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ERRATA

FACING PAGE 305, line 2; for "EDDIE" read "EDDY".
PAGE 340, legend to Fig. 2; for "HABBANIYAH" read "HABBANIYA".
See also pages 93, 117, 244, 281, 298 and 335.

LIST OF ILLUSTRATIONS

M.O. 559 AIR MINISTRY

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THE METEOROLOGICAL MAGAZINE

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FORECASTING METHODS BASED ON BAROTROPIC WAVE THEORY

By F. H. BUSHBY, B.Sc.

Introduction.—In 1922 L. F. Richardson[1] suggested a method of forecasting the weather by numerical processes. His worked example gave very poor results, and, as the time taken to produce a forecast was very considerable, little further attention was given to the problem until quite recently. However, with much more detailed upper air information available than when Richardson made his attempt at numerical weather forecasting and with the advent of modern electronic computing machinery, research workers have again turned their attention to the problem of weather forecasting by numerical methods.

In America, Prof. Charney has produced certain methods of forecasting changes in the height of the 500-mb. contour surface by using a model in which the actual atmosphere is replaced by an "equivalent barotropic" atmosphere. The purpose of the present article is to describe briefly the methods suggested by Charney and to give an account of tests of those methods which have been carried out in the Forecasting Research Division at Dunstable. The mathematics involved in the derivation of the formulæ used are not given here, but can be seen by reference to the original papers of Charney[2–4].

Equivalent barotropic atmosphere.—A barotropic fluid is one in which density is a function of pressure alone. The atmosphere is not barotropic in general and could be so only if there were no temperature gradients in the isobaric surfaces. There would then be no thermal wind and the geostrophic wind would be the same at all levels.

Charney[2] has shown that, if certain assumptions about the behaviour of the atmosphere are made, there is one level in the atmosphere (approximately in mid troposphere) at which the flow does correspond to the flow in a barotropic fluid. This level is called the equivalent barotropic level. Charney[3] now estimates this level to be between 450 and 500 mb. although previous estimates suggested a value between 550 and 600 mb. As observations of the 500-mb. height are readily available over a wide area, it is convenient to use the 500-mb. level as an approximation to the equivalent barotropic level.

One of the main assumptions made by Charney in deriving his formula was that the wind direction is the same at all heights and that the increase of wind with height is the same along any vertical. Experienced forecasters will know these conditions are rarely satisfied very closely. However, the results which Charney has obtained do show that this simple atmospheric model possesses some of the properties of the real atmosphere. The vertical advection of vorticity is also neglected.

A barotropic fluid is approximately non-divergent; the vertical component of the absolute vorticity of an air particle is therfore conserved. This can be expressed by the following equation:

$$\frac{d}{dt}(f+\zeta) = 0 \qquad \ldots\ldots (1)$$

where f represents the Coriolis parameter, ζ the vertical component of vorticity at 500 mb. relative to the earth, and the operator d/dt denotes the rate of change with respect to time following the motion of the fluid. In order to forecast changes in the 500-mb. level, Charney uses the geostrophic approximation to solve equation (1).

One-dimensional method.—Charney[4] first attempted to solve equation (1) by assuming that the motion at 500 mb. consists of small perturbations superimposed upon a west–east zonal current constant with respect to time and longitude, and that these perturbations depend on the north–south co-ordinate in such a way as to be expressible by a sine function. This reduces the problem to one involving only one space variable, the longitude. The equation can be solved analytically for z, the height of the 500-mb. contour surface, by Fourier analysis. The solution can be written in the form

$$z\,(x + Ut,t) = z\,(x,0) + \sum_{n=1}^{N} A_n . z\,(x + 10n,0) \qquad \ldots\ldots (2)$$

where x is the distance along a line of latitude measured in degrees of longitude, U is the zonal current in degrees of longitude per unit time, t is the time variable and in equation (2) expresses the length of the forecast period, and the coefficients A_n are dependent upon latitude and the length of the forecast period. Values of these coefficients for $t=1$ day are given by Charney[4] for latitude 45°N. and by Bushby[5] for latitudes 40°, 50° and 60°N. This solution does provide an objective method of forecasting changes in the 500-mb. contour height, and it takes only 20 min. for a competent assistant to prepare a forecast for a range of 120° of longitude.

In view of the simplicity of equation (2) it is important to know how far this equation actually represents the motion of the 500-mb. surface. Therefore a series of tests were carried out in the Forecasting Research Division at Dunstable to see how 24-hr. forecasts of the 500-mb. level produced by the use of this formula compared with forecast charts produced by the conventional forecasting methods in use at Dunstable.

Preliminary experiments confirmed the theoretical deduction that the computed forecast would be in error in a region where one of the following synoptic features existed:—

(i) A closed circulation in the 500-mb. contour pattern.

(ii) A trough or ridge in the 500-mb. contour pattern whose axis is inclined at an appreciable angle to a meridian, or a U-shaped trough whose axis is parallel to a meridian with strong meridional flow along its sides.

(iii) A flat area of the 500-mb. contours.

(iv) A strong thermal field with surface isobars at right angles to the isotherms (generally a fast-moving front).

Forecast 500-mb. charts were then prepared for 34 days in June and July 1950 by means of Charney's formula. Values were computed at intervals of ten degrees of longitude from 80°W. to 20°E. along the latitude circles 40°, 50° and 60°N. In drawing forecast charts the computed values were treated with circumspection if they occurred in a region where the preliminary experiments showed the formula unlikely to work.

Correlation of the forecast 500-mb. contour heights with the actual heights at latitude 50°N. gave a value of 0·52 for Charney's method and 0·70 for the conventional methods. The root-mean-square errors for the same forecast values were 200 ft. and 170 ft. respectively. Correlation of the forecast movement of trough and ridge lines at 50°N. with their actual movement gave a value of 0·64 for Charney's method and 0·60 for conventional methods. The root-mean-square errors for the same forecast values were respectively 3·2 degrees and 3·6 degrees of longitude. This implies that over the period examined, Charney's method would have given approximately the same or slightly better results, for the forecast position of trough and ridge lines, than the conventional methods, but in other respects conventional methods gave rather better results than the use of Charney's formula.

Charney's method consists of two essentially independent parts: the first representing a displacement of the existing profile eastward with the zonal current and the second representing the contribution of various terms in which the variation of the Coriolis parameter with latitude plays an important part. To test whether the second set of terms do contribute significantly to the success of Charney's formula, forecasts were prepared on the basis of the first term only—namely on the assumption that the 500-mb. profile moves eastward with the zonal current. Similar tests were applied to these forecasts as were applied to those based on Charney's method. The results show conclusively that the forecasts based on the complete formula were much more accurate than those based on the first term only.

Two-dimensional method.—The one-dimensional barotropic model is a very restricted one, but Charney[3] has described a method of solving equation (1) when the flow at 500 mb. is considered as two-dimensional. Equation (1) can be transformed to

$$\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right) \frac{\partial z}{\partial t} = \frac{\partial (\zeta + f)}{\partial x} \cdot \frac{\partial z}{\partial y} - \frac{\partial (\zeta + f)}{\partial y} \cdot \frac{\partial z}{\partial x} \qquad \ldots\ldots (3)$$

where x and y are rectangular co-ordinates on a suitable plane projection of the earth's surface. At any one instant of time the right-hand side of equation (3) can be calculated from the 500-mb. contour values. Equation (3) can therefore be treated as a Poisson equation in $\partial z/\partial t$, the instantaneous 500-mb. contour-height tendency. For hand computation the equation can best be solved by relaxation methods[6] but it is first necessary to know the value of $\partial z/\partial t$ along the boundary. A plausible boundary condition is $\partial z/\partial t=0$ near the equator, but this entails preparing a forecast for most of the northern hemisphere. However, as large-scale features move approximately with the speed of the wind it is possible to use an arbitrary boundary condition without significantly affecting the forecast.

Charney[2] presented one example which suggested that close agreement between the observed and calculated 500-mb. height tendency was possible.

In view of the fundamental significance of the work it was decided to perform similar calculations in the Forecasting Research Division at Dunstable so as to form an opinion of the validity of the method. Calculations of the height tendency have been made on two synoptic charts and compared with the observed values.

The agreement between the computed and actual height tendency was rather poor, although some of the large-scale features were fairly accurately forecast. As 500-mb. charts of the northern hemisphere are only prepared every 12 hr. it was necessary to compare the computed instantaneous height tendencies with actual values averaged over 24 hr. centred at the time used for the computations, and this may have been partially responsible for some of the apparent inaccuracies of the formula.

It is possible to use this method to prepare 24-hr. forecasts by moving forward through time in short steps of, say, 2 hr. This would mean that the whole calculation of the height tendency would have to be repeated 12 times to produce a 24-hr. forecast. The time factor involved would be prohibitive if human computers were employed, but Charney[3] has used the ENIAC, a high-speed electronic computing machine to prepare 24-hr. forecasts by repeatedly solving equation (3). The forecast values of the instantaneous height tendency were used as a basis for forecasting new values of the 500-mb. contour level for a forecast period of 2 hr. These forecast values were then used as initial values in the next stage of the integration. The problem of boundary conditions is discussed at length by Charney[3]. It is of interest to note that it took 24 hr. to produce a 24-hr. forecast, but the ENIAC is not the most suitable electronic machine for this type of problem. The results obtained by Charney again show significant success, but rather less than that obtained by conventional forecasting methods both here and in America.

Conclusion.—The tests of Charney's one- and two-dimensional formulæ indicate that the "equivalent barotropic model" is an inadequate basis for numerical integration of the equations of motion. However, the degree of success obtained by Charney does show that the advection of absolute vorticity at the 500-mb. level is relevant to the changes in height at that level. Moreover Charney has shown that it is possible to use high-speed electronic computing machines to obtain solutions of partial differential equations which are relevant to the problem of forecasting.

However, it seems that it will be at least necessary to introduce baroclinity into Charney's equations before their solution can be of any practical use. It may ultimately be possible to combine the "development" ideas of Sutcliffe[7], as modified by Sumner[8] with those of Charney[3], and produce a set of equations which will represent the behaviour of the earth's atmosphere with sufficient accuracy to be practically useful, and which can be solved by electronic computing machinery.

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RAIN AND SNOW IN RELATION TO THE 1000–700-mb. AND 1000–500-mb. THICKNESSES AND THE FREEZING LEVEL

By R. MURRAY, M.A.

Introduction.—Frequently it is fairly certain that precipitation will occur but doubtful whether it will be in the form of rain or snow. The physical processes involved are complex, although the lower tropospheric air-mass temperature is probably the most important factor which determines whether the precipitation will be rain or snow. The forecaster draws thickness and pre-thickness charts, and is accustomed to think in terms of these thickness charts when considering the thermal structure of the air. Hence the standard thicknesses (1000–700 mb. and 1000–500 mb.) are useful synoptic parameters in deciding what the form of the precipitation is likely to be. Clearly, rain tends to be associated with "warm" thicknesses (high values) and snow with "cold" thicknesses (low values). However, it is desirable to have statistics of the frequency of occurrence of different forms of precipitation in association with various thickness values so as to form a firmer basis for the use of the relationship; this note presents such statistics.

Some additional statistics of the frequency of occurrence of different forms of precipitation in relation to the freezing level and the surface temperature are also given.

Data.—The occurrence of different types of precipitation observed during the periods 0200–0300, 0800–0900, 1400–1500 and 2000–2100 G.M.T. at or near the British upper air stations was related to the upper air soundings made at these times. The months November, December, January, February and March of the period November 1948 to March 1951 were examined. The upper air stations used, together with the relevant surface observing station in brackets, were as follows: Lerwick (Lerwick), Stornoway (Stornoway), Aldergrove (Aldergrove), Leuchars (Leuchars), Liverpool (Manchester), Downham Market (Mildenhall) and Camborne (Lizard or St. Eval). The slight discrepancy due to the different locations of some of the upper air and surface stations can scarcely be important in a statistical investigation of this nature.

All the stations are at altitudes below 300 ft., and the average height is about 150 ft. above M.S.L.

The observed precipitation was placed in one of three main groups: (i) rain (including drizzle) and rain showers, (ii) sleet and sleet showers, and (iii) snow and snow showers. Hail was grouped separately. Various subgroupings were made according to the synoptic situation. For brevity the term "rain" includes rain and rain showers, and similarly for "sleet" and "snow".

1000–700-mb. and 1000–500-mb. thicknesses.—The form of precipitation occurring at the ground was analysed in relation to the 1000–700-mb. thickness in Table I, and in relation to the 1000–500-mb. thickness in Table II.

