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WEATHER SYSTEMS ASSOCIATED WITH SOME OCCASIONS OF SEVERE TURBULENCE AT HIGH ALTITUDE

By J. K. BANNON, B.A.

Introduction.—Turbulence in the atmosphere causes the irregular up and down motion of aircraft known as "bumps". Such turbulence can occur at high altitudes above 20,000 ft., but the severity of the resulting bumps is described as slight or moderate in the majority of cases; occasionally it is described as severe or even frightening. A few cases of severe turbulence at high altitude have been discussed in some detail[1,2].

This note describes a brief analysis of all cases of high-altitude turbulence classed as severe which have been reported over the British Isles at heights above 20,000 ft. Slight or moderate turbulence is probably not of great practical importance in the operation of aircraft, and it therefore seemed best to restrict the investigation to the well marked severe cases, especially as any relationship between turbulence and meteorological features would be expected to be strongest in these cases. The analysis is merely an attempt to associate the severe turbulence with broad features of the general weather picture, lows and troughs in the upper air, jet streams and discontinuities in the tropopause surface. As was expected, jet streams are the weather features most frequently associated with severe turbulence, and the analysis in this note is mainly concerned with the position of the turbulence relative to the jet-stream axis.

Observations of severe turbulence.—There is a small body of instrumental measurements of high-altitude turbulence experienced over Great Britain since 1946. These observations were made by recording accelerometers carried on aircraft of the Royal Aircraft Establishment[3], also on special flights by British European Airways[1] and on a few flights by Meteorological Research Flight aircraft. For the purposes of this analysis the turbulence was classified as severe when the measured acceleration imparted to the aircraft by the gust[4] was greater than or equal to $0 \cdot 4g$; eight such occasions were recorded over Great Britain at heights above 20,000 ft.

Many other qualitative observations of high-altitude turbulence have been made by aircraft of the Royal Air Force, the Meteorological Research Flight and the De Havilland Aircraft Company* over or near Great Britain since 1948: 84 of these observations at heights above 20,000 ft. specified the turbulence as severe, heavy or violent. Thus, in all, 92 cases of what may be broadly classed as severe turbulence were available for analysis.

* Readings from an accelerometer mounted in the cockpit of Comet aircraft were noted on several occasions; these readings, however, are not considered as reliable as indications of the accelerations experienced at the centre of gravity of the aircraft. See Hislop[1].

Unfortunately, the qualitative assessments of turbulence are probably not comparable in all cases; there is the risk that a pilot may describe turbulence as severe at, say, 30,000 ft. because he considers it severe compared with the usual level of turbulence at that level rather than severe on an absolute scale independent of height.

Weather situations associated with severe turbulence.—Table I gives the numbers of cases of severe turbulence occurring in various weather situations. The majority were associated with jet streams. These together with those classed as "probably near jet stream" constitute 67 per cent. of the total. The six unclassified cases occurred in comparatively featureless upper air situations.

TABLE I—WEATHER SITUATIONS ASSOCIATED WITH OCCASIONS OF SEVERE TURBULENCE ABOVE 20,000 FT.

WEATHER SITUATION	NO. OF CASES
Near jet stream...	56
Probably near jet stream (i.e. jet stream almost certainly present but details of wind speed, breadth, etc., not available)	6
Upper trough	8
Upper low	2
Discontinuity in tropopause surface at same level as turbulence and within 100 miles of it	2
Discontinuity in tropopause surface at same level as turbulence, within 100 miles of it and near upper trough	4
Discontinuity in tropopause surface at same level as turbulence, within 100 miles of it and near upper low	2
Strong upper winds but not a well defined jet stream	6
Unclassified	6
Total	92

Jet streams.—The 56 cases of severe turbulence occurring above 20,000 ft. and in the vicinity of jet streams have been analysed with regard to their position relative to the jet-stream axis; the method adopted was that used previously[2]. Fig. 1 shows a schematic vertical cross-section at right angles to the general flow of a composite jet stream, obtained by taking a mean of three typical jet-stream cross-sections. The horizontal unit of measurement is the distance from the centre of the jet stream, on the low-pressure side, over which the wind velocity at the same level as the jet axis falls to half its maximum value; the vertical unit is pressure relative to the pressure at the jet axis on a logarithmic scale. As a guide to general characteristics the diagram shows isopleths of wind speed normal to the section and expressed as a percentage of the maximum, and also the mean position of the tropopause surfaces, all referring to the composite jet that was discussed previously[2]. On this diagram too is plotted the position, relative to its jet axis, of each of the 56 turbulent zones associated with jet streams.

TABLE II—MEAN VALUES AND EXTREMES OF VARIOUS PARAMETERS OF 56 JET STREAMS IN WHICH SEVERE TURBULENCE OCCURRED

	Maximum speed kt.	Pressure at axis mb.	Horizontal scale n. miles
Mean	115	293	141
Extremes	80 (min.) 160 (max.)	...	54 (min.) 240 (max.)*

The horizontal scale is the distance from the axis at the same level on the low-pressure side at which the wind speed is half the value at the axis.

* The maximum scale value occurred with a jet speed of 90 kt.

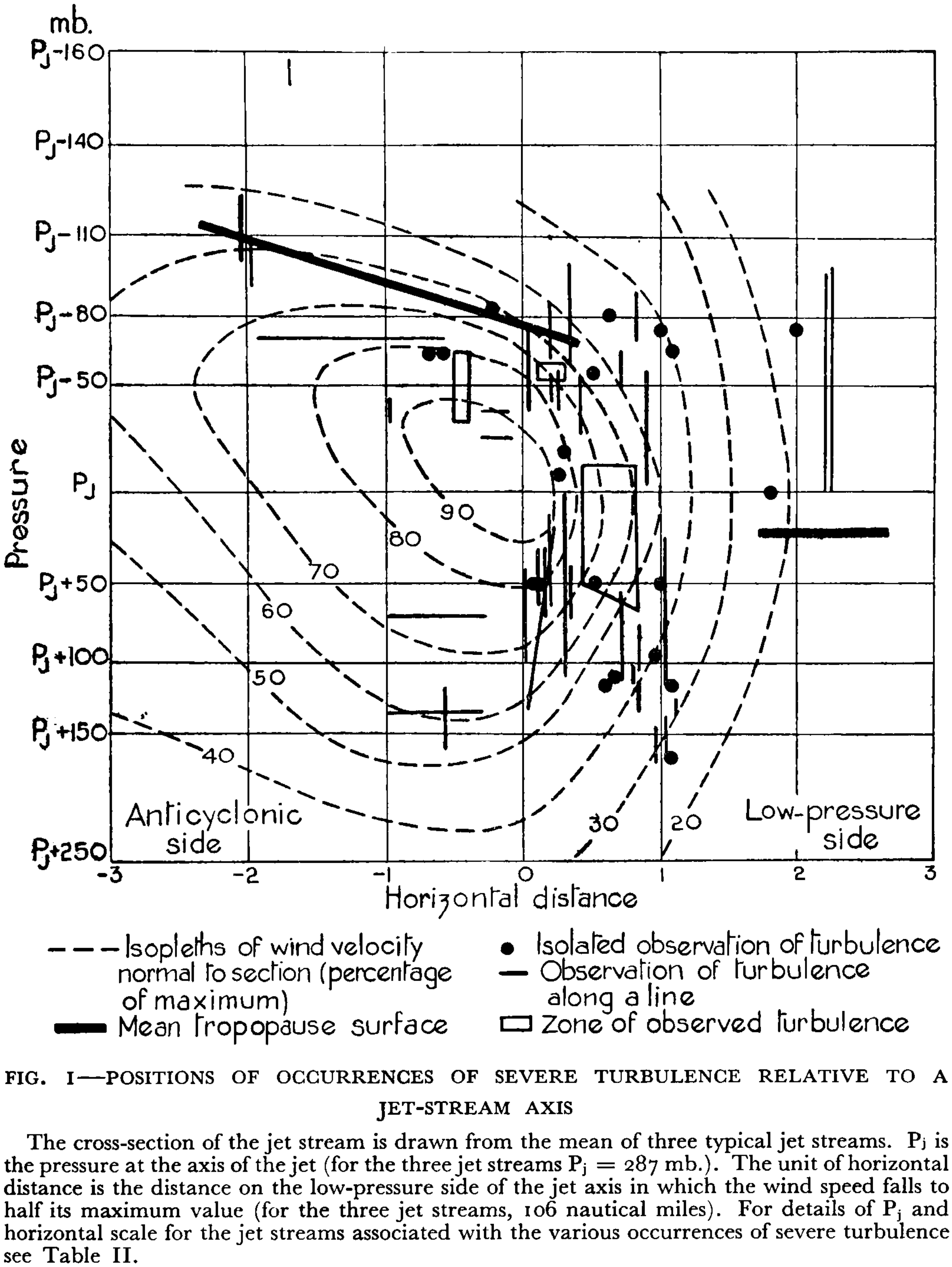

FIG. 1—POSITIONS OF OCCURRENCES OF SEVERE TURBULENCE RELATIVE TO A JET-STREAM AXIS

The cross-section of the jet stream is drawn from the mean of three typical jet streams. P_j is the pressure at the axis of the jet (for the three jet streams $P_j = 287$ mb.). The unit of horizontal distance is the distance on the low-pressure side of the jet axis in which the wind speed falls to half its maximum value (for the three jet streams, 106 nautical miles). For details of P_j and horizontal scale for the jet streams associated with the various occurrences of severe turbulence see Table II.

The definition of a jet stream is necessarily somewhat arbitrary. The criteria used in this analysis are best illustrated by the mean values and extremes of various jet-stream parameters given in Table II. Estimates of the maximum wind speed and the position of the jet axis were made by a scrutiny of the wind observations from the British upper air observing stations and from those observations from continental stations which are plotted in the *Daily Aerological Record.* Since observing stations are of the order of 200 miles apart and observations are made at six-hourly intervals, there is necessarily some doubt as to the exact position of a jet-stream axis at a particular time and its exact height (pressure) and the wind speed there, though errors in these have been reduced as far as possible by considerations of continuity. It is thought, however, that the accuracy is sufficiently good to ensure that the general zones of occurrence of turbulence shown in Fig. 1 are reasonably reliable; the number of observations should be sufficiently large to counteract the effect of casual errors.

The most striking result of Fig. 1 is that severe turbulence was reported only on three occasions in the quadrant of the diagram below and on the high-pressure side of the axis (i.e. lower left part of the diagram). The greatest numbers of observations were just to the right of the jet axis in the diagram, and nearly all observations to the left of the axis were above the level of the axis, six being in the stratosphere. The distribution of observations shown in Fig. 1 is consistent with the scheme that most cases of severe turbulence near a jet stream are associated with:—

(i) The frontal surface which is almost invariably associated with a jet stream. Note the large number of cases just to the right of and below the axis and possibly the three cases to the left of and below the axis in the diagram. For typical positions of the frontal surface relative to the axis see the paper by Durst and Davis[5].

(ii) The zone near which the tropopause is usually discontinous. Note the large number of cases just above and to the right of the jet axis in the figure.

(iii) The zone above the jet axis on the anticyclonic side (i.e. on the left of the diagram) associated with the rapid decrease of wind speed with height.

Regarding (iii), it is a fact of observation that the height of the level of maximum wind usually increases with distance from the jet axis on its anticyclonic side, and the height of the zone of rapid decrease of wind with height necessarily follows suit. There is a tendency for the observations of turbulence shown in Fig. 1 to slope upwards in a corresponding manner.

Zones (i) and (iii) above are usually associated with large shear of wind with height, but zone (ii) is not always in a region of wind change with height. Well to the low-pressure side and above the jet axis there is usually little change of wind with height, though from Fig. 1 it is seen that severe turbulence sometimes occurs there; in this region, however, there is considerable shear in the horizontal. It is impossible to argue from the general to the particular in this connexion, of course, as individual jet streams do vary significantly from each other. All that can be said is that most of the observations of severe turbulence near a jet stream were probably associated with large wind shear in the vertical, but that it seems likely that a few cases were not associated with large vertical shear but with large horizontal shear. This would be consistent with the general results in an earlier paper[6] where it was shown that turbulence, not necessarily near a jet stream and usually of slight intensity, was associated with general shear of wind in the vertical in three cases out of four, and that both the cases of vertical shear and those of no general vertical shear were associated with large isentropic or horizontal shears.

Ten cases of severe turbulence occurred near the entrance and eight near the exit of jet streams. Four of the eight cases near a jet exit were on the anticyclonic side of and above the jet axis whereas none of the 10 cases near a jet stream entrance was in this zone. However, as the numbers of cases involved were so small, this apparent difference between entrance and exit of a jet stream may not be significant. No other peculiarities or variations in the occurrence of turbulence with respect to position along the jet stream were noted.

Discontinuity in tropopause surface.—It is noted from Table I that eight cases of severe turbulence were associated with probable discontinuities in the tropopause surface at the same levels and within 100 miles; six of these cases were in the stratosphere and another was probably at or near the discontinuity. The decision as to whether the tropopause surface was discontinuous or not was made after scrutiny of available temperature soundings and using continuity considerations of both time and space. This analysis was necessarily somewhat subjective, and there is the possibility that another analyst would have reached different conclusions in some cases.

Many of the other cases of severe turbulence plotted in Fig. 1 were near and at the same level as the discontinuous tropopause surface which is a feature of most well defined jet streams.

In the earlier paper[6] it was pointed out that the neighbourhood of a discontinuity in tropopause surface may often be a region of large wind shear in the vertical or large isentropic shear, because of the proximity of cold tropopause and comparatively warm stratospheric air at the same level on either side of the discontinuity of tropopause respectively. Presumably the six cases of severe turbulence discussed above were associated with one or other of these large shears; and in the same paper[6] it is suggested that isentropic shear might be the more likely, but there is no evidence either way in these cases.

