was warm on the whole from about the 10th to 12th and 26th to 31st, though the last days were cooler in eastern districts. Snow or sleet showers occurred on the 1st–6th (particularly on the 1st–3rd), and locally in north-west England on the 22nd. On the slopes of the Dunstable Downs, the snow was fairly heavy from 1700 to 1800 on the 2nd.

Duration of snow-cover on British mountains.—The mean number of days of snow-cover at 2,500 ft. on four mountain groups used as indices was 71 as compared with an average of 83 for the past seven seasons. The stations used were Glenbrittle (Cuillin Hills), Meggernie (Glen Lyon), Capel Curig (Snowdonia) and Tairbull (Brecon Beacons). Diagrams showing the distribution of snow-cover relative to height for 10 stations are given in Fig. 2.

Harris, in the Outer Hebrides, reported snow-cover on some days in each month from November to May. The maximum number of days, 21, occurred in February at heights above 1,500 ft. The snow-line reached sea level on seven days during the season.

The Cuillins of Skye had some cover on one day in October and in each month from December to April; at 3,500 ft. there was continuous cover from January 13 to April 3. The snow-line reached sea level on eight days in February and three days at the beginning of March.

The peaks around Glen Lyon had snow-cover on October 28 and in each month from November to May; it lay continuously down to 3,000 ft. from January 21 to April 11, and at station level (760 ft.) from January 25 to February 16, and from February 24 to March 7.

The Paps of Jura were snow free until January 5 and from March 16 to April 30, but on May 1 snow lay down to sea level for the one day. At 2,500 ft. it lay continuously from January 26 to February 9 and February 16 to March 9.

Ben Nevis was snow free until October 24. The summit was under continuous cover from October 26 until January 9 and from January 12 until the end of the season. In the period up to January 9, however, snow-cover came down to 2,000 ft. on only 10 days. Between January 13 and March 7 there was cover at station level (30 ft.) on 11 days.

The peaks near Capel Curig had no snow-cover until January 6, but they were under cover on some days in each month during the rest of the season. Snow-cover came down to station level (700 ft.) from January 26 to February 6 and from February 28 to March 5. Cover was observed on three days in early April and on the first two days of May.

In south Snowdonia there was no snow-cover until January 7 and then it only lasted two days; there was continuous cover at 2,500 ft. from January 26 to February 8 and from February 25 to March 5. Snow-cover was observed on three days in early April but none from April 7 to the end of the season.

The Brecon Beacons were snow free until January 6. Cover was continuous at 2,500 ft. from January 26 to March 28. It came down to station level (660 ft.) from January 26 to February 9, on February 19 and 20 and on six days in the first half of March. There were two days with snow-cover in the first week in April and three in early May.

Cross Fell was snow free until December 24 when snow persisted for three days. The summit was covered continuously from January 29 to February 20 and February 24 to March 11. Snow-cover was observed on 2 days in April and on 5 days in May, the latest date being May 22. Snow was observed below 1,000 ft. on January 14, continuously from January 29 to February 12 and February 25 to March 7, and on March 22.

Helvellyn was snow free until January 7 apart from some cover on December 25. The summit was covered continuously from January 26 to 31 and February 4 to March 9. Snow-cover was observed also on April 5 and May 6 and 22. Snow lay at station level (520 ft.) on January 26 and 31, February 4, 7–12 and 26–28 and March 3.

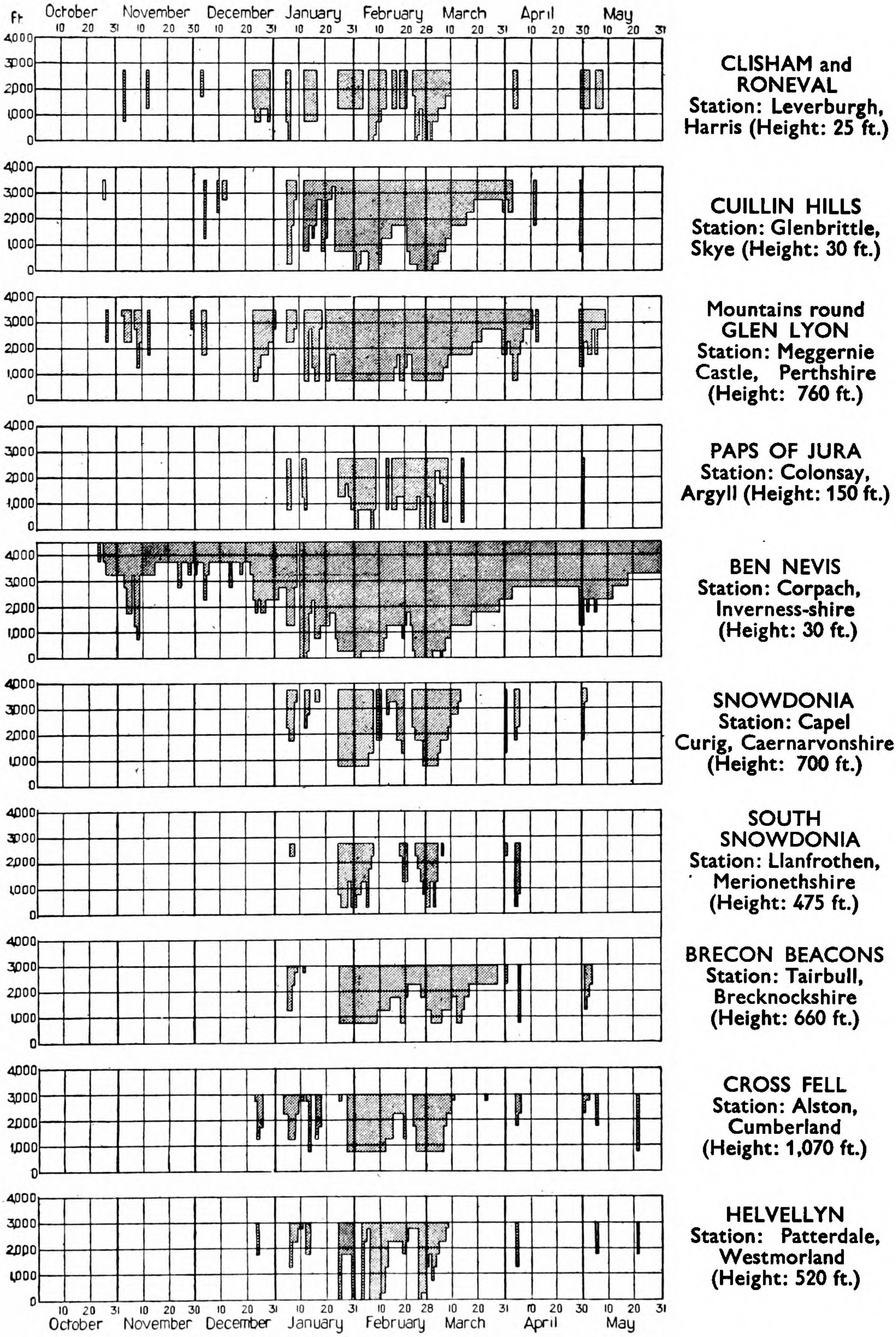

FIG. 2—DISTRIBUTION OF SNOW-COVER IN RELATION TO HEIGHT

Curves showing the total seasonal duration at six stations are drawn in Fig. 3; 200 days' cover was exceeded on Ben Nevis above 3,500 ft. and 100 days' cover was exceeded on the mountains about Glen Lyon above 2,500 ft.

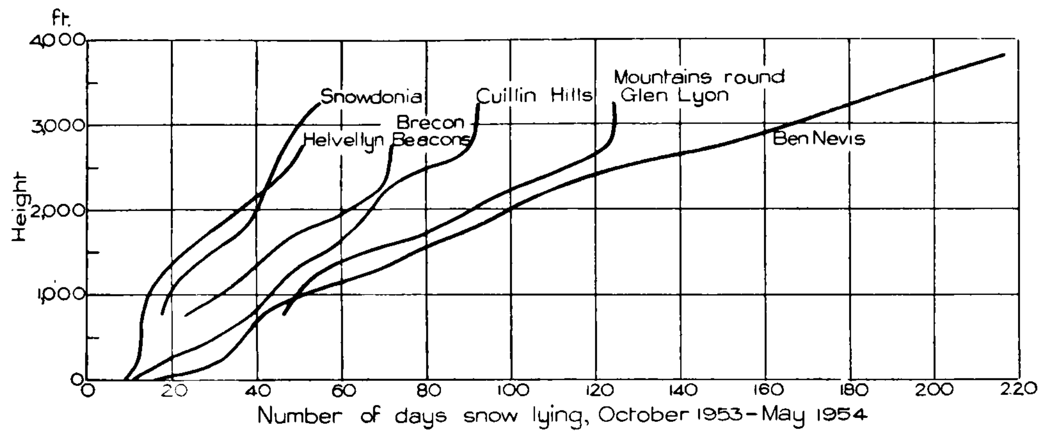

FIG. 3—SEASONAL DURATION OF SNOW-COVER

Snowfall in British coastal waters.—Returns were received for the 1953–54 season from 91 lighthouses and lightships round the coasts of England and Wales and from 60 lighthouses and lightships round the Irish coast; 18 returns were received from merchant ships. The earliest snowfall at sea was reported by the Morecambe Bay light-vessel on December 13. Most of the snowfall reported at sea occurred between the beginning of January and the end of the first week in March. The number of days with snow during the season ranged from only 2 at the Scarweather light-vessel in the Bristol Channel and at the Eddystone, Bishop Rock and Wolf Rock lighthouses to 24 at the Cromer and Inner Dowsing light-vessels. The last report of snowfall at sea came from the M.V. *Lochiel* who experienced scattered snow showers on May 1 when she was on passage from Port Askaig, Islay, to Loch Tarbert, Jura.

REFERENCE

1. LEWIS, L. F.; Exceptional weather of November 1953 to early February 1954. *Met. Mag., London,* **83,** 1954, p. 143.

PROBABILITY PAPER AND ITS APPLICATIONS IN UPPER AIR CLIMATOLOGY

By N. GOLDIE, B.Sc.

The traditional picture of a tropopause surface sloping steeply in middle latitudes but extending continuously from pole to equator has tended in late years to be replaced, for each hemisphere, by that of two tropopause surfaces of which both the upper, characteristic of the tropics, and the lower, characteristic of poleward regions, extend into middle latitudes so that there is a zone of overlap between latitudes 30° and 40°. Loewe and Radok[1] show that this is consistent with tropopause observations over Australia. Between 32°S. and 38°S. in winter, they find the frequency distributions of height of tropopause to be compounded each of two normal distributions with means in the neighbourhood of 10 and of 15 Km., while to the south (at Macquarie Island, 54°S.) the 10-Km. distribution prevails and to the north (at stations north of 27°S.) the 15-Km. distribution. Their analyses were performed by means of probability paper.

This type of graph paper was used in the Upper Air Climatology Branch of the Meteorological Office in an early attempt to sort out some of the irregularities found in the tropopause pressures reported at British stations overseas. Shortly after the present article was first circulated[2], more complete investigations were made by the Meteorological Office into the incidence and true nature of the tropopause (both single and multiple), and definitions of stratosphere and troposphere were proposed which would remove ambiguities earlier inherent in the determination of tropopauses.

The present article is concerned primarily with outlining the principles underlying the construction and use of probability paper, the brief discussion of the tropopause over Habbaniya being included mainly in illustration of a somewhat unusual application of probability paper. Reference is made also to its use in estimating the likelihood of strong winds on aircraft routes.

The symbols used in this description of probability paper include the following:—

X = a variate, plotted as abscissa
x = the departure of any specified value of X from the mean of the frequency distribution of X
σ = the standard deviation of X
N = the number of observations in the frequency distribution
t = a standardized variate, i.e. x/σ
P = the probability integral.

Probability scale.—Probability paper may be obtained from most printing firms who specialize in the production of different types of graph paper. It has been widely used in America where it was applied to a meteorological problem as early as 1924, when W. R. Gregg and J. P. van Zandt[3] demonstrated by means of probability paper the normality of a frequency distribution of westerly wind components at 1,500 ft. over the United States.

The use of probability paper for the examination of frequency distributions is analogous to the use of semi-logarithmic paper in examining a relationship of the form $Y = ab^X$ between the two variates X and Y, which gives a straight line when Y on the logarithmic scale is plotted against X on the linear scale. Similarly, a normal frequency distribution gives a straight line on probability paper, the logarithmic scale of semi-logarithmic paper being replaced by a "probability" scale in which the ordinate Y is the cumulative frequency of X.

On semi-logarithmic paper, the scale of Y is linear with respect to log Y; on probability paper, the probability scale is linear with respect to the standardized normal deviate, i.e. with respect to t when t is distributed normally. It is easily seen that this arrangement of scale results in a straight line when a normal distribution is plotted, for

$$t = \frac{x}{\sigma} = \frac{1}{\sigma} X + \text{a constant}.$$

The markings on the probability scale give values of $100P$ where P is the "probability integral" defined by the expression

$$P = \frac{1}{(2\pi)^{\frac{1}{2}}} \int_{-\infty}^{t} \exp(-t^2/2).dt.$$

Corresponding values of $100P$ and $t = x/\sigma$ are given in Table I.