TABLE I—FREQUENCY OF TYPES OF PRECIPITATION ASSOCIATED WITH VARIOUS 1000–700-MB. THICKNESSES (EXCLUDING HAIL)

	1000–700-mb. thickness (ft.)								
	≤ 9,020	9,030 to 9,070	9,080 to 9,120	9,130 to 9,170	9,180 to 9,220	9,230 to 9,270	9,280 to 9,320	9,330 to 9,370	9,380 to 9,420
	percentage frequency								
Rain	0	2	30	69	85	97	99	99	100
Sleet	0	0	8	8	5	1	1	0·4	0
Snow	100	98	62	23	9	1	0	0·4	0
Occurrences ...	47	56	102	150	275	354	302	283	159
	degrees Fahrenheit								
1000-mb. S.A.T.	≤31	32·5	35	37·5	40	42·5	44·5	47	49

TABLE II—FREQUENCY OF TYPES OF PRECIPITATION ASSOCIATED WITH VARIOUS 1000–500-MB. THICKNESSES (EXCLUDING HAIL)

	1000–500-mb. thickness (ft.)										
	≤ 16,890	16,900 to 16,990	17,000 to 17,090	17,100 to 17,190	17,200 to 17,290	17,300 to 17,390	17,400 to 17,490	17,500 to 17,590	17,600 to 17,690	17,700 to 17,790	≥ 17,800
	percentage frequency										
Rain	0	3	17	48	71	89	94	97	98	99	100
Sleet	0	0	8	7	7	4	2	0·7	1	0·4	0
Snow	100	97	75	46	21	8	4	2	0·7	0·4	0
Occurrences ...	21	34	65	92	188	236	246	273	274	238	...
	degrees Fahrenheit										
1000-mb. S.A.T.	≤31·5	33	35	37	39·5	41·5	43·5	45·5	47·5	50	≥51

The last row in each of Tables I and II (1000-mb S.A.T.) contains values of the temperature at 1000 mb. of an atmosphere which has the same thickness as that corresponding to the middle of the selected thickness range but with a saturated adiabatic lapse rate of temperature.

Four main conclusions are readily drawn from Tables I and II:—

(i) Rain and snow are equally likely when the 1000–700-mb. thickness is about 9,120 ft. or when the 1000–500-mb. thickness is about 17,140 ft. —these may be regarded as critical values.

(ii) Rain is rare when the 1000–700-mb. thickness is less than 9,050 ft. or when the 1000–500-mb. thickness is less than 17,000 ft.

(iii) Snow is extremely rare when the 1000–700-mb. thickness is greater than 9,350 ft. or when the 1000–500-mb. thickness is greater than 17,700 ft.; it is rather uncommon even when the 1000–700-mb. thickness is greater than 9,250 ft. or when the 1000–500-mb. thickness is greater than 17,400 ft.

(iv) Sleet is uncommon in comparison with the other types of precipitation, but most likely at about the critical thickness values.

Examination of the synoptic charts enabled the different types of precipitation to be classified as: warm frontal, cold frontal, occlusion, depressional and non-frontal (shower) precipitation. However, the frequency distributions of the different forms of precipitation in each synoptic group are substantially the same as those shown in Tables I and II, and so are not reproduced here.

All observations of hail were neglected in preparing Tables I and II. The distribution of hail in relation to the 1000–700-mb. thickness is shown in Table III.

Table III indicates a tendency for hail to be more frequent when the 1000–700-mb. thickness is less than about 9,200 ft. This is probably related to the fact that non-frontal precipitation is more frequent with smaller thicknesses. Examination of the synoptic situations giving rise to hail showed that about 85 per cent. of the reported falls of hail was non-frontal in character.

TABLE III—FREQUENCY OF HAIL ASSOCIATED WITH CERTAIN VALUES OF THE 1000–700-MB. THICKNESS

	1000–700-mb. thickness (ft.)								
	⩽ 9,020	9,030 to 9,070	9,080 to 9,120	9,130 to 9,170	9,180 to 9,220	9,230 to 9,270	9,280 to 9,320	9,330 to 9,370	9,380 to 9,420
Number of reports	5	7	18	27	18	10	6	2	0
	percentage frequency with respect to all types								
Frequency ...	10	11	15	15	6	3	2	0·7	0

Hail may occur with a wide variety of values of the 1000–500-mb. thickness. However, the maximum frequency of occurrence of hail is in association with the 1000–500-mb. thickness range 17,000–17,200 ft.—roughly 20 per cent. of the occasions of precipitation occurring in this thickness range are likely to be hail.

Freezing level.—The frequencies of occurrence of the three main precipitation types associated with freezing levels observed at about the same time are presented in Table IV.

TABLE IV—FREQUENCY OF TYPES OF PRECIPITATION ASSOCIATED WITH VARIOUS FREEZING LEVELS (EXCLUDING HAIL)

	Freezing level (ft.)							
	0 to 400	500 to 900	1,000 to 1,400	1,500 to 1,900	2,000 to 2,400	2,500 to 2,900	3,000 to 3,400	3,500 to 3,900
	percentage frequency							
Rain	2	16	55	72	92	99	99	100
Sleet	1	8	10	7	3	0·4	0·5	0
Snow	97	77	35	21	5	1	0	0
Occurrences ...	100	51	153	181	249	277	204	168

The following points may be deduced:—

(i) The critical freezing level at which rain (and rain showers) or snow (and snow showers) become equally probable is about 1,000 ft.

(ii) Precipitation is invariably (or practically so) in the form of rain rather than snow when the freezing level is higher than 3,500 ft. Even with the freezing level down to 2,500 ft. there is a 95 per cent. chance that the precipitation will be rain.

Surface temperature.—The analysis of precipitation in relation to surface temperature is shown in Table V.

The main features of Table V are:—

(i) The critical temperature at which the precipitation is equally likely to be in the form of rain or snow appears to be 34·2°F.

(ii) Snow rarely occurs in association with temperatures higher than 39°F.

TABLE V—FREQUENCY OF TYPES OF PRECIPITATION ASSOCIATED WITH VARIOUS SURFACE TEMPERATURES (EXCLUDING HAIL)

	Temperature (°F.)														
	⩽30	31	32	33	34	35	36	37	38	39	40	41	42–44	45	⩾46
	percentage frequency														
Rain	0	4	2	15	34	62	73	83	95	93	98	99	100	99	100
Sleet	0	0	7	8	17	14	5	4	3	1	0·8	0	0	0·9	0
Snow	100	96	91	77	49	24	21	13	1	5	0·8	0·7	0	0	0
Occurrences ...	35	28	46	52	47	84	79	103	133	145	125	148	314	118	...

A sample of the observations was examined to see whether there is a significant difference between the temperature occurring before the commencement of precipitation and the temperature at the time of precipitation. For the rain type the mean temperature difference is −0·02°F. with standard deviation 1·8°F. (118 occasions); and for the snow type the mean temperature difference is −0·09°F. with standard deviation 1·7°F. (53 occasions). Thus, on the average, the surface temperature is almost as likely to rise as to fall when precipitation occurs.

Conclusion.—The main results are given below. In particular, (*a*) and (*b*) are useful in forecasting practice by virtue of relating forecast thickness charts to the form of precipitation. Conclusions (*a*) to (*d*) apply almost equally well to frontal and non-frontal precipitation. They refer to precipitation falling on low-lying ground in the British Isles.

(*a*) The critical 1000–700-mb. thickness at which rain and snow are equally probable is about 9,120 ft. The probability of precipitation being in the form of snow increases rapidly with decreasing thickness values; and the precipitation may confidently be forecast to be snow when the thickness is less than about 9,050 ft. It is highly probable that precipitation will be rain when the thickness is greater than about 9,300 ft.

(*b*) The critical 1000–500-mb. thickness is about 17,140 ft. When the 1000–500-mb. thickness is less than about 17,000 ft. the precipitation is almost certainly in the form of snow; when the thickness is greater than about 17,500 ft. the rain form becomes very probable.

(*c*) The critical freezing level is about 1,000 ft. The probability that the precipitation is in the form of snow decreases as the freezing level rises, so that it becomes very probable that it will be in the form of rain when the freezing level is higher than about 2,500 ft.

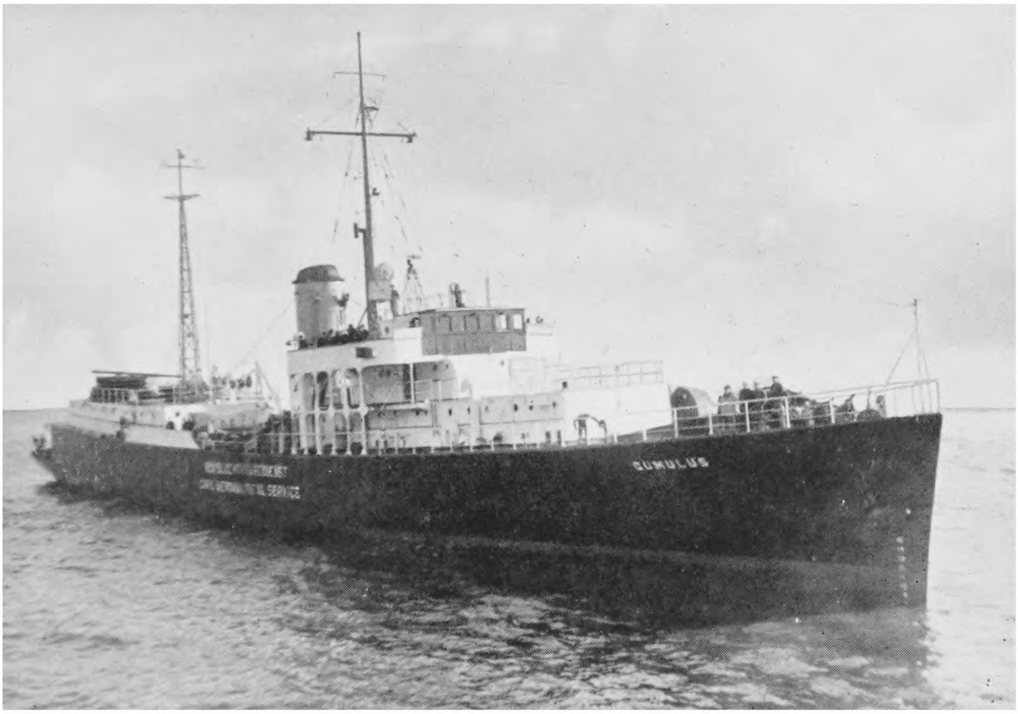
(*d*) The critical surface temperature is about 34°F. Snow rarely occurs in association with surface temperatures greater than 39°F.

RELATION OF VISIBILITY TO WIND IN CYRENAICA

By D. W. JOHNSTON, B.Sc.

Attention has been called to the fact that during the period April 1–2, 1951, the visibility over Cyrenaica remained consistently good in spite of strong southerly winds.

In desert regions, the extent of visibility deteriorations caused by sand in suspension must depend on the following factors: strength of wind, fetch of strong wind, instability of the atmosphere, and nature of the surface of the ground, both locally and up-wind.



NETHERLANDS O.W.S. *Cumulus*

This is one of the Netherlands ocean weather ships which take turns with the British ocean weather ships at station JIG

O.W.S. *Weather Recorder* IN HEAVY WEATHER AT STATION JIG

SKETCH OF TWO WATERSPOUTS SEEN IN THE INDIAN OCEAN

These waterspouts, which were sketched aboard s.s. *Dallas City* when she was at 10°09′N., 87°24′W. on May 31, 1950 at 2125 G.M.T., were observed coming from 2 oktas cumulonimbus, base 4,600 ft. and lasted for about 10 min. Spray was clearly visible to an estimated height of 150 ft. The barometer was steady at 1008·8 mb. and there was no change in wind direction or force.

Photograph by M. L. Jinks

UNUSUAL CLOUD FORMATION

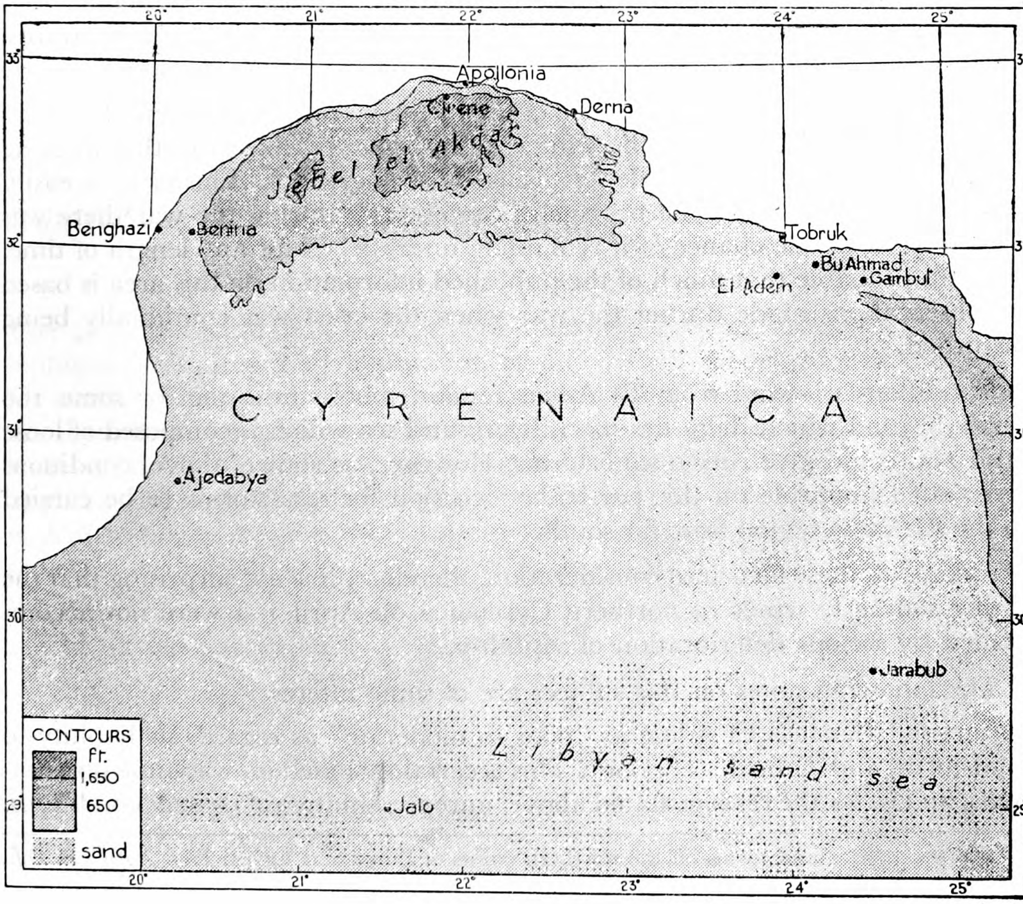
This photograph was taken aboard O.W.S. *Weather Recorder* from near Ailsa Craig in the Firth of Clyde on July 28, 1950, at 1740 G.M.T.