Conclusions.—This brief analysis of occasions of severe turbulence occurring over or near Great Britain at heights above 20,000 ft. has shown that the majority occur in association with well defined jet streams, and that most of the other cases were associated with upper lows, upper troughs, discontinuous tropopause surfaces or strong winds not associated with jet streams. Less than seven per cent. of cases appeared to have no obvious association with any configuration of the upper air pattern. The cases associated with jet streams appeared to be grouped in particular zones relative to the jet axis, the majority (75 per cent.) occurring on the low-pressure side of the stream.

Turbulence in the upper troposphere and lower stratosphere, like many turbulence phenomena, appears to be somewhat haphazard in its occurrence. Forecasting such turbulence must therefore remain largely a statement of risks. The few results presented here may, it is hoped, be of use in helping forecasters to be more precise as to those regions in which the risk of severe turbulence is greatest.

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VARIATIONS IN AIR TEMPERATURE AND HUMIDITY ON THE WEATHER SLOPE OF A COASTAL HILL

By L. P. SMITH, B.A.

In a previous article[1] the variations of mean temperature and hours of sunshine over the period 1929–48 were discussed for the three stations at Aberystwyth:—

Station	Height above M.S.L. ft.
1. Aberystwyth, Health Resort Station ...	12
2. Aberystwyth, Plant Breeding Station, Crop Weather Station ...	452
3. Llety-evan-Hen, Crop Weather Station ...	950

The monthly means of minimum, 0900, and maximum temperature, the 0900 relative humidity and the 0900 vapour pressure for the same 20-year period have now been examined. Table I shows, on a monthly and seasonal basis, the difference in average temperature between stations 1 and 2 and between stations 2 and 3; the difference in average relative humidity between stations 2 and 1, 3 and 2, and 3 and 1; and the ratios of average vapour pressure between stations 2 and 1, 3 and 2, and 3 and 1. The findings may be summarized as follows:—

Temperature.—*Minimum temperature.*—The greatest difference between station 1 (12 ft.) and station 2 (450 ft.) occurs in summer; the least difference is in winter. This seasonal change is reversed between station 2 and station 3 (950 ft.) when the greatest difference is in winter.

0900 temperature.—For the lower pair of stations, the difference is highest in winter and lowest in summer; for the higher pair the reverse is true.

Maximum temperature.—The greatest difference at lower levels is in autumn, the least in spring, and the same variation is observed at higher levels.

We thus know the differences in average temperature at three times during the 24-hr. day and can estimate the diurnal change. For stations 1 and 2 the difference is greatest about dawn in summer and 1–2 hr. after dawn during the rest of the year; the difference is least in late afternoon in spring and summer and in the early part of the night in autumn and winter. For stations 2 and 3, the difference is least 1–2 hr. after dawn in winter and around dawn for the rest of the year; it is most in mid afternoon in winter and between 1000 and noon in the other three seasons.

Relative humidity at 0900.—The average value decreases with height from sea level on the coast to the 452-ft. station throughout the year; the decrease is greatest in spring especially in May. From 452 ft. to 950 ft. there is generally an increase in average relative humidity at 0900 except in March.

These average differences show an interesting but inexplicable similarity in annual variation with a time lag of two months between the two sets of stations as is illustrated in Fig. 1 (see p. 104).

Vapour pressure at 0900.—The ratios of average vapour pressure show a reasonable constancy throughout the year except that in winter the ratio is least for the lower pair and greatest for the higher pair.

If we reject the values for the lower pair owing to the coastal influence and accept a formula $e_3 = e_2 (1 - \alpha z)$
where z is in hundreds of feet, we find that the average for α (shown in Table I) is 0·014 mb. per 100 ft.

REFERENCE

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TABLE I—DIFFERENCES IN TEMPERATURE, RELATIVE HUMIDITY AND VAPOUR PRESSURE AT THREE STATIONS AT ABERYSTWYTH

	Difference in dry-bulb temperature $T_1 - T_2$			$T_2 - T_3$			Difference in relative humidity at 0900			Ratios of vapour pressures at 0900			
	Min.	0900	Max.	Min.	0900	Max.	$U_2 - U_1$	$U_3 - U_2$	$U_3 - U_1$	e_2/e_1	e_3/e_2	e_3/e_1	α
	degrees Fahrenheit						per cent.			per cent.			
December	1·21	2·51	1·45	1·47	1·06	2·36	−2·55	+1·95	−0·60	89·3	97·0	86·6	0·006
January	1·68	2·08	1·24	1·45	1·68	2·42	−1·05	+1·85	+0·80	91·3	95·0	86·9	0·010
February	1·72	2·06	1·16	1·64	1·56	2·42	−1·15	+1·55	+0·40	91·2	96·3	87·8	0·007
Winter	1·54	2·22	1·28	1·52	1·43	2·40	−1·58	+1·78	+0·20	90·6	96·1	87·1	0·008
March	1·47	1·81	0·59	1·20	2·01	1·68	−1·15	−1·45	−2·60	92·0	91·3	85·0	0·017
April	1·78	1·52	0·79	1·56	2·81	1·89	−2·75	0·0	−2·75	92·2	89·8	82·8	0·020
May	1·56	0·84	0·74	1·30	2·80	1·94	−6·10	+0·05	−6·05	90·7	89·4	81·0	0·021
Spring	1·60	1·39	0·71	1·35	2·54	1·84	−3·33	−0·47	−3·80	91·6	90·2	82·7	0·019
June	1·98	0·87	0·88	1·33	2·73	2·08	−3·50	+1·85	−1·65	93·1	92·6	86·2	0·015
July	1·85	1·41	1·27	1·44	2·86	2·56	−2·45	+2·55	+0·10	92·3	92·9	85·8	0·014
August	1·94	1·80	1·37	1·25	2·74	2·26	−1·70	+1·10	−0·60	91·8	91·7	84·2	0·017
Summer	1·92	1·36	1·17	1·34	2·78	2·30	−2·55	+1·83	−0·72	92·4	92·4	85·4	0·015
September	1·67	1·87	1·70	1·51	2·91	2·42	−1·65	+1·50	−0·15	91·7	91·5	83·9	0·017
October	1·52	2·11	1·75	1·48	2·37	2·64	−1·95	+0·90	−1·05	90·6	92·1	83·5	0·016
November	1·51	2·37	1·54	1·31	1·86	2·47	−2·85	+1·40	−1·45	88·3	94·7	83·6	0·011
Autumn	1·57	2·12	1·66	1·43	2·38	2·54	−2·15	+1·27	−0·88	90·2	92·8	83·7	0·015
Year	1·66	1·77	1·21	1·41	2·28	2·27	−2·40	+1·10	−1·30	91·2	92·9	84·7	0·014

Suffix 1 = Aberystwyth Health Resort Station (12 ft.)
Suffix 2 = Aberystwyth Plant Breeding Station (452 ft.)
Suffix 3 = Llety-evan-Hen Crop Weather Station (950 ft.)

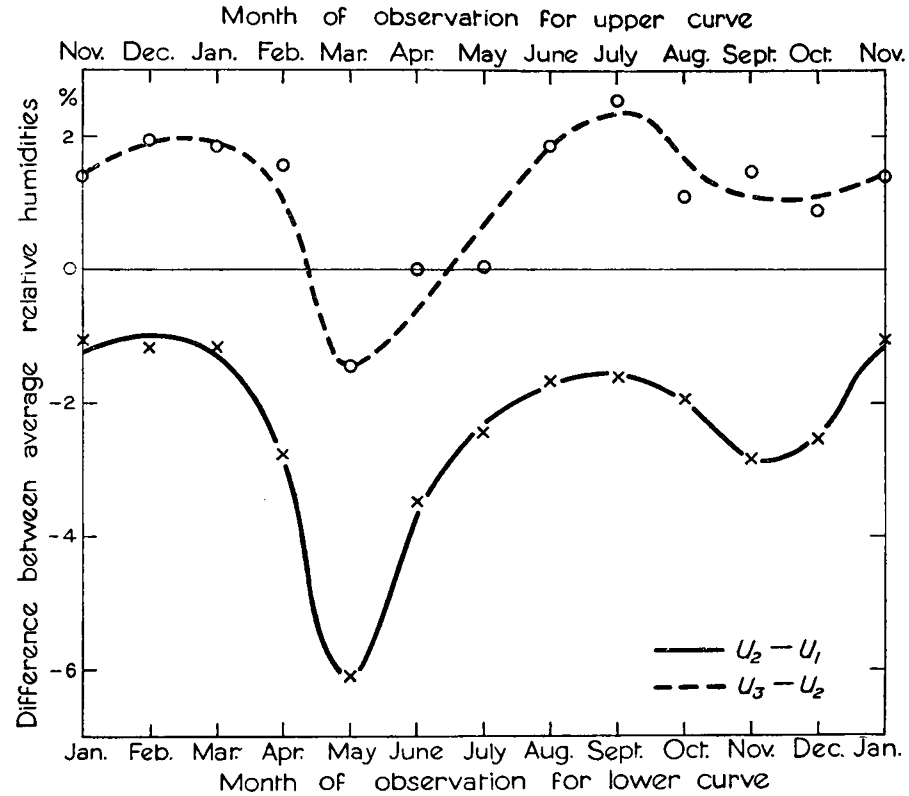
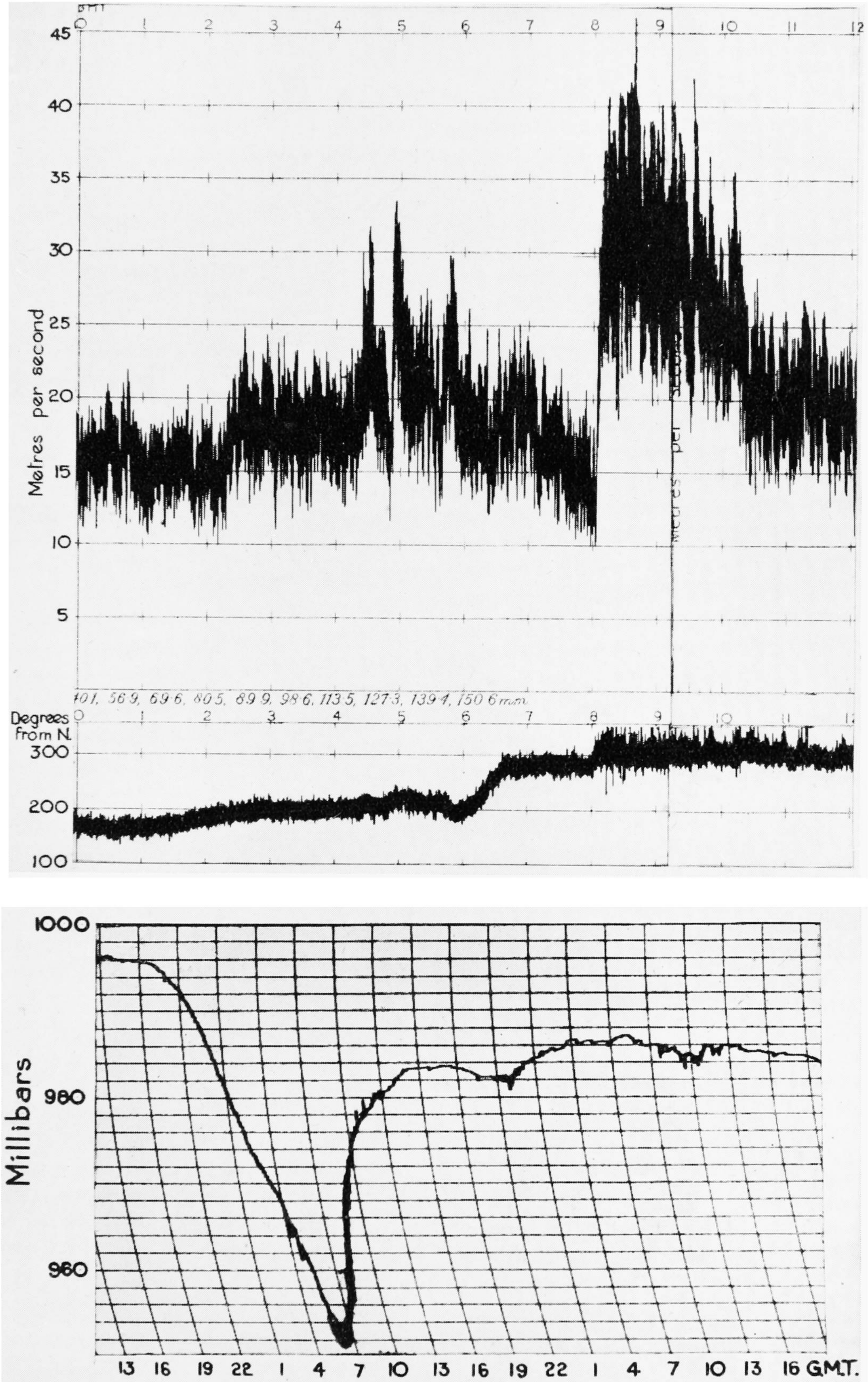


FIG. 1—ANNUAL VARIATION OF HILL-SIDE HUMIDITY DIFFERENCES (see p. 102).