TABLE I—CORRESPONDING VALUES OF t AND $100P$ FOR A NORMAL DISTRIBUTION

(*a*) For evenly-spaced values of t

t:	−3·0	−2·5	−2·0	−1·5	−1·0	−0·5	0·0
$100P$:	0·13	0·62	2·3	6·7	15·9	30·9	50·0

t:	0·0	0·5	1·0	1·5	2·0	2·5	3·0
$100P$:	50·0	69·1	84·1	93·3	97·7	99·38	99·87

(*b*) For standard values of $100P$

$100P$:	0·1	0·2	1·0	2·0	5·0	10·0	20·0	30·0	40·0	50·0
t:	−3·09	−2·88	−2·33	−2·05	−1·64	−1·28	−0·84	−0·52	−0·25	0·00

$100P$:	50·0	60·0	70·0	80·0	90·0	95·0	98·0	99·0	99·8	99·9
t:	0·00	0·25	0·52	0·84	1·28	1·64	2·05	2·33	2·88	3·09

A more detailed table of $100P$ in terms of t is given by Yule and Kendall[4], and t in terms of $100P$ by Fisher and Yates[5] under the heading "Probits".

Plotting a frequency distribution.—In plotting a frequency distribution on probability paper, the ordinates are determined by numbering the observations in order of magnitude and multiplying the numbers so obtained by $100/N$ to convert them to percentages. In place of the usual ordinal numbers, 1, 2, 3, . . . N, it is preferable to adopt the series $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, . . . , $(N - \frac{1}{2})$. The ordinates are then symmetrical about the 50-per-cent. line, and the mean as well as the standard deviation of a distribution which is normal can be estimated directly from the graph; also, this avoids the difficulty of plotting a probability number of 100 per cent. which, to be correct, would have to be placed at an infinite distance from the 50-per-cent. line.

The plotting of grouped observations is described in an appendix.

Estimating the mean and standard deviation.—In order to estimate graphically the mean and standard deviation of a normal, or almost normal, distribution, a straight line is fitted by eye to the plotted points. The mean is then read off, being the abscissa of the intersection of this line with the 50-per-cent. line. For example, in Fig. 6 the mean for curve (*b*) is 83 mb. and for curve (*c*) 212 mb. while for the curve in Fig. 7 the mean is 85 mb.

The standard deviation is given by the slope of the fitted line. With the aid of Table I, σ can be determined from the difference between almost any two values of X; but the most accurate method is to read off values corresponding to the probability numbers, $100P = 6{\cdot}7$ and $100P = 93{\cdot}3$, and to divide the difference between them by 3. As a check, it may be verified that the result is the difference between the mean and the value of X corresponding to $100P = 84{\cdot}1$.

Effect of combining two normal frequency distributions.—The straight lines (*a*) and (*c*) of Fig. 1 show on probability paper the plot of two normal frequency distributions with the same standard deviation (10 units) but different means (25 and 55 units). If in each there are 25 observations which fit exactly the straight line, they will have the following values:—

Probability number ...	2	6	10	14	... 50 ...	86	90	94	98
Curve (*a*)	4·5	9·5	12·2	14·2	... 25 ...	35·8	37·8	40·5	45·5
Curve (*c*)	34·5	39·5	42·2	44·2	... 55 ...	65·8	67·8	70·5	75·5

Plotting the whole 50 observations as one distribution yields the curve ABCD shown at (*b*). The circles are observations comprising distribution (*a*) and the crosses those comprising distribution (*c*). The normal distribution with the

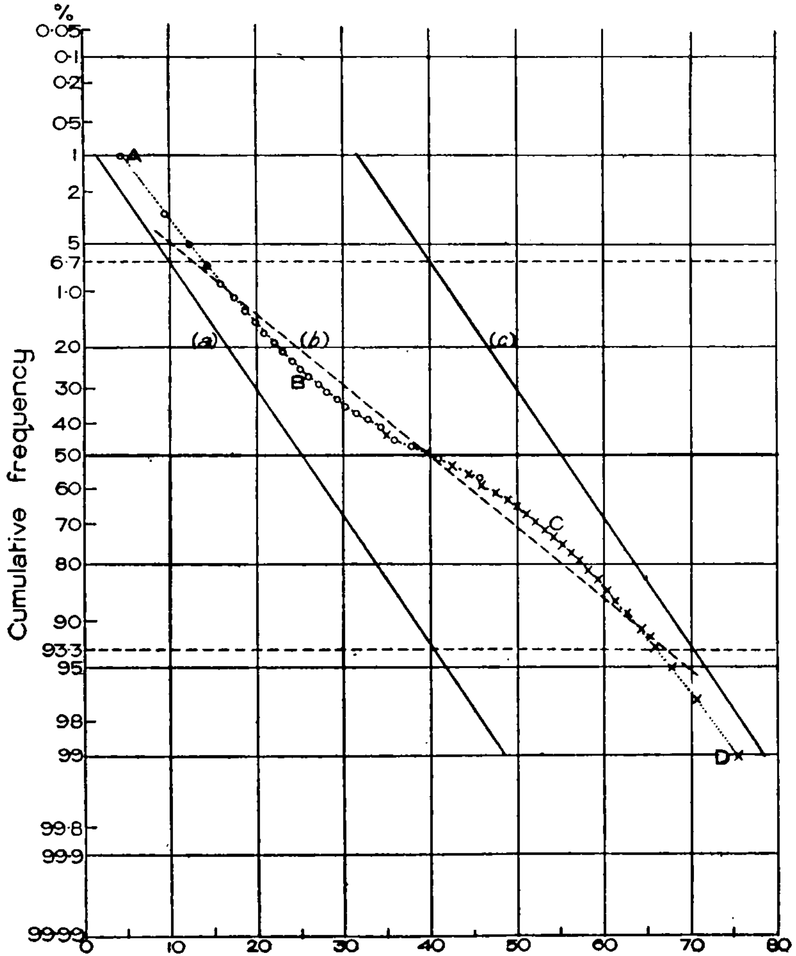

FIG. I—COMBINATION OF NORMAL DISTRIBUTIONS WITH DIFFERENT MEANS

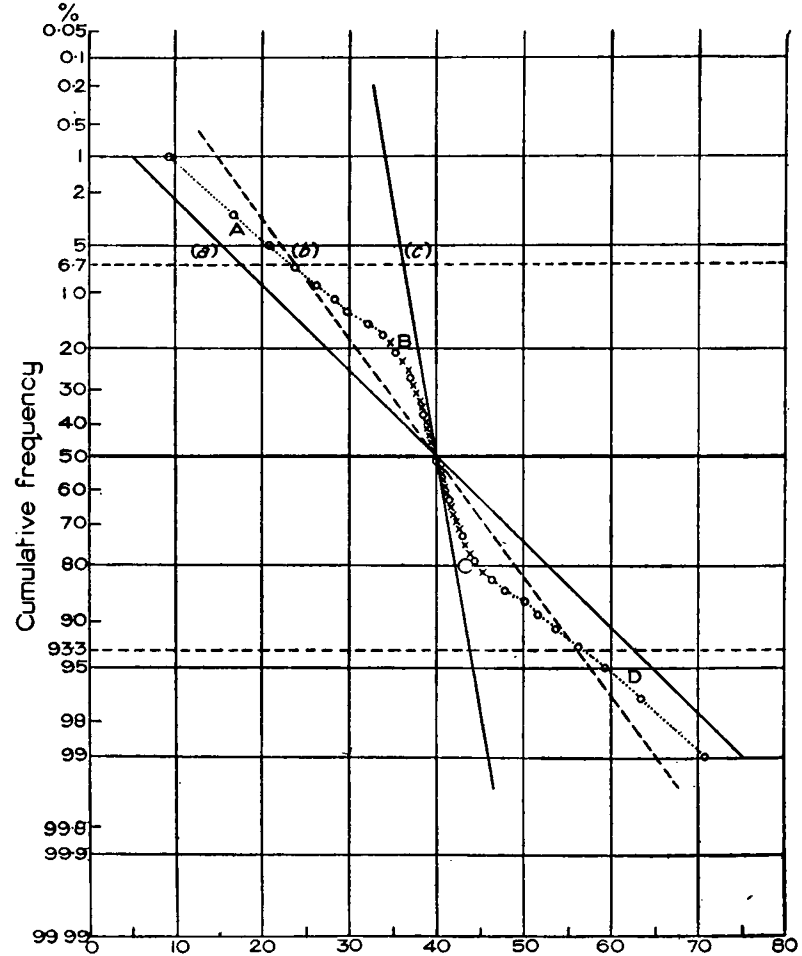

FIG. 2—COMBINATION OF NORMAL DISTRIBUTIONS WITH DIFFERENT STANDARD DEVIATIONS

same mean and standard deviation as the composite distribution is shown by a broken line; mean = 40; σ = 18. It will be seen that between A and B and between C and D the slope of the curve is steeper than that of the broken line whereas between B and C it is less steep. In other words, there are more observations between $0 \cdot 8\sigma$ and $2 \cdot 0\sigma$ on either side of the mean than would be expected in a normal distribution and fewer within $0 \cdot 8\sigma$ of the mean. This type of distribution which has an excess of medium-sized deviations from the mean and a deficit of small deviations is termed platykurtic (flat-topped).

Fig. 2 shows, in similar fashion, the effect of combining two normal distributions with the same mean (40 units) and different standard deviations (15 and 2·5 units). In this, the composite curve shows an excess of small deviations (within $0 \cdot 4\sigma$ of the mean) and a deficit of medium-sized deviations (between $0 \cdot 4\sigma$ and about $2 \cdot 0\sigma$ from the mean). This type is leptokurtic (humped).

Meteorological examples.—Examples of nearly normal, platykurtic and leptokurtic frequency distributions of meteorological elements are shown in Figs. 3, 4 and 5. In each of Figs. 4 and 5, the equivalent normal distribution is shown by a broken line.

The nearly normal distribution of upper air temperatures at 300 mb. over Downham Market, shown in Fig. 3, has a slight tendency to positive skewness since the curve indicated by the crosses is slightly steeper than the straight line at the top of the diagram and less steep at the foot, showing that observations of temperature between −70° and −60°F. are bunched more closely together, but that temperatures above −40°F. are further apart, i.e. tend to be more extreme, than would be expected if the distribution were normal. The platykurtic distribution in Fig. 4 of temperature at 200 mb. also shows lack of symmetry. The curve in Fig. 5 is based on data given by Hesselberg[6]. These data were also used for illustration in the "Handbook of statistical methods in meteorology"[7]; markedly leptokurtic distributions of meteorological elements appear to be somewhat rare. It may well be that each frequency distribution in meteorology can quite often be represented by a combination of two normal distributions with different standard deviations and approximately the same mean; but, unless the discrepancy in the standard deviations is very large, the compound distribution is not readily distinguished from one that is genuinely normal.

Analysis of tropopause pressures.—During the period January 1948 to November 1950 radio-sonde staff at British stations were required to report for each ascent only one tropopause; towards the end of 1950, those at British stations overseas were instructed to note also on their returns any second tropopause observed, and to punch, on the appropriate Hollerith card, the lower of the two tropopauses.

When the observations for 1948 to 1950 were summarized, remarkable inconsistencies appeared in the monthly means of the tropopause pressures. At Bahrein (26° 16′N. 50° 37′E.) for instance in December 1950 the tropopause pressure, which for 35 months had been in the neighbourhood of 75–100 mb., increased suddenly to about 180 mb. It was evident that before December 1950 the upper tropopause had been reported almost invariably; but, in accordance with the new instruction, the lower tropopause now appeared in the Hollerith tabulations. This was confirmed by plotting the December data, as summarized, on probability paper. The resulting curve was conclusively

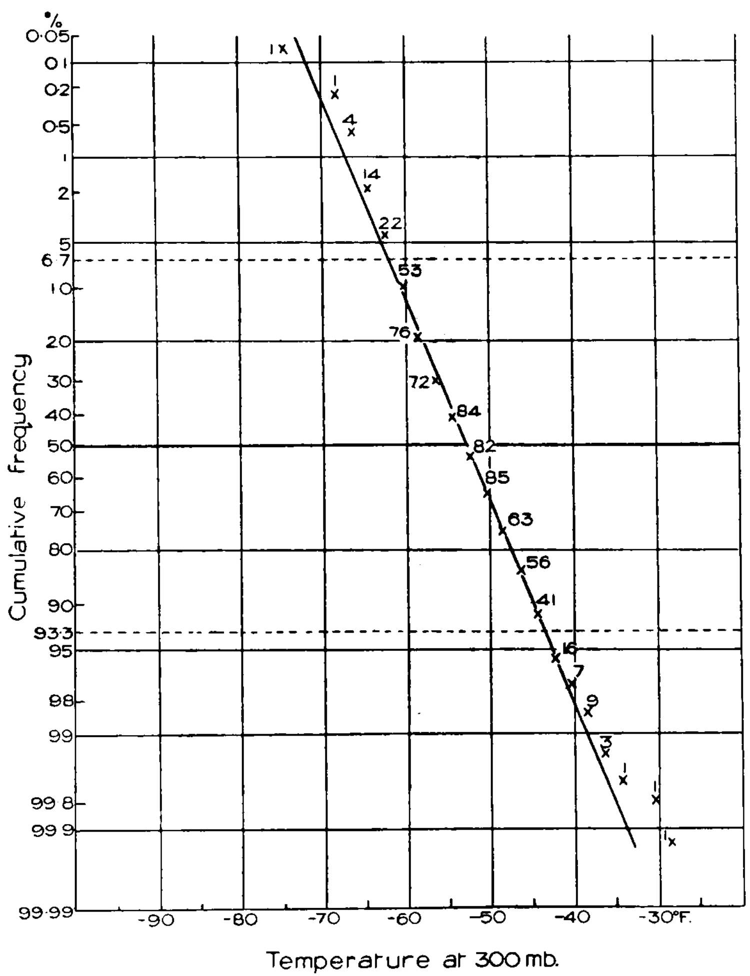

FIG. 3—TEMPERATURE AT 300 MB. OVER DOWNHAM MARKET, APRIL 1946–51

Distribution almost normal. The figures shown against the plotted points give the numbers of observations.