As regards the strength of the wind, it is of course the high degree of turbulence normally associated with strong winds that is responsible for loose sand being carried up and held in suspension in the air.

As regards instability loose sand would be carried to greater heights in unstable than in stable air, but the degree of turbidity at low levels would not necessarily be greater. The very intense sandstorms produced at cold fronts must depend on the high degree of turbulence in the squall itself, rather than directly on the instability. However, sandstorms produced in an atmosphere having a deep unstable layer will persist a much greater distance down-wind from the source region than shallow sandstorms.

During the period April 1–2, 1951, a complex trough of low pressure approached Cyrenaica from the west giving generally southerly gradient winds, and mainly SSE. surface winds over Cyrenaica.

Strength of wind.—In northern Cyrenaica winds were often strong, reaching force 6 at times at El Adem, and force 10 on one occasion at Cirene. However the strength of the wind at Cirene is much affected by local conditions, and is not related to the pressure gradient in the normal way. Cirene is about 2,000 ft. above sea level, and is almost the highest point of Jebel el Akdar, with a fairly gentle downward slope to the south, but with a precipitous drop to the north to the coastal plain near Apollonia (600 ft. above sea level) and the cliffs on the coast. Two wadis lead down into the plain, one on each side of the observing station. Winds are therefore often much stronger than they would be at a station with a normal exposure.



Fetch of strong wind.—On the two days in question only the stations on or near the north coast had strong winds. Ajedabya, Jalo and Jarabub had winds mostly of force 2–3, although Jalo reported force 5 on two occasions. Owing to the sparseness of the reporting stations it is hard to estimate how far south the strong winds started, but there was not the very long fetch necessary for sandstorms on a large scale.

Instability of the atmosphere.—Upper air ascents at Benina have been used to assess stability. The early morning ascent (0200 G.M.T.) of both the 1st and 2nd showed small inversions (3–4°F.) from the surface up to 2,000 or 2,500 ft. The afternoon ascents (1400 G.M.T.) showed practically dry adiabatic lapse rates up to 6,000 ft. on the 1st, but only up to about 2,000 ft. on the 2nd. Above those levels the air was more stable. Relative humidities were low in the layers concerned.

It seems from this, that, even if other things had been favourable, a deep layer of turbidity would not have been produced except for a short period in the hottest part of the day, and that conditions of poor visibility would therefore not have been carried very far down-wind from a source region.

Nature of the surface of the ground.—This is probably the most important single factor. At Cirene there is rock and soil, not loose sand. There is considerable vegetation, partly cultivated and partly overgrown with low shrubs. In the immediate vicinity of the observing station there is a forest of pine trees. To the south of Cirene the vegetation gradually thins out, but even as far south as 50 miles from Cirene there is still considerable scrub. Any dust haze that existed at Cirene would therefore have been carried a long distance northwards, and, as shown above, conditions were not favourable for such transport.

"Loose" sand is not characteristic of the country around El Adem. The sand there, after being wetted by the winter rains, becomes caked together forming a thin crust, and is not suitable for lifting by strong winds. This crust is easily broken up, e.g. even by the passage of camels, and during the war there was probably very little chance of it remaining undisturbed for any length of time. It seems probable that much of the published information on this area is based on observations made during the war when the crust was continually being disturbed.

Conditions up-wind from El Adem remain much the same for some 160 miles, beyond which there lies the Libyan sand sea which is composed of loose sand and could give rise to sandstorms. However, as shown above, conditions were not favourable on this particular occasion for sandstorms to be carried to the El Adem region from far south.

Taking all these facts into consideration, therefore, it is not surprising that the strong southerly winds in northern Cyrenaica on April 1–2 were not accompanied by serious deterioration of visibility.

The following notes on this subject are of some interest:—

Lunson* classifies El Adem as "poor to moderate" as regards its liability to sandstorms and Tobruk as "poor". This is certainly based on war-time observations, and is, for the reasons stated above, unrepresentative of present conditions.

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*LUNSON, E. A.; Sandstorms on the northern coasts of Libya and Egypt. *Prof. Notes met. Off., London*, 7, No. 102, 1950.

In the same publication, Derna and Benghazi are classified as "good". This is no doubt because of the existence of much vegetation in the area, and still holds good.

In an unpublished typescript by M. K. Miles entitled "Notes on meteorological characteristics of airfields in Cyrenaica" of which there are copies at Malta and Middle East stations, the following statements are made:—

> "Gambut and Bu Ahmad are more seriously affected by local rising sand than El Adem. A gusty force 4 wind from south has been known to bring visibility at Gambut below 1,000 yd. making diversion necessary.
>
> "A force 5 wind is always required to make El Adem unserviceable in rising sand, and in S.–SW. currents it more often than not remains serviceable with a force 6 wind.
>
> "Derna.—Owing to the amount of surface vegetation in this area real sandstorms are not experienced, but in strong southerly winds visibility may be reduced to a few miles in general sand haze."

This pamphlet, although undated, is undoubtedly based on war-time experience. As regards El Adem, Miles' assessment disagrees with Lunson's, but is in accord with present-day observations.

Post-war experience at El Adem may be summarized in the following "forecaster's rule":—

> "Sand haze is likely to occur with winds having a southerly component and stronger than 25–30 kt., especially if the strong winds have a long fetch from the south. However, in these conditions visibility is not generally less than a few miles. Real sandstorms, with visibility less than 50 yd., occur rarely (about once or twice a year) and are almost invariably associated with the squall at a cold front or a thunderstorm".

HUMIDITY CORRECTIONS IN THE EVALUATION OF HEIGHT FROM A TEPHIGRAM

By R. A. BUCHANAN, M.A.

The accurate evaluation of height or thickness from an ascent plotted on a tephigram requires the computation of the virtual temperature at each level for which temperature and humidity are reported. These virtual temperatures are then plotted to give a modified ascent curve and the height of any pressure level, or the thickness between two standard pressure levels, is obtained by applying the normal methods to this modified curve. The purpose of this note is, first to devise a table for the computation of the virtual temperature, and secondly to develop a readier procedure for correcting heights and thicknesses for humidity.

The virtual temperature T' is defined[1] as

$$T' = \frac{T}{1 - \frac{3}{8}\frac{e}{p}}$$

where T is the absolute temperature, e the partial pressure of water vapour in the atmosphere and p the total pressure. If x is the humidity-mixing-ratio in grammes of water vapour per gramme of dry air,

$$x = \frac{0\cdot622e}{p-e} = \frac{5}{8}\frac{e}{p} \text{ approximately.}$$

Therefore $$T' = \frac{T}{1 - \frac{3}{5}x} = T\left(1 + \frac{3}{5}x\right) \text{ approximately,}$$

since x is small. In words, if the temperature at a given pressure level is T, then the virtual temperature T' is found by adding to T the quantity $\frac{3}{5}T$ for each gramme of water vapour per gramme of dry air. This gives rise to Table I where T is in degrees Fahrenheit, x is in grammes per kilogramme, and the body of the table gives the increment in degrees Fahrenheit to be added to T to obtain the virtual temperature T'.

TABLE I—DIFFERENCE BETWEEN DRY-BULB TEMPERATURE AND VIRTUAL TEMPERATURE FOR VARIOUS MIXING RATIOS

Dry-bulb temperature	Increment to be added to T to obtain T' for mixing ratios grammes/kilogramme										
	2	3	4	6	8	10	14	18	24	30	36
°F.					degrees Fahrenheit						
100	1	1	1	2	3	3	5	6	8	10	12
90	1	1	1	2	3	3	5	6	8	10	...
80	1	1	1	2	3	3	5	6	8	...	...
70	1	1	1	2	3	3	4	6	...	...	...
60	1	1	1	2	3	3	4	6	...	...	...
50	1	1	1	2	2	3	4	...	...	...	...
40	1	1	1	2	2	3	...	...	...	...	...
30	1	1	1	2	2	...	...	...	...	...	...
20	1	1	1	...	...	...	...	...	...	...	...
10	1	...	...	...	...	...	...	...	...	...	...
0	1	...	...	...	...	...	...	...	...	...	...
−10	1	...	...	...	...	...	...	...	...	...	...

An example of a plotted tephigram is given in Fig. 1. The virtual temperature for each level is entered as a circle and the modified curve is shown by a pecked line. The thicknesses of the 1000–700-mb. and 700–500-mb. layers, as computed from the modified curve, are given at the left-hand side.

This process of constructing a modified ascent curve of virtual temperatures and then computing the height of a pressure level is somewhat lengthy. It is, however, possible to devise a shorter method without undue sacrifice of accuracy:—

$$\rho = \frac{p}{RT}\left(1 - \frac{3}{8}\frac{e}{p}\right)$$

where ρ is the air density and R is the gas constant, giving

$$\rho = \frac{p}{RT}\left(1 - \frac{3}{5}x\right).$$

Also $$\frac{\partial p}{\partial z} = -g\rho$$

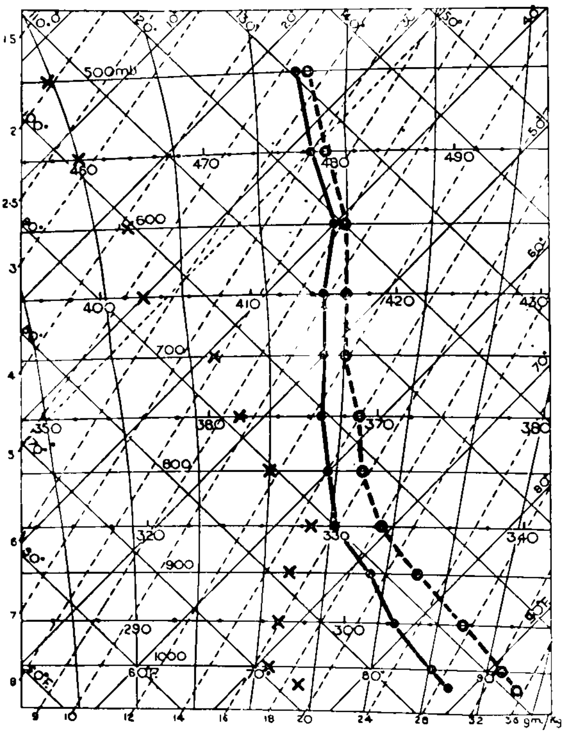
$$= -\frac{gp}{RT}\left(1 - \frac{3}{5}x\right)$$

or $$\frac{dp}{p} = -\frac{g}{RT}\left(1 - \frac{3}{5}x\right) dz$$

Thickness as calculated by first method

700–500 mb.
$t' = 8{,}960$ ft.

1000–700 mb.
$t' = 10{,}070$ ft.



Thickness as calculated by second method

700–500 mb.
$t = 8{,}930$ ft.
$x = 5$gm./Kg.
$t' = 8{,}930 + 5 \times 5$
$= 8{,}955$

1000–700 mb.
$t = 9{,}990$ ft.
$x = 13$gm./Kg.
$t' = 9{,}990 + 13 \times 6$
$= 10{,}070$ ft.

● — ● Dry bulb
x x Dew point
o - - - o Virtual temperature

FIG. I—TEPHIGRAM SHOWING COMPUTED THICKNESSES

This equation can be integrated if T and x are functions of z or constant. Thus, if mean values of T and x are used for the layer of the atmosphere p_0 to p the integration yields

$$\log_e p_0 - \log_e p = \frac{g}{R\,T}\left(1 - \frac{3}{5}x\right) z$$

or

$$z = \frac{R\,T}{g \log_{10} e} \cdot \frac{1}{1 - \frac{3}{5}x} (\log_{10} p_0 - \log_{10} p)$$

which may be compared with Brunt's equation for height

$$z = \frac{R\,T}{g \log_{10} e} (\log_{10} p_0 - \log_{10} p).$$

If p_0 and p are taken as standard levels of the atmosphere, this equation may be written

$$t' = \frac{t}{1 - \frac{3}{5}x}$$

where t' is the true thickness of the layer and t is the thickness obtained by using only dry-bulb temperatures in the computation. Since x is of a low order this may be written:

$$t' = t\left(1 + \frac{3}{5}x\right).$$

In words, if the thickness t of a layer is computed on the assumption that the air is dry, then allowance for humidity is made by adding to t the quantity $3t/5$ for each gramme of water vapour per gramme of dry air, this water vapour content being an estimated mean value for the layer. In practice the values of t for the layer 1000–700 mb. lie normally in the range 8,600 ft. to 10,200 ft. and x is normally expressed in grammes per kilogramme. Thus the correction factor $\frac{3}{5}t \times 10^{-3}$ ranges from 5·16 ft. to 6·12 ft. For the layer 700–500 mb. the corresponding values are 7,600 ft. to 9,200 ft. and 4·56 ft. to 5·52 ft. Above 500 mb. the absolute vapour content is so low that the correction is negligible.