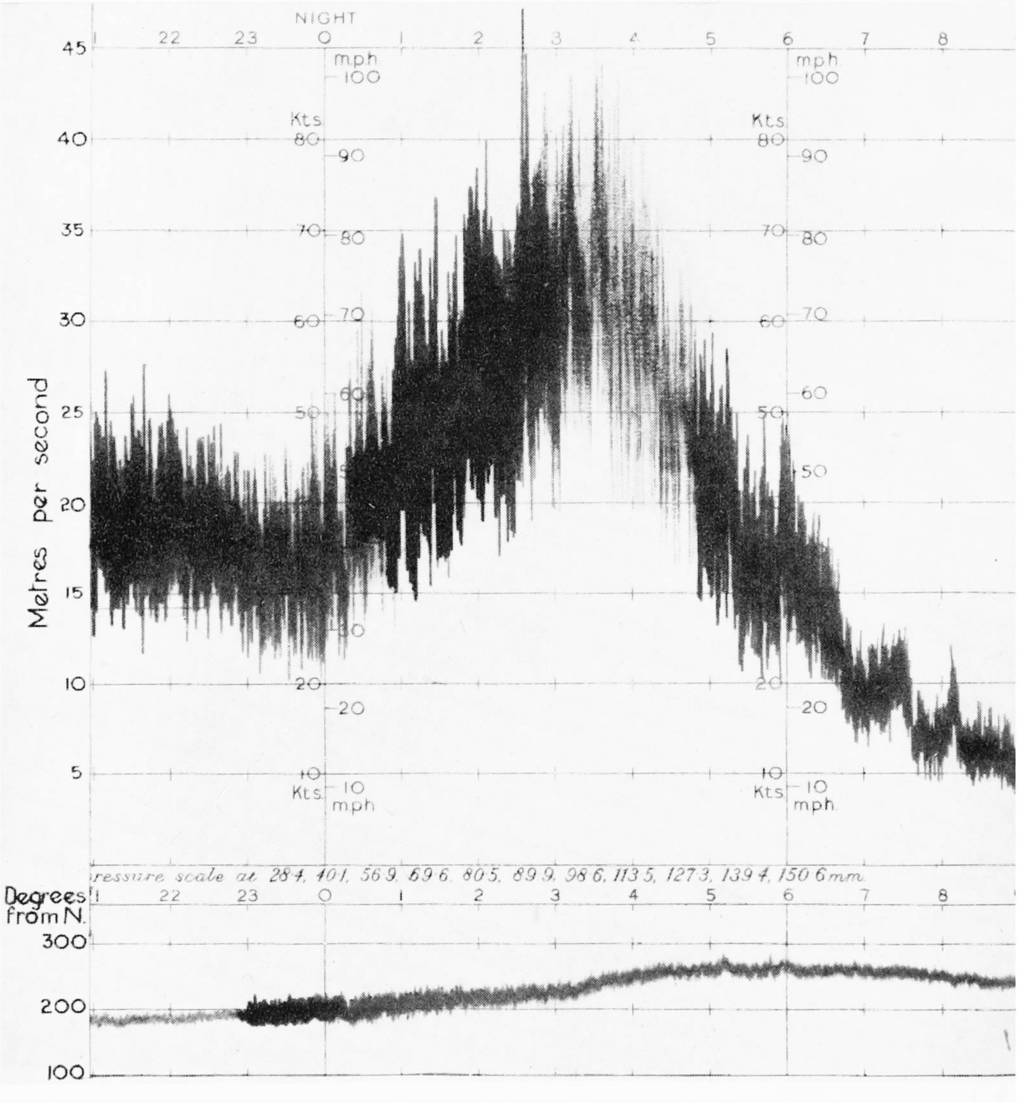
SYNOPTIC ASPECTS OF THE STORM OVER NORTH SCOTLAND ON JANUARY 15, 1952

By C. K. M. DOUGLAS, B.A.

The hurricane was due to an extreme example of the normal type of storm-producing depression, which starts with a large warm sector, deepens greatly while moving quickly, often for a long distance, and attains great intensity just after occlusion, forming a moving vortex with a great concentration of isobars to the right of the track. The chart for 0600 G.M.T. on January 15 is reproduced, including the track from the evening of the 14th till 1800 on the 15th. The relevant anemogram and barogram for Lerwick and the anemogram for Stornoway are shown in the photographs facing pp. 104 and 105. The centre was just west of Lerwick at 0600, and the lowest pressure recorded, 952 mb., occurred there at 0700. The largest 3-hr. fall was 16·5 mb. at Lerwick between 0300 and 0600. The extreme recorded speed was at Grimsetter in the Orkneys, with gusts exceeding 105 kt. (120 m.p.h.) at the trough of the depression. Topographical influence favoured a concentration of wind near the north Scottish coast, and the fact that the centre passed 100 miles from the Orkneys also favoured extreme winds—very near the centre there is a large curvature effect. At Lerwick the worst of the gale, with gusts up to 90 kt. (104 m.p.h.), occurred behind the centre at 0830, when pressure had been rising very rapidly for 1½ hours. (In the three hours to 1000 the rise was 21·6 mb.) Wick recorded gusts of 100 m.p.h. at 0500; this is very remarkable for an off-shore wind. The meteorological officers at Grimsetter and Wick report that, between 0500 and 0600, the needles of the cup generator anemometers were hard against the stop [about 93 kt. (107 m.p.h.)] for periods



ANEMOGRAM AND BAROGRAM FROM LERWICK OBSERVATORY, SHOWING THE PASSAGE OF THE HURRICANE OF JANUARY 15, 1952

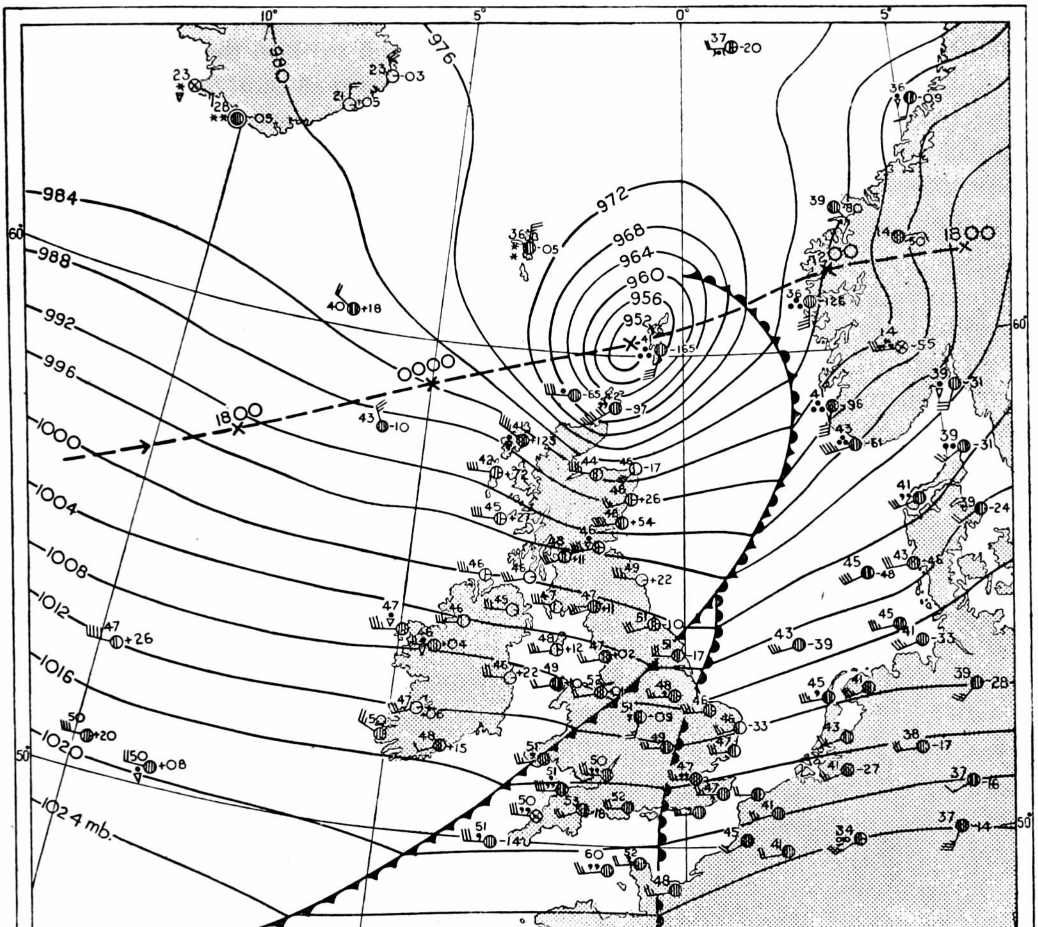


ANEMOGRAM FROM STORNOWAY SHOWING THE PASSAGE OF THE HURRICANE OF JANUARY 15, 1952

The metres-per-second scale on the left-hand side has a small error, 90 kt. is equivalent to 46·3 m./sec., 80 kt. to 41·2 m./sec., and so on.

of 10 sec. at a time. The assistant on duty at Wick did not dare to open the screen at 0700 to read the thermometers. Winds of force 10 occurred generally up to 200 miles from the track of the centre, and also at Bell Rock, 250 miles from the track.

The depression was first shown as a well marked system at 1800 on January 12, at 34°N., 53°W., between Bermuda and the Azores. It moved slowly for the first twelve hours, and then entered a strong thermal field and moved quickly north-east, curving slightly to the right as it neared the Scottish coast. At 0600



SYNOPTIC WEATHER MAP, 0600 G.M.T., JANUARY 15, 1952

on the 14th the centre was at 52°N., 32°W., with pressure about 990 mb., and at 1800 it was at 57½°N., 17°W. with pressure about 978 mb., probably not yet occluded. So far as can be judged without actual observations at the centre, the most rapid deepening was between midnight and 0600 on the 15th, when the distance from the centre to the point of occlusion increased from about 100 to 350 miles. There was evidence of elongation from west-south-west to east-north-east at midnight, along the direction of motion, as is frequent just after the occlusion of a deep depression, when the occlusion has been bent in such a way that it protrudes out ahead of the centre along its track; a short back-bent occlusion is formed, but when the vortex becomes intense both parts of the occlusion are soon twisted up. The trough which was behind the centre at midnight can be detected on the 0600 chart to the south of the centre, and it contributed to the extreme concentration of wind in the neighbourhood of the Orkneys. It was a typical vortex trough, with the air at 2,000 ft. (and in this case even at sea level) travelling rapidly round it. By 0600 the main occlusion was off Norway, and it is not drawn into the centre of the depression owing to the twisting in progress.

The succession of 1000–500-mb. thickness charts showed a large and pronounced thermal wedge over the warm sector, and at 0300 on January 15 the wedge had become thinner with sharply curved thickness lines, its crest being over the occlusion about 150 miles east of the sea-level centre. This was a favourable situation for deepening, but it does not in itself explain the severity of the storm. The development of intense vortices just after occlusion is not yet understood. Continued fast movement after occlusion helps to maintain the severe gale on the right of the track, and a strong general gradient is important. The extreme phase is short, and the depression soon becomes weaker.

Rainfall in the 24 hours ending 0900 on January 15 amounted to 11 mm. at Lerwick and 5 mm. at Grimsetter and Sule Skerry, but most of it was due to the occlusion, and it was slight during the storm as often happens when severe gales are in progress. There was no rain during the severe gale in southern England on March 16, 1947, but one in the same area on December 6, 1929, was accompanied by thunderstorms and heavy rainfall. There are also occasional rainy vortices in the autumn, like weak tropical cyclones, but these are in a different class.

Very great damage was caused by the storm in Orkney and Caithness. The most serious economic loss appears to have been produced by the sweeping away of haystacks and such light farm structures as hen houses, with serious consequences for the large Orkney egg industry. Trees, telegraph poles and walls were blown down and houses unroofed. Early morning workers in towns such as Wick and Thurso had to dodge flying sheets of corrugated iron, slates and masonry as they made their way through the debris-strewn streets.

Just over a fortnight earlier, on December 30, 1951, an almost equally severe storm affected Scotland, differing only in small details from that of January 15. The centre (down to 961 mb.) passed very close to the north coast of Scotland, which did not get the worst of the gale, so that the topographical effect was unimportant in that area, though it was important in the Clyde-Forth valley where extensive damage was done. The gale was not quite so concentrated and it affected a somewhat wider belt with a lower extreme velocity, and there was less back-bent trough, the isobars in the vortex being more nearly circular.

The whole period from December 24 to January 18 was stormy, but of the four outstanding storms which affected some part of the British Isles three occurred in late December. During the stormy period there were also three depressions in the Iceland area with a central pressure below 950 mb., and one (January 5) with a central pressure probably just below 940 mb. with actual readings of 941 mb. in Iceland. The other very deep Iceland depressions, on December 24–25 and on January 13, were followed by the British storms of December 27 and January 15; and they influenced the tracks of the more southerly storms and the severity of the gales. Six of the great storms (four in our own area, two in the Iceland area) were associated at one period with pressure falls exceeding 16 mb. in 3 hours, due to combined movement and deepening.

EXCEPTIONAL RAINFALL OF TRINIDAD, FEBRUARY 1951

By R. FROST, B.A.

Introduction.—According to popular belief, the weather of Trinidad can be divided into two seasons—a dry season from January to mid May and a long wet season from mid May to December. Garbell[1], referring to the dry season, states that in the southern Windward Islands, Trinidad and the adjacent Venezuelan coast, little weather of an orographic nature and no frontal weather whatsoever is experienced from January to June. An examination of the rainfall records, however, whilst confirming the popular belief in a relatively dry season, suggests that, apart from the fact that from mid May Trinidad is experiencing its wet season, Garbell's statement is altogether too sweeping.

At the St. Clair experimental station in Port Trinidad where rainfall records have been kept for 90 years, the average rainfall in February is 1·56 in. Before 1951 only twice in February has a monthly rainfall of 6 in. been exceeded, namely 6·36 in. in 1867 and 6·53 in. in 1880. In February 1951 all rainfall records in Trinidad and the neighbouring islands were broken, and at St. Clair 10·92 in. were recorded.

In the island of Barbados, 220 miles to the north-east, the rainfall for February 1951 was 13 in., or more than six times the normal (2·10 in.) which is based on records at eight stations which have maintained continuous records for the 100-year period 1851–1950.