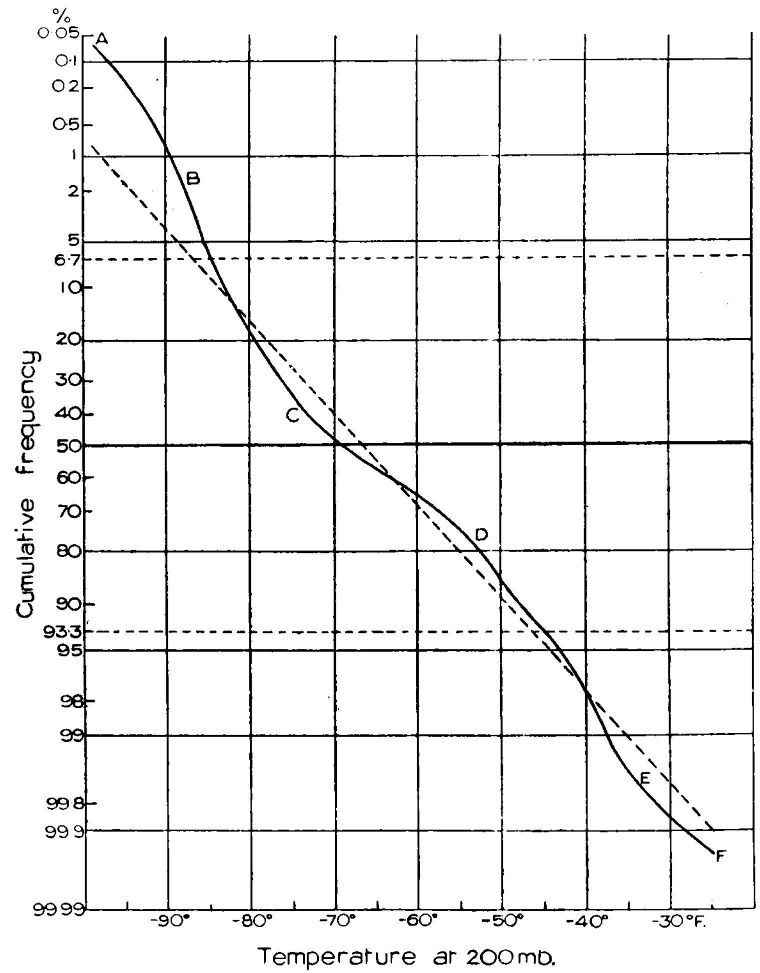

FIG. 4—TEMPERATURE AT 200 MB. OVER DOWNHAM MARKET, APRIL 1946–51

Platykurtic distribution, i.e. excess of medium-sized deviations from the mean.

platykurtic and the aggregate distribution split readily into two normal distributions with means at 99 mb. and 187 mb., all but two observations of the 187-mb. distribution (lower tropopause) having been recorded in December 1950 and only three observations from this month being included in the 99-mb. distribution (upper tropopause). At Habbaniya (33° 22'N. 43° 34'E.) similar discrepancies were found, e.g. in the first half of 1949 considerably higher tropopauses were recorded than in the same months of 1948 and 1950. A cursory examination of the discontinuities of temperature in 1949 suggested that lower tropopauses also were present.

The present brief examination of the tropopause over Habbaniya consisted of an analysis of the tropopause pressures recorded in 1948–50 for the mid-season months, January, April, July and October. The probability graphs for April and July are shown in curve (*a*) of Fig. 6 and in Fig. 7. They are plotted from observations grouped into 10-mb. classes. The curve for July in Fig. 7 is the more striking: there is no doubt whatsoever as to the normality of this distribution. The curve for April, Fig. 6, is definitely platykurtic. It approximates to two straight lines with a short transition region between. The numbers of observations in the different frequency classes, shown by small figures against the plotted points, are seen to fall off in the transition region. A break was made where the observations were fewest, as indicated in Fig. 6, and each of the portions so obtained was replotted, individual observations being used for the upper tropopauses, for these numbered only 27. Replotting resulted in curves (*b*) and (*c*). It is seen that the two component distributions are roughly normal, departures from the normal distribution (full line) being sufficiently small to be attributable to the scantiness of the data.

The analyses made for January and October 1948–50 showed similar features to that for April. A summary for all four months is given in Table II; apart from those for the April lower tropopause, the means and standard deviations were estimated from the graphs by the method described in this article. The lower tropopause seems to be entirely absent in July; a fact which was confirmed by examination of data for July 1951.

It may be concluded that, for the greater part of the year, Habbaniya is situated in the region of overlap of the tropical and polar tropopauses, the latter being the more frequent in January and April and the former in October —provided, of course, that this concept of a discontinuous tropopause surface is true. In July, the tropical régime prevails.

TABLE II—TROPOPAUSES RECORDED AT HABBANIYA, 1948–50

Observations were made at 0200 and 1400 G.M.T.; only one tropopause, either upper or lower, was recorded for each observational hour each day.

	Upper tropopause				Lower tropopause			
	Mean pressure	Standard deviation	No. of obs.	Period	Mean pressure	Standard deviation	No. of obs.	Period
	mb.	mb.			mb.	mb.		
January	100	10	23	1949, 1950	224	45	82	1948, 1950
April	83	13	27	1949	212	33	117	1948, 1950
July	85	15	118	1948–50	...	...	...	...
October	106	19	106	1948–50	181	11	26	mainly 1950

Plot of probability graph from mean and standard deviation.— Another use of probability paper in upper air work is in estimating the magnitude of equivalent headwinds or tailwinds likely to be equalled or exceeded on

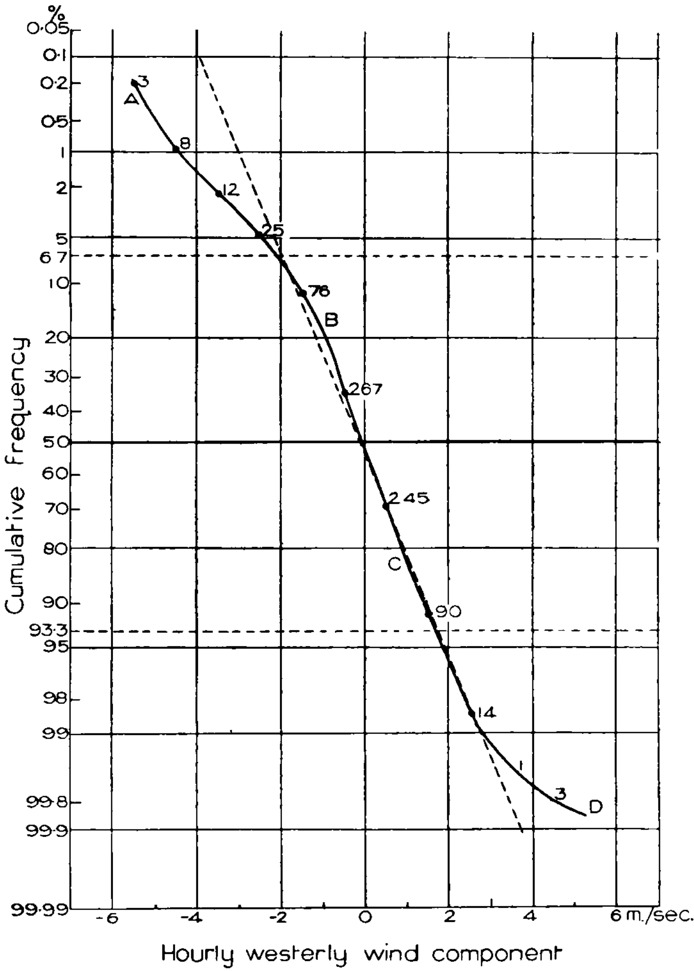

FIG. 5—HOURLY WESTERLY WIND COMPONENTS AT AAS, NORWAY, 59° 40′N. 10° 46′E., JANUARY 1929

Leptokurtic distribution, i.e. excess of small and large deviations from the mean.

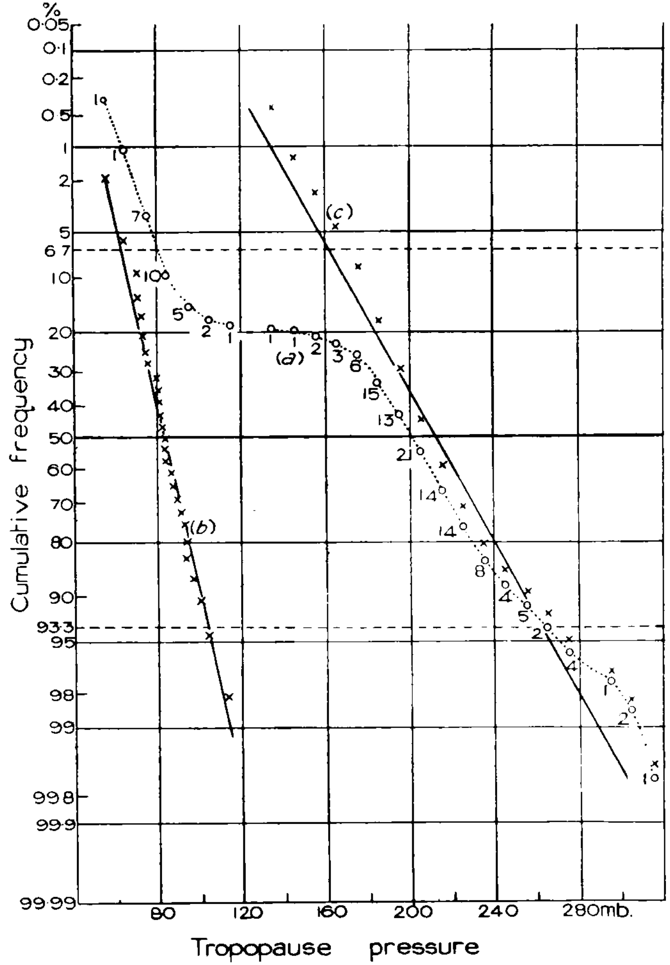

FIG. 6—TROPOPAUSE PRESSURES RECORDED AT HABBANIYA IN APRIL 1948–50

(*a*) Total recorded distribution
(*b*) and (*c*) Replot

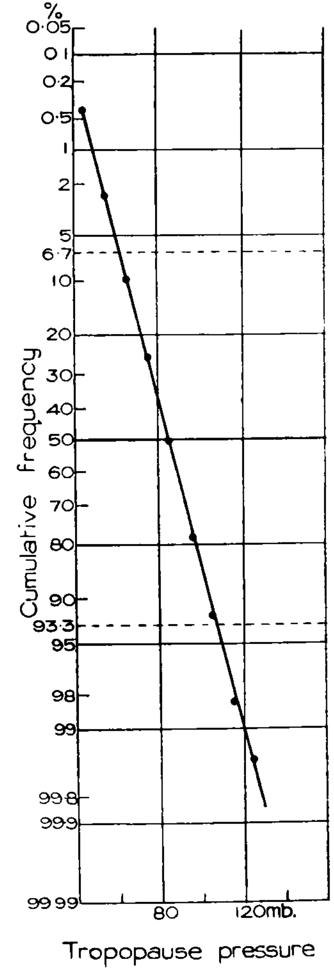

FIG. 7—TROPOPAUSE PRESSURES RECORDED AT HABBANIYA, JULY 1948–50

a specified number of occasions over an aircraft route. From the vector mean and standard vector deviation of winds at places along the route, values can be computed[8] for the mean and standard deviation of the expected distribution of headwinds and tailwinds in the direction required, tailwinds being treated as negative values of headwinds. The mean and standard deviation are plotted on probability paper in the following manner:—

A scale of wind speeds is chosen such that about six times the standard deviation will fit into the width (i.e. along the linear scale) of the graph paper, the mean value being central or nearly so.

The values, Mean $-\frac{3}{2}$ (standard deviation), Mean, and Mean $+\frac{3}{2}$ (standard deviation) are then marked on the linear scale and points are plotted with these as abscissae and the probability numbers, 6·7, 50·0 and 93·3 respectively, as ordinates.

A straight line is drawn through the three points (any two of them of course will suffice, but a third makes the setting of the ruler more certain).

The straight line shows the required normal frequency distribution and from it can be read off wind speeds corresponding to any percentile, e.g. the headwind expected to be equalled or exceeded once in ten occasions will be the abscissa corresponding to the ordinate 90·0 on the probability scale.

The method of plotting just described applies to any normal distribution of which the mean and standard deviation are known. It is not necessary, however, to know the mean and standard deviation specifically; any two parameters (e.g. two percentile values) can be plotted to fix the straight line on probability paper.