These figures give rise to a simple rule for use in computing the 1000–700-mb. and 700–500-mb. thicknesses from a plotted tephigram:

(i) Compute t, using dry-bulb temperatures (t in feet).

(ii) Estimate by eye a mean value of x (the water vapour content in grammes per kilogramme), using the plotted dew points and the (pecked) water-vapour-content lines.

(iii) Multiply this mean value of x by the appropriate factor, 5 if t is less than or equal to 9,160 ft. and 6 if t is greater than 9,160 ft.

(iv) Add the result to t, so obtaining the true thickness t' of the layer.

In the example given in Fig. 1 the thicknesses of the 1000–700-mb. and 700–500-mb. layers, computed by the use of this rule, are given on the right-hand side. To the nearest 10 ft. they are in exact agreement with the thicknesses obtained by the virtual temperature method which was outlined first.

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METEOROLOGICAL OFFICE DISCUSSION
Winds in the stratosphere over Great Britain

The second Discussion of the present series was held on November 12, 1951, the subject being "Winds in the stratosphere over Great Britain".

Mr. T. H. Kirk, who opened the discussion, remarked on the increasing practical importance of a knowledge of high-level winds, and the rapid growth of the demand for upper air data. Most of his opening statement dealt with a recent paper by E. Hovmöller[1], though sufficient references were made to other papers to present a picture of average winds in the stratosphere up to a height of 100,000 ft.

The establishment of radio wind stations about 1940 first provided regular routine observations of wind in the stratosphere. Before this, direct observations had been limited to clear weather, and usually to anticyclonic conditions. Beginning in 1945, routine measurements of wind were made by radar from a network of stations covering Great Britain. These measurements set a new high standard of accuracy and regularity up to a level above 100 mb. The observations were homogeneous in the sense that substantially the same technique was used at all the stations. These observations were the subject matter of Hovmöller's paper. Winds at 100,000 ft. had been measured during the last war by Murgatroyd and Clews[2] who made observations on smoke shells fired from a high-velocity gun. Recent information of winds up to 100,000 ft. had been derived from special balloon ascents described by Scrase[3,4]. These observations established the "monsoon" effect foreshadowed by the earlier work of Whipple[5].

Hovmöller's paper was concerned with a statistical analysis in terms of four basic quantities: mean zonal wind, mean meridional wind, mean westerly wind, and mean southerly wind. His work supplied the answer to the question "How do these four basic quantities at 100 mb. compare with the same quantities at 300 mb. at Lerwick and Larkhill?" Of the data used in the investigation those at the 300-mb. level were equally distributed throughout the year. At 100 mb., on the contrary, there was a marked seasonal variation. The most probable reason for this was the effect of strong winds blowing the balloon and target out of range of the radar. Hovmöller used adjusted frequencies of both wind speed and direction at 100 mb. to afford a comparison with conditions at 300 mb., the basis of the adjustment being one of simple proportion. Diagrams were used to show the increased predominance of westerly wind frequency at 100 mb. as compared with 300 mb. Frequency diagrams for wind speed showed that at the 300-mb. level speeds from 10 to 60 kt. were relatively frequent throughout the year, whereas at the 100-mb. level a marked frequency maximum was found between 30 and 40 kt. in winter and between 10 and 20 kt. during the other seasons. Day-to-day comparisons of wind speed at the two levels showed that at 100 mb. there was considerably less variation than at 300 mb. A diagram by Hovmöller showed the annual variation of wind speed at levels between 300 mb. and 50 mb. over Larkhill and Lerwick. At Lerwick in winter there was a maximum wind speed between 300 mb. and 250 mb. and another, equal if not superior to the first one, at or above 50 mb. Both at Lerwick and Larkhill the amplitude of the annual variation of wind speed in the stratosphere appeared to increase with height. Another feature was the asymmetry of the curves of annual variation.

Hovmöller's comparisons gave the following results:—

(*a*) In the lower stratosphere the zonal wind decreases with height on the average, the ratio of the zonal wind at 100 mb. to the zonal wind at 300 mb. being about 0·7 at Lerwick and 0·6 at Larkhill. There is, however, a marked seasonal variation. At Lerwick the ratio varies from 1·1 in winter to 0·4 in summer, while at Larkhill the corresponding variation is from 0·8 to 0·3.

(*b*) The ratio of the meridional wind at 100 mb. to the meridional wind at 300 mb. at Lerwick varies from 0·8 in winter to 0·3 in summer. At Larkhill the corresponding variation is from 0·5 to 0·3.

(*c*) At 300 mb. the average meridional wind is about 75–95 per cent. of the zonal wind. At 100 mb. the average meridional wind is about 50–70 per cent. of the zonal wind.

Mr. Kirk criticized in some detail the further generalizations given by Hovmöller, and suggested that the results justified only the following modified statements:—

(*d*) In spring, summer and autumn the average temperature between 300 mb. and 100 mb. over the British Isles increases to the north. In winter, in the neighbourhood of Lerwick the average temperature between 300 mb. and 100 mb. decreases to the north. At Larkhill, however, the horizontal temperature gradient is either small or very variable.

(*e*) In the lower stratosphere, in spring, summer and autumn the troughs are generally warm and the ridges cold. In winter the evidence is insufficient to permit of a safe generalization, but it is probable that whereas warm troughs and cold ridges predominate, warm ridges and cold troughs are also possible.

The results of Dr. Scrase were based on 66 successful ascents of which 81 per cent. reached 80,000 ft. and 30 per cent. reached 100,000 ft., the highest being 110,000 ft. They were shown in two groups October–March and April–September. In the winter half-year, winds with a westerly component persisted at all levels in the stratosphere. From a minimum at 60,000 ft. the wind speed increased with height up to the highest levels reached. Average speeds at 100,000 ft. exceeded 40 kt. Murgatroyd and Clews had found winds at this level averaging 75 kt., and occasionally as strong as 130 kt. The increase of wind above 60,000 ft. agreed with the result noted by Hovmöller of an increase of wind speed in winter at Lerwick above about 50 mb. In summer, easterly winds became established above about 60,000 ft., and increased to about 100,000 ft. At the highest level there was a suggestion of a decrease of the easterly component. A diagram prepared by Dr. Scrase showed the boundary between winds with easterly and westerly components. This represented average conditions. Murgatroyd and Clews had noted that at 100,000 ft. the time of change-over in 1945 appeared to be about a month earlier than in 1944. It was also known that on particular occasions near the time of reversal temporary reversions from one type to the other had occurred. The occurrence of easterly winds in the lower stratosphere in summer had been established at other places, and there was little doubt of its being a hemispherical feature.

Mr. Kirk then emphasized that the following general considerations helped to systematize the results. The first was the tremendous importance of seasonal change. The results we had seen helped us to comprehend the great difference in cyclonic activity evident on our synoptic charts in winter and summer, a difference hardly capable of explanation in terms of thermal differences at the surface. The differential variation of amplitude of the annual variation of temperature was the factor modifying the wind distribution in the lower stratosphere. This was closely linked with the distribution of ozone. Theoretical discussion led inevitably from wind to temperature distribution, thence to the distribution of ozone. The reversed thermal field appeared to be characteristic only of the lower stratosphere. Above about 70,000 ft. in winter and 85,000 ft. in summer, temperature decreased to the north over the British Isles. It appeared probable that the stratosphere, particularly in winter, was not as dynamically inert as had commonly been supposed.

Concluding, Mr. Kirk said that the problem of forecasting winds in the stratosphere was practically untouched. Experience of drawing 200-mb. contour charts for use with flights by Comet aircraft had been disappointing. Much of the trouble was due to shortage of observations and inconsistency between observations. Difficulties arose in extending the thickness method due to the discontinuity of temperature gradient at the tropopause. It was also somewhat illogical to attempt to extend this technique because the disturbances at the tropopause were greater than those in the lower stratosphere.

The Director said that contrary to Mr. Kirk's remark about restricting the discussion to conditions over the British Isles he would like to hear contributions dealing with other places. He wanted to hear from those concerned with instruments about the possibility of getting more continuous observations at these high levels, and from the Upper Air Climatology Branch some comments on the statistical aspects of Hovmöller's paper.

Mr. N. E. Davis showed how Hovmöller's factor q, the ratio of the mean meridional wind to the mean zonal wind, could be calculated from the assumption of a normal distribution of wind about the vector mean with an assumed value of the standard vector deviation. Hovmöller's assertions about q amounted to the statement that the vector mean was between SW. and NW. Using upper wind data from Malta, Mr. Davis showed the importance of taking account of the loss of observations at high levels in any comparison with observations at lower levels.

Mr. M. K. Miles spoke of his experience at Dunstable in the drawing of upper air charts at 100 mb. using the thickness interval 200–100 mb. Features of the thickness pattern were generally conserved but on gridding with 200-mb. heights a confusion of lines was obtained. In his opinion, flow in the lower stratosphere was approximately geostrophic, but large departures from geostrophic balance occurred at the tropopause level.

Dr. F. J. Scrase said that later high-level observations had now become available. In the summer substantially the same results were obtained. The increased number of observations made it possible to group the three winter months separately, and here some differences became apparent. Lerwick was found to be colder than Downham Market at all levels. Last winter, in February, a change to easterly winds in the stratosphere persisted for a week at both Lerwick and Downham Market. This occasional occurrence of easterly winds in winter agreed with observations made in America by Gutenberg. Commenting on the falling off with height of the number of observations Dr. Scrase said that evidence was available which cast doubt on the usual assumption that the loss was due to the balloon getting out of range of the radar, and that the balloon performance might be suspect.

Miss N. Carruthers also spoke on the effect of loss of observations of high winds. The winds lost were those nearest to the vector mean and therefore the omission of high winds gave increased scatter. This result had been verified at 300 mb. In "Upper winds over the world"[6] pilot-balloon observations in the troposphere were completed for losses, but the effect of losses in the statosphere was not investigated. Dobson had found that light winds changed little on passing through the tropopause, but that winds increasing up to the tropopause decreased in the lower stratosphere. This implied that the method used in compensating for loss in pilot-balloon observations would not be valid in the lower stratosphere. Miss Carruthers ended with some remarks on the temperature distribution at 200 mb. as shown on the chart of average temperature prepared in the Upper Air Climatology Branch.

Mr. Hawson stressed the need for care in assuming that the winds at 100 mb. over Great Britain were representative of the continent. He also mentioned that systematic differences existed between the soundings of different countries.

Mr. S. P. Peters spoke of the persistence of the thermal pattern between 200 mb. and 100 mb. Forecasts of wind at 100 mb. for the route London–Prestwick had shown only a small improvement on "forecasts" based on persistence.

Mr. E. Gold asked if there was any indication of drift from north to south in Hovmöller's results. Could ozone have any effect on the wind in the lower stratosphere in February?

Mr. T. H. Kirk, in reply to Mr. Gold, said that Hovmöller gave figures for the mean southerly wind. Disclaiming any expert knowledge of ozone he said that he found it difficult to argue directly from absorption of ultra-violet light to temperature distribution. Was it not a fact that the reaction $3O_2 \rightarrow 2O_3$ was endothermic, implying an absorption of energy, here in the form of ultra-violet light? The heating of the air was due to the reverse reaction in which the ozone was partially transformed to oxygen.

Dr. D. N. Harrison spoke of the radio-sonde trials in Switzerland, and said that the large error found in the French radio-sondes during the trials was not representative.

Mr. D. D. Clarke said that if all the ultra-violet radiation was absorbed by ozone at the 50-Km. level it was difficult to explain how the temperature was affected at 20 Km.

Mr. H. W. Absalom mentioned the relevance of Gowan's calculations on the variation of temperature in the lower stratosphere.

The Director, in concluding the discussion, remarked that the ozone layer used to be regarded as of theoretical importance only, but now we are reaching this layer with direct observations.

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OFFICIAL PUBLICATIONS

The following publication has recently been issued:—

METEOROLOGICAL REPORTS

No. 9—Ice accretion on aircraft.

This pamphlet deals with the meteorological aspects of ice accretion on aircraft and is intended primarily for aircrew. Following a brief résumé of the physical properties of air and water, which are of importance in consideration of ice accretion, the types of ice which occur on aircraft are described and the factors which determine the type of ice are discussed. The amount of ice which forms is notably dependent upon the shape of the affected part of the aircraft and this is the subject of the third section. Since ice accretion can occur only in clouds composed of liquid water section 4 discusses the constitution of clouds of various types and the severity of icing likely to occur in them. The next two sections deal with the effects of ice accretion on airframe and engine respectively, and the final section describes the precautions which may be taken, both before and during flight, to avoid ice accretion.