A description of the rainfall of Trinidad in February 1951 is given in the present note and the main synoptic features responsible for this rainfall are briefly discussed. A fuller discussion will be given elsewhere.

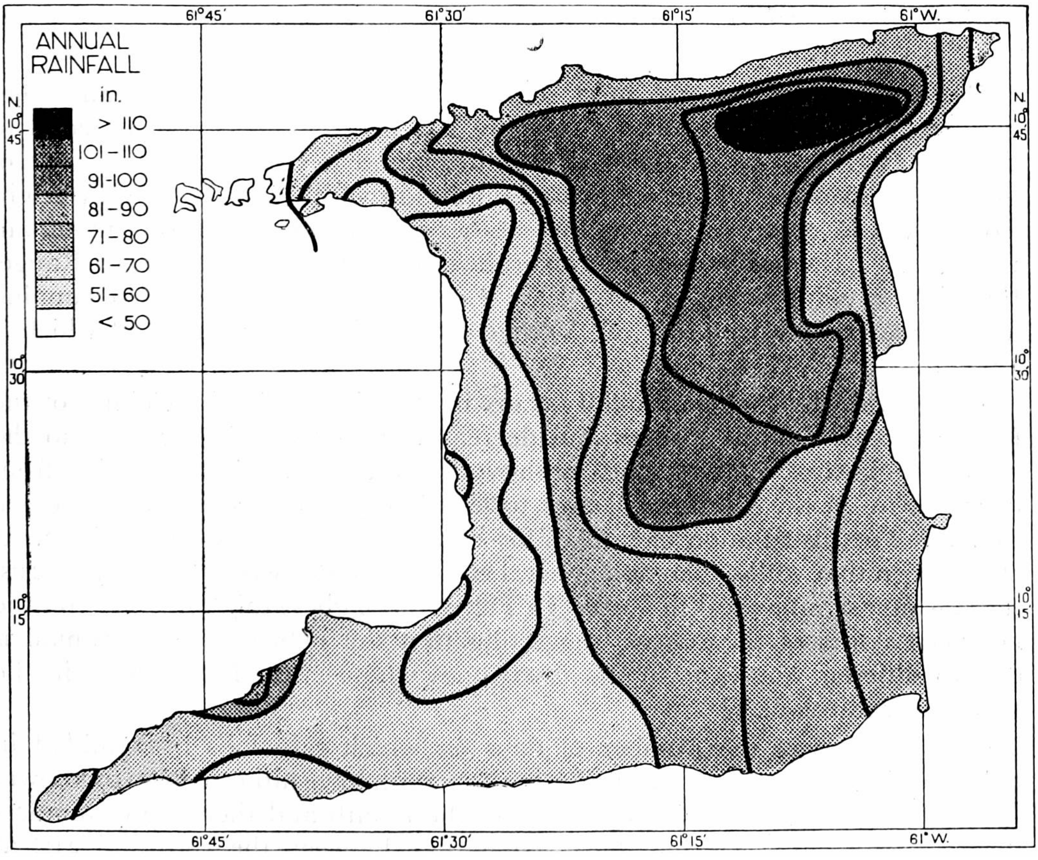


FIG. 1—ANNUAL RAINFALL DISTRIBUTION OVER TRINIDAD

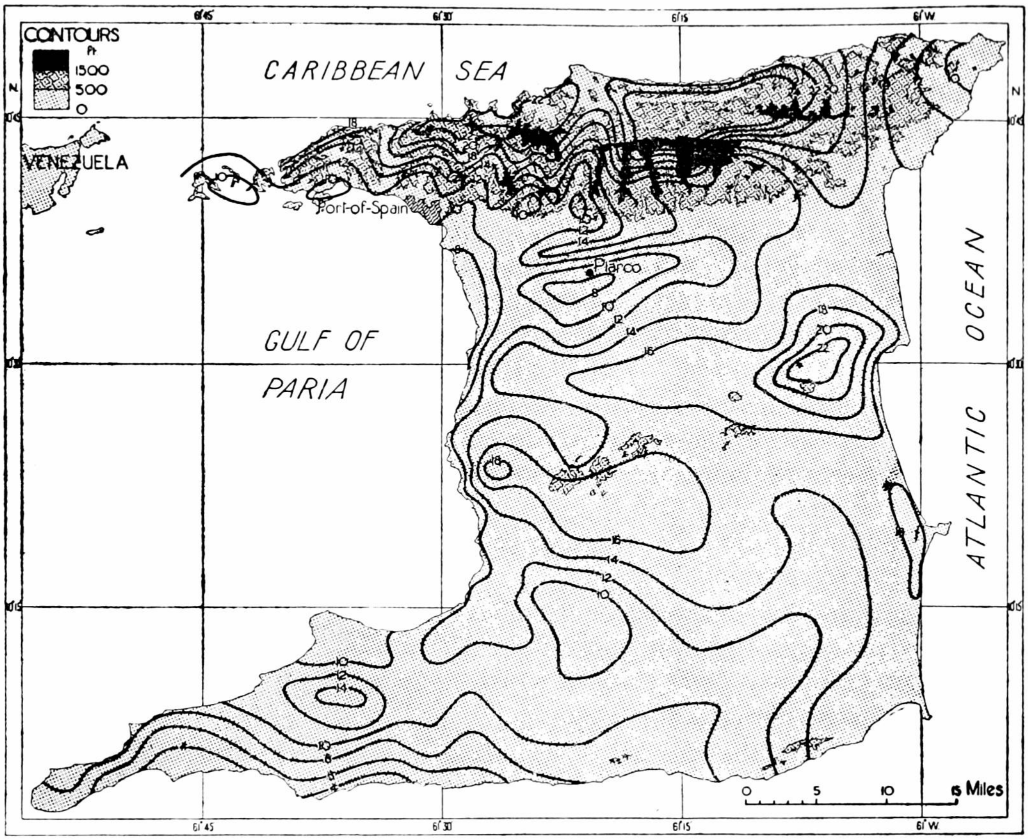


FIG. 2—RAINFALL DISTRIBUTION OVER TRINIDAD IN FEBRUARY 1951
The isohyets are in inches

General.—Trinidad, the most southerly of the West Indian islands, lies between 10° and 11°N. and 61° and 62°W., just off the north-east coast of South America. The northern side of the island is bounded by a range of densely wooded mountains, eight to ten miles in width, and varying in height from 1,500 to 3,000 ft. Along the southern coast there is also a mountain range, but it is considerably inferior in height to that of the Northern Range, the highest point being 997 ft. In the centre of the island, also running approximately east-west is a third range of hills the highest point of which is 1,009 ft.

In general, the highest rainfall occurs in the districts in the vicinity of the Northern and Central Ranges and decreases away from these ranges to the coastal regions of the west and south-west, the annual rainfall varying from over 110 in. in the Northern Range to less than 50 in. in the south-west (see Fig. 1). The distribution of rainfall for February 1951 is shown in Fig. 2. It can be seen that whilst there is a general resemblance between the two patterns, there is one significant difference. In Fig. 2 the highest rainfall occurs on the northern slopes of the ranges, suggesting that the February 1951 rainfall is due to different causes from the usual ones whose effect is expressed in the annual distribution.

On the average the number of days on which rain falls in Trinidad in February is nine, and thunderstorms in this month have hitherto been unknown. In February 1951 rain fell on 25 days of the month and there were thunderstorms on six days. During the worst period, between the 19th and 21st at stations in valleys in the Northern Range, falls of over 7 in. in 24 hours were recorded.

Synoptic aspects of the period February 12–21, 1951.—In the light of these rainfall totals Garbell's statement that little orographic and no frontal weather occurs in Trinidad in the dry season is clearly erroneous.

The causes of the rainfall in the dry season are however open to dispute. Riehl[2], Powis and Thompson[3], and others consider that the rainfall of the Lesser Antilles in the dry season is due to outbursts of polar air from the North American continent which move south-east across the Caribbean Sea giving rise generally to lines of instability showers but occasionally to prolonged spells of disturbed weather. Marsden and Fairley[4], who investigated the weather of the Lesser Antilles during the dry season, January to March 1946, concluded that the rainfall was not due to any cold outburst moving down from the North American continent but occurred in definite belts of two types which moved into the Caribbean Sea from the Atlantic. They suggested that these might be the remains of old cold fronts which had moved along the eastern side of the Azores high. They further noted that, to an observer on the ground, the cloud formations and sequences of the type which gave the worst weather were similar to those of warm fronts of temperate latitudes.

As the rainfall during the wet season, in which most of the annual rainfall occurs, is due to waves in the deep easterlies and to quasi-periodic oscillations in the intertropical convergence zone which is then south of Trinidad, the difference in pattern between Figs. 1 and 2 suggests that the rainfall of Trinidad in February 1951 was caused by disturbances moving down from the north-west. This is confirmed by a study of the synoptic charts for February 1951 which showed that the weather in Trinidad was mainly due to three outbreaks

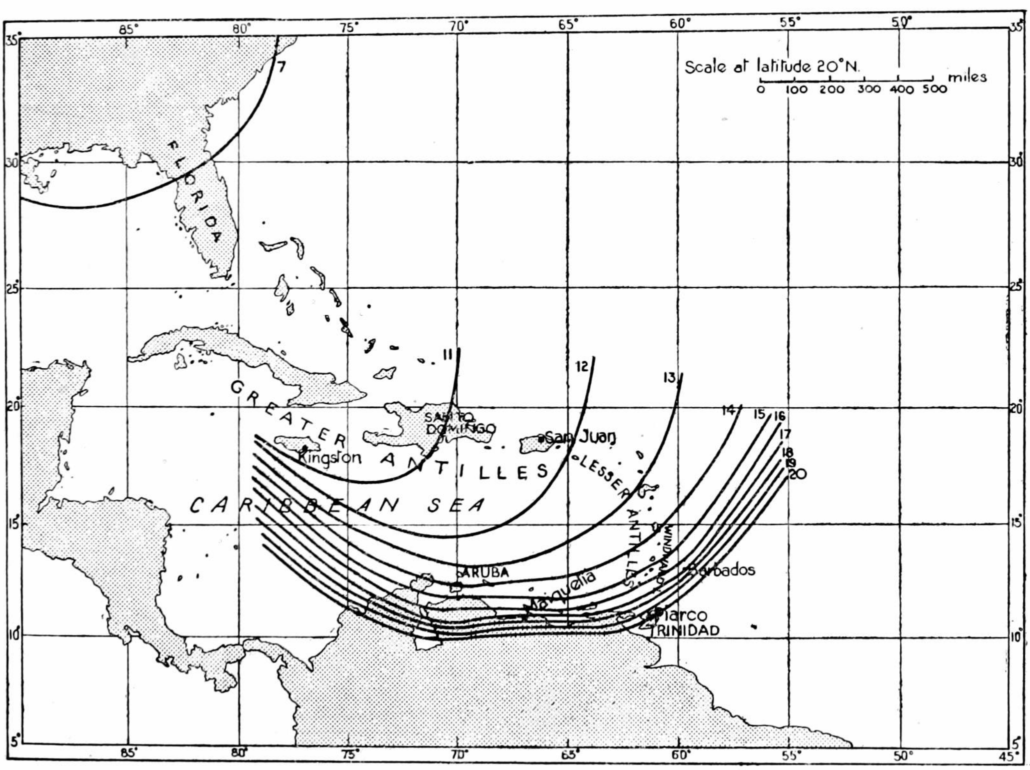


FIG. 3—ISOCHRONES OF THE COLD FRONT, FEBRUARY 11–20, 1951

of cold air at approximate intervals of nine days from the North American continent. The disturbance responsible for the spell of bad weather in Trinidad from the 19th to the 21st could easily be followed through the islands from Santo Domingo, and the isochrones of this front are shown in Fig. 3. It was accompanied by a wind shift from SE. to NE., the winds were stronger on the poleward than the equatorial side, and there was a deterioration behind the front. Through the islands of the Greater Antilles where the front moved at a speed of about 13 kt. the weather deterioration was slight, but over the islands of the Lesser Antilles where the front rapidly decelerated the weather deterioration was more severe and heavy rainfall occurred. Fig. 4 shows the position of