Summary.—Probability paper may generally be said to have three main uses:—

(i) It provides a fairly quick method of determining whether or not a given frequency distribution is approximately normal. Also, if the distribution is not normal, the type of non-normality may often be assessed from the probability graph.

(ii) From the plot of a normal distribution, the values of mean and standard deviation can very rapidly be determined without the necessity of going back to the original figures.

(iii) When any two parameters of a normal distribution are known, other parameters are found merely by drawing a straight line and reading off on one or other scale of co-ordinates.

As described in this article, probability paper has been used also to separate out two normal components of a compound frequency distribution; but this has been in instances where the overlap was extremely small. Analysis of compound distributions into normal components is not generally possible by means of probability paper.

Acknowledgement.—The author is indebted to Miss E. E. Austin for her helpful criticism of an earlier draft of this article.

REFERENCES

1. LOEWE, F. and RADOK, U.; A meridional aerological cross section in the southwest Pacific. *J. Met., Lancaster Pa*, **7**, 1950, p. 58.
2. CARRUTHERS, N.; Probability paper—an application in upper-air climatology. *Met. Res. Pap., London*, No. 711, 1952.
3. GREGG, W. R. and ZANDT, J. P. VAN; The frequency of winds of different speeds at flying levels between New York and Chicago: a further analysis of the records of the air mail service. *Mon. Weath. Rev., Washington D.C.*, **52**, 1924, p. 153.
4. YULE, G. U. and KENDALL, M. G.; An introduction to the theory of statistics. 11th edn, London, 1937, Appendix, Table 2.

5. FISHER, R. A. and YATES, F.; Statistical tables for biological, agricultural and medical research. 4th edn, Edinburgh, 1953, Table IX.
6. HESSELBERG, T.; Die Verwendung des Maxwellschen Verteilungsgesetzes auf meteorologische Häufigkeitskurven. *Geofys. Publ., Oslo*, **13**, No. 9, 1943.
7. BROOKS, C. E. P. and CARRUTHERS, N.; Handbook of statistical methods in meteorology. London, 1953.
8. SAWYER, J. S.; Equivalent headwinds. Application of upper-wind statistics to air-route planning. *Met. Rep., London*, **2**, No. 6, 1950.

Appendix

Method of plotting grouped observations on probability paper

In plotting grouped observations on probability paper, it is convenient to plot the probability number associated with the middle observation of each class against the middle point of the range covered by that class. Table III shows the tabulation for the April tropopause pressures plotted in Fig. 6, curve (*a*).

TABLE III—METHOD OF PLOTTING GROUPED OBSERVATIONS ON PROBABILITY PAPER

Pressure (1)	Frequency (2)	Cumulative frequency (3)	Mid value of pressure range (4)	Probability number (5)
mb.			mb.	%
50–9	1	½	54½	0·35
60–9	1	1½	64½	1·04
70–9	7	5½	74½	3·8
80–9	10	14	84½	9·7
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
290–9	1	140½	294½	97·5
300–9	2	142	304½	98·6
310–9	1	143½	314½	99·7

Column (1) shows the range of pressure in each class and column (2) the frequency. The cumulative frequency in column (3) is the number of observations from the beginning of the table up to the middle observation of the class considered, the middle observation contributing ½. The simplest method of computing the cumulative frequency corresponding to any specified class is to add the cumulative frequency assigned to the preceding class to the mean of the actual frequencies of these two classes in column (2). For the class 50–9 mb., by taking the frequencies and cumulative frequencies of preceding classes to be zero, the cumulative frequency is found to be

$$0 + \tfrac{1}{2}(0 + 1) = \tfrac{1}{2}$$

for the next class,

$$\tfrac{1}{2} + \tfrac{1}{2}(1 + 1) = 1\tfrac{1}{2}$$

and for the next,

$$1\tfrac{1}{2} + \tfrac{1}{2}(1 + 7) = 5\tfrac{1}{2}$$

and so on throughout the column.

Column (4) of Table III gives the central pressure value of each class; and column (5) gives the probability number, obtained by multiplying the cumulative frequency, column (3), by $100/N$. In this example, $N = 144$. In plotting, the figures of column (4) are the abscissae, those of column (5) the ordinates, of the plotted points. The ordinates are, of course, plotted on the probability scale in order that a normal distribution may be immediately apparent as a straight line.

WORLD GLIDING CHAMPIONSHIPS 1954

By C. E. WALLINGTON, M.Sc.

Few sports are so dependent on the weather as that of gliding and soaring, and, at the request of the British Gliding Association, a temporary meteorological office was set up at the 1954 World Gliding Championships held at Camphill, Derbyshire, from July 21 until August 4, 1954 for the purpose of providing the competition organizers and pilots with necessary information.

For the purpose of supplying the two Meteorological Office forecasters, Mr. C. E. Wallington and Mr. G. A. Marshall, with adequate basic data,

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METEOROLOGICAL SECTION AT CAMPHILL, DERBYSHIRE, FOR THE WORLD GLIDING CHAMPIONSHIPS

In the background is the briefing board with the forecast for July 27; on the right-hand side are the facsimile recorders on which data were received

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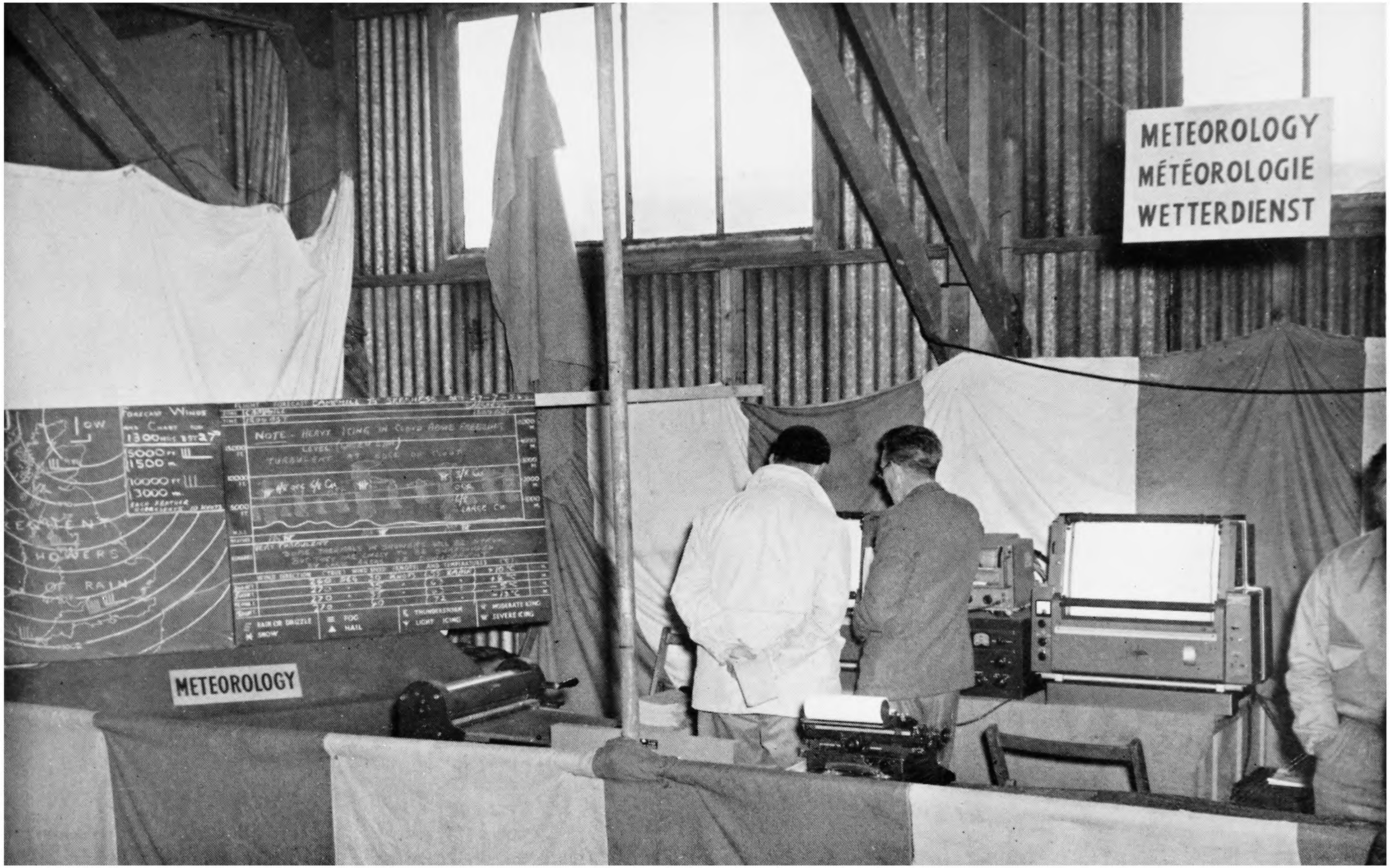
METEOROLOGICAL SECTION AT CAMPHILL, DERBYSHIRE

Mr. W. Main, of the Meteorological Communications Centre, Dunstable, is tuning in the recorder whilst Mr. J. Knight is watching a 1 : 10,000,000 synoptic chart being recorded (see p. 368).



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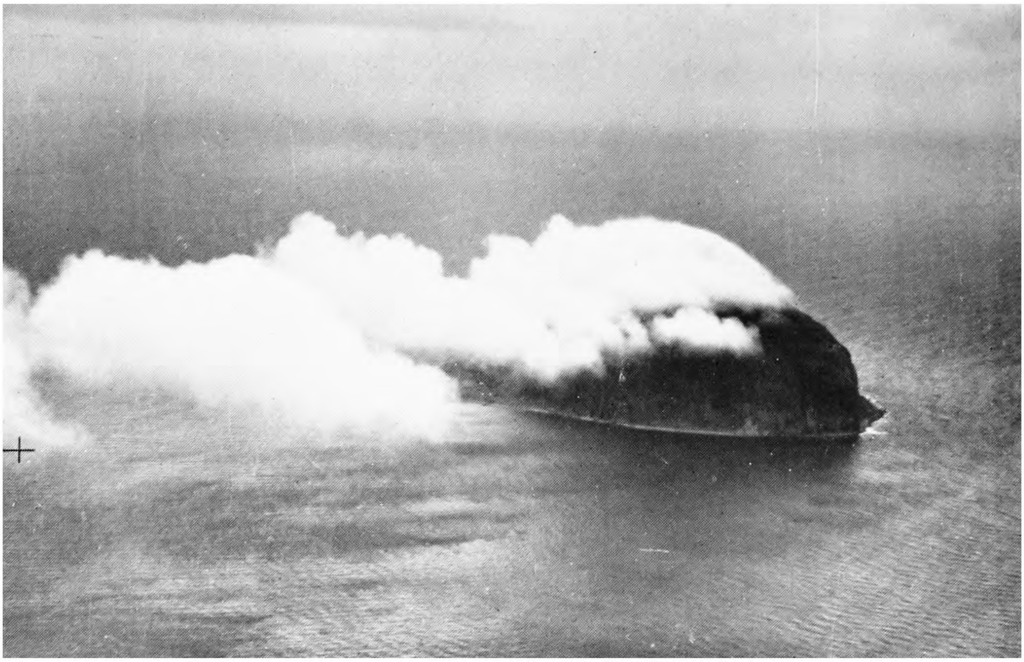
METEOROLOGICAL SECTION AT CAMPHILL, DERBYSHIRE

An official of the World Gliding Championships having the weather explained to him as the chart is received by facsimile. The international character of the contest can be seen by the three-language notice in the background (see p. 368).



Photograph by R.A.F.

0810 G.M.T.

Photograph by R.A.F.

0813 G.M.T.

OROGRAPHIC CLOUD OVER AILSA CRAIG

These photographs were taken from a height of 2,500 ft. on March 23, 1940, when a moist air stream was blowing up the Firth of Clyde. It is clear that the eddies formed in the lee of the rock are of the same dimensions as the rock itself. In these conditions, with a rather stable lapse rate (as was shown by the morning ascent at Aldergrove), the air fails to circumnavigate an obstacle of the comparatively small horizontal dimensions of Ailsa Craig, but ascends over its summit (1,114 ft.).

recording equipment was installed to receive facsimile charts radioed from Dunstable. Initially, radio reception was frequently subject to interference from cars, tractors and other sources and the charts suffered some mutilation. This difficulty was overcome, however, with the co-operation of British Petroleum and Shell Services Ltd. in the supply of a quantity of suppressors and the individual efforts of Messrs. J. Knight and W. Main of the Meteorological Communications Centre, Dunstable, who, in the course of the meeting, fitted no less than 69 suppressors to the offending vehicles and equipment.

Far from being a mere substitute for the usual supply of teleprinter data this facsimile service with its prompt and copious supply of charts and tephigrams was practically indispensable in the circumstances. The plotting of charts on the spot would have been at least unpleasant in the damp and often cold atmosphere, but the hourly British Isles facsimile charts were usually available about 70 min. after the time of observations. Furthermore, the fortnight's excessive rainfall would almost certainly have rendered teleprinter landlines unserviceable, as were the telephone lines on many occasions.

Information on local upper air conditions was provided by a Spitfire THUM aircraft which, from its base at Woodvale, made an ascent at 0830 G.M.T. whenever possible over Camphill, instead of over Worcester, its normal position for ascent.