METEOROLOGICAL RESEARCH COMMITTEE

The 17th meeting of the Synoptic and Dynamical Sub-Committee was held on October 11, 1951.

The main discussion concerned upper winds. Papers on this subject included Mr. R. Murray's on the practical value of contour charts as a method of representing upper winds[1] and also some notes on the wind field of middle latitudes by Mr. R. Murray and Mr. D. H. Johnson[2] in which the illustrations of jet streams aroused much interest. Winds at high altitude over the tropics were also discussed. Mr. C. S. Durst presented a paper[3] containing many useful statistics of upper air temperatures.

The accuracy of forecasts of fog at certain airfields and the reasons leading to errors in such forecasts were also considered.

The 12th meeting of the Instruments Sub-Committee was held on October 23, 1951. The Committee considered a paper by Mr. Clark[4] which dealt in detail, on a theoretical basis, with the probable causes of variation of the speed-correction coefficient of aircraft thermometers. Another paper by Mr. Clark[5] dealt with a possible method of detecting thin ice films on metal surfaces—a problem in the design of frost-point hygrometers.

Other matters discussed included the accuracy of the height of a given pressure level as determined from radio-sonde and radar data and the results of an international comparison of radio-sondes.

[1]*Met. Res. Pap., London,* No. 663, 1951.
[2]*Met. Res. Pap., London,* No. 667, 1951.
[3]*Met. Res. Pap., London,* No. 668, 1951.
[4]*Met. Res. Pap., London,* No. 677, 1951.
[5]*Met. Res. Pap., London,* No. 661, 1951.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on November 21, 1951, Sir Charles Normand, President, in the Chair, the following papers were read:—

*Sansom, H. W.—A study of cold fronts over the British Isles**

In this paper, which was read in the author's absence by Dr. R. S. Scorer, Dr. Sansom had analysed 50 cold fronts which crossed the British Isles in 1944–48. The sole criterion of choice was whether or not there were two radio-sonde stations 50–150 miles on either side of the front with the line joining them nearly normal to the front. It had been possible to divide the fronts into two types: A with the ratio of the difference between humidity-mixing-ratios on either side of the front to the mixing ratio in the warm air more than 0·65, and C with the ratio less than 0·30. Type A was found to have the further properties that the air above the frontal surface was descending (as was shown by increasing normal wind components with height) and had much lower relative humidity. This type of front, which he called katafront following Bergeron, gave little rain, only a small change of surface temperature, and very gradual wind veer, but usually a rapid and often complete clearance of cloud. Type C had ascending air above the frontal surface (the normal wind component was less than the speed of the front at all heights) and the air was generally saturated. This type, called anafront, often had a large, maybe sudden, fall in surface temperature, usually a sharp wind veer and marked drop in wind, and with a slow clearance

**Quart. J. R. met. Soc., London,* 77, 1951, p. 96.

of the cloud behind the front rather like a warm front in reverse. There was generally fairly heavy rain at the frontal passage with steady rain for some time behind the front.

Dr. Scorer showed a few diagrams and charts illustrating both particular cases and mean conditions. He closed with a plea that the description "ana-front" or "katafront" might be included in regular broadcast analysis messages from the Central Forecasting Office, Dunstable.

In the discussion that followed, doubt was raised as to the reality of the katafronts. Mr. Harley thought there was confusion with subsidence inversions. Mr. Sawyer thought that it was immaterial since a katafront could be regarded as a dynamical front without associated weather. Mr. Miles thought the air above a katafront was subsided cold air, the true front being more nearly vertical, or even past the vertical, near the surface frontal position. Dr. Sutcliffe was pleased to see that the fronts had been those placed by the Central Forecasting Office, and quoted Mr. Douglas as saying that the paper was very good so long as it was not expected to improve present forecasting. Mr. Matthewman remarked that the hodograph and isobaric distinction between fronts should be treated with caution.

*Kay, R. H.—The apparent diurnal temperature variation in the lower stratosphere**

Dr. Kay described an investigation he had made of the mean monthly diurnal temperature changes at heights of 150, 100 and 80 mb. averaged over the five radio-sonde stations, Lerwick, Aldergrove, Downham Market, Larkhill and Penzance, during 1947 and 1948. During 1947, when the routine times of ascent were 0000, 0600, 1200 and 1800, only in winter did three of the daily ascents take place in darkness; in 1948, when the times of ascent were 0300, 0900, 1500 and 2100, there were always two night ascents except at Lerwick in summer. It was therefore possible to estimate the nocturnal cooling throughout the year with some degree of accuracy, but in day-time there was a comparatively sudden rise in the measured temperature about sunrise and a similar fall at sunset, the effect being more pronounced in summer (range 3°C.) than winter (range $1\frac{3}{4}$°C.), and up to twice as large at 80 mb. as at 150 mb. Since the estimated nocturnal cooling of about 0·05°C./hr. agreed with theoretical estimates of radiative cooling and radiative processes could not account for the sudden rise and fall near sunrise and sunset, only two alternatives remained: the temperature changes may be due to dynamical causes (sudden increase and decrease of pressure of the order of 4 or 5 mb. at about sunrise and sunset), or to a radiation error due to solar radiation directly on the temperature element of the radio-sonde during day-time. The dynamical causes leading to sudden inflow and outflow of 4 mb. of air at higher levels would also require similar compensatory movements of air at lower levels in the atmosphere; and there is no direct evidence of such complex processes. It seems more likely therefore that a large part of the error is due to radiation error of the thermometer.

Dr. Scrase agreed there might be some radiation errors in the British radio-sonde, but to find out what they were would require a lot of special ascents. He had, however, tried to calculate the theoretical radiation error treating the temperature element as a flat plate, and had found errors up to half the variation found by Dr. Kay at 100 mb. for June:—

**Quart. J. R. met. Soc., London,* 77, 1951, p. 427.

	Difference in temperature from that at midnight at 0600	0900	1200	1500	1800
			degrees Fahrenheit		
As observed	2·6	3·2	3·5	3·4	2·6
As calculated ...	0·9	1·8	1·8	1·8	0·9

He had also made similar calculations at heights of 10, 20 and 30 Km. obtaining similar results. The Meteorological Office were now experimenting with fine-wire temperature elements so as to get rid of the radiation error.

Mr. Gold remarked that he had found a bigger difference between the 0300 and 2100 temperatures than was explained by radiation theory, but he thought that it could be accounted for by the difference in the surface temperature of the earth, which, although leading to an increased radiation of only a small amount of the order of 0·02 gm.cal./cm.^{2}/min., was big enough to account for temperature differences of the order of 0·1°C.

CONGRESS OF MARITIME METEOROLOGY AT GENOA

A Congress of Maritime Meteorology was included in the programme of the Genoa Columbus Celebrations for the year October 1950–October 1951, and was held in the Palazzo Regio of the University of Genoa on September 20–22, 1951. Among the delegates to the Congress were meteorologists from France, Germany, Great Britain, Italy and the United States. A total of over twenty papers were read on a variety of subjects in the general field of marine meteorology.

The delegates assembled in the Palazzo Regio at 10 a.m. on September 20, where an exhibit of meteorological and oceanographical instruments was examined with interest. The Congress was then formally opened by Prof. C. Cereti, Rector of the University of Genoa, who emphasized the importance of marine meteorology, our knowledge of which, at present still scarce and insufficient, needed to be enlarged and diffused. Afterwards Prof. M. Bossolasco, Director of the Geophysical Institute of the University and organizer of the Congress, reviewed briefly the history of the science of meteorology since the time of Columbus.

The first paper to be read was by Prof. G. Wüst, Director of the Oceanographic Institute of the University of Kiel on "The hydrological balance of the Baltic and Mediterranean Seas". The processes controlling the hydrological balance between ocean and atmosphere can be evaluated most easily from an analysis of data obtained from more or less completely closed seas such as the Baltic and Mediterranean. An equilibrium equation can be set up representing the mean annual water circulation,

$$A - E = N + Z - V,$$

where A is the current flowing out of the sea, E is the current flowing in, N is the rainfall over the sea, Z is the amount of water emptied into the sea by rivers and run-off, and V is the evaporation. All these values can be evaluated or calculated approximately from observations. An estimate of the evaporation can also be obtained from the Jacobs formula

$$V = k(e_w - e_a)\ W,$$

where k is a constant, e_w the saturation vapour pressure at the temperature of the sea surface, e_a the vapour pressure of the air at the level of the deck of the ship, and *W* is the wind velocity. The results of the calculations showed that there is a loss of about 965 mm./yr. of fresh water in the Mediterranean and a gain of about 1,243 mm./yr. in the Baltic. Mean evaporation over the Mediterranean was found to be over four times as great as mean precipitation, while over the Baltic precipitation and evaporation were approximately equal.

The afternoon session was opened by Dr. Kuhlbrodt of Hamburg with a paper on "Winds along the maritime route Cape Verde—La Plata". Dr. Kuhlbrodt discussed in some detail the analysis he had made of surface winds and pilot-balloon observations collected from the *Meteor* expedition. He showed lantern slides depicting the distribution of the wind in a number of ways, as, for example, the variation of the mean vector wind with height for various latitudes and longitudes, the distribution of the magnitude of the east and west components of velocity of the mean vector wind and of the mean scalar velocity as a function of height and latitude. The average position of the jet stream could be identified from the latter diagrams. Although such analyses had already been undertaken in detail over the land there was little available information over the ocean, and the *Meteor* pilot-balloon ascents provided a useful coverage to extend the analysis of upper wind circulation to regions of the atmosphere over the oceans.

Subsequently a paper by J. C. Thams and E. Zenone was read on "The influence of the cyclones of the Gulf of Genoa on the weather in the Ticino canton of Switzerland". Orographical effects caused heavy rainfall when such depressions developed.

"The employment of the radar set of the Oceanographical Museum in Monaco for meteorological observations" by J. Rouch of Monaco was read by Prof. Bossolasco in the absence of the author. The paper evoked a lively discussion on the possibilities of radar as a means of obtaining meteorological observations for the measurement of upper winds and for the identification of clouds, thunderstorms and tropical storms.

F. Musella of Genoa continued with a paper entitled "The contribution of ships to meteorology in general and maritime meteorology in particular" in which the means of obtaining accurate observations at sea were discussed. At the conclusion of the paper controversial views were expressed by members of the Congress regarding alternative methods of either estimating visually or measuring instrumentally the wind velocity at sea, and also regarding the measurement of the sea-surface temperature by the bucket or intake methods. Prof. Wüst expressed the opinion that it was the temperature of the surface layer of the water that was required rather than that of the depth of the intake. In particular it was necessary to increase the scientific knowledge of the Mediterranean by undertaking voyages to measure depth profiles of temperature and salinity.

I. Dagnini of Genoa concluded the first day's session with a paper entitled "The annual variation of pressure in the Mediterranean". The annual variation of pressure had been harmonically analysed and isopleths of the amplitude of the pressure variation drawn on a chart of the Mediterranean.

The programme on the second day was opened by Dr. Wüst with the introduction of A. H. Gordon who read his paper entitled "The relation between the mean vector wind and the mean vector pressure gradient over the oceans". Pressure and wind data had been treated by Hollerith machines for 5° squares over the oceans and the mean difference in direction between the mean vector wind and the isobars drawn from the mean vector pressure gradient computed as a function of latitude. Slides were shown illustrating the variation with latitude of the angle of deviation and of the ratio of the actual mean vector surface wind velocity to the theoretical mean vector geostrophic wind velocity.

A stimulating discussion followed in which great interest was shown in the ways in which the analysis of marine data by Hollerith methods could contribute to meteorological knowledge of such subjects as the general circulation.

The next paper was one by Dr. Jonchay of Lyons on the importance of upper winds, particularly for aircraft flying along southern-hemisphere routes. The lack of upper air information over the oceans necessitated the enlistment of the various scientific organizations to assist in the development of services for the observation of such data.

Other papers read during the morning session of September 21 were "The condition of visibility in the Mediterranean" by E. G. El-Fandy in which the variation of visibility in different synoptic situations was discussed, and two papers by S. Polli of Trieste, "The diurnal, seasonal and annual variation of visibility in the Gulf of Trieste" and "Optical reflection of a sea surface".

In addition to the papers on the agenda for the morning of September 21, an officer from the Statistics Bureau in Rome discussed the relation between marine meteorology and statistics. An intense discussion then developed regarding the general unification of all meteorological services in Italy and the best means of developing marine meteorology in a progressive way, using the punched-card system of recording and analysing the collected data.

The afternoon session of September 21 opened at 3 p.m. with a paper by H. Berg of Cologne on "The importance of the marine climate for climatherapy". This consisted of a very thorough analysis of the medicinal aspects of marine climates as contrasted with mountain climates. The true marine climate was found either on islands or along a very narrow belt of shore line. Marine characteristics disappeared very rapidly as the distance from the shore line increased.

A. D'Arrigo of Catania then read two of his papers. The first discussed the influences characterizing wave motion in the sea, and the relation between the form of the sea bottom, the fetch, the potential energy of the wave oscillations and the kinetic energy of their breaking. The second dealt with the topography of the sea bottom of the Mediterranean reconstructed from British Admiralty and Italian Hydrographic Institute Charts.