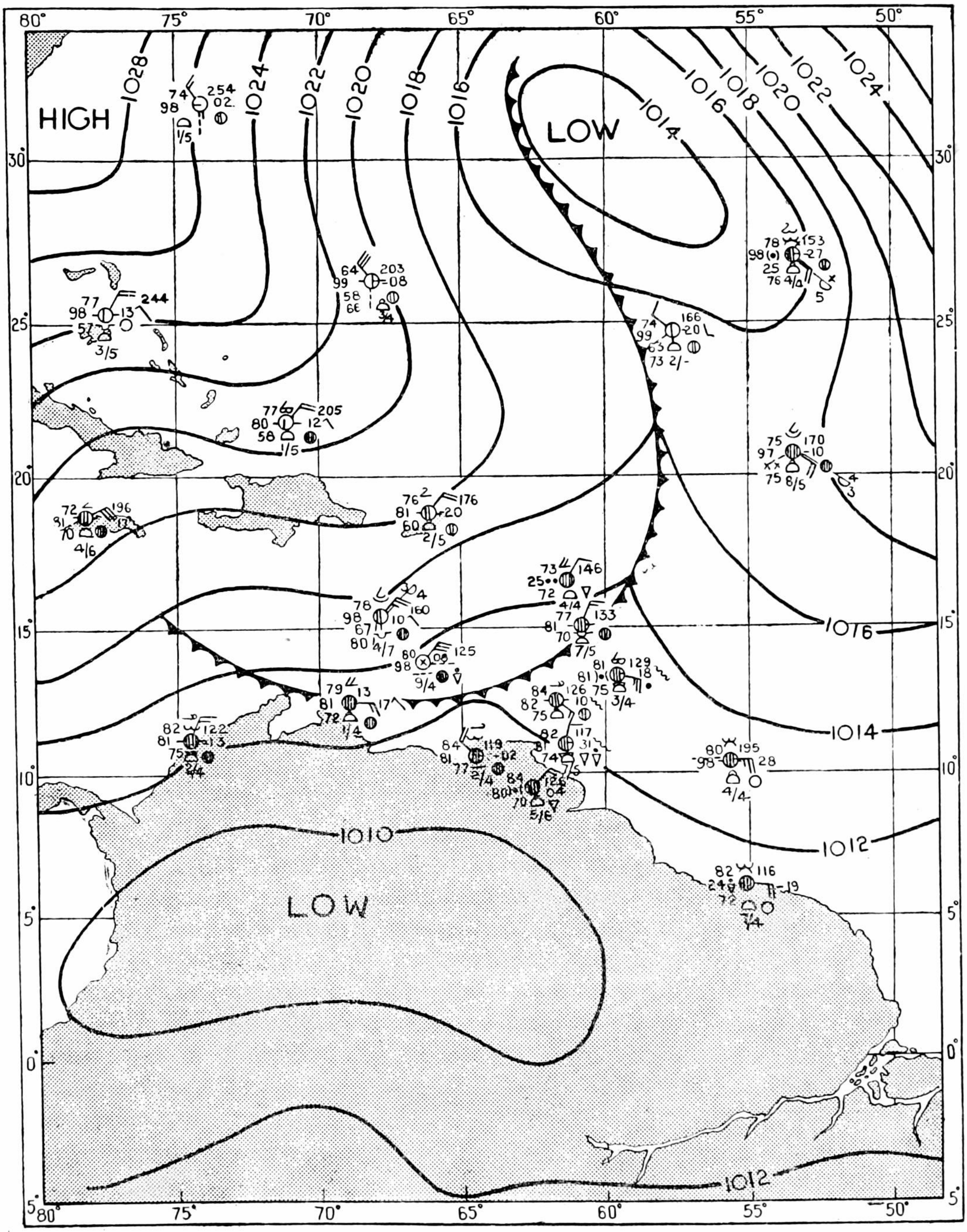


FIG. 4—SYNOPTIC WEATHER MAP, 1800 G.M.T., FEBRUARY 14, 1951

the front at 1800 G.M.T. (1400 local time) on the 14th. It is of interest to note that on this chart there is a noticeable fall of temperature and dew point behind the front.

Ground observations in the Greater and Lesser Antilles and the air observations from daily flights between Kingston (Jamaica) and Maiquetía (Venezuela) and Piarco (Trinidad) show clearly that the disturbance moved south-east across the Caribbean Sea and was associated with an outburst of cold air from the North American continent. These observations do not however appear to fit either the typical cold front of temperate latitudes or the various possible transformations of a cold front in tropical latitudes but in fact appear to fit a warm front. Coyle[5] has noted a similar effect in South America where cold

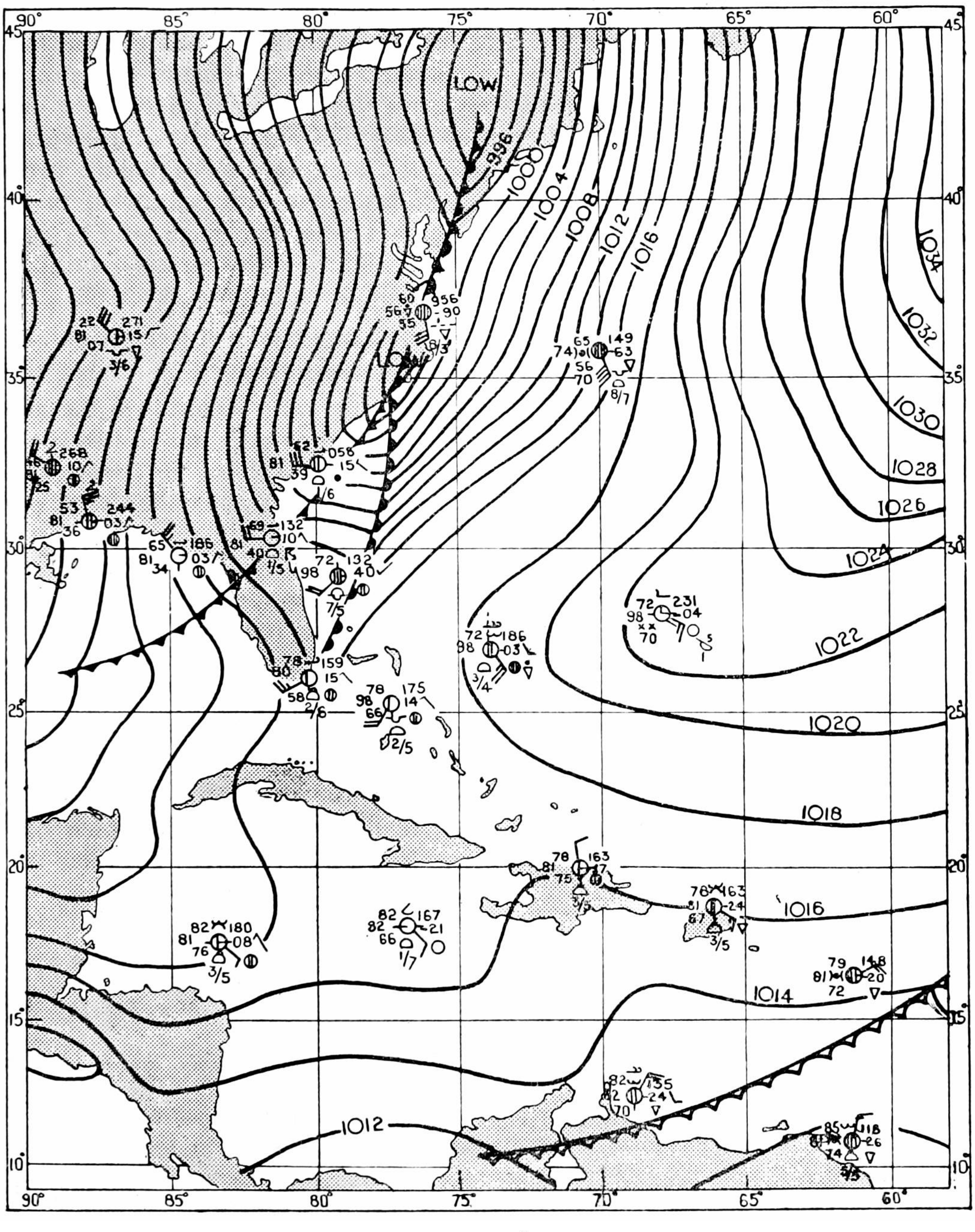


FIG. 5—SYNOPTIC WEATHER MAP, 1800 G.M.T., FEBRUARY 7, 1951

fronts, which pass Buenos Aires, frequently look like warm fronts by the time they reach Rio de Janeiro.

At San Juan, Puerto Rico, for example, on the 11th there was increasing cirrus and cirrostratus cloud with small amounts of low cloud at first, which by 0900 local time on the 12th had increased to three complete layers of cloud at 3,000 ft., 15,000 ft. and 25,000 ft. The medium and low cloud broke and decreased after 1100, and there were intermittent showers in the afternoon and evening. On the 12th a pilot flying at 18,500 ft. from Maiquetía to Kingston reported 8 oktas high cloud at 20,000 ft. thickening towards the island of Aruba, with a row of cumulonimbus tops at 18,000 ft. with 8 oktas high cloud above, 140 miles north of Aruba. Between there and Kingston there was 8 oktas high cloud at about 30,000 ft. with cumulus cloud decreasing from 5 to 2 oktas with tops at about 6,000–8,000 ft. On the 19th when the front was approaching Trinidad, the weather at Piarco was cloudy with 7–8 oktas cirrostratus, altostratus and altocumulus clouds, but until the afternoon there were only small amounts of low cloud. After 1500 local time heavy showers occurred along the Northern Range but the rainfall at Piarco, in the flat plain between the Northern and Central Ranges, was slight and no rain occurred in the south. On the morning of the 20th the medium cloud thickened, and by 0400 local time had become 8 oktas of nimbostratus and there was almost continuous rain for eight hours, a most unusual phenomenon even in the wet season.

Such observations are very difficult to fit into any model of a cold front, but they can easily be fitted to an occlusion of the cold-front type.

It is suggested that the weather was, in fact, due to an occlusion of the cold-front type, and that the change in the weather régime over the United States in the early part of February was responsible for this. During the first week of February 1951 the eastern part of the Caribbean Sea was flooded with cold air which moved southwards round a slow-moving high in the south-east of the United States. On the 6th another high moved over the central United States, and the interaction between the cold polar air spreading rapidly over this area from the new high and the cold maritime air returning round the old high resulted in the formation over southern Texas of a small low which in turn caused warm moist air from the Gulf of Mexico to move in over Florida on the 7th (see Fig. 5). It is suggested that this warm moist air was overtaken and trapped by the cold air which moved southwards over Florida between the 8th and 11th and continued to move south-east over the Caribbean Sea.

It is possible that the prolonged spells of disturbed weather which have affected the Lesser Antilles in other years have been caused by similar cold occlusions.

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METEOROLOGICAL OFFICE DISCUSSION

Measurement of free air temperature from aircraft

The fifth discussion of the present series was held on February 11, 1952, the subject being "Measurement of free air temperature from aircraft".

Mr. D. R. Grant, who opened the discussion, said that, apart from calibration errors, there are four important sources of error in measurement of air temperature from aircraft.

(i) Position of the thermometer on the aircraft.—The thermometer must be in a position where the air flowing past it has not been heated previously by passing over a warm surface of the aircraft.

(ii) Solar radiation on the thermometer.—Absorption of solar radiation raises the temperature of the thermometer above the air temperature. Radiation shields reduce the error, but it is customary to fix the thermometer in a position where it is shielded from solar radiation by the aircraft itself, e.g. under the wing or nose.

(iii) Lag.—When air temperature is changing, thermometers do not show the true air temperature at any instant, but a temperature related to it by the equation

$$\frac{dT}{dt} = -\frac{1}{\lambda}(T - T_a)$$

where T is the thermometer temperature, T_a the air temperature, t the time and λ a constant called the lag coefficient. If λ is known and a continuous record of T against time is obtained, T_a can be calculated from this equation. It is, however, preferable to use a thermometer with a small value of λ so that the error due to lag, $T - T_a$, is small for all values of dT/dt likely to be encountered.

(iv) Heating due to the speed of the aircraft.—An aircraft thermometer is heated by compression of the air at the thermometer or by friction with the air flowing past it. The rise in temperature is

$$T - T_a = \alpha \left(\frac{v}{100}\right)^2$$

where v is the true airspeed and α is a constant called the speed-correction coefficient. If $T - T_a$ is expressed in degrees Fahrenheit and v in knots α has a value of 1·3 to 2·4 depending on the type of thermometer.

The speed-correction coefficient is determined experimentally by flying the aircraft in air of uniform temperature and taking readings of T for different values of v. If T is plotted against $(v/100)^2$ the slope of the straight-line graph obtained is α. In practice it is impossible to find air in which T_a is constant, and, as a result of this, the values of α obtained from a number of determinations show a large scatter. It requires many hours flying time to obtain an accurate mean value of α. Also, α varies slightly from one position on an aircraft to another, and there is some evidence that the speed-correction coefficients of certain types of thermometers have a small variation with height.

In cloud some of the heat generated by the speed of the aircraft may be used in evaporation of the water in the cloud. Moreover, the cloud drops are colder than the air near the thermometer and cool the thermometer if they fall on it. If the cloud is supercooled, the latent heat of fusion released when ice forms on the thermometer further complicates the problem. As a result, it is not generally possible to measure temperature as accurately in cloud as in clear air.

Mr. Grant then described three types of thermometer, the first being the Meteorological Office aircraft electrical resistance thermometer (often called the "flat-plate" thermometer) with its balanced-bridge indicator.

The second type of thermometer described was designed in the United States to have a zero speed-correction coefficient. The thermometer is at the centre of an air vortex where the temperature can be made equal to the true air temperature at all airspeeds.

The third thermometer described is known as the ultra-rapid thermometer and was designed by the Meteorological Research Flight. It has a lag coefficient of about 4 milliseconds and can therefore record rapid changes of temperature. The element consists of a freely exposed platinum wire 0·001 in. in diameter.

Mr. Grant then showed some examples of the type of result which can be obtained by the use of aircraft thermometers in the Meteorological Research Flight. He illustrated how by flying in a grid-shaped pattern, isotherms in a horizontal surface can be mapped out. These show the existence of 2–3°F. variations of temperature in a "uniform" air mass. It is these fluctuations which cause errors in the determination of the speed-correction coefficient. He also showed that in a "uniform" air mass there can be an inversion of temperature of 2°F. at one place but no inversion at all only five miles away. Examples of results obtained from flights through frontal surfaces were then shown. A flight on August 11, 1949, showed that the change in temperature at 18,000 ft. was spread over a distance of about 100 miles. In this transitional region there was a well marked periodic fluctuation in temperature. This periodicity was even more noticeable on entering the warm air. A flight on November 3, 1950, at 19,000 ft. through a front showed a change of temperature of 18°F. in 80 miles. Again there were large fluctuations of temperature in the frontal zone, but on this occasion the most interesting feature was the dryness of the air in the area in which the temperature change took place. The isotherms in a vertical cross-section through this front were also shown. Similar cross-sections have been obtained at the tropopause and a typical example was illustrated.