There was, therefore, an ample supply of meteorological raw material on which to base the short-range, but extremely detailed, forecasts required by championships organizers and pilots.

Dissemination of meteorological advice to the 43 competing pilots usually began with a general briefing at which a broad outline of the appropriate forecast would be presented with the help of English, French, Spanish and German speaking interpreters to the 19 teams of different nationalities. Immediately after that each pilot would discuss the details personally with the forecasters, occasional language difficulties being simplified by the use of blackboard sketches to show the synoptic situation and a pictorial version of the forecast (see photograph facing p. 368). Nine of the visiting teams brought their own meteorologists with them to act as tactical advisers.

Assessment of up-currents associated with convection cloud and local topography forms the principal element of a soaring forecast but such up-currents seldom exceeded 10 ft./sec. throughout the fortnight's meeting, and even these weak currents could not be fully exploited in the Camphill locality. All too often the site, situated at 1,300 ft. above sea level midway between Sheffield and Buxton, was befogged with orographic cloud in the persistently moist westerly air streams while the longed-for cumulus developed only a few miles away to the east. When, at last, vigorous-looking instability cloud did appear overhead it was accompanied by a gale-force wind blowing up and over the steep 450-ft. escarpment forming the long western boundary of the 1,400 yd. × 400 yd. flying field; for a whole day, although it might have been just possible for sailplanes to take off, the pronounced eddying of the surface wind would have made landing at Camphill extremely dangerous.

No records were broken and no spectacular results were achieved. But before a gliding championship can be declared valid a certain minimum amount and type of flying must be performed, and the fact that this was accomplished in such difficult conditions is a tribute to the high standard of sailplane flying today. In the circumstances some flights could be considered remarkable, especially those by Philip Wills of Great Britain in his single-seat Sky sailplane and the Yugoslav, Zvonimir Rain, with his radio operator in the two seat Kosava aircraft. Flying over the top of almost unbroken cloud, both of these pilots used a series of standing waves to out-distance their competitors. Wills landed near Cranwell while the Yugoslavs flew on to Marham, 106 miles from Camphill. But for many pilots who vainly struggled until dusk to reach these elusive waves it was yet another disappointing day. Fortunately the depressing effect of the weather was admirably off-set by the excellent social spirit which pervaded Camphill throughout the championships.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

Handbook of weather messages. 2nd edition. Parts II and III.

Changes which have been agreed internationally are being made in most of the surface and upper air codes to be used in synoptic reports and aeronautical forecasts with effect from January 1, 1955. These are the first major changes of this nature to be made for six years. Some modifications in weather recording and the preparation of synoptic charts will be introduced on the same date. The revised "Handbook of weather messages" constitutes a complete guide to internationally and regionally approved practices on these matters. A feature of the new edition is that pages are in loose-leaf form to facilitate the entry of amendments which are issued periodically.

Part II contains the codes and specifications used in the compilation of surface reports, upper air reports, reports from aircraft, forecast codes and upper air analyses. The book contains 28 forms of coded messages, 121 code specifications and more than 225 different combinations of letters to describe the various elements dealt with in the codes. Part III gives detailed information concerning the entry of the readings into the registers, coding the information for transmission, decoding messages received from other sources and finally plotting the information on synoptic charts.

A new edition of Part I containing particulars of meteorological reports, forecasts, warnings etc. issued by radio in the United Kingdom and from certain centres overseas is in course of preparation.

Instructions for the preparation of weather maps.

The symbols used for plotting weather maps have been necessarily changed as a result of the new synoptic codes which are being introduced, with international agreement, on January 1, 1955. The full codes and specifications relating to surface observations from land stations and ships are reproduced in an appendix to this booklet.

Amateur meteorologists, who receive the GFA morse broadcasts from Dunstable and plot their own weather charts, no less than aircraft pilots and navigators who are required to read weather charts plotted in the conventional symbols as part of their professional qualifications, will find the information contained in this new edition of "Instructions for the preparation of weather maps" essential.

A copy of this new edition will be supplied as part of the present edition of "Meteorology for aviators".

INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

General Assembly, Rome, 1954

The International Union of Geodesy and Geophysics (U.G.G.I.) holds a general assembly once every three years, the meeting place changing from one assembly to the next. The tenth assembly was held at Rome from September 14 to 25, 1954, by invitation of the Italian National Committee. The meetings of the assembly itself were preceded by a conference on atmospheric radiation organized by the Radiation Commission of the Association of Meteorology and by a symposium on ozone organized by the Ozone Commission.

Some 900 delegates from more than 40 countries attended the meetings which were held in one of the buildings of the "Exposition Universelle de Rome", known locally as E.U.R. The erection of a group of large buildings on this extensive site outside Rome was commenced before the war for an exhibition which, but for the war, would have been held in 1942. Some of the buildings have not yet been completed, but the "Palais des Congres" provided an admirable meeting place for the Assembly of U.G.G.I. A large number of lecture rooms of various sizes were available and an exhibition of geodetic and geophysical equipment was staged in two large halls within the building. This exhibition continued throughout the assembly and manufacturers and organizations from all over Europe were represented.

The International Union of Geodesy and Geophysics comprises seven distinct associations each concerned with one aspect of the physics of the earth, the oceans or the atmosphere. These are:—

International Association of Geodesy
International Association of Seismology and Physics of the Interior of the Earth
International Association of Meteorology
International Association of Magnetism and Atmospheric Electricity
International Association of Oceanography
International Association of Volcanology
International Association of Hydrology.

During the course of the assembly it was decided that electrical phenomena of the atmosphere below the ionosphere fall within the domain of the International Association of Meteorology and a consequent change of title of the International Association of Magnetism and Atmospheric Electricity was agreed.

The formal opening meeting took place on the morning of September 14 when the delegates were welcomed on behalf of the Italian Government and addressed by Prof. Sydney Chapman, president of U.G.G.I. over the past three years.

Most of the time of the assembly was taken up by meetings of the separate associations at which scientific papers were presented and discussed, and at which the progress in particular fields of geophysics was reviewed. The individual associations met concurrently, and, indeed, the number of papers presented was such that within one association more than one meeting might be in progress at one time.

Scientific meetings of the Association of Meteorology opened on September 15 with the presidential address by Prof. K. R. Ramanathan on "Atmospheric ozone and the general circulation of the atmosphere". The meetings which followed covered a wide range of subjects: synoptic meteorology, cloud physics, climatology, ozone, dynamical meteorology, the upper atmosphere, radiation and instruments. In all more than 70 scientific papers were presented to the Association of Meteorology alone, and it is impossible to review them individually.

Perhaps the two symposia which showed the most coherent and systematic progress in meteorological research were those devoted to meridional large-scale phenomena and to numerical methods in dynamic and synoptic meteorology. From the former meeting one gained the impression that from painstaking work, particularly in America and Australia, a consistent statistical picture of the general circulation is being built up, not only in terms of the mean values of wind, temperature, etc., but also in terms of the statistical properties of its large-scale eddies and the heat and momentum transport which results from them. Although the authorities differ in the details of their interpretation a reasonably coherent picture is beginning to emerge.

The colloquium on numerical methods ranged widely over the use of numerical techniques in meteorology from predicting the motion of depressions to predicting the dispersal of smoke, but main interest centred on the problems of predicting the changes in the synoptic chart. Very similar degrees of success are being achieved by experimenters in America, Sweden, Germany and the United Kingdom. Interest was stimulated by the results reported from Sweden in which a barotropic model had been used to compute a forecast chart for 72 hr. ahead, and had achieved a correlation between observed and predicted change of more than $+0\cdot7$. R. Fjörtoft claimed similar success in calculations by graphical techniques over 72-hr. periods.

A symposium of storm surges held jointly between the Associations of Meteorology and Oceanography was also of considerable interest to the meteorologist, and showed the systematic research effort which is being expended on this problem.

A discussion of some interest was held regarding proposals by Dr. T. E. W. Schumann of South Africa for a planned programme of international meteorological research. Although there was considerable agreement as to the way that meteorological research should be encouraged to go, it was agreed that no formal international planning of the lines of research was needed or desirable. However, a motion proposed by Prof. Rossby calling attention to the significance and interest of the mineral constituents of rain-water was adopted.

The formal closing session of U.G.G.I. took place on Saturday September 25. It was then announced that the President for the coming three years will be Prof. K. R. Ramanathan of India. The next assembly will be held by invitation in Argentina. The President of the Association of Meteorology for the next three years will be Prof. C.-G. Rossby, Sweden, and the Secretary Dr. R. C. Sutcliffe, United Kingdom. Following the assembly, meetings continued in Rome for the planning of the scientific work of the International Geophysical Year which is to be held in 1957–58.

The success of such large assemblies as the three-yearly meetings of U.G.G.I. is not to be measured only by the papers which are read and the formal discussions which take place. Probably more important are the informal contacts which take place outside the conference rooms. Scientists from different countries get to know one another as individuals, they exchange plans and little bits of specialist information and experience which are unlikely ever to be published.

Such friendly contacts and meetings were greatly facilitated at Rome by the arrangements made by the Italian Organization Committee for the entertainment of the delegates and their families. Delegates were received at the Capitol on September 22, and on September 24 they were granted an audience by the Pope who addressed them for 16 min. in French. On these and on the less formal excursions a very friendly spirit existed among the delegates, and those who attended are greatly indebted to their Italian hosts for these opportunities to get together with workers in similar fields from other lands.

J. S. SAWYER

BRITISH ASSOCIATION

Oxford meeting 1954—Symposium on weather forecasting*

The discussion on weather forecasting arranged by Section A (Mathematics and Physics), as might be expected after a disastrous summer with weather more than usually a matter of public concern, drew a large gathering to the Sheldonian Theatre on September 6. The chair was taken by Prof. E. H. Neville and later by Sir Harold Spencer Jones who introduced the guest speaker from Sweden, Prof. C.-G. Rossby, now Director of the Meteorological Institute of the University of Stockholm but equally renowned for his work in the United States, having held chairs in both Chicago and the Massachusetts Institute of Technology.

In opening the discussion with a paper on weather forecasting as a problem in physics, Dr. R. C. Sutcliffe first remarked that weather forecasting was something more than the science on which it rested, it was a scientific profession with some hundreds of practitioners issuing some thousands of forecasts daily for a wide variety of purposes. In a short paper it would be possible only to indicate the general nature of the scientific problems, but in weather forecasting where it was impossible for every interested member of the public to be given personal advice on his own particular problem it was particularly important that the client should have some understanding of the subject.

The problems of weather forecasting might be regarded as falling within the scope of hydrodynamics, but the methods which had been successful in other fields had so far contributed relatively little to the practical problems of weather prediction as they arise from day to day. This was because the problems were extremely complex being concerned with non-steady and turbulent motions in the compressible fluid of a heat engine working against friction. The system was not even closed and the composition of the fluid was continuously changing by evaporation, condensation and precipitation. Meteorology had therefore to be studied as a science in its own right and predictions about the atmosphere must depend on its observed structure and behaviour.

Dr. Sutcliffe was mainly concerned to emphasize the different scales of atmospheric systems. On any one day the circulation of the atmosphere differed widely from the long-term climatological mean, and examples from surface and upper air weather maps of the northern hemisphere were used to show how depressions and anticyclones frequently formed over periods of one or two days. These systems were well understood scientifically and, as Prof. Rossby would show, could be predicted by hydrodynamical theory but they were essentially a form of large-scale turbulence and after a period of one or two days predictions became very uncertain.

Variability was present on many smaller scales—frontal systems, vertical convective systems through to variations on the scale of kilometres and metres. Much of this variability was beyond the reach of regular observations and could only be treated in statistical terms.

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Weather forecasting could be regarded as based on five considerations:—

(i) The change in the large-scale synoptic situation. This could give for one or two days ahead the broad character of the weather and wind.

(ii) The effects of fronts—allowing fairly accurate timing of rain areas and major changes of wind, temperature, etc. for periods of some 12 hr. ahead.

(iii) The convective properties of the air masses—permitting statistical-probability statements on showers, thunderstorms, convective cloud, visibility, etc.

(iv) Diurnal changes—these were major considerations for temperature, humidity, convective phenomena and visibility.

(v) Topographical effects—these introduce many local differences in weather.

Although formally these aspects may be considered separately they are not independent.

Owing to the rapidity with which changes take place and to the element of dynamical instability which enters into the developments, there seemed no present prospect of eliminating uncertainty from weather forecasts. Dr. Sutcliffe was optimistic about dynamical meteorology which had made great progress in very recent years but he was not optimistic about persuading the atmosphere to behave in a more orderly way.

Mr. V. R. Coles spoke of the work of a practising forecaster. He depended in the first place on obtaining adequate observations and the absence of reporting ships in some areas, for example south of Greenland and even in the Bay of Biscay, was often a serious handicap. The stationary ocean weather ships in the Atlantic were a great boon. The erratic behaviour of depressions was illustrated by examples where extrapolation would give a good prediction and others where it failed completely. In recent years much attention had been given to upper air conditions and relationships between the consideration of the upper thickness or thermal patterns and the development and movement of surface depressions were established. Mr. Coles illustrated the success of this method with an example of the rapid formation of a new anticyclone which had been very satisfactorily predicted. The methods of extrapolation, the use of tendencies and the indications from the upper air were not always consistent and Mr. Coles thought that if much greater accuracy in forecasting was to come it would probably be by the use of objective methods of calculation using electronic methods.