The meeting closed at 5 p.m. to enable the Congress to visit the International Columbus exhibition at St. Georges' Palace.

The programme of the final session on September 22, was opened at 9 a.m. with Mr. Gordon in the Chair. The first speaker was Dr. H. Roll, with his paper "Is there a critical wind velocity for physical processes in the limited air-sea boundary layer?" There was evidence that discontinuities appeared at wind velocities of about 7m./sec. in the processes governing the behaviour of stress, evaporation, gull soaring and the formation of white caps. A number of wind profiles over the sea, as found by various authors, were shown on slides.

Dr. Roll was followed by an officer from the Marine Hydrographic Institute of Genoa, who read papers on "The relation between wind velocity and wave motion in the open sea and along the coast", and on "The organization of meteorological observations aboard Italian mercantile marine ships".

Next, Prof. M. Kovačević from Belgrade read a paper on some aspects of the climate of Yugoslavia, after which Prof. Bossalasco read his paper entitled "Evaporation and fog over the sea".

The final session concluded with a discussion of the various resolutions which had been drawn up recommending measures to develop and improve the science of marine meteorology in Italy. Some slight amendments were made to the resolutions, after which they were approved by the Congress.

The Congress was closed with a few words of appreciation of the hospitality and organization of the Congress by the chairman on behalf of the foreign visitors present. The members met again at 3 p.m. outside the University to embark on an excursion by auto-pullman to the attractive tourist centre of Rapallo. After a delightful drive along the Mediterranean coast, members visited the Foreign Visitors Club at Rapallo where they were met by the Mayor. Afterwards tea was served on the terrace.

Finally the return journey was made and the foreign visitors were entertained to dinner by Prof. Bossolasco in the roof garden on the 31st floor of a sky-scraper building; from here an extensive view of the city of Genoa could be obtained.

The meeting of the Congress was very successful, providing a stimulating atmosphere for the exchange of ideas between workers in maritime meteorology of several nations. The arrangements were well organized, and the assistance and hospitality shown were excellent. It is certainly in the interests of the advancement of science that such international meetings should be arranged from time to time. The availability of foreign scientific literature cannot altogether eliminate a tendency in many cases for individual workers to plan and execute research in water-tight compartments.

INSTITUTION OF CIVIL ENGINEERS

Relation between daily rainfall and flow of the River Shin, Sutherland

A meeting of the Institution of Civil Engineers, Public Health Division, was held on October 23, 1951, to discuss a paper by R. H. MacDonald on "The relation between daily rainfall and flow of the River Shin".

Mr. MacDonald, briefly introducing his paper, explained first the limitations of the available data. In particular, values of daily rainfall over the Shin catchment area had to be deduced from only two rain-gauges, one just within the catchment in a locality of relatively low rainfall, and one a few miles outside but in a locality with a much higher rainfall—comparable with the highest mean annual value which any part of the catchment area itself is likely to experience. Further, values of run-off were obtained during the period under investigation (1947–49) from single daily readings of river level and not from continuous records.

The treatment of the data was very bold and based on strikingly simple assumptions, so that it was rather surprising that good agreement was obtained between calculated and observed mean daily run-off throughout the three-year period. Extension to 1950 and the first part of 1951, after the main work of the paper had been completed, showed that agreement was not maintained at the

Reproduced by courtesy of H. W. Pemberton

FUNNEL CLOUD AT BRAUNSTONE, LEICESTER

This cloud was observed by Mr. Pemberton at 1915 G.M.T. on July 14, 1951; the tail from the end of the cloud was spinning violently like a top and lasted for roughly five minutes before travelling up into the cloud and disappearing.

To face p. 25]

Reproduced by courtesy of A. E. Wallis

Time: 16h. 55m. 00s. G.M.T.

Reproduced by courtesy of A. E. Wallis

Time: 16h. 55m. 45s. G.M.T.

FUNNEL CLOUD AT HEACHAM, NORFOLK

same high level, but nevertheless seemed fairly satisfactory. One of the objects of the paper was to extend the analysis backwards over a 20-year period to obtain estimated values of run-off (which had not been measured before 1947) from known values of the rainfall at the two stations. The information thus obtained would be of value for hydroelectric purposes.

In the ensuing discussion the paper was subjected to forceful criticism from a number of aspects. Several speakers pointed out that the Shin catchment area happened to be very favourable for the particular treatment adopted. They thought that unless the basic equations could first be generalized it was unlikely that much would follow from the author's suggestion of extending the method to other areas.

More serious and fundamental criticism came from Dr. Glasspoole and Dr. Penman. The former aimed at showing from climatological data that the quantity derived as "evaporation" in MacDonald's paper could not be regarded as true evaporation, but must be a complex quantity combining evaporation and storage effects; the point was clearly brought out by a slide showing graphs of the annual cycles of the relevant data. The latter pursued the topic more specifically, and insisted that in any adequate treatment evaporation must be introduced as an independent variable, whilst storage must be dealt with initially as the unknown quantity to be derived from measured and estimated terms in the water-balance equation.

The paper and a fuller account of the discussion will be published later in the *Proceedings of the Institution of Civil Engineers*, Part III.

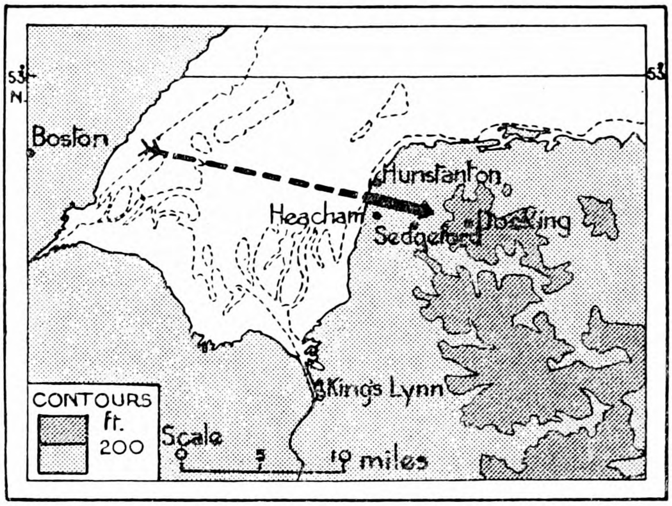
LETTERS TO THE EDITOR

Funnel cloud over the Wash

On Sunday, September 16, 1951, a belt of rain associated with the trough in the unstable west-north-westerly air stream, crossed the Wash during the late afternoon moving east-south-east at approximately 24 kt. The belt appeared to be stormy when approaching the east coast of the Wash, with a thick roll of black cloud (thunderstorm collar). At 1635 G.M.T. slight rain started to fall on Heacham beach, slowly intensifying. With the passage of the roll cloud at 1653, the wind became squally and heavy rain fell for 12–15 min. No thunder was heard.

The column of funnel cloud was first seen at 1652, approaching the beach between Heacham and Hunstanton from over the Wash. The column extended downwards from black cloud, the base of which was estimated to be 500 ft. The length of the vortex was about 300 ft., thinning downwards and carrying below it to the surface a dense and diffuse mass of mist, suggesting rather strong activity over the sea. The mist quickly thinned and finally dispersed some 300–400 yd. inland. The cloud base steadily lifted over the rising land and the length of the column decreased. When at a distance of 1,500–2,000 yd. from the beach, the lower part of the vortex performed two complete revolutions, apparently swinging slowly clockwise and after the first revolution bending back the tail almost parallel to the ground.

The photographs opposite were taken by Mr. A. E. Wallis of Heacham, from a position 1,200 yd. south of the path of the funnel cloud, during the second and less pronounced revolution. The first one, taken at 1655 G.M.T., shows the funnel slightly bent towards the direction of movement. The second one, taken 45 seconds later, shows the funnel tailing back again. The revolutions were probably caused by a sudden eddy in the gusty wind over the uneven and more steeply rising ground



MAP SHOWING TRACK OF FUNNEL CLOUD

In its last stage, when moving over hilly ground towards Sedgeford and Docking, the already short column broke up into fragments which soon lifted and merged with the cloud bulge above them. Between 1658 and 1659, the phenomenon completely disappeared, being then about 3½ miles inland.

From the observed track the funnel cloud would appear to have crossed the sea from the direction of Boston, on the other side of the Wash.

S. SZCZYRBAK

Freezing days in Great Britain

Readers of the article on "Freezing days in Great Britain" published in the August 1951 number of this magazine may like to have the following additional information:—

FREQUENCY OF WINTERS WHEN THERE WAS AT LEAST ONE T'-FREEZING DAY WITH A MEAN TEMPERATURE BETWEEN SPECIFIED LIMITS

Period: 20 winters, 1927–28 to 1946–47

	Temperature (°F.)																
	31·6 to 32·5	30·6 to 31·5	29·6 to 30·5	28·6 to 29·5	27·6 to 28·5	26·6 to 27·5	25·6 to 26·5	24·6 to 25·5	23·6 to 24·5	22·6 to 23·5	21·6 to 22·5	20·6 to 21·5	19·6 to 20·5	18·6 to 19·5	17·6 to 18·5	16·6 to 17·5	15·6 to 16·5
	Number of winters																
Kew	16	17	13	9	10	10	7	5	6	0	1	2	1	0	0	0	0
Aberdeen ...	18	14	13	12	10	8	4	5	4	4	2	0	0	0	0	0	0
Edinburgh ...	17	18	14	14	9	10	5	5	3	3	0	1	0	0	0	0	0
Newcastle ...	20	19	19	16	16	7	7	5	5	2	3	2	2	0	0	0	1
Birmingham ...	20	18	16	16	14	8	7	4	6	4	3	3	2	2	1	0	0
Bristol ...	18	15	14	10	14	11	11	3	5	4	1	2	2	1	1	0	0
Manchester ...	18	15	14	12	10	9	5	4	2	5	1	3	0	2	0	0	0

J. E. BELASCO

October 19, 1951

BOOK RECEIVED

Jaarboek A. Meteorologie (*Yearbook, A. Meteorology*) 1948, Koninklijk Nederlands Meteorologisch Instituut. 13¼ in. × 9½ in., pp. xii+96, Staatsdrukkerij-en Vitgeverijbedrijf, 's-Gravenhage, 1950. Price: *fl.* 5.00.

NOTES AND NEWS

Director of the Naval Weather Service

Captain R. F. Nichols, A.D.C., R.N. ceased to hold the appointment of Director of the Naval Weather Service on November 11, 1951. He was succeeded by Instructor Captain P. Bracelin, O.B.E., M.A., B.Sc., R.N.

Instructor Captain P. Bracelin is the first Instructor Officer to fill the post which has hitherto been filled by an Executive Officer. He joined the Royal Navy as an Instructor Lieutenant in 1926 after carrying out research work at the Cavendish Laboratory. He qualified as a Meteorological Officer in 1936 and has been continuously employed in the Naval Weather Service since 1939. During the war he was a forecaster, afloat in H.M.S. *Ark Royal* and ashore at home and in the West Indies, and later Admiralty member of the Combined Meteorological Committee, Washington, D.C. Since the war he has been in charge of the Forecast and the Research and Investigations Sections at the Naval Meteorological Branch (Admiralty), Staff Meteorological Officer to Flag Officer (Air) Home, and, finally, Deputy Director of the Naval Weather Service.

The Meteorological Office wishes the new Director every success in his responsible task.

Exceptionally unsettled weather in Malta, Autumn 1951

Summer in Malta normally consists of a period of three or four months of almost uninterrupted fine weather. In September, however, thundery outbreaks begin to occur, these being generally neither very frequent nor very prolonged. October is normally somewhat similar to September, but, of course, cooler, and with more frequent outbreaks of bad weather of a thundery character.

This year the amount of rain which fell during these two months was unprecedented. The total rainfall amounts recorded at Luqa for September and October were 163·0 mm. (6·42 in.) and 476·5 mm. (18·76 in.), respectively, these figures representing 526 per cent. and 851 per cent. of the normals for the two months in question. Normals are based on records for Valetta for the period 1911–1940 and not for Luqa. However there are no major topographical features to give either station a marked advantage over the other in respect of rainfall. The Royal Malta University in Valetta has actually recorded rather more rainfall than Luqa during the present season.

The total rainfall for the two months, 639·5 mm., represents about 125 per cent. of the normal annual rainfall, and during the period September 15 to October 18 inclusive (i.e. less than five weeks) the normal annual rainfall was slightly exceeded. The University rainfall records go back to 1868, and these (as well as those of the Meteorological Office, dating back to 1923) have been examined for figures comparable with those of the present season. In September 1879, 6·85 in. of rain were recorded, but in no other September was the figure for September 1951 approached. The figure for October 1951 has no parallel in the records, the previous highest being 12·8 in. in October 1913. In fact the rainfall for October 1951 is the highest for any month of any year for which records exist.

A comparison of the number of rain days (days with 0·1 mm. or more), 10 for September and 17 for October, with the normal figures of 3 and 7 respectively is of some interest. Thunder occurred on 8 days in September and on 10 days in October.

Very rapid falls of rain were recorded on a number of occasions, that on October 4—about 70 mm. (2·8 in.) in one hour—being outstanding.