Finally some of the results from flights using the ultra-rapid thermometer were given. These showed the fluctuations of temperature associated with high-level turbulence. They also gave proof of the existence at high levels of large changes of temperature occurring in distances of a few yards, and of small patches of warm and cold air up to 4°F. different in temperature from their surroundings. They also showed the temperature structure in the horizontal at a low level over the sea in unstable conditions. An ascent through an inversion taking simultaneous observations on the ultra-rapid thermometer and a standard Meteorological Office aircraft thermometer illustrated the errors introduced by lag.

The Director said that the results shown by Mr. Grant emphasized once again the patchiness of the air at all levels. He asked how the vortex thermometer is adjusted so that it reads the true air temperature at all speeds. Mr. Grant, in reply, said that there is a valve which is adjusted at some arbitrary airspeed until the vortex thermometer reads the same temperature as the flat-plate thermometer after the latter has been corrected for airspeed. The positioning of the valve can then be checked by flying at different airspeeds and observing that the vortex thermometer reading does not alter.

Mr. D. D. Clark gave an account of the work being done in the Instruments Division of the Meteorological Office. He quoted the results of theoretical investigations into the value of the speed-correction coefficient of the flat-plate thermometer, and explained that the decrease of α with height is probably due to a transition from turbulent to laminar flow in the boundary layer. He referred to two devices which had been tried to overcome variations due to transition. One device was the use of suction slots behind the leading edge of the flat plate to keep the boundary layer on the surface at this point. The other was to use a conical shape to maintain laminar flow. The former gave the more promising results. Mr. Clark also described the total dynamic pressure thermometer of Malmquist, but explained that such a thermometer is not sufficiently robust for routine use on an aircraft and is susceptible to icing. Finally, Mr. Clark mentioned a thermometer in which the air is accelerated to the speed of sound before its temperature is measured. The true air temperature is then always the same fraction of the indicated temperature, but this type of thermometer is not suitable in moist air because condensation would take place during the acceleration. In reply to the Director, Mr. Clark said that if he had to recommend a thermometer for jet aircraft now, he would advise the flat-plate, provided care was taken in manufacture to make it really flat.

Dr. Scrase asked if it would be possible to put the sensitive element at a place where the flow was always either turbulent or laminar. Mr. Clark replied that this was not easy, owing to the variation of the transition point on a surface.

Dr. Frith said that if the transition to turbulent flow takes place at speeds which Meteorological Research Flight aircraft can reach, then surely the flow will always be turbulent at high speeds, and, if Mr. Clark's theory is correct, there should be no variation of α with height in high-speed aircraft.

Mr. Murgatroyd said that airspeed indicators may have errors of about 2 kt. which would cause an error of 0·2–0·3°F. He also emphasized the need for a small lag coefficient.

Mr. Shellard suggested that the vortex thermometer might be suitable at high speeds if it could be made small enough.

Mr. Day said that tests at the Meterological Research Flight showed that the vortex thermometer departed no more than 0·5°F. from the true air temperature at heights 12,000 ft. above and below the height at which the valve was set, and at airspeeds over a range of about 100 kt.

Dr. Scrase asked if more accurate temperatures would be obtained by having the thermometer well in front of the aircraft. Dr. Frith and Mr. Grant both replied that no improvement would be obtained.

Dr. Robinson asked if there is any need for high accuracy if temperature fluctuations of 2–3°F. are present at all levels.

The Director said that there are two requirements (*a*) an accurate thermometer with fast response for research, and (*b*) a thermometer for service use giving a reliable indication of the mean temperature at a given height.

Mr. Grant said, in reply to points raised by Mr. Houghton and Mr. Caton, that the larger-scale temperature patchiness is in the form of shallow bubbles and is unlikely to cause appreciable static pressure variations at the surface. He said the patterns in the isotherms are unrecognizable after about an hour, but it is possible that this is due to the difficulty of flying an aircraft in the same air for such a long time. It takes about an hour to obtain a pattern in an area of 600 square miles, but adjacent parts of the pattern are obtained within five to ten minutes of each other.

There was some discussion on the possibility that fine-wire thermometers were not recording air temperature fluctuations but variations in strain caused by vibration of the wires. Both Dr. James and Mr. Grant said this was almost certainly not the case.

Mr. Gold asked about the performance of the vortex thermometer in cloud. Mr. Grant said that even if the thermometer does not get wet because the drops are centrifuged out in the vortex motion, it may still not read the true air temperature if evaporation has taken place at any stage. He mentioned that a wet-bulb thermometer might be useful in measurement of cloud temperature, as its reading is the same whether or not evaporation from cloud droplets takes place during a compression.

METEOROLOGICAL RESEARCH COMMITTEE

The thirteenth meeting of the Instruments Sub-Committee of the Meteorological Research Committee was held on February 1, 1952. Progress with the development of the high-altitude searchlight method of measuring atmospheric density was discussed, and it appears that there is every hope that the two-station technique will give reproducible results, but little progress has been possible with solving the problem of obtaining a more rapid rate of decay with a spark source of light. Solution of this problem is essential to the adoption of the single-station technique.

Good progress has been made with an automatic frost-point hygrometer, and one very successful flight has been made with this instrument.

The Committee also considered recommendations for revision of the instrumental part of the Research Programme for 1952–53.

The 19th meeting of the Synoptic and Dynamical Sub-Committee of the Meteorological Research Committee was held on February 7, 1952.

At this meeting the Chairman's report to the Meteorological Research Committee was discussed, and recommendations were formulated for the revision of Part II of the Research Programme.

The problem of forecasting ice in the Icelandic fishing grounds was discussed at some length, and it was decided that until observations from a wider field were available there was little prospect of improvement in such forecasts.

OFFICIAL PUBLICATION

The following publication has recently been issued:—

GEOPHYSICAL MEMOIRS

No. 87—Characteristics of air masses over the British Isles. By J. E. Belasco, Ph.D.

This Memoir is a contribution to the synoptic climatology of the British Isles, and is an investigation into the characteristics of the more important physical properties of the atmosphere in subdivisions of tropical and polar air masses. The Memoir is in three parts and there are six appendices.

A discussion of the data used, the classification of the air masses selected, and the results of a statistical test into the reality of the temperature differences between the air masses form Part I. In Part II is a discussion of the influence, in summer and winter, of the different air masses on the vertical distribution of temperature and water vapour and the degree of thermal stability of the atmosphere from 950 to 450 mb. The effect of radiation is considered where possible. A discussion of the changes which the physical properties of tropical maritime and direct polar air undergo as these air masses travel to the British Isles is included. An examination of the incidence of the different air masses at Kew, Scilly and Stornoway and of the influence of these air masses upon the surface temperature and humidity at Kew comprises Part III.

The appendices are tables giving the incidence, temperature, wet-bulb potential temperature, vapour pressure and the degree of thermal stability of each air mass. Tephigrams of the average conditions in summer and winter in most of the air masses and maps showing the generalized tracks of the air masses are included in the Memoir.

ERRATA

February 1952, PAGE 43, equation (1), *for* "$-\frac{\partial}{\partial z}\left(\mu\frac{\partial V}{\partial z}\right)$" *read* "$-\frac{\partial}{\partial z}\left(\mu\frac{\partial \mathbf{V}}{\partial z}\right)$".

PAGE 63, AIR TEMPERATURE, column "Difference from average daily mean",

	"+18		"+1·8
for	+08	*read*	+0·8
	+09"		+0·9".

LETTERS TO THE EDITOR

Distribution of rainfall round a house

An attempt to interpret the results of the observations of rainfall recorded round a house in the July 1951 issue of the *Meteorological Magazine* raises a number of points which may be of general interest.

A rain-gauge only records a fair sample of the local rainfall while the wind at the level of the rim of the gauge does not exceed about 10 m.p.h. Owing to the wind eddies set up round the house in question and round buildings adjacent it is likely therefore that on occasions some of the gauges may have given somewhat less than the proper rainfall for that spot. It is unlikely, however, that the proper rainfall would as a result have been much greater from this cause, and then only in instances where the wind between buildings was canalized.

There may well be an error, in the other direction, arising from splashing from the roof and the walls, with winds from certain directions, although for the purpose of these experiments it is reasonable to include any such addition to the normal rainfall.

The addition explained in the preceding paragraph may well account for the fact that the normal rainfall was found to be recorded only 8 ft. from the walls to the north and east and 3 ft. from walls to the south and west of the house. Cases could be quoted where a rainfall record has appeared reliable when examined by the British Rainfall Organization, but on inspection the gauge has been found to be badly sheltered. The observations in the original paper should not be taken therefore to justify an exposure for a rain-gauge reporting to the British Rainfall Organization so close to a house, or for departing from the standard requirement that a rain-gauge should be at a distance from a house of twice the height of the house, which is about 37 ft. in this case.

It was found that an area of ground round the house, approximately equal to the area of the house itself, received less than the amount of rain falling on open ground away from the effects of the house, and that near the house on the north and east sides there was less than half the amount recorded away from the house. Clearly this rain was obstructed by the walls of the house, especially on the south and west sides. Part of this rain would be absorbed by the bricks and re-evaporated, but part would undoubtedly run down the walls and reach the ground. These experiments are of importance, therefore, in giving some measure of the additional rain falling on the walls and adjacent ground.

It is still not possible to give a clear picture of the amount of rain for which the gutters and walls need to cope. As a first approximation the rain falling on the roof surface is the same as on nearby open ground over a similar horizontal area. In so far as there will be wind eddies round the roof in its elevated position the amount would be somewhat less, the loss being distributed by the wind over a fairly wide area. Moreover some rain would be lost by splashing from the roof and this loss would reach the ground on the leeward side of the house. On the other hand any roof surface above the horizontal, and the chimneys, would obstruct rain on the windward sides. The walls of the house would also obstruct rain on the windward sides.

The final result would be that after the erection of the house less rain would reach the ground than previously, because rain would be carried off by the gutters (and this run-off could well be measured) and also because some of the rain would be absorbed by the bricks of the walls and re-evaporated, especially where the walls are well exposed to the wind. On the other hand the roof and wall surfaces are drier than the ground for a much longer period during the year, and much of the rain reaching the ground is evaporated. In London with an annual rainfall of 25 in. the evaporation from the ground may well be as much as 18 in. Presumably too, some of the moisture reaching the ground in the neighbourhood of the house percolates sideways into the ground under the house and maintains some moisture there.

As a householder, with a clay subsoil, I hope the Building Research Station will carry their investigations further and contribute a further note to the *Meteorological Magazine*, explaining whether or not the loss referred to in the paragraph above ought to be made good in some circumstances, e.g. in dry years such as 1921. It is a common practice, and one which is very convenient, to have impervious paths, etc., of crazy paving and concrete round the house on all sides, which still further reduce the amount of rain reaching the ground under and immediately round the house. Is this a good practice or not, as regards avoiding subsidence of the soil?

J. GLASSPOOLE

December 12, 1951

[As Dr. Glasspoole points out, the results quoted in the paper should not be used to justify the installation of a rain-gauge in an over-sheltered position, although it is interesting to see how little the error was in the case of some of the gauges near the house. It seems that it might be possible to get fairly reliable records of rainfall on a difficult site, for example in a heavily built up area, if such data were required for a particular purpose, although the results might not have the accuracy of those obtained on a normally exposed site.

Most building materials are porous, and it is doubtful whether much rain-water runs down the surface, except perhaps in a heavy downpour, and the major part will be absorbed, to be evaporated later. It was hoped to make measurements of the moisture content of the ground round this house and correlate the readings with the rainfall readings, but the soil proved to be so variable in type that no reliable readings could be obtained.

An impervious area round a house which prevents the growth of shallow-rooted vegetation may be an advantage in preventing drying out of the ground in summer, but if there are trees growing near it may do more harm than good. A tree evaporates a large quantity of water and the paving would hinder the replacement of this water by rainfall. Certainly it may on occasion be useful to make good the moisture in the ground which has been lost by evaporation. Some of the problems associated with building on clay soils are dealt with in *Building Research Digest* No. 3, 1949.—R. E. LACY]

Turbulence associated with a jet stream

Bannon* has reported several cases of turbulence encountered in the vicinity of jet streams. On November 14, 1951, another such case occurred; it was particularly interesting because it confirmed advice previously given on the basis of the routine upper air charts at Dunstable.

The 300-mb. contour charts for the 13th had suggested the fairly steady progress eastwards of a belt of strong winds (or jet stream). By 0300 on the 14th it was possible to trace across this country the forward edge of the jet stream and also to estimate its later positions. Inspection of the tephigrams showed that the "jet" was associated with the advance of warm air across the country, and, using the 0900 G.M.T. observations, it was possible to make a rough estimate of the slope of the incoming warm frontal surface.

Using the combined evidence of the contour charts and the tephigrams, the upper-air forecaster was able to estimate the regions of strong wind shear for the early afternoon. Basing the advice on these estimates it was suggested, to a pilot interested in observing clear-air turbulence, that he should fly between Felixstowe and Salisbury Plain and at heights between 25,000 and 30,000 ft.

Reports later showed that clear-air turbulence was encountered by an aircraft over Hatfield between 1200 and 1300 and at heights between 27,000 and 40,000 ft., the most marked turbulence being between 27,000 and 30,000 ft. This turbulence was described as being the most severe in the experience of the pilot. On the route between Felixstowe and Salisbury Plain the original inquirer encountered slight turbulence when flying at heights of 27,000, 30,000 and 32,000 ft., again the most marked turbulence being between 27,000 and 30,000 ft. Yet another aircraft reported severe turbulence at 35,000 ft. around 1500 in a position almost due south of London along the south coast.

Observations of wind from the three stations of Camborne, Larkhill and Downham Market (on a line approximately at right angles to the axis of the jet stream) illustrate the passage of the jet across the country. They are given in Table I.