The first two speakers had been mainly concerned with forecasts for some 24 hr. ahead made familiar to the public by press and broadcasting and it fell to Dr. J. M. Stagg to consider the possibilities of prediction for longer periods. Experience had shown that attempts to extend the forecasts to a few days ahead by the methods discussed by earlier speakers met with little success; the accuracy falls away very quickly after the first 30–36 hr. But nevertheless it was a commonplace observation that weather has a "moodiness" and generally bright or dull or rainy weather may persist for long periods. Meteorologists have therefore looked for something in the atmosphere more enduring than the simple depressions and anticyclones.

Dr. Stagg referred first to certain purely empirical methods to which much attention had been given. The field of surface pressure had been elaborately analysed for periodicities and correlated with measures of geomagnetic and solar activity, and although much had been learned about the modes of oscillation of our atmosphere little of prediction value had resulted. A phenomenon referred to as symmetry in the pressure-time curve had been discovered in Germany; variations of pressure were shown to repeat in reverse order after a point in time known as a "symmetry point". But tests made in England were no more successful than others based on extrapolations of pressure trends; by the time a trend had become established it was already on the way to another rhythm or pattern. Methods of correlation, although they had had some success in India for monsoon prediction, generally failed in a similar way. It was not surprising if the atmospheric machine produced good relationships for a time in a particular area as these would reflect the mode of circulation during the period, but if the mode changed so would the correlations and their prediction value might well be slight.

Dr. Stagg saw more of scientific interest in the dynamical-synoptic studies using mean weather charts for periods of days. In the United States the Weather Bureau had introduced forecasts for five days and more recently for 30 days ahead on the basis of continuity in the evolution of mean upper air charts over these periods. The methods had apparently had a measure of success but were still mainly empirical, depending largely on the extrapolation of trends which may suddenly change for no known reason.

In Russia most attention had been given to the movements of anticyclones as the more enduring features of the synoptic patterns, and Dr. Stagg thought it was no coincidence that it was in the great continental areas that long-range forecasting was established. Over the British Isles we were next door to one of the world's worst cockpits of weather disturbances and even a slight error in predicting the mean tracks of depressions could make a forecast completely wrong for the whole country. Dr. Stagg stressed the need for physical understanding of the processes and referred to research going on in the Meteorological Office, but he had in mind a remark made by Sir Gilbert Walker, speaking to the Association 21 years ago: "Though the prestige of a meteorological service may be raised for a year or two by the issue of longer-range forecasts, the harm done to the science will inevitably outweigh the good if the prophecies are found unreliable".

Prof. Rossby introduced the subject of "numerical weather forecasting" by referring again to the broad spectrum of frequencies in atmospheric disturbances which had been the theme of Dr. Sutcliffe's paper. "Weather", in the sense of clouds and rainfall, was produced mainly by the smaller-scale disturbances which had relatively large vertical components of motion. The largest-scale motions, with dimensions of some 5,000 Km., were necessarily quasi-horizontal and it was these motions which had now been shown to be amenable to direct calculation with useful accuracy. The calculations will not produce a detailed weather forecast but they may still prove to be of much assistance to the forecaster by keeping him on the correct broad lines over periods of one or two days.

The conception of forecasting by calculation on the basis of the physical equations originated in England with L. F. Richardson some 30 years ago but the ideas were at that time quite premature as there was no practicable way of carrying out the heavy computations. It was not until 1947 that the subject was taken up seriously at the Institute of Advanced Studies in Princeton, and since then there had been rapid progress on a research basis not only in America but also in England where the work of Sawyer and Bushby was outstanding. In Sweden, with its present limited facilities for electronic computing, Dr. Rossby had confined attention to the simplest model of large-scale atmospheric behaviour but expected to be in a position to introduce more elaborate and realistic calculations in the near future. The basic idea was put very simply. It had been shown that the vorticity (about the vertical axis) of the mean motion of the atmosphere was nearly a conservative property. It could therefore be advected with the mean motion. But by integration, with known boundary conditions, the motion itself could be calculated from the vorticity field so that, using a step-by-step method, it was possible to begin with the present known motion, determine the new field of vorticity for say one hour ahead by advection, compute the new field of motion by integration and so continue indefinitely until such time as accumulated errors rendered the calculations worthless. Mathematical refinements had improved on this simple scheme but the principle remained the same.

Prof. Rossby remarked that "a weather forecast was a rather perishable commodity which must be marketed quickly". Only electronic methods could reduce the time of calculation to anything reasonable as even in his present simple model 10^7 operations were needed to produce a 24-hr. prediction. But it now seemed that the time spent in calculation would not be the most serious item. Much more time was spent in making, transmitting and collecting the observations from the large area involved (some 6 hr.) and in plotting and analysing the charts (some 3 hr.). Attention would need to be given to these factors and already objective analysis and diagrammatic recording were being studied.

To show once more that the computations could deal only with the broad synoptic situation and not with the details of weather, Prof. Rossby showed a diagram illustrating the distortion which may take place in a layer of fluid over a period of a day or two. Beginning as a chequered square of some 500-Km, side, the "fluid element" altered shape by hydrodynamical "deformation" as though it were a handkerchief flourished in the magician's hand, with all pattern becoming confused in the folds. To analyse such motion in the practical case would require the number of observations to be increased by one or two orders of magnitude.

It was regrettable that time did not permit of general discussion after the papers but perhaps the mistake had been in making the subject so broad. Weather forecasting is concerned to some extent with almost the whole science of meteorology and any one of the four papers could have provided the basis for a profitable morning's symposium.

INTERNATIONAL SYMPOSIUM ON EXPERIMENTAL METEOROLOGY

Zurich, October 4–6, 1954

The Swiss Federal Commission for the Study of Hail Formation and Prevention organized an International Symposium on Experimental Meteorology which took place under the presidency of Prof. Dr. R. Sanger at the Swiss Federal Institute of Technology in Zurich during October 4–6, 1954. The symposium, which was arranged with characteristic Swiss hospitality, included visits to Swiss research stations and was attended by representatives of many different countries. Lectures were given by delegates from Switzerland, France, Italy, Germany, Sweden, Japan, the United States, and the United Kingdom. Other sessions were devoted to open discussions of cloud physics and weather modification problems. It is possible in this note to give only a brief summary mentioning some of the striking new facts and experimental methods described in the subsequent lectures. It is planned however to publish in the near future all the papers presented in a special issue of the *Archiv fur Meteorologie, Geophysik und Bioklimatologie.*

Following the address of welcome by the President, who described the attempts being made in Switzerland to prevent hail and their great economic importance, the scope of the symposium was reviewed in opening speeches by H. Dessens of the Observatoire du Puy-de-Dôme, Clermont-Ferrand and B. J. Mason of the Imperial College of Science, London. The latter presented a broad survey of our present knowledge of natural-precipitation processes including the action of both the Bergeron and the coalescence mechanisms, while the former considered various theories concerning artificial nucleation of clouds. It was evident at this stage that, although our understanding of natural rainfall processes has increased considerably in the last few years, much more information is required before we can hope to be in a position to modify the weather in a scientific manner. There are many problems to be solved in the laboratory and also in the field concerning, for example, the conditions which produce inactivation of silver iodide as a freezing nucleus, the regions in which there is a scarcity of natural freezing nuclei in the free atmosphere, whether over-seeding is possible, the respective importance and rates of action of the Bergeron and coalescence processes in different clouds, the importance of splintering in crystallization processes and chain reactions in coalescence processes, to mention only a few.

The papers on laboratory work included Dr. W. Rau's investigations of the spectrum of freezing nuclei in which it was found that they have three maxima around −4°C., −11°C. and −19°C., respectively. The first maximum is most marked in polar air masses which suggests that the earliest acting nuclei have a maritime origin. Dr. Rau has also repeated his previous experiments in which he supercooled water droplets to about −70°C., below which cubic ice crystal modifications were observed. Both the observation of this high degree of supercooling and that of freezing nuclei at temperatures near freezing point provide new data and aroused considerable discussion. Another interesting paper in this section was that by G. Soulage who described the detailed characteristics and shapes of some natural freezing nuclei he had isolated, while L. Facy described how the process of vapour transfer during evaporation or condensation of droplets can be observed directly, and gave details of the mechanical operation of these processes. Dr. O. Vittori then described new chromographic techniques for the detection of the chemical nature of aerosols. These are based on the microscopic observation of Liesegang rings formed by precipitates when salts dissolved in gelatine react with the aerosol. This technique is already being applied successfully to identification of aerosols sampled on the ground and in flight.

American flight observations for cloud physics researches were described by Dr. H. R. Byers. He showed how cumulus in semitropical maritime areas differs from that in continental temperate latitudes. The former is characterized by slow up-draught speeds and rain when the cloud does not extend to the freezing level, while the latter has vigorous up-draughts and requires a considerable depth before precipitation can commence.

New measurements of large salt nuclei concentrations and their relations to air trajectories at various heights over the United States were presented, and evidence given that the coalescence mechanism is also important in temperate regions. This finding was supported by R. J. Murgatroyd who described cloud-physics investigations made over England by the Meteorological Research Flight and gave details of the instrumental techniques at present in use. Dr. E. M. Fournier d'Albe describing measurements of large salt nuclei over Pakistan and the variation in their concentration with distance from the sea also emphasized the importance of the coalescence mechanism in all clouds of base temperature more than 10°C. (which includes most of the British Isles and Europe in summer). It appears that in Pakistan the nuclei concentration well inland is not sufficient to account for the rainfall observed, and that multiple fragmentation with a chain reaction must be an important factor in producing heavy rainfall there. Considerable information on the question of nuclei distribution in relation to its sources was also given in a paper by Prof. C.-G. Rossby who presented charts of the distribution of elements brought down by rainfall in Sweden. Sodium, potassium and the chlorides for instance are found to have their greatest concentration near the sea, ammonium near agricultural regions, calcium rather a constant distribution, etc. Other papers in this section included a contribution by Dr. M. Bossolasco on the relation of temperature to solid precipitation (values of −4°C., −11°C., and −19°C. being significant, in agreement with the laboratory studies of freezing-nuclei spectra quoted above).

Although the symposium was very successful in producing an up-to-date resumé of the work being carried out in various countries and an exchange of ideas and information between the workers involved it did not result in any new ideas in the problem of hail prevention, which is of considerable importance in Switzerland. It is to be expected however that the new work now being started there, which includes field experiments and also the construction of a wind tunnel to investigate hail formation, will result in important progress in this problem, and all meteorologists will join in wishing our Swiss colleagues every success in their new ventures.

R. J. MURGATROYD

LETTER TO THE EDITOR

Definition of dry and wet periods

The present definitions of droughts, wet spells, and rain spells may serve certain statistical ends but from most points of view they seem quite inadequate. Using Alston, Cumberland, as an illustration it is unsatisfactory that a place with almost 50 in. of rain a year cannot claim to have had a wet spell since January 1948, and, in fact, only 7 wet spells within the 26 yr. of observations. This may satisfy official tastes but it is not a representative picture of conditions as they exist.

Examination of the records shows clearly the gaps which have been left because of the insufficient number of categories into which to place certain periods of dry and wet weather. For example, the exceptionally wet November and December of 1951 which gave the greatest aggregate for two consecutive months for the entire 26 yr. (i.e. slightly over 20 in.) gave neither a wet nor a rain spell; 47 days received 0·01 in. or more of rain, 41 had 0·04 in. or more, and 6 had over 1 in. of rain. Between November 1 and November 21 there were 20 rain-days and 19 wet-days but "trace" appeared against the 13th so that officially the period must be regarded as normal. Surely precipitation of this order deserves some special mark of distinction.

This kind of event might be claimed to be analogous to a record of 0·99 in. in the rain-gauge which is so very near to 1 in. that there is a sense of disappointment when it must be ignored as a very wet day. However the case is not comparable because the fraction 0·01 in. required to change 0·99 in. into 1 in. is so very much smaller than that required to make 14 days of wet weather into the 15 necessary to make a wet spell.

From the statistical point of view definitions must be fixed and adhered to, but the present system seems over-simplified. The term "partial drought" (29 days with a mean daily rainfall not exceeding 0·01 in.) is helpful for dry periods and a "partial wet spell" could be used following the same pattern, such as 29 days with a mean daily rainfall of 0·30 in. or more.

This would give six categories: absolute drought, partial drought, dry spell, rain spell, partial wet spell, and wet spell. However these six are still inadequate, since the severity of the wet-spell criteria is such that many stations are excluded from ever attaining it, whilst the suggested "partial wet spell" also will not be easily achieved. On the other hand the difficulty of attaining either an absolute or a partial drought at wet stations calls for another dry-weather category. Two more varieties would greatly assist observers to analyse their records on standard lines. A period of 29 days with a mean daily rainfall of 0·04 in. or less might be adopted and called a "partial dry spell" and also one of 29 days with a daily mean of 0·20 in. or more which could be called a "partial rain spell".

This gives the completed list of categories as follows:—

Dry periods

*Absolute drought—at least 15 consecutive days each with less than 0·01 in. per day
*Partial drought—at least 29 consecutive days with a daily mean of 0·01 in. or less
Partial dry spell—at least 29 consecutive days with a daily mean of 0·04 in. or less
*Dry spell—at least 15 consecutive days each with less than 0·04 in. per day.

Wet periods

*Rain spell—at least 15 consecutive days with 0·01 in. or more per day
Partial rain spell—at least 29 consecutive days with a daily mean of 0·20 in. or more
Partial wet spell—at least 29 consecutive days with a daily mean of 0·30 in. or more
*Wet spell—at least 15 consecutive days each with 0·04 in. or more per day.

*Already adopted.

Such a classification, whilst slightly more complex than that in use, does find room for those annoying days of slight rain which cause dry periods to be registered as normal, or for the single day of "trace" which leaves events like the rains of November and December 1951 with no special significance in the examination of climatic history.

W. E. RICHARDSON

The Grove, Alston, Cumberland, October 23, 1954

NOTES AND NEWS

Hail from clear sky

Flying Officer R. H. Fortescue of Royal Air Force Station, North Weald, noticed the following phenomenon whilst flying at 0935 G.M.T. on Sunday September 5, 1954, about 22 miles from North Weald on a true bearing of 50°.

The aircraft was flying above 3 oktas cumulus with tops at about 6,000 ft. and 5 oktas altocumulus, base 12,000 ft. and tops about 15,000 ft. The east coast could be seen before entering an 8 oktas layer of cirrus. The pilot did not see any cumulonimbus cloud. On climbing through thick, almost solid, cirrus base 21,000 ft. tops 31,000 ft. there was generally moderate and occasionally heavy turbulence. According to the pilot conditions similar to those found in flying through cumulus cloud were experienced. There was no cloud above the cirrus.

At 32,000 ft., in clear air and sunshine, average-sized hailstones were encountered; these were quite easily visible and very numerous. The noise of the impact of the hailstones could clearly be heard. It was also very turbulent. The pilot described the conditions as being very like those found when flying through a normal (low-level) hailstorm associated with cumulonimbus. The aircraft continued on track, still climbing, and the hail ceased on reaching 34,000 ft. about 15 miles further on. The pilot believes that he left the edge of the hailstone belt rather than climbed above it. On account of the nature of the exercise on which the aircraft was engaged it was impossible to ascertain the extent of the hailstone belt.

No condensation trails were formed by the aircraft and no icing or hailstones were observed in the cirrus cloud.

The indicated speed of the aircraft was 240 kt.; the aircraft was not fitted with a thermometer so no temperatures are available. There was no structural damage to the aircraft although it is possible that some of the paint was removed by the hailstones.

On the 0900 G.M.T. chart there was a shallow depression over north-east France and a shallow anticyclone covering East Anglia. Both were almost stationary. At levels above 500 mb. there was a shallow trough of axis orientated from north-north-east to south-south-west which was over central England at 0300 and moved eastwards to the North Sea during the day.

Slight rain was reported by stations on the east coast from Dungeness to Yarmouth. The only station in south-east England reporting cumulonimbus cloud at 0900 was Yarmouth and then only 2 oktas at 1,200 ft. Most stations were reporting approximately 7 oktas altocumulus and altostratus at about 10,000 ft.

The 0200 G.M.T. radio-sonde ascent from Crawley confirms the existence of cumulus tops at about 6,000 ft. and a layer of altocumulus between 600 and 500 mb. The ascent above 400 mb. appears to be potentially unstable and rather moist.

P. R. CRISPIN

[F. Rossman* describes a fall of large hailstones on May 27, 1931, at Feldberg Observatory, Black Forest, with a large cumulonimbus nearby but with partially blue sky overhead. H. Wichmann† explains the phenomenon as hail shot out of an inclined updraft in a cumulonimbus cloud.—Ed., M.M.]

REVIEWS

Indian Ocean oceanographic and meteorological data, 2nd edn, 12¼ in. × 8¾ in., pp. 31 + 24 charts, 31¾ in. × 27½ in. Koninklijk Nederlands Meteorologisch Instituut, De Bilt, 1952. Price: Text *fl.* 1.50, each chart *fl.* 2.50.

There are two schools of thought on the best way to publish charts of marine meteorological data. The charts are used mainly on the one hand by meteorologists and other scientists and on the other by mariners. Whereas the former users generally prefer to have their data on many separate charts for each month bound together in the form of an atlas, many mariners prefer to have all the data for one month on a single sheet. The ideal way of meeting these two requirements is to publish both, but this involves considerable extra expense and the Dutch Meteorological Institute have chosen a compromise. They have published their meteorological and surface ocean current data for the Indian Ocean on two separate sheets A and B for each month, together with a text in booklet form.

There are many representations of data on each of the main charts, but the use of several different colours has helped in their clarity. The omission of certain information has been necessary and none is given on swell, lightning or difference between air and sea temperatures.

The text explains how the statistics shown on the charts have been derived and also contains a detailed account of the occurrence of tropical cyclones in the Indian Ocean.

On sheet A for each month the following information is given on a main chart:—

(*a*) Surface ocean current roses for specified areas shown on the chart

(*b*) Direction and velocity of the mean vector currents for two-degree squares, together with the constancy of the current

(*c*) Isotherms of mean air temperature

(*d*) Isotherms of mean sea temperature.

On one smaller side chart on sheet A are shown the surface current circulation, based on the computed predominant currents, and the standard deviation of sea-surface-temperature observations, while on another are shown the mean

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* ROSSMANN, F.; Ein bemerkenswerter Hagelfall: Sehr grosse, vereinzelt fallende Hagelsteine. *Met. Z., Braunschweig*, 57, 1940, p. 43.

† WICHMANN, H.; Über das Vorkommen und Verhalten des Hagels in Gewitterwolken. *Ann. Met., Hamburg*, 4 Jahrg., 1951, p. 218.

cloud amount, the percentage of fog duration, the percentage duration of precipitation and the standard deviation of air-temperature observations.

On chart B the following information is given:—

(*a*) Wind roses for five-degree squares

(*b*) Direction and velocity of the mean vector winds for two-degree squares together with the constancy of the wind

(*c*) Mean isobars

(*d*) Percentage frequency of gales (Beaufort force 8 or more)

(*e*) Number of tropical cyclones observed in each five-degree square.

On the side charts of sheet B are shown the tracks of tropical cyclones and the years in which they were observed.

The printing of these charts is really excellent, and the Dutch, while they have been limited in the amount of information that could be shown on the two sheets, have succeeded in including the most important data. The charts will be a most useful reference work on the meteorology and ocean currents of the Indian Ocean.

P. R. BROWN

An introduction to climate, 3rd edn. By G. T. Trewartha. McGraw-Hill Series in Geography, 10 in. × 7½ in., pp. vii + 402, *Illus.*, McGraw-Hill, London. 1954. Price $7.00 or 50*s*.

This third edition of a book which is meant chiefly for geographers has been extensively revised to give more of a dynamical approach to the subject of climatology. The book is in two parts.

In Part I the author gives a very brief introduction, listing the climatic controls: (*a*) sun or latitude, (*b*) land and water, (*c*) semipermanent low-pressure and high-pressure cells, (*d*) wind and air masses, (*e*) altitude, (*f*) mountain barriers, (*g*) ocean currents, (*h*) storms; which, acting upon the climatic elements temperature, precipitation and humidity, air pressure and winds, produce types and varieties of weather and climate. Then follow chapters on each of the elements, air temperature, pressure and winds, moisture and precipitation, air masses and fronts, atmospheric disturbances and associated weather types, in that order. But each section, although admirable for the completeness of the description of the element, fails to emphasize the essential unity of all the chapters. What is needed is an expansion of the brief introduction into a chapter which shows the production of weather on a seasonal basis; the interrelation of temperature over land and sea with air-mass source regions and frontal zones; pressure and wind and transport of and modification of air masses, with a general account of consequent changes in associated weather. This chapter would necessarily be rather generalized, and some repetition would occur later, but it would give a most helpful background for the understanding of the following chapters. The reader would not then have to digest (in Chapter 2) a discussion on the jet stream and upper air waves before reading something about air masses and fronts.

Chapter 1 gives an account of solar energy and the heating and cooling of the earth's surface and atmosphere, and the temporal and geographical distribution of temperature, with sections on the mean duration of certain temperatures. I would have liked to have seen some discussion of within-month variations of temperature, with perhaps world maps for January and July of the average highest and lowest temperatures recorded in those months.

Chapter 2 describes the distribution of pressure and wind at the surface and 700 mb.; modifications of the surface winds and climate produced by terrestrial and oceanic influences; and in a section on the general circulation the author describes the westerly jet stream and its relation to weather cycles. The mean westerly jet stream of the northern-hemisphere winter is rather stronger over Japan (150–160 kt.) and north-east Africa and Arabia (100–120 kt.) than shown by the author; and although his notion of a westerly jet stream completely girdling the earth is probably true for the southern hemisphere (with winter speeds of 80–120 kt.) this is not true of the winter northern hemisphere jet stream, which shows very marked variations in speed and direction over the eastern Atlantic and eastern Pacific, with resultant vector means of only about 50 kt.

Mention should have been made of the strong easterly jet stream of the northern-hemisphere summer, associated with the furthest northerly progress of the intertropical front over the Asian and African continents. The mean jet-stream speed is 70–80 kt. at 100 mb. Over the Atlantic and Pacific Oceans the intertropical front is weak and there is no mean easterly jet stream. In fact over the Hawaiian Islands there is at 200 mb. a mean westerly wind of 30 kt., and at times westerly winds of over 100 kt. are recorded.

Chapter 3 gives an account of humidity and fog, formation of clouds, and the origin and forms of precipitation. Chapter 4 describes the origin and classification of air masses and fronts over the world, with further illustrative detail about air masses over North America, Asia, Europe and South America (but none for Africa or Australia).

Chapter 5, on atmospheric disturbances describes the middle-latitude cyclones and anticyclones, with illustrative detail chiefly for the North American continent; and gives an account of tropical cyclones and easterly waves. This chapter also has a long section on thunderstorms.

Part II begins by discussing various well known world classifications of climate. The author uses a modified form of the Köppen system, and gives a very clear description of his climatic groups, together with an excellent world map in colour (although it is a pity that the upland Aw subtype is not given in the legend).

The chapters that follow deal in turn with five great groups of climate: tropical rainy, dry, humid mesothermal, humid microthermal, and polar, together with their various subdivisions. Highland climates are also described.

The treatment is very systematic. For each group, a brief description of the type, location and boundaries and precipitation régime is followed by an account, for each subdivision, of the climatic elements and associated vegetation and zonal soils. Attention is paid first to properties which are common to the whole subdivision, and then variations in particular regions are mentioned.

This is a good scheme, but I feel that the upland Aw (tropical wet and dry) subtype has received inadequate attention. For the areas of Africa and South America concerned the reader is referred to the account of the Aw subdivision and the section on highland climates. In view of the size of the African area the author might have given illustrative local detail for this region.

Throughout the book there is an abundance of most useful diagrams, many of them large world maps. Data of average monthly temperature and rainfall for 167 stations are given in an appendix.

The book is an excellent work of introduction to climate, and with its emphasis on the world pattern of distribution of climate it offers to the student a very sound background for further climatological study and research.

A. F. JENKINSON

OBITUARY

Major-General the Right Hon. Sir Frederick Sykes, P.C., G.C.S.I., G.C.I.E., G.B.E., K.C.B., C.M.G.—We regret to report the death on September 30, 1954, of Sir Frederick Sykes, who was Controller-General of Civil Aviation in the Air Ministry from 1919 to 1922 and, as such, the member of the Air Council responsible for the Meteorological Office, during and for some years after, the transfer of the Office to the Air Ministry in October 1919.

He was appointed President of the Meteorological Committee, Sir Napier Shaw remaining Chairman, in October 1919. On the retirement of Sir Napier Shaw a year later, the post of President of the Committee was abolished and Sir Frederick became Chairman. He remained Chairman until he ceased to be Controller-General of Civil Aviation on the re-organization of the Department of Civil Aviation in 1922.

Sir Frederick was one of the first 100 men to obtain the Aero Club's pilot's certificate and he had a very distinguished career in the Royal Flying Corps before becoming Controller-General of Civil Aviation.

Sir George Simpson writes:—

The transfer of the status of the Meteorological Office in 1919 from that of a practically independent body under the control of a committee composed largely of scientists to a Government Department under a Ministry, and that a military Ministry, gave rise to very serious doubts, not only of the staff of the Office, but of scientists in general, especially those who took an active interest in the work of the Office. That the transfer was carried through with good feelings on the parts of both the Ministry and the Office was largely due to Sir Frederick Sykes.

Instead of finding itself ruled by uninterested soldiers and controlled by civil servants with their legendary red tape, as forecast by the critics, the Office found itself under the control of a distinguished soldier indeed, but one whose experience in the Royal Flying Corps and responsibility for the young and rapidly developing Department of Civil Aviation taught him the value of an efficient meteorological service.

Sir Frederick Sykes was deeply interested in the work of the Office; he took the Chair at all the meetings of the Meteorological Committee and was always ready to put the view of the Office before the Air Ministry and the Treasury. He started the Office on its new course and ensured those good relations between the staff of the Office and the civil servants which have been of inestimable value both to the Office and to the Ministry. As the new Director I was grateful for all the help he gave to me, and we remained good friends to the end of his life.

AWARDS

The L. G. Groves Memorial Prize for Meteorology has been awarded this year to Mr. G. A. Corby, B.Sc., Principal Scientific Officer, Meteorological Office, whose work at Northolt Airport has been such as to inspire the utmost confidence, not only in his own staff but in all connected with aircraft operation and aerodrome management. The meteorological service provided by Northolt has been of a standard probably unexcelled anywhere, and has been an important factor in the safety and regularity of short and medium haul aircraft operations. He has also played a leading part in developing the meteorological aspects of the variable fuel method of operations. Mr. Corby has devoted much time to the study of air flow over mountains and has recently produced a critical summary of the state of our current knowledge on this problem.

The L. G. Groves Memorial Award for Meteorological Air Observers has been awarded to Sergeant J. A. McCubbin (3032716) for meritorious work while serving as a Meteorological Air Observer with No. 202 Squadron. He joined the Squadron in February 1952, and since then he has completed over 100 meteorological reconnaissance flights involving 900 flying hours. He quickly reached a high standard of efficiency, which he has consistently maintained by reason of his great enthusiasm for his work and keen devotion to duty. His attitude towards flying and meteorology has been most praiseworthy, his morale has been of the highest order, and he has at all times set an admirable example to his colleagues.

BOOKS RECEIVED

Weers verwachtingen op lange termijn. By W. van der Bijl. 8 in. × 5½ in., pp. 128, *Illus.*, Koninklijk Nederlands Meteorologisch Instituut, Staatsdrukkerij-en Uitgeverijbedrijf, 's-Gravenhage, 1954. Price: *fl.* 1.75.

Yearbook, B. Geomagnetism, 1950. Koninklijk Nederlands Meteorologisch Instituut. No. 102, 13½ in. × 9½ in., pp. iv + 28, Staatsdrukkerij-en Uitgeverijbedrijf, 's-Gravenhage, 1953. Price: *fl.* 3.00.

Yearbook, A. Meteorology, 1952. Koninklijk Nederlands Meteorologisch Instituut. No. 104, 13½ in. × 9½ in., pp. xiii + 94, Staatsdrukkerij-en Uitgeverijbedrijf, 's-Gravenhage, 1953. Price: *fl.* 7.50.

METEOROLOGICAL OFFICE NEWS

Academic success.—To the lists published in the October and November numbers should be added:

General Certificate of Education (Advanced Level).—Physics, R. H. Powell.

Sports activities.—*Swimming.*—The Air Ministry Swimming Gala was held at Marshall Street Baths on September 15. Miss C. W. Fleming, Scientific Assistant at Renfrew, retained the Civil Service Breaststroke Championship and the Air Ministry Ladies' Championship. Miss L. Carter, Scientific Assistant at Shoeburyness was second in the latter event. In the Air Ministry Ladies' Relay Championship, the Meteorological Office "A" team (Misses Fleming, Carter and Earl) were first, and the Meteorological Office "B" team (Misses Jack, Wayne and Bowen) were second.

At the station swimming gala held at Bahrein, Senior Aircraftman J. Armitage won five cups and was declared Victor Ludorum.

WEATHER OF OCTOBER 1954

Mean pressure was below normal over the region north of the latitude of the Azores to Greenland and north-eastward to Scandinavia. The lowest mean pressure was 996 mb. between Greenland and Iceland, where the deficit below normal was 8 or 9 mb. The mean pressure was above normal over west and central Europe reaching 1021 mb. (5 mb. above normal) over south-west France.

The mean temperature was generally 2–4°F. above normal over much of Europe. This was to be expected from the mean pressure gradient which corresponded to south-westerly winds over Europe.

In the British Isles the weather was mild generally, excessively wet in the west and north but drier than usual over much of south and east England, with less than the average sunshine in most places.

The month opened with the arrival of moist air from the Atlantic bringing fog to the English-Channel coasts and cloudy, close weather inland. In southern districts temperature reached 70°F. locally on each of the first three days. A temporary influx of colder air on the 3rd was marked by local thunderstorms and considerable rainfall in places. The return of a south-westerly air stream on the 4th and 5th was accompanied by heavy rain in some areas, particularly in Wales, for example 3·95 in. at Blaenau Festiniog, Merionethshire, 2·84 in. at Corris, Montgomeryshire and 2·80 in. at Maesteg, Glamorganshire on the 4th. An anticyclone moved in from the Atlantic on the 6th and gave 7–9 hr. sunshine in most districts with frost here and there in the early hours of the following day. In some southern and western districts, even as far north as Prestwick, Ayrshire, night temperature fell below 50°F. for the first time this month. On the 8th a belt of rain and drizzle was followed by the development of fog which became widespread in the Midlands and north of England on the morning of the 9th. By the 9th a low-pressure area, reinforced by a tropical cyclone from 2,000 miles further south, had moved north-east from south Greenland and this maintained fresh or strong west-south-westerly winds and changeable weather over the British Isles for several days; there was some sunshine and occasional rain or showers in all parts on most days and hail was recorded in north Scotland on the 10th. During the 13th cold air penetrated southward to northern England and small depressions moving along its boundary gave unsettled, rainy weather for nearly a week. Rainfall was heavy and prolonged in south Scotland, north Wales and north England, causing floods in these districts. Among the heavier daily falls were 4·00 in. at Blaenau Festiniog and 3·28 in. at Corris on the 14th, 3·28 in. at Borrowdale, Cumberland on the 15th, 2·44 in. at Blaenau Festiniog on the 16th, 2·93 in. at Borrowdale, 2·78 in. at Omagh, County Tyrone, 2·47 in. at Glenkiln, Kirkcudbrightshire and 2·41 in. at Cape Wrath, Sutherland on the 17th and 3·25 in. at Glenshiel, Inverness-shire and 2·98 in. at Patterdale, Westmorland on the 18th. On the other hand rainfall in south-east and east England during this period was mainly slight. Weather was generally cloudy, though warm; Holyhead had no sunshine for the week 12th–18th. Temperature reached 70°F. in East Anglia on the 17th and was nearly as high on the following day. From the 19th weather became somewhat brighter and cooler, but with substantial rainfall (particularly in Wales and northern England) on the 22nd and 23rd, 3·84 in. at Blaenau Festiniog, 3·00 in. at Wet Sleddale, Westmorland and at Bethesda, Caernarvonshire, and 2·48 in. at Slaidburn, West Riding of Yorkshire, on the 23rd. On the 23rd floods caused a landslide on the Holyhead road in the Nant Ffrancon pass. In the early morning of the 24th 1·34 in. was registered in about 90 min. at Hastings. Cool northerly winds spread over the country on the 24th and 25th and in spite of 7–10 hr. sunshine on the 25th the temperature did not exceed 50°F. in most places and the arrival of an anticyclone from the Atlantic was accompanied by the most widespread frost of the autumn on the morning of the 26th, with a grass minimum of 17°F. at such widely separated places as Shoeburyness, Castle Archdale and Eskdalemuir. On the 26th, however, rain and strong south-easterly winds spread in from the Atlantic over the whole country followed by bright weather until the 30th, though with showers that were heavy in the north and west. More flooding occurred in south Scotland and the Lake District; on the 27th 2·30 in. rain was registered at Onich, Inverness-shire, and on the 28th 3·19 in. at Haweswater and 2·21 in. at Ettrich, Selkirkshire. During this period it was generally mild and, on the 27th, London had its warmest late October day for five years. A trough of low pressure moving east across England and Wales gave mainly cloudy weather with rain or showers in that area on the 31st.

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 ...	73	23	+3·2	122	+3	84
Scotland	68	23	+1·0	190	+5	89
Northern Ireland ...	65	25	+1·9	191	+5	62

RAINFALL OF OCTOBER 1954

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.
London	Camden Square ...	2·19	83	*Glam.*	Cardiff, Penylan ...	6·52
Kent	Dover	1·58	41	*Pemb.*	Tenby	6·83
,,	Edenbridge, Falconhurst	2·47	69	*Radnor*	Tyrmynydd	8·84
Sussex	Compton, Compton Ho.	3·62	79	*Mont.*	Lake Vyrnwy	12·91
,,	Worthing, Beach Ho. Pk.	1·73	48	*Mer.*	Blaenau Festiniog ...	31·09
Hants.	Ventnor Park	3·50	87	,,	Aberdovey	9·80
,,	Southampton (East Pk.)	3·20	81	*Carn.*	Llandudno	5·29
,,	South Farnborough ...	2·12	66	*Angl.*	Llanerchymedd ...	7·76
Herts.	Royston, Therfield Rec.	2·14	79	*I. Man*	Douglas, Borough Cem.	8·97
Bucks.	Slough, Upton	2·52	90	*Wigtown*	Newton Stewart ...	8·49
Oxford	Oxford, Radcliffe ...	2·15	74	*Dumf.*	Dumfries, Crichton R.I.	8·15
N'hants.	Wellingboro' Swanspool	2·05	81	,,	Eskdalemuir Obsy. ...	12·48
Essex	Shoeburyness	1·35	57	*Roxb.*	Crailing...	4·65
,,	Dovercourt	1·46	61	*Peebles*	Stobo Castle	7·00
Suffolk	Lowestoft Sec. School ...	1·59	57	*Berwick*	Marchmont House ...	5·24
,,	Bury St. Ed., Westley H.	1·91	70	*E. Loth.*	North Berwick	5·67
Norfolk	Sandringham Ho. Gdns.	3·22	106	*Midl'n.*	Edinburgh, Blackf'd. H.	6·17
Wilts.	Aldbourne	2·77	82	*Lanark*	Hamilton W. W., T'nhill	8·67
Dorset	Creech Grange... ...	4·03	79	*Ayr*	Colmonell, Knockdolian	7·59
,,	Beaminster, East St. ...	3·74	84	,,	Glen Afton, Ayr San. ...	10·05
Devon	Teignmouth, Den Gdns.	2·44	63	*Renfrew*	Greenock, Prospect Hill	10·75
,,	Ilfracombe	6·45	141	*Bute*	Rothesay, Ardencraig ...	8·98
,,	Princetown	10·15	121	*Argyll*	Morven, Drimnin ...	9·83
Cornwall	Bude, School House ...	3·90	96	,,	Poltalloch	11·01
,,	Penzance	3·28	70	,,	Inveraray Castle ...	15·51
,,	St. Austell	4·09	78	,,	Islay, Eallabus	7·60
,,	Scilly, Tresco Abbey ...	2·57	67	,,	Tiree	5·50
Somerset	Taunton	1·75	54	*Kinross*	Loch Leven Sluice ...	8·23
Glos.	Cirencester	3·80	115	*Fife*	Leuchars Airfield ...	5·71
Salop	Church Stretton ...	3·86	105	*Perth*	Loch Dhu	13·75
,,	Shrewsbury, Monkmore	4·36	156	,,	Crieff, Strathearn Hyd.	7·20
Worcs.	Malvern, Free Library...	2·97	100	,,	Pitlochry, Fincastle ...	6·11
Warwick	Birmingham, Edgbaston	3·51	126	*Angus*	Montrose, Sunnyside ...	5·14
Leics.	Thornton Reservoir ...	3·65	130	*Aberd.*	Braemar	6·04
Lincs.	Boston, Skirbeck ...	2·51	92	,,	Dyce, Craibstone ...	5·14
,,	Skegness, Marine Gdns.	2·29	84	,,	New Deer School House	5·37
Notts.	Mansfield, Carr Bank ...	3·15	104	*Moray*	Gordon Castle	5·02
Derby	Buxton, Terrace Slopes	8·16	166	*Nairn*	Nairn, Achareidh ...	5·47
Ches.	Bidston Observatory ...	4·38	134	*Inverness*	'Loch Ness, Garthbeg ...	7·25
,,	Manchester, Ringway...	5·50	177	,,	Glenquoich	17·46
Lancs.	Stonyhurst College ...	9·19	205	,,	Fort William, Teviot ...	14·62
,,	Squires Gate	7·60	215	,,	Skye, Broadford ...	13·97
Yorks.	Wakefield, Clarence Pk.	3·27	114	,,	Skye, Duntuilm ...	8·64
,,	Hull, Pearson Park ...	3·95	133	*R. & C.*	Tain, Mayfield... ...	6·29
,,	Felixkirk, Mt. St.John...	4·15	144	,,	Inverbroom, Glackour...	9·30
,,	York Museum	2·95	110	,,	Achnashellach	13·39
,,	Scarborough	3·78	121	*Suth.*	Lochinver, Bank Ho. ...	8·13
,,	Middlesbrough... ...	3·83	128	*Caith.*	Wick Airfield	5·67
,,	Baldersdale, Hury Res.	7·19	194	*Shetland*	Lerwick Observatory ...	5·17
Norl'd.	Newcastle, Leazes Pk....	4·40	142	*Ferm.*	Crom Castle	6·80
,,	Bellingham, High Green	7·32	187	*Armagh*	Armagh Observatory ...	5·24
,,	Lilburn Tower Gdns. ...	4·39	119	*Down*	Seaforde	7·01
Cumb.	Geltsdale	9·13	245	*Antrim*	Aldergrove Airfield ...	5·79
,,	Keswick, High Hill ...	13·58	243	,,	Ballymena, Harryville...	7·76
,,	Ravenglass, The Grove	7·53	174	*L'derry*	Garvagh, Moneydig ...	5·19
Mon.	A'gavenny, Plâs Derwen	4·56	99	,,	Londonderry, Creggan	5·30
Glam.	Ystalyfera, Wern House	15·14	220	*Tyrone*	Omagh, Edenfel ...	8·63

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

Wt-34. K16.