Considerable damage to property was sustained, largely as the result of flooding following the rapid falls of rain, and a number of casualties were reported. On October 4, after the rapid fall of rain mentioned above, a man was drowned in a flooded street in Misida. On the same day a man was killed by lightning in a country district. On October 17 a house in the village of Pawla collapsed following a stroke of lightning, killing three people and injuring eight others. On the same day a house in Valetta which had been weakened by flooding collapsed but without causing any casualties.

Many farms were repeatedly flooded, crops being washed out of the ground, and much valuable soil carried out to sea, a serious loss on this rocky island. Road transport was frequently seriously hampered by flooding, some of the more unfavourably situated roads becoming torrents, and being left with barriers of debris after the subsidence of the floods.

Landline communications suffered considerably, as is often the case with flooding. Of special interest is that during much of the period October 15–17 nearly all the transmitters operated from Luqa airport were out of action due to landline trouble, the meteorological broadcast transmitter being one of those affected.

The synoptic conditions associated with the individual spells of bad weather distributed over the two months were very varied, and the exceptional rainfall cannot be ascribed to any one single principal factor. However, over much of the period pressure was abnormally high over Europe, and the average pressure at Malta showed a negative departure from normal amounting to 1·0 mb. in September and 2·7 mb. in October.

There were two rather prolonged spells of bad weather September 14–17 and October 14–19. In each of these spells Malta lay within and on the eastern flank of the circulation of almost stationary low-pressure systems. In the first spell a trough extended northwards from a depression centred near Tripoli, Malta being in an unstable south-easterly air stream. In the second spell, a cold pool became practically coincident with a surface depression over the western Mediterranean causing it to become slow-moving. Subsequently this low extended south-eastwards, finally amalgamating with a depression over north Africa and forming a large complex low-pressure system. Once again Malta was in an unstable south-easterly air stream.

All the other excessive falls were of short duration and were associated with the passage of cold-frontal troughs, mostly extending from depressions centred well to the north or to the east of Malta.

Green flash

We have received from Mr. Masao Hanzawa of the Central Meteorological Observatory, Tokyo, a colour photograph of the green flash which he took from a whaling vessel in the Antarctic Ocean. Mr. Hanzawa was one of four meteorologists who accompanied the Japanese whaling fleet during the 1950–51 season.

The photograph was taken at 63°39′S., 115°59′E. at sunset on January 4, 1951, during the 2–3 sec. for which the green final segment of the sun was visible. As the sun was about to set it became a luminous golden point which suddenly changed colour to a vivid green.

The copy sent, a half-tone reproduction, clearly shows the green segment of the sun on the sharp sea horizon. There is no apparent distortion. A long roll of stratocumulus cloud is seen a few degrees above the horizon. Air temperature was −0·6°C. and sea temperature 0·8°C.

As Mr. Hanzawa remarks this is probably the first colour photograph ever taken of the green flash.

Upper air data and special synoptic observations

We welcome the publication by the Royal Netherlands Meteorological Institute of the series *Upper air data and special synoptic observations* which constitutes a continuation and extension of the Institute's pre-war series *Ergebnisse Aerologischer Beobachtungen.*

Three volumes of the new series covering in all the period June 1, 1945, to December 31, 1948, have recently been published. No upper air observations could be made during the period May 13, 1940 to May 31, 1945.

The volumes include the upper air temperature and wind observations made at De Bilt and from the Dutch ocean weather ship *Cirrus*, and both surface and upper air observations made from the whaling ship *Willem Barendsz*. The upper air temperature observations were all made by radio-sonde. The upper wind observations from De Bilt and *Willem Barendsz* were obtained visually but most of those from *Cirrus* were made by radar.

REVIEW

Meteorology with marine applications. By W. L. Donn. 9 in.×6 in., pp. xx+465, *Illus.*, McGraw-Hill Book Company, New York, Toronto, London, 2nd edn, 1951. Price: $5.50 or 47*s*.

W. L. Donn was formerly Head of the Meteorology Section of the United States Merchant Marine Academy, and his book has been designed primarily to meet the needs of young men training for careers in the merchant navy. He has included material that he hopes will enable the reader (i) to understand weather changes and their causes, (ii) to take weather observations, (iii) to make short-period weather forecasts from synoptic maps, and (iv) to relate weather information to the problems of seamanship and navigation. These are large enough subjects for three distinct volumes of this size if the author was to see his hopes fulfilled, but as in his presentation he has assumed little or no knowledge of physics and very little of mathematics, it was inevitable that his success should be limited. Over-simplification of a subject must lead to confused thinking on the part of the reader, and any such textbook which assumes the reader knows nothing when he starts but will be able to make weather forecasts when he finishes, misrepresents weather forecasting as it known today.

This general criticism of the publication going too far without enough of the higher physics and mathematics being included to point out the pitfalls of synoptic and dynamical meteorology or even to discuss upper air analyses, must not, however, detract from its special merits. The author has presented his elementary introduction to the subject in a most lucid manner, and criticisms of over-simplification at this level would be mere carping. His diagrams are plentiful, and, with two most noticeable exceptions, they are very helpful. The two exceptions are Figs. 2.12 on p. 31 and 7.12 on p. 122. The first is confusing in so far as the caption and the text disagree. The caption states specifically that the lengths of the horizontal arrows in the figure are not proportional to actual pressure decreases; the text states that the arrow lengths are proportional to the air pressure and indicate the decrease of pressure. It is thought that this disagreement has been caused by a correction to the figure as shown in the first edition without a corresponding correction to the text. The lengths of the arrows are not proportional to pressure decreases. The second diagram, 7.12, is an illustration of common isobar patterns and shows a wedge of high pressure as an inverted V, a pattern that is dynamically impossible as in anticyclonic motion the angular velocity about the centre must be less than $\omega \sin \varphi$, the angular velocity of the horizon.

The publication has, of course, been written principally for American use, and we find the usual difference in the definition of sleet. The American definition of sleet is that it is true frozen rain, i.e. ice pellets, and not, as we understand, melting snow or a mixture of snow and rain.

Complete chapters have understandably been devoted to tropical cyclones, and the oceans. The latter embodies details of temperature, salinity, currents, sources of ice, an introduction to wave motion and tides, and the monthly average weather conditions over the North Atlantic and the North Pacific. In addition to these chapters, written mainly for mariners, the author has done well to introduce marine applications whenever opportunity occurs. Thus, in the chapter on humidity he has devoted a section to cargo ventilation, and the chapter on winds has a section on true and apparent wind.

There is an excellent appendix giving average monthly weather summaries for 149 of the principal ports and islands of the world. The use of films as an aid to instruction at the United States Merchant Marine Academy is perhaps borne out by the list of visual aids given at the end of the volume to supplement some of the material in the book. Unfortunately this correlated list can have only limited use in this country as most of the films are not generally available to us.

G. J. EVANS

WEATHER OF NOVEMBER 1951

Mean pressure over most of Europe was between 1005 and 1015 mb., but fell to below 1000 mb. in the north of the British Isles. Pressure was below normal over all this region, the deficit varying from 2 mb. to 10 mb., and reaching 12 mb. in the British Isles. The area with a deficit of pressure extended north-west, west and south-west of the British Isles to about longitude 25°W.; further west mean pressure rose to 2–6 mb. above normal and west of the Azores, it reached 1024 mb. The region north-east of Iceland with mean pressure between 1010 and 1015 mb., was about 5–9 mb. above normal.

Mean temperature over Europe generally was between 45° and 55°F., and was about 5°F. above normal; over the Mediterranean region mean temperature was generally 60°F. Mean temperature over North America was below normal, as much as 9°F. in the region of the Great Lakes.

In contrast to October the weather of November was exceptionally wet; as far as can be estimated at present, in England and Wales it was the wettest

November, apart from those of 1940 and 1929, in a record going back to 1869, and in Scotland it was the wettest on record. The month was also unusually mild.

In the opening days a depression south of Iceland moved east and filled, while a secondary off south-west Ireland moved north-east to the North Sea and then turned west across the north of Scotland. Rain fell generally and was heavy in places (2·20 in. at Felindre, Glamorgan and 2·01 in. at Princetown, Devon, on the 3rd) and thunderstorms occurred locally in the west on the 2nd. On the 4th and 5th secondary depressions over south Ireland moved north-north-west; widespread south-easterly gales occurred and rainfall was heavy in many places (3·59 in. at Thirlmere, Cumberland, and 3·06 in. at Rhondda Waterworks, Glamorgan on the 4th and 3·04 in. at Danby, Yorkshire and 2·72 in. at Dyce, near Aberdeen, on the 5th). Thereafter pressure was low off our south-west coasts; from the 7th to the 9th associated troughs of low pressure moved north over the British Isles, and on the 10th and 11th a secondary depression moved north-north-west from the south of France to the west of the Hebrides. Rain occurred daily (2·21 in. at Bwlchgwyn, Denbighshire, on the 8th) and it was very mild. A temporary improvement occurred on the 12th and 13th, though there were scattered showers and local thunderstorms on the 12th. On the 14th and 15th a trough associated with a complex, deep depression in the Atlantic moved north over the British Isles giving further rain. A period of showery weather ensued from the 16th to the 21st with thunder in places and heavy rainfall at times. Gales were registered in the west on the 21st and 22nd. On the 24th a depression moved from the Hebrides to south Sweden, and on the 25th an associated trough moved south over England and Wales; heavy rain fell in England and Wales on the 24th and some snow or sleet in Scotland on the 24th and 25th. Northerly winds of polar origin behind this depression caused a fall in temperature, and in the wedge that followed widespread frost occurred. A minimum temperature of 24°F. was registered at Eskdalemuir and 27°F. at Shawbury, Shropshire, on the morning of the 26th. Fair sunny weather prevailed in England and Wales on the 26th. Subsequently high pressure was established to the south and south-west of the British Isles, while Icelandic depressions moved east or north-east in the far north and, although showers occurred, the very wet spell was ended over most of the country, particularly in England and Wales. Gales occurred locally at exposed stations in the north-west and north from the 27th to the 30th, especially on the 28th.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	62	23	+3·9	206	+6	97
Scotland	60	21	+3·0	167	+5	74
Northern Ireland ...	58	28	+2·6	160	+4	64