These observations show clearly the large vertical shear between 400 and 250 mb. at Camborne (0300), Larkhill (0900) and Downham Market (1500). The horizontal shear is equally well marked, being generally over 50 kt. in

* BANNON, J. K.; Severe turbulence encountered by aircraft near jet streams. *Met. Mag., London*, **80**, 1951, p. 262.

TABLE I—UPPER WINDS OBSERVED AT CAMBORNE, LARKHILL AND DOWNHAM MARKET ON NOVEMBER 13 AND 14, 1951

	Camborne, 13th and 14th						Larkhill, 14th						Downham Market, 14th					
	2100		0300		0900		0300		0900		1500		0300		0900		1500	
mb.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.
200	320	28	324	61	...	...	319	33	324	80	326	89	318	21	311	38	...	...
250	323	28	325	111	314	97	318	21	327	110	317	89	341	18	305	25	315	114
300	light,		328	90	311	86	292	14	324	85	317	77	358	16	309	16	332	91
350	variable		330	66	316	70	319	7	324	55	325	61	358	15	309	14	324	39
400	333	9	327	37	322	51	340	10	286	21	316	57	331	15	299	12	282	11
450	345	13	296	22	313	39	339	24	286	21	309	51	319	19	311	20	285	7
500	345	15	290	18	318	36	335	26	300	22	310	48	320	19	323	23	299	12

100 miles. Thus both the features mentioned by Bannon as being favourable for the occurrence of clear-air turbulence were clearly satisfied on this occasion.

We can note also that the horizontal shear increased steadily from 350 to 250 mb. (compare the winds over Larkhill and Camborne for 0300, and over Larkhill and Downham Market for 0900), whilst the maximum vertical shear was between 400 and 300 mb. and most probably between 350 and 300 mb. The aircraft reports showed the most marked turbulence between 27,000 and 30,000 ft., or approximately between 350 and 300 mb. Thus this example could be taken as an indication that the vertical shear is the more important factor.

Dunstable, December 18, 1951 J. BRIGGS

Snow drifts at Wick

During the latter part of January 1952 there was much drifting snow at Wick, Caithness. The meteorological enclosure at the Civil Airport seemed to cause drifting, as shown by the photographs facing this page.

Snow showers occurred during the night of January 8–9 and by 0900 on the 9th snow lay half an inch deep. Further showers fell during the day and night of 9th–10th and the wind force increased to westerly, 17–25 kt. The temperature did not rise above 32°F. between 0700 on the 9th and 0200 on the 10th, falling as low as 26°F. The strong wind blew the snow off the ground causing drifts, and the upper photograph shows the drift in the instrument enclosure of the meteorological office. This drift built up till it was level with the top of the fence (3 ft. 6 in.) after which it ceased to grow in height and it was noticed that the wind seemed to suck it off in swirls. The fence probably broke up the wind causing eddies and lighter breezes inside the enclosure as this was the deepest drift on the airfield and the level of the snow around the enclosure was only about 2–3 in. Although attempts were made to keep the rain-gauge uncovered, the drifting made it impossible to measure the equivalent rainfall amounts at 1800 and 2100 on the 9th and 0600 on the 10th.

On the 25th, 26th and 27th there were further falls of snow with heavy drifting. The lower photograph, taken during the forenoon of the 28th, shows the enclosure partly cleared, the snow having been thrown out on the further side of the fence. The drift against the fence nearest the camera was created by the wind and is not due to snow being thrown from the enclosure.

At about 0400 on the 26th the wind increased and by 0700 was force 8 from 350–360°; this caused very heavy drifting. Further snow fell during the day and night and further drifting occurred; by the morning of the 27th the enclosure was completely drifted over. There were higher drifts around the hangars than in the enclosure on this occasion.

Wick, January 31, 1952 W. C. GLANDER

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SNOW DRIFTS AT WICK AIRPORT, JANUARY 10, 1952

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SNOW DRIFTS AT WICK AIRPORT, JANUARY 28, 1952

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FLOODS AT KEW, RICHMOND, JANUARY 1, 1952

NOTES AND NEWS

Floods at Kew

The River Thames flooded in the late afternoon of December 31, 1951, and the flood waters remained until late on January 2, 1952. Photographs of the flooding are reproduced facing this page. The upper photograph was taken at 0900 on January 1 from the golf course, approximately north-east of the Observatory, and the lower photograph at noon from the Observatory roof looking north.

The flood was not so severe as the one in the early morning of November 29, 1951, when the depth of water at the fence shown in the lower photograph reached a maximum of about 2 ft. 6 in.

Electrical phenomenon observed in flight over southern England

On the afternoon of Tuesday, August 7, 1951, a Hastings aircraft of the Meteorological Research Flight was engaged in the investigation of the droplet size distribution in cumulus and cumulonimbus clouds over southern England. One cloud chosen was a large cumulonimbus which had developed to above 22,000 ft., but at the time of observation had assumed a fibrous appearance at the top which was dissolving fairly rapidly. Several runs were made through the top on reciprocal headings, descending 2,000 ft. between each set of two runs. The method of collecting the drops was to hold out an instrument known as an impactor through the second pilot's window, and, by means of a spring-loaded shutter, to expose momentarily a glass slide coated with a thin layer of magnesium oxide. The size of the droplets impinging on this slide are related to their impressions on the magnesium oxide. The instrument itself is made of brass, and it was not bonded to the airframe. During the run at 8,800 ft. the observer holding the impactor experienced an electric shock as it passed through the plane of the window. This also caused a loud crackle over the intercom which was already affected by static interference. The explanation offered at the time was that the impactor had touched the outside skin of the aircraft which was presumably carrying a charge, although the holder was fairly sure that it had been kept clear of the airframe. The instrument was again held out, care being taken not to touch any metal parts of the aircraft. Immediately the impactor came into line with the window, the observer again experienced another shock (both shocks incidentally were felt only in the back of the head and neck and not in the arm holding the impactor). The instrument was immediately withdrawn into the cabin, and whilst it was being pulled in, approximately 1 sec. after the shock, an extremely loud bang was heard, and the cockpit was illuminated by an intense light which seemed to last for about 1 sec. Observers in different parts of the aircraft saw different effects as follows:—

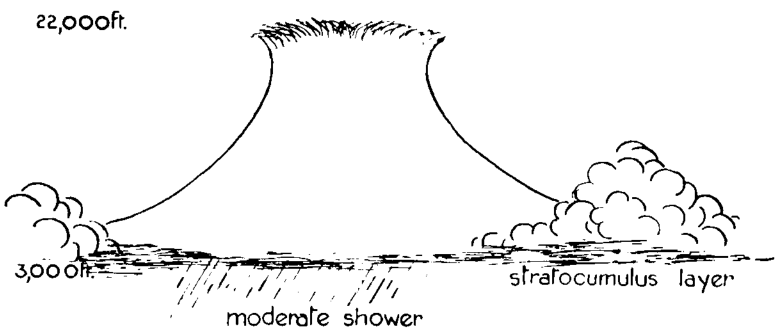
(i) From the co-pilot's seat, the flash appeared to be between himself and the pilot, near the instrument panel and the aircraft controls, and appeared as a white floating ball of fire. Its disappearance and the bang were simultaneous.

(ii) A second observer immediately behind this position also saw the flash in the same place, and also reported that the observer holding the impactor was surrounded by a bluish glow.

OBSERVATIONS DURING DESCENT THROUGH CUMULONIMBUS, AUGUST 7, 1951

Height	True air speed*	True air temperature*	Remarks
ft.	kt.	°F.	
22,000	...	...	Approximate top of cloud (time: 1530 G.M.T.)
21,000	143	−12·0	Fairly thin ice-crystal cloud becoming thicker immediately below.
20,000			
19,000	157	− 3·6	Still ice-crystal cloud.
18,000			
17,000	149	+ 4·2	Cloud becoming thin; ice crystals visible.
16,000			
	...	...	White ice appeared quite suddenly over spinners and leading edges.
15,000	148	+10·7	Ice crystals again visible.
14,000			
13,000	142	18·3	Ice crystals at first, then supercooled water; more rime ice and moderate to severe continuous bumpiness, estimated 0·2*g* to 0·3*g*; heavy hail between 12,500 ft. and 12,000 ft.
12,000			
11,000	142	22·4	More hail and clear icing now.
10,000			Snowing.
			Out of cloud for a short time.
9,000	...	...	Liquid water giving clear ice then changing to snow; atmospherics affecting aircraft radio.
8,000	...	...	Still in snow.
7,000			
6,000	...	...	Liquid water down to cloud base.
5,000			
4,000			
3,000	...	...	Cloud base (time: 1600 G.M.T.)
2,000			
1,000			
Surface			Moderate rain shower at Farnborough from this cloud.

* Taken on a level run.



(iii) A third observer in the rear portion of the aircraft, whose duty was to note such things as density of the cloud, icing, temperature, etc., saw streaks of lightning passing along the leading edge of the wing on the starboard side. This however may have been reflection of light inside the cockpit. There was no one observing from the port side.

After these incidents it was decided in the interest of safety to abandon any further investigation. On return to base this cumulonimbus was just crossing the airfield from the west, giving a moderately heavy rain shower. The general weather, as reported by the synoptic office at Farnborough during the afternoon, was 7 oktas cumulus and stratocumulus, becoming cumulonimbus. Showers were reported, but no thunder or lightning.

The cloud diagram on p. 122 shows the constitution of the cloud as observed from the aircraft.

V. J. TRAVERS

[Ross Gunn* measured the electrical field normal to the surface of a metal aircraft in nine thunderclouds. The average of the maximum values in individual clouds was 1,300 v./cm. Just before a flash of lightning 3,400 v./cm. was measured. These electric fields, more than 1,000 times the fine-weather vertical electric field, no doubt account for the shocks and flash as the charged impactor was brought back to aircraft potential.

The Senior Meteorological Officer of the Meteorological Research Flight states that the impactor is now bonded to the aircraft.—Ed., *M.M.*]

Meteorology in relation to the carriage of goods by sea

Commander C. E. N. Frankcom, Marine Superintendent of the Meteorological Office, gave an interesting talk on December 12, 1951, to the Honourable Company of Master Mariners on the subject of meteorology in relation to the carriage of goods by sea.

The shipmaster's problem begins with the weather during loading. During the voyage a considerable variation in temperature of air and sea water, and in air humidity, may be encountered. Whatever the cargo, condensation in the form of sweat is liable to occur if the humidity of the atmosphere in the hold is high and outside temperature low.

With a hygroscopic cargo a rise of hold temperature causes the cargo to give off moisture, and hence to increase the hold humidity. If there are non-hygroscopic goods in the cargo these will remain relatively cool and sweat will

* GUNN, R.; Electric field intensity inside of natural clouds. *J. appl. Phys., Lancaster Pa.*, **19**, 1948, p. 481.

probably form on them, as well as on the steel sides and deckhead of the hold. Canned goods and other metal goods may rust or stain as a result. Goods stowed near relatively hot parts of the ship, such as engine-room bulkheads, will become locally heated and thus give off more moisture than other parts of the cargo.

Grain cargoes, if not ventilated, may become mouldy and grow out; and damage will inevitably be done to other cargoes if sweating is allowed to continue unchecked.

The decision as to when to ventilate is not a simple one and on some occasions, e.g. when outside dew point is higher than the hold temperature, ventilation may add to the damage. Vigorous ventilation should, however, be given when outside humidity is low and whenever outside temperature is much colder than that of the hold atmosphere. In rough weather ventilation may not be practicable because of risk of spray or rain getting down ordinary ventilators.

A hygrometer is a useful instrument to have aboard any ship—both on deck and, if possible, in the hold. In ships fitted with insulated holds the problem is not so difficult, and some ships are now fitted with mechanical ventilation and air-conditioned holds.

Some cargoes such as cotton and Esparto grass may catch fire due to spontaneous combustion if humidity and ventilation are not carefully watched.

Even refrigerated cargoes have their meteorological problems.

Cmdr. Frankcom concluded by pointing out the value of ships' officers having an elementary knowledge of atmospheric physics in handling these problems; and that, thanks to a century of voluntary observation work at sea, a vast amount of data on the weather over the oceans was now available which could be used in planning the safe carriage of goods by sea.

A full report will appear in the April 1952 *Marine Observer.*

REVIEW

The Aurorae. By L. Harang. *International Astrophysics Series, London,* **1**, 10 in. × 8½ in. pp. x + 166, *Illus.*, Chapman & Hall Ltd., London, 1951. Price 25*s.* 0*d.*

I know of no other book which covers the whole range of auroral phenomena and auroral research as does this by Dr. Harang. It covers much work which has been available only in scientific journals, some not readily available, and it has a valuable bibliography. The editors' claim that it is suitable for both students and specialists is justified. It is clearly written, and has many graphs, tables and photographs.

It is the first volume of a series intended to cover all branches of astrophysics. If the high standard of this first volume is maintained the series will be a most valuable one. The editors are Dr. M. A. Ellison of the Royal Observatory, Edinburgh, and Prof. A. C. B. Lovell of the University of Manchester, whose work at Jodrell Bank on radar techniques for the study of meteor trails and other ionization clouds has excited such interest in the last few years. It is to be hoped that Prof. Lovell will himself contribute to the series. Further volumes already announced are "Comets" by J. G. Porter, "Astronomical photometry" by D. S. Evans, "Stellar constitution" by D. H. Menzel and

H. K. Sen, "The earth and the planets" by W. H. Ramsay, and "Interstellar matter" by L. Spitzer.

It is fitting that this book should have been written by a Norwegian. It is true that few other peoples are able to study these strange phenomena with such natural advantages, for the main auroral zones, in the vicinity of which some evidence of auroral activity can be seen on almost any clear night, lie either close to the icebound coasts of Antarctica, or to the desolation of the coasts of northern Siberia and arctic Canada, and only approach populated countries in northern Norway and Iceland. Norwegian research has contributed in really outstanding measure to our knowledge of the aurora.

