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.

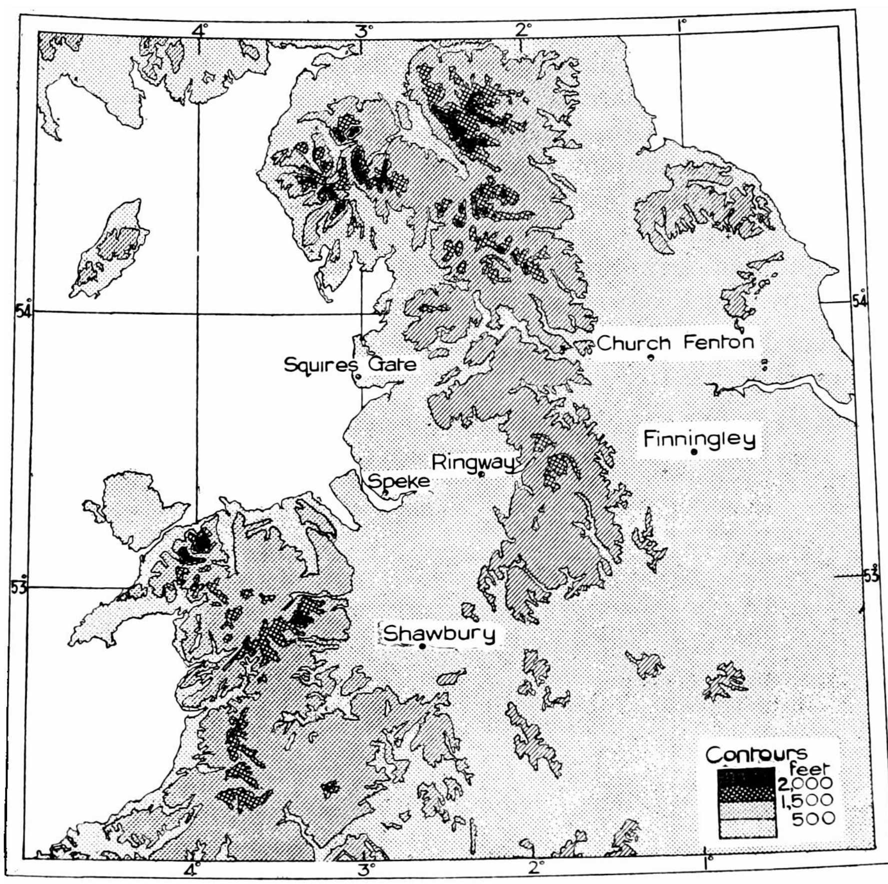
The values for 1950 and 1951, for the months June to September, are summarized in Table I.

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.

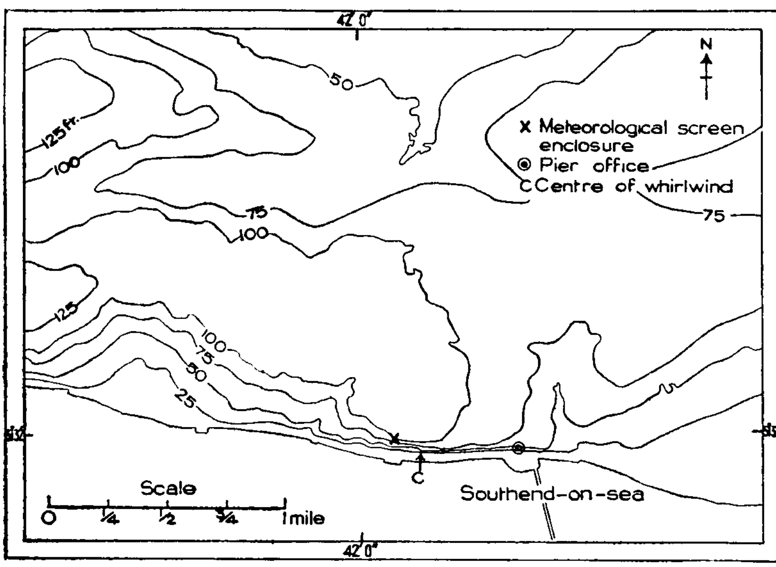


FIG. 1—CONTOURS AROUND SOUTHEND-ON-SEA

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.,

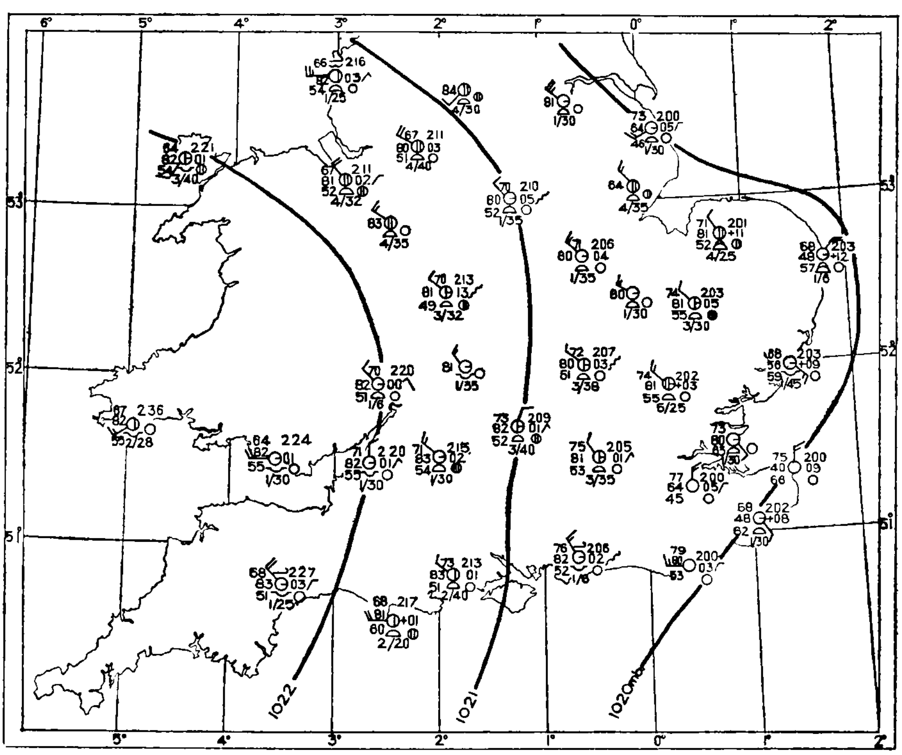


FIG. 2—SYNOPTIC CHART, AUGUST 10, 1953, 1500 G.M.T.

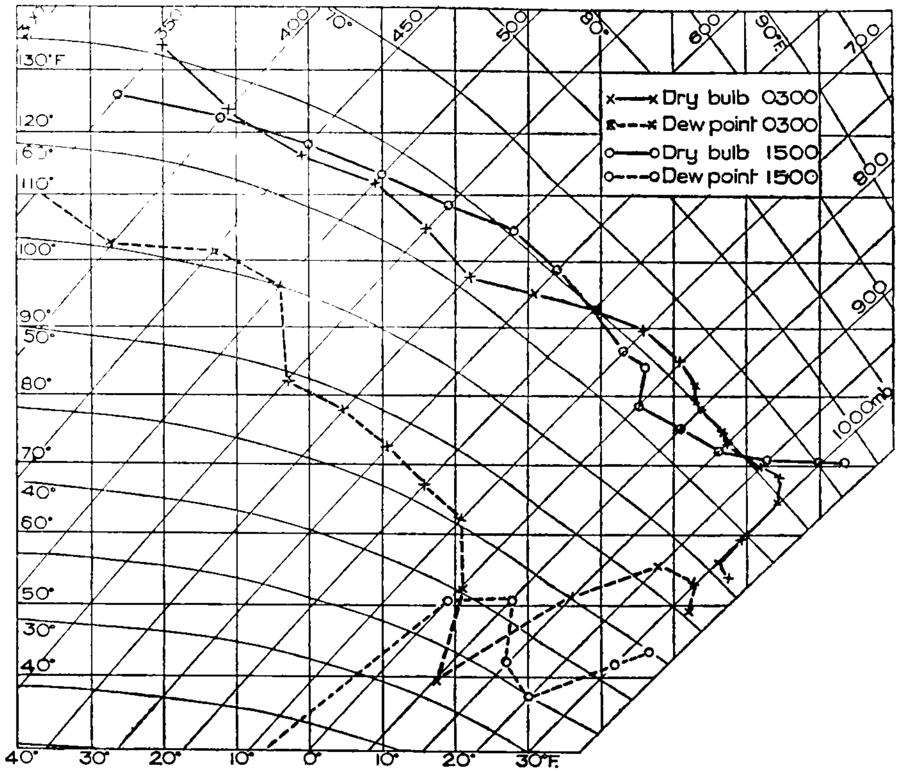


FIG. 3—UPPER AIR SOUNDINGS, CRAWLEY, AUGUST 10, 1953

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: Dry bulb	Wet bulb	Max.	Min.	Grass min.	Relative humidity	Wind: Direction	Beaufort force	Visibility	Rainfall
G.M.T.	*degrees Fahrenheit*					%			miles	mm.
0900	66·8	61·8	75	60	57	74	N.	4	6¼–12½	nil
1800	76·1	63·9	81	..	..	48	E.	2	12½–18⅔	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

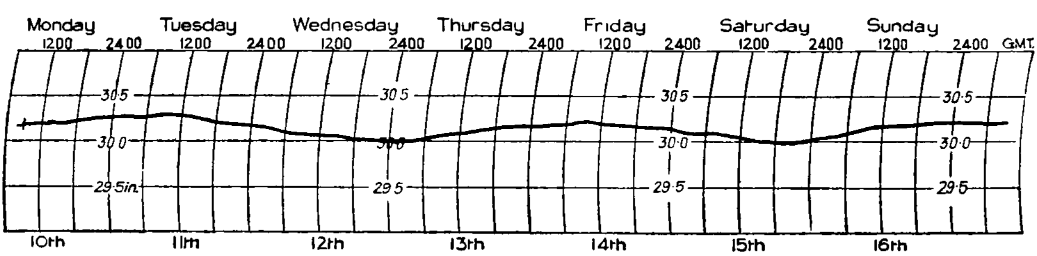


FIG. 4—BAROGRAM, SOUTHEND-ON-SEA, AUGUST 10–16, 1953

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.),

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

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

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

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.

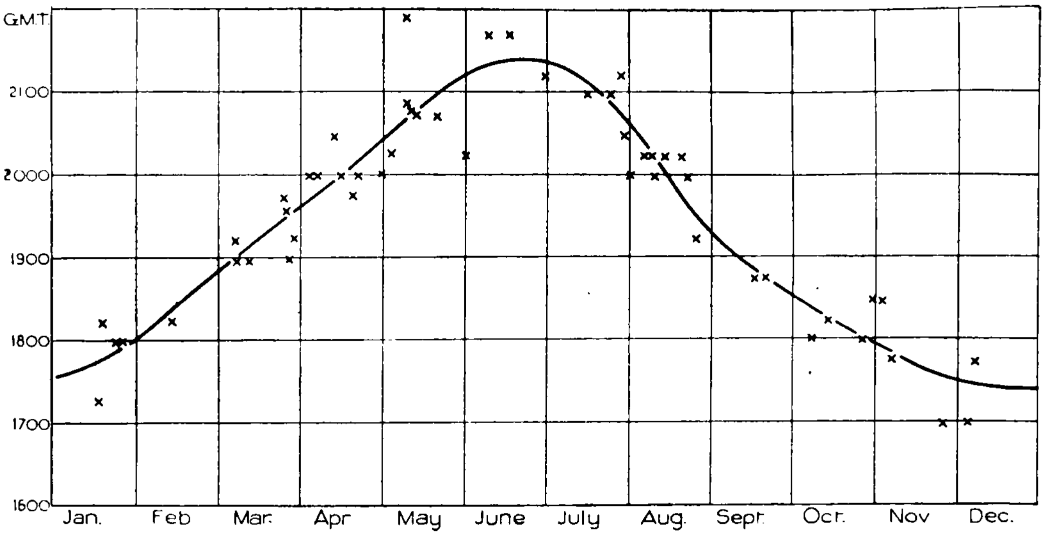


FIG. 1—VARIATION OF TIME OF EVENING TEMPERATURE DISCONTINUITY, EXETER, 1950

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.

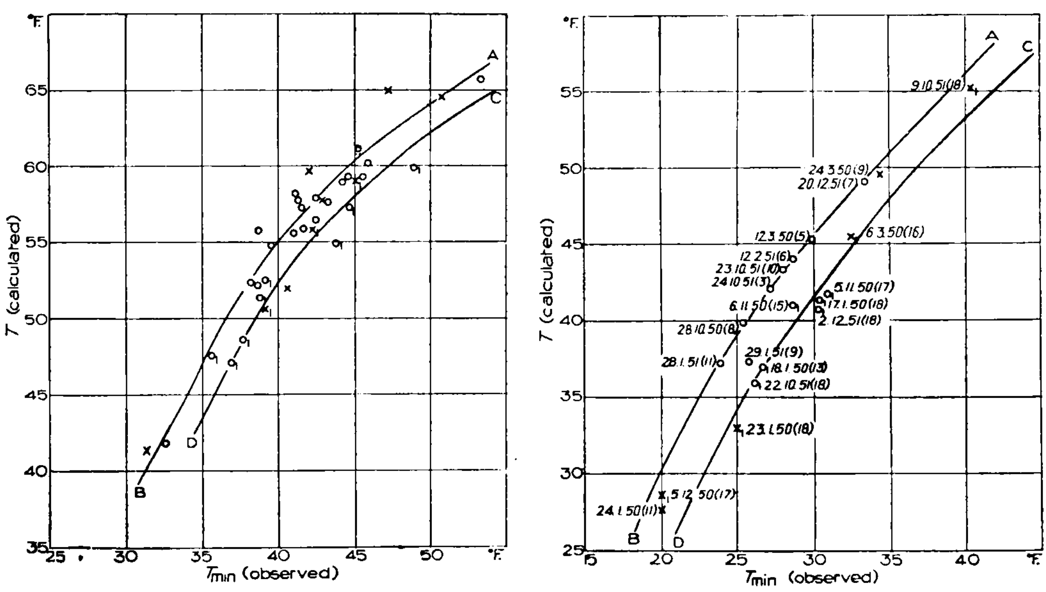


FIG. 2—RELATION BETWEEN INITIAL AND FINAL TEMPERATURES OF THE PERIOD OF SUBSEQUENT COOLING FOR OCCASIONS OF CALM (MEAN GRADIENT WIND 0–12 KT.) AND LIGHT WIND (MEAN GRADIENT WIND 13–18 KT.)

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.

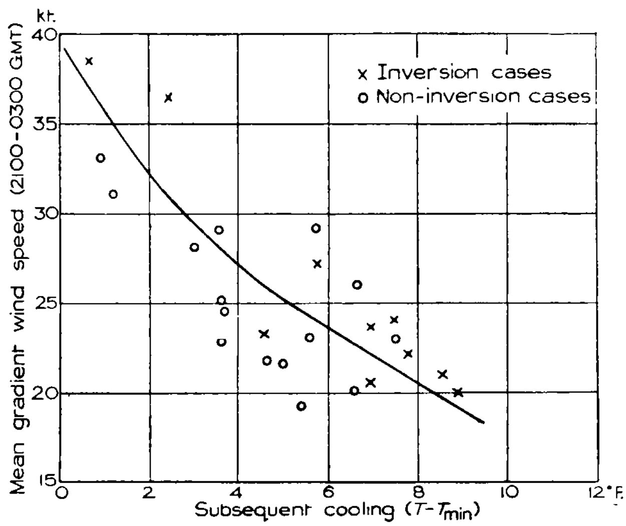


FIG. 3—RELATION BETWEEN THE MEAN GRADIENT WIND SPEED AND THE SUBSEQUENT COOLING FOR OCCASIONS OF STRONGER WIND

Mean gradient wind speed $\geqslant$ 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

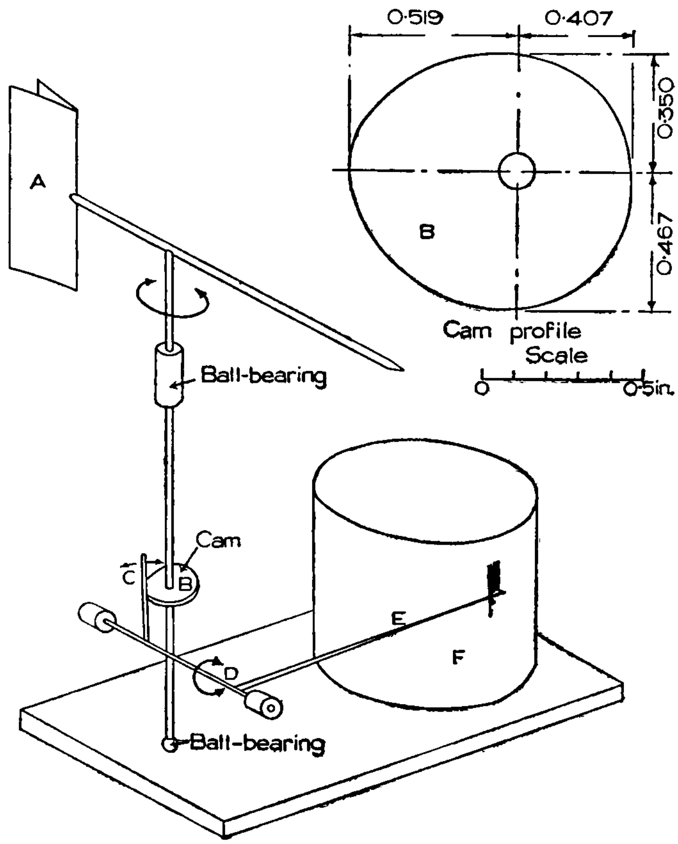


FIG. 1—WIND-DIRECTION RECORDER

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.

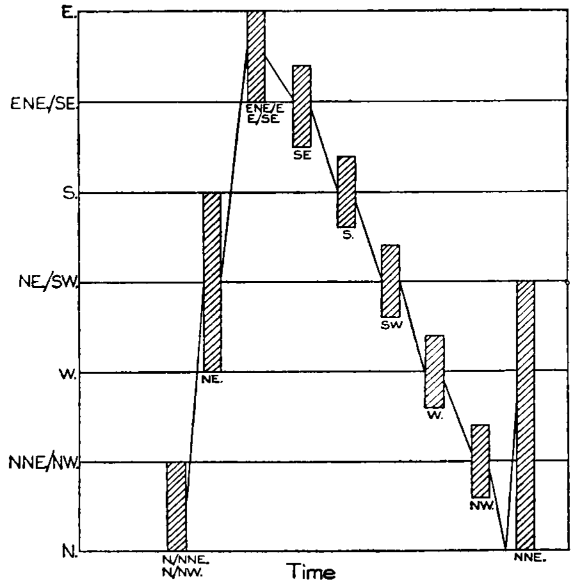


FIG. 2—TYPE OF TRACE OBTAINED FROM WIND-DIRECTION RECORDER

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 wavelengths 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.

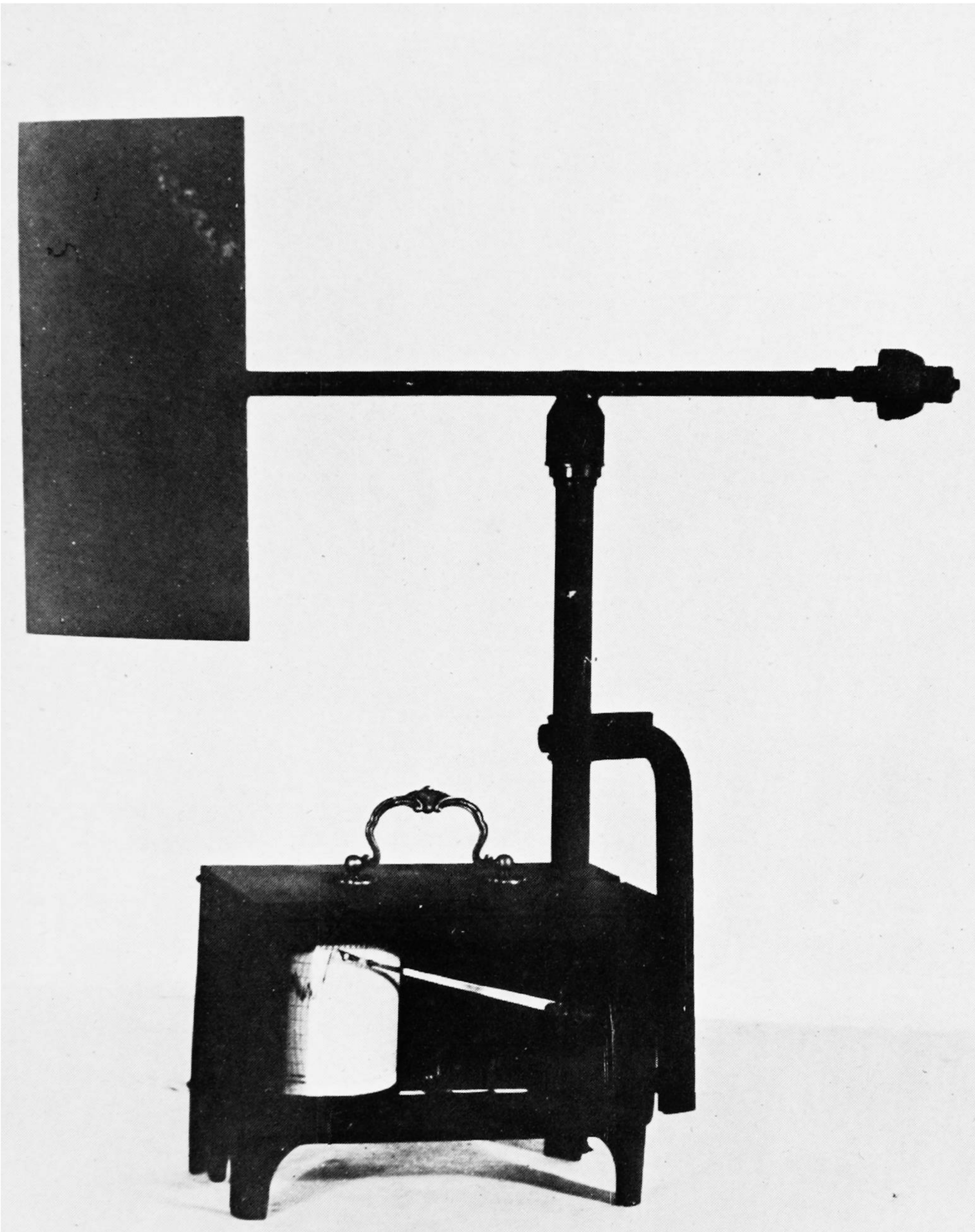
Langlo, in his discussion of the various types of ozone variation, used data from about 10 northern hemisphere stations, some of which had not previously been discussed. A comparison over ten years of the year-to-year changes of mean annual ozone amount at Tromsø and Dombaas in Norway and Arosa in Switzerland, 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".

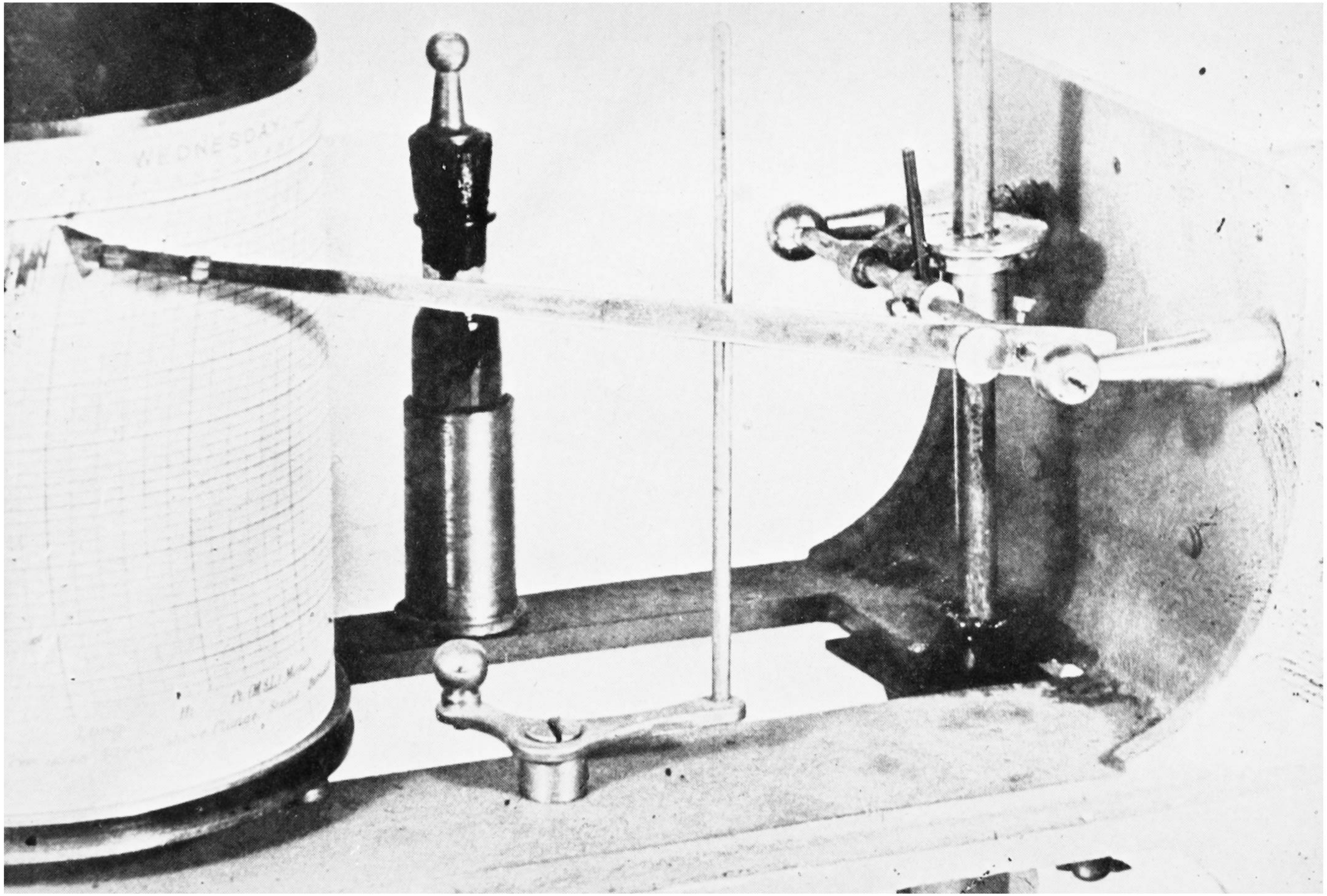
Investigating the part played by horizontal advection in longer-period ozone variations, Langlo found that the ozone amounts in the early months of 1949 were below average, while the winds in the ozone incline region (15 to 18 Km.) had zonal components far above average strength. From this fact Langlo 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

[To face p. 16



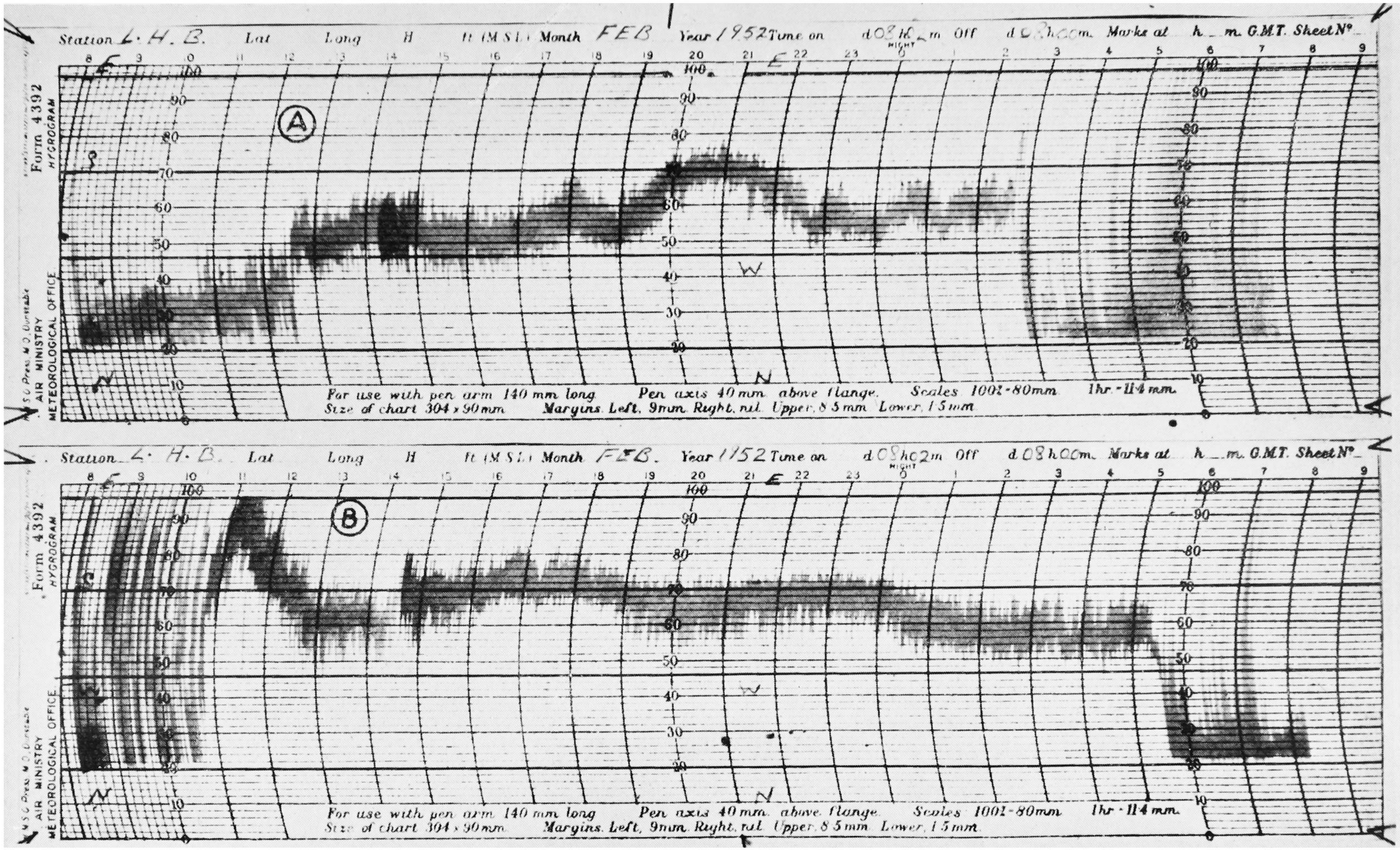
WIND-DIRECTION RECORDER

(see p. 11)



WIND-DIRECTION RECORDER, SHOWING CAM AND LEVER SYSTEM

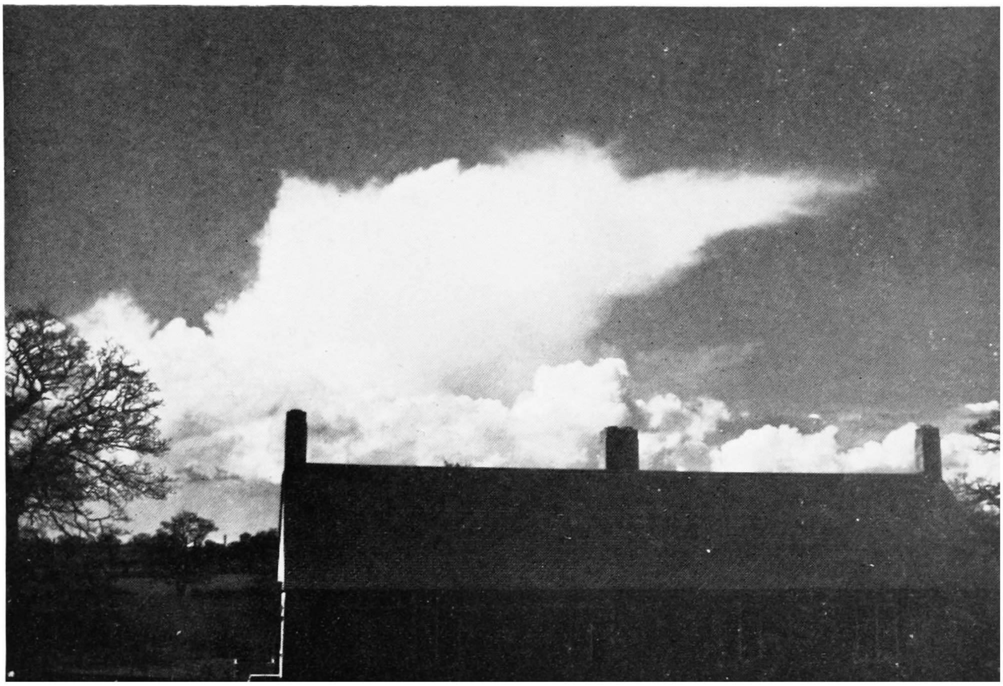
(see p. 11)



TWO TYPICAL CHARTS OBTAINED FROM THE WIND-DIRECTION RECORDER

(see p. 11)

To face p. 17]



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 $> 0 \cdot 2$ 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.

* *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

* *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.