RAINFALL OF NOVEMBER 1951

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	4·83	205	*Glam.*	Cardiff, Penylan ...	8·02	198
Kent	Folkestone, Cherry Gdn.	5·12	158	*Pemb.*	Tenby	6·79	156
„	Edenbridge, Falconhurst	6·59	186	*Card.*	Aberdovey (Plas Penhelig)	6·48	143
Sussex	Compton, Compton Ho.	10·15	266	*Radnor*	Tyrmynydd	12·72	191
„	Worthing, Beach Ho. Pk.	4·57	143	*Mont.*	Lake Vyrnwy	10·63	186
Hants.	Ventnor, Cemetery ...	8·57	261	*Mer.*	Blaenau Festiniog ...	13·73	129
„	Bournemouth	10·00	294	*Carn.*	Llandudno	6·10	211
„	Sherborne St. John ...	7·79	273	*Angl.*	Llanerchymedd ...	7·27	173
Herts.	Royston, Therfield Rec.	3·84	165	*I. Man*	Douglas, Borough Cem.	7·65	162
Bucks.	Slough, Upton	5·71	257	*Wigtown*	Port William, Monreith	...	...
Oxford	Oxford, Radcliffe ...	5·19	226	*Dumf.*	Dumfries, Crichton R.I.	8·87	241
N'hants.	Wellingboro', Swanspool	4·64	216	„	Eskdalemuir Obsy. ...	10·31	178
Essex	Shoeburyness	2·51	118	*Roxb.*	Kelso, Floors	4·86	210
„	Dovercourt	3·31	154	*Peebles*	Stobo Castle	7·87	238
Suffolk	Lowestoft Sec. School ...	3·77	160	*Berwick*	Marchmont House ...	5·47	182
„	Bury St. Ed., Westley H.	3·90	170	*E. Loth.*	North Berwick Res. ...	4·26	190
Norfolk	Sandringham Ho. Gdns.	3·09	125	*Midl'n.*	Edinburgh, Blackf'd. H.	4·23	189
Wilts.	Aldbourne	7·42	254	*Lanark*	Hamilton W. W., T'nhill	5·15	144
Dorset	Creech Grange... ...	8·85	215	*Ayr*	Colmonell, Knockdolian	7·81	157
„	Beaminster, East St. ...	10·33	260	„	Glen Afton, Ayr San. ...	12·08	220
Devon	Teignmouth, Den Gdns.	5·53	173	*Bute*	Rothesay, Ardencraig ...	7·96	157
„	Cullompton	6·72	195	*Argyll*	Morvern, Drimnin ...	8·32	123
„	Ilfracombe	4·80	122	„	Poltalloch	7·83	139
„	Okehampton, Uplands	9·35	176	„	Inveraray Castle ...	11·73	139
Cornwall	Bude, School House ...	3·84	108	„	Islay, Eallabus	9·01	167
„	Penzance, Morrab Gdns.	7·33	160	„	Tiree	6·96	144
„	St. Austell	6·87	140	*Kinross*	Loch Leven Sluice ...	5·38	150
„	Scilly, Tresco Abbey ...	5·46	158	*Fife*	Leuchars Airfield ...	6·01	262
Glos.	Cirencester	6·75	227	*Perth*	Loch Dhu	...	...
Salop	Church Stretton ...	7·53	243	„	Crieff, Strathearn Hyd.	7·76	179
„	Shrewsbury, Monkmore	4·94	219	„	Pitlochry, Fincastle ...	8·13	219
Worcs.	Malvern, Free Library	6·98	277	*Angus*	Montrose, Sunnyside ...	7·15	270
Warwick	Birmingham, Edgbaston	7·82	329	*Aberd.*	Braemar	8·02	209
Leics.	Thornton Reservoir ...	4·90	217	„	Dyce, Craibstone ...	8·72	267
Lincs.	Boston, Skirbeck ...	3·45	173	„	Fyvie Castle	7·62	220
„	Skegness, Marine Gdns.	...	...	*Moray*	Gordon Castle	5·67	197
Notts.	Mansfield, Carr Bank ...	7·02	289	*Nairn*	Nairn, Achareidh ...	3·58	159
Derby	Buxton, Terrace Slopes	11·36	243	*Inverness*	Loch Ness, Garthbeg ...	3·93	94
Ches.	Bidston Observatory ...	6·34	254	„	Glenquoich	12·54	103
Lancs.	Manchester, Whit. Park	...	...	„	Fort William, Teviot ...	10·12	123
„	Stonyhurst College ...	9·42	209	„	Skye, Duntuilm ...	5·32	89
„	Squires Gate	7·95	241	*R. & C.*	Tain, Tarlogie House ...	4·67	158
Yorks.	Wakefield, Clarence Pk.	6·17	291	„	Inverbroom, Glackour...	8·67	139
„	Hull, Pearson Park ...	3·23	147	„	Applecross Gardens ...	6·42	99
„	Felixkirk, Mt. St. John	5·93	242	„	Achnashellach	7·44	86
„	York Museum	5·26	252	„	Stornoway Airfield ...	5·83	105
„	Scarborough	4·10	166	*Suth.*	Loch More, Achfary ...	...	...
„	Middlesbrough... ...	3·56	168	*Caith.*	Wick Airfield	5·11	163
„	Baldersdale, Hury Res.	8·66	234	*Shetland*	Lerwick Observatory ...	5·99	141
Norl'd.	Newcastle, Leazes Pk....	5·26	224	*Ferm.*	Crom Castle	3·85	111
„	Bellingham, High Green	7·07	206	*Armagh*	Armagh Observatory ...	5·50	194
„	Lilburn Tower Gdns. ...	7·11	212	*Down*	Seaforde	6·85	181
Cumb.	Geltsdale	7·30	223	*Antrim*	Aldergrove Airfield ...	6·05	187
„	Keswick, High Hill ...	13·11	232	„	Ballymena, Harryville...	7·29	180
„	Ravenglass, The Grove	14·18	317	*L'derry*	Garvagh, Moneydig ...	6·65	169
Mon.	Abergavenny, Larchfield	9·87	258	„	Londonderry, Creggan	4·76	116
Glam.	Ystalyfera, Wern House	12·39	189	*Tyrone*	Omagh, Edenfel ...	5·43	143

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SOUTH POLAR ATMOSPHERIC CIRCULATION AND THE NOURISHMENT OF THE ANTARCTIC ICE-CAP

By H. H. LAMB, M.A.

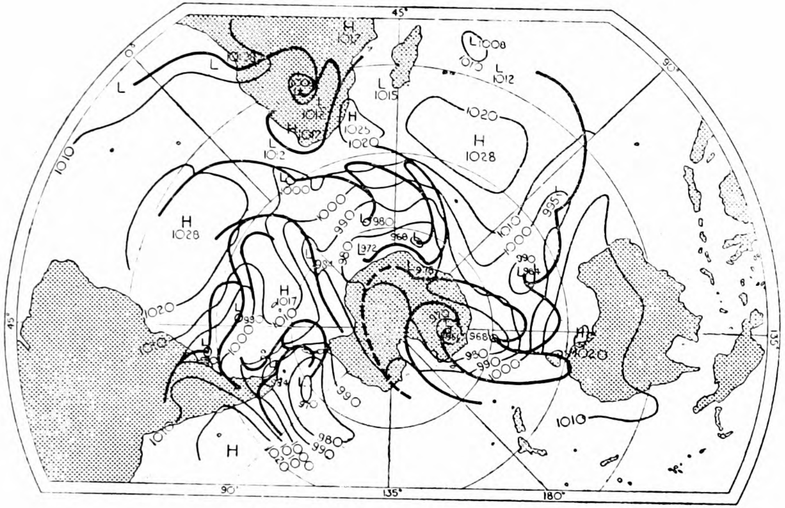
Introductory.—This article overlaps, and to a considerable extent summarizes, a paper, read before the Hydrology Association (Commission for Snow and Ice) of the International Union of Geodesy and Geophysics at Brussels in August 1951, on meteorological situations in the South Polar regions and the nourishment of the Antarctic ice-cap. This summary, however, covers also certain more general aspects of the atmospheric circulation over the southern hemisphere which are of interest to synoptic meteorologists.

The material used came out of the work of the *Balaena* expedition 1946–47, which has already been briefly described in this magazine[1] with some reference to the manner in which it was found possible to draw the daily surface weather maps covering much of the southern hemisphere. Later study of the original maps for November 1946–March 1947, using data for a region in 60–65°S. from which no information was available when they were first plotted, showed probable errors amounting to ±6·8 mb. in pressure and 150–190 miles in the positions of the major frontal systems. The 8-day series of re-analysed maps, March 18–25, 1947, presented in Fig. 1 was chosen as one of the best sequences in the original maps; the analysis shown here incorporates a good deal of additional observational material from ships' logs which came in later, including radio-sonde observations made by the Dutch whaling factory *Willem Barendsz*, south of 60°S. in the Atlantic sector.

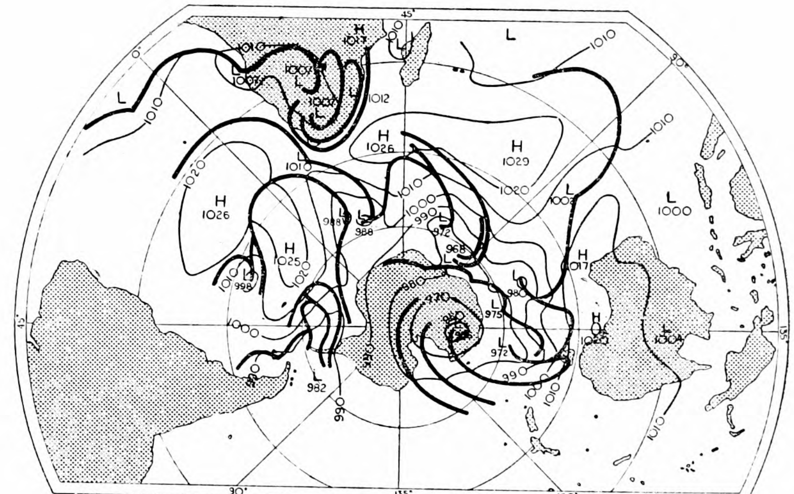
These maps should therefore be closer to fact than the original series, and the major features can hardly be in doubt. Isobars are shown at 10-mb. intervals. Fictitious isobars over the antarctic continental massif have been drawn in relation to the surface winds and pressure values observed when the pressure systems concerned passed over the coastal regions.

This re-analysis was the product of collaboration between Mr. B. L. Cardozo, the meteorologist who accompanied the Dutch whaling factory, and the author who was kindly invited to de Bilt for the purpose in 1948 by Dr. Bleeker of the Koninklijk Nederlandsch Meteorologisch Instituut.

Occurrence of antarctic anticyclones as a variable and impermanent feature of the general circulation.—The most striking feature of the maps is that there is not always an anticyclone present over Antarctica. Indeed, however tentatively these maps were completed, there was clearly no room for any anticyclone between the known depressions in several sectors south of 60°S. either on March 18–20, 1947, or for some days before that.



0600 G.M.T., March 18, 1947



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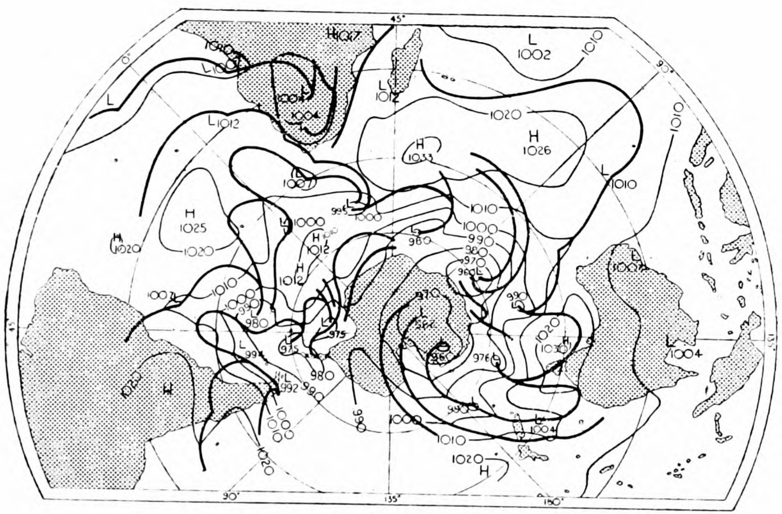

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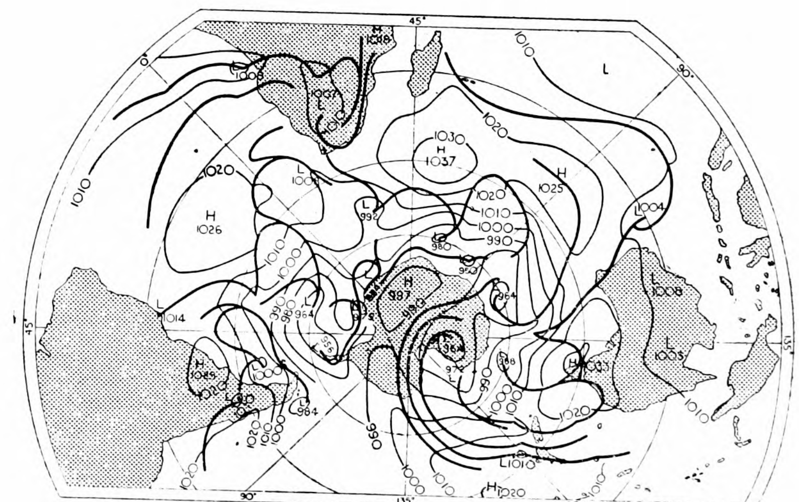

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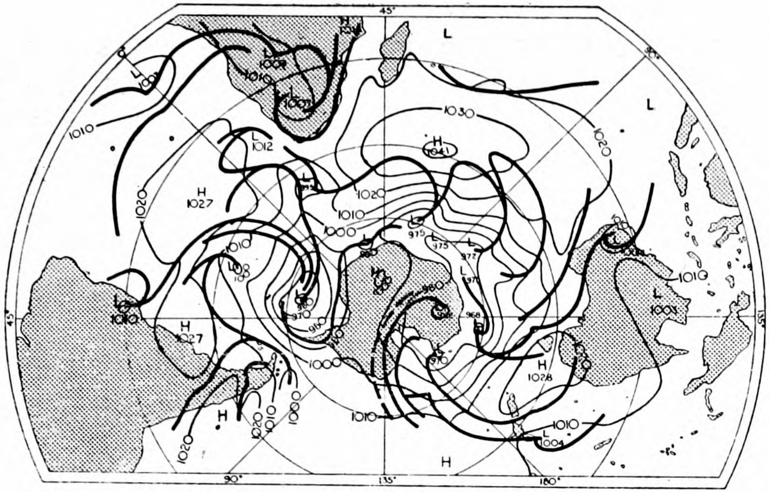

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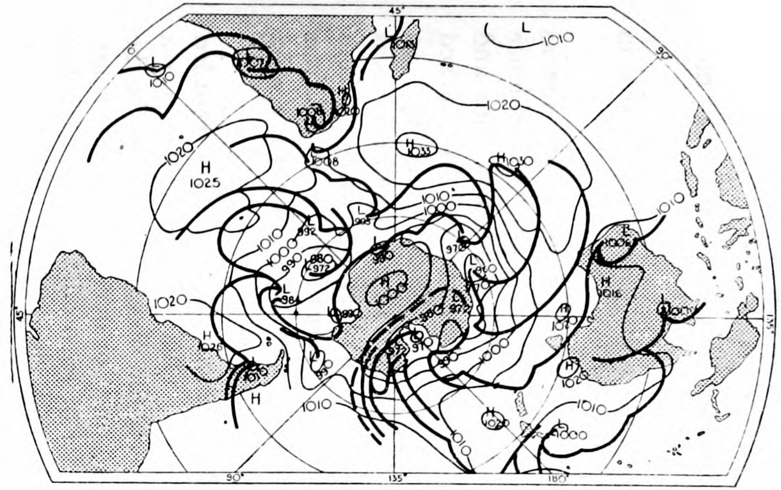

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