The first half of the book covers the observational material. A general description of the normal forms and appearance of aurorae is followed by a clear picture of modern parallactic photography, using base-lines up to 250 miles in length. The graphical methods used for determinations of auroral heights and positions in space are described in detail. The monumental labours of Størmer in making more than 12,000 auroral-height determinations over southern Norway alone can be appreciated.

The height distribution curves show very vividly the sharp maximum at a height of 100 Km. for aurorae in the earth's shadow, compared with the far greater height of aurorae in sunlight, which have a broad maximum around 300 Km. The decrease of height of the auroral forms with increasing intensity is also clearly shown, with a normal lower limit 80 Km. above the earth's surface. The rare intense auroral arcs with deep crimson lower border seem to be the only exception to this, at an average height of 70 Km. Reports of aurorae at really low altitudes (some even below the observing mountain station) have never been confirmed scientifically. Equally the author holds no brief for auroral sounds, usually reported as a whizzing, rustling or crackling sound, sometimes like "burning grass or faggots", but suggests that these are due to earth current discharges. Voltage gradients of up to 60 v./Km. have been recorded in telegraph cables near the auroral zone during intense magnetic storms. It seems possible that voltage gradients of this order could cause coronal discharges in long cables.

Almost a quarter of the book is on the auroral spectrum, with a natural emphasis laid on the brilliant work of Vegard. Meteorologists will be much interested in the ionospheric temperatures determined from the nitrogen bands.

The first half of the book leads naturally to modern corpuscular theory of the aurora. Størmer's mathematical treatment of charged-particle orbits, the terrella experiments of Birkeland, and the later use of electron-ray technique by Brüche, are described in some detail, with many clear diagrams and photographs. Agreement and disagreement between observation and theory are stressed.

The last chapter gives a short account of the propagation of radio waves in the E and F layers of the ionosphere, mainly to show how some of the special effects observed are associated with magnetic storms and aurorae. It is to be hoped that the wide region of ionospheric research will be the subject of a later volume in the series.

W. G. HARPER

METEOROLOGICAL OFFICE NEWS

Obituary.—We regret to announce the death on March 3, as the result of an accident, of Mr. Andrew Smyth, Scientific Assistant at Aldergrove. Mr. Smyth, who was in his 26th year, joined the Office in January 1945. His death has deprived the Office of a capable assistant, who will be greatly missed by all his colleagues.

The death occurred on December 28, 1951, of Mr. A. W. Lloyd, within a month or so of his 81st birthday. He will be remembered by members of the Staff who served at, or were connected with, the meteorological office at Shoeburyness in the nineteen-twenties.

Ocean weather ships.—Evening classes with voluntary instructors have been introduced aboard o.w.s. *Weather Observer*. The subjects include photography, basic French, navigation, radio, mathematics, first aid and meteorology. The Master's report indicates that these classes are very popular.

Emergency in the desert.—The Cyrenaican oasis of Jalo, which lies about 160 miles south-east across the desert from Ajedabya, was the scene last summer of an incident in which the meteorological staff rendered more than weather service.

A party of twelve students from Aberdeen University, under the leadership of Dr. W. B. Fisher, was carrying out a geographical survey in the territory during their summer vacation. The party arrived by truck and jeep at Jalo in the second week of September.

A small radio station installed for transmitting meteorological messages to El Adem and manned by Libyan meteorological staff affords the only means of telecommunication between the oasis and the rest of the world. So when one of the students was taken ill, it was to the meteorological unit that the call for assistance came. An airlift was impossible, as the airfield at Jalo is sanded over, and an immediate return by jeep to Benghazi (250 miles) was advised.

The Medical Officer at El Adem signalled instructions for the patient's treatment on the way and the Observer in Charge was authorized to act as guide during the night to Ajedabya, where an ambulance awaited their arrival to take the patient on to Benghazi.

Annual Soirée.—About 200 members of the Staff with their friends and families attended the twentieth annual soirée of the Office on March 8. The organizers are to be congratulated on a most successful party. Sir George Simpson, Mr. Ernest Gold, Mr. Leonard Powers and Miss Johnson, retired members of the staff, were present.

WEATHER OF FEBRUARY 1952

Mean pressure over western Europe exceeded 1020 mb. in most places, being about 3–7 mb. above normal, but in eastern Europe, where mean pressure was between 1010 and 1015 mb., it was about 5 mb. below normal; a similar deficit of pressure occurred in Scandinavia where mean pressure was about 1005 mb. Over the North Atlantic, the Azores anticyclone was transferred north-eastwards; west of the British Isles mean pressure in the region of 15°W. was 1021 mb., which was 12 mb. above normal, and 1010 mb. at 45°W., which was 5 mb. above normal. At the Azores mean pressure fell to 1015 mb.; this was about 7 mb. below normal.

Mean temperature over most of Europe, excepting Scandinavia, was below normal. It was about 40°F. in France, decreasing to about 30°F. in Poland;

in the Mediterranean region it was generally 50°F. The deficit varied between 2° and 5°F. In Scandinavia where mean temperature was between 20° and 30°F. it was a little above normal for the month.

In the British Isles the weather was dry, except in the extreme north of Scotland, and sunny on the whole. It was cold during the first 16 days but the week ending on the 23rd was mild, particularly in Scotland where the deviation from the average for the week was +5·3°F.

In the opening days a complex depression was situated over south Norway and Denmark, and on the 2nd a depression south of Iceland moved east-south-east. Rather cold westerly winds prevailed with wintry showers and long bright periods in most areas. On the 4th an anticyclone off our south-west coasts moved north-east and subsequently south-east. Meanwhile a depression moved north-north-east to Iceland and turned north-east, while an associated trough moved across Scotland giving precipitation in northern districts of the British Isles on the 5th and scattered rain or showers on the 6th. A very deep depression, centred north-east of Iceland on the 6th, moved east and became less deep; gales occurred at exposed stations in the north of Scotland on the 6th and 7th and showers and local thunderstorms were recorded on the 7th. Behind the depression cold northerly winds prevailed over the British Isles with scattered, mainly wintry, showers but long sunny periods in most places. On the 10th a depression off north-west Scotland moved east-south-east to Denmark; more precipitation, mainly rain, occurred and it was heavy locally (2·87 in. at Cwm Dyli, Snowdon). There was another break-through of polar air behind this depression and cold weather prevailed with widespread sleet or snow showers, but with long bright periods in some parts from the 10th to the 12th. On the 13th and 14th a depression moved from east Iceland across the British Isles to France; further precipitation occurred and temperature continued low. On the 15th and 16th a trough of low pressure moved south-east across the country and on the 16th–17th a secondary depression moved from west of Iceland to the North Sea. Slight precipitation, mainly rain or drizzle, occurred in the northern half of the country on the 15th and more generally on the 16th and 17th. Subsequently the anticyclone westward of Ireland moved south-east to the English Channel by the 21st and then slowly north and dominated conditions over most of the British Isles until the 28th. Temperature rose, the week ending on the 23rd being unusually mild in the northern half of the country. On the 28th and 29th a trough of low pressure moved south-east across the country causing some rain, chiefly in the north. Considerable fog developed from the 24th to the 29th, mainly at night and in the morning but it was persistent at times in some places. Fairly severe frost also occurred locally on some nights.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	56	10	−1·5	43	−5	116
Scotland	57	12	−0·7	55	−3	114
Northern Ireland ...	53	20	−1·3	46	−5	92

RAINFALL OF FEBRUARY 1952

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	0·90	54	*Glam.*	Cardiff, Penylan ...	0·86	29
Kent	Folkestone, Cherry Gdn.	2·26	111	*Pemb.*	Tenby	0·59	20
,,	Edenbridge, Falconhurst	1·06	48	*Mer.*	Aberdovey	2·06	69
Sussex	Compton, Compton Ho.	0·94	36	*Radnor*	Tyrmynydd	3·11	59
,,	Worthing, Beach Ho. Pk.	0·79	40	*Mont.*	Lake Vyrnwy	1·65	36
Hants.	Ventnor Cemetery ...	0·92	43	*Mer.*	Blaenau Festiniog ...	3·87	47
,,	Bournemouth	0·95	25	*Carn.*	Llandudno	1·61	83
,,	Sherborne St. John ...	0·72	33	*Angl.*	Llanerchymedd ...	1·97	78
Herts.	Royston, Therfield Rec.	0·56	36	*I. Man*	Douglas, Borough Cem.	0·95	30
Bucks.	Slough, Upton	0·75	14	*Wigtown*	Newton Stewart ...	1·03	27
Oxford	Oxford, Radcliffe ...	0·51	31	*Dumf.*	Dumfries, Crichton R.I.	0·57	17
N'hants.	Wellingboro' Swanspool	0·74	46	,,	Eskdalemuir Obsy. ...	1·23	25
Essex	Shoeburyness	0·94	76	*Roxb.*	Kelso, Floors	0·53	31
,,	Dovercourt	0·86	68	*Peebles*	Stobo Castle	1·05	38
Suffolk	Lowestoft Sec. School ...	1·05	75	*Berwick*	Marchmont House ...	0·64	31
,,	Bury St. Ed., Westley H.	0·97	65	*E. Loth.*	North Berwick Res. ...	0·57	37
Norfolk	Sandringham Ho. Gdns.	0·84	51	*Midl'n.*	Edinburgh, Blackf'd. H.	0·47	28
Wilts.	Aldbourne	0·95	44	*Lanark*	Hamilton W. W., T'nhill	1·14	39
Dorset	Creech Grange... ...	0·84	29	*Ayr*	Colmonell, Knockdolian	1·18	31
,,	Beaminster, East St. ...	0·73	24	,,	Glen Afton, Ayr San. ...	2·19	50
Devon	Teignmouth, Den Gdns.	0·55	21	*Renfrew.*	Greenock, Prospect Hill	2·61	49
,,	Cullompton	1·17	42	*Bute*	Rothesay, Ardencraig ...	2·21	55
,,	Ilfracombe	1·01	36	*Argyll*	Morven (Drimnin) ...	3·26	62
,,	Okehampton Uplands...	1·56	36	,,	Poltalloch	2·54	59
Cornwall	Bude, School House ...	1·23	49	,,	Inveraray Castle ...	3·96	58
,,	Penzance, Morrab Gdns.	1·70	51	,,	Islay, Eallabus	2·28	54
,,	St. Austell	1·51	39	,,	Tiree	1·95	57
,,	Scilly, Tresco Abbey ...	1·23	44	*Kinross*	Loch Leven Sluice ...	0·59	21
Glos.	Cirencester	0·63	28	*Fife*	Leuchars Airfield ...	0·53	30
Salop	Church Stretton ...	0·68	29	*Perth*	Loch Dhu	2·25	30
,,	Shrewsbury	0·62	39	,,	Crieff, Strathearn Hyd.	0·83	24
Worcs.	Malvern, Free Library...	0·46	26	,,	Pitlochry, Fincastle ...	1·11	38
Warwick	Birmingham, Edgbaston	0·63	37	*Angus*	Montrose, Sunnyside ...	0·79	43
Leics.	Thornton Reservoir ...	0·71	43	*Aberd.*	Braemar	1·24	44
Lincs.	Boston, Skirbeck ...	0·46	32	,,	Dyce, Craibstone ...	1·39	61
,,	Skegness, Marine Gdns.	0·70	46	,,	New Deer School House	2·34	110
Notts.	Mansfield, Carr Bank ...	0·37	19	*Moray*	Gordon Castle	1·50	78
Derby	Buxton, Terrace Slopes	3·43	91	*Nairn*	Nairn, Achareidh ...	1·06	65
Ches.	Bidston Observatory ...	0·97	58	*Inverness*	Loch Ness, Garthbeg ...	1·81	52
Lancs.	Manchester, Whit. Park	1·19	62	,,	Glenquoich	7·32	71
,,	Stonyhurst College ...	1·80	54	,,	Fort William, Teviot ...	3·76	50
,,	Squires Gate	0·96	45	,,	Skye, Duntuilm ...	2·60	57
Yorks.	Wakefield, Clarence Pk.	0·41	24	,,	Skye, Broadford ...	4·40	68
,,	Hull, Pearson Park ...	0·72	43	*R. & C.*	Tain, Tarlogie House ...	1·64	72
,,	Felixkirk, Mt. St. John...	0·67	40	,,	Inverbroom, Glackour...	5·67	111
,,	York Museum	0·38	25	,,	Achnashellach	7·44	108
,,	Scarborough	1·00	60	*Suth.*	Loch More, Achfary ...	...	...
,,	Middlesbrough... ...	0·47	36	*Caith.*	Wick Airfield	2·43	107
,,	Baldersdale, Hury Res.	0·81	28	*Shetland*	Lerwick Observatory ...	2·05	65
Norl'd.	Newcastle, Leazes Pk....	0·65	42	*Ferm.*	Crom Castle	1·08	37
,,	Bellingham, High Green	0·84	33	*Armagh*	Armagh Observatory ...	0·78	35
,,	Lilburn Tower Gdns. ...	0·50	25	*Down*	Seaforde	0·54	18
Cumb.	Geltsdale	1·43	55	*Antrim*	Aldergrove Airfield ...	0·75	31
,,	Keswick, High Hill ...	1·23	25	,,	Ballymena, Harryville...	1·26	39
,,	Ravenglass, The Grove	1·14	37	*L'derry*	Garvagh, Moneydig ...	1·94	62
Mon.	Abergavenny, Larchfield	0·60	19	,,	Londonderry, Creggan	2·67	84
Glam.	Ystalyfera, Wern House	1·80	35	*Tyrone*	Omagh, Edenfel ...	1·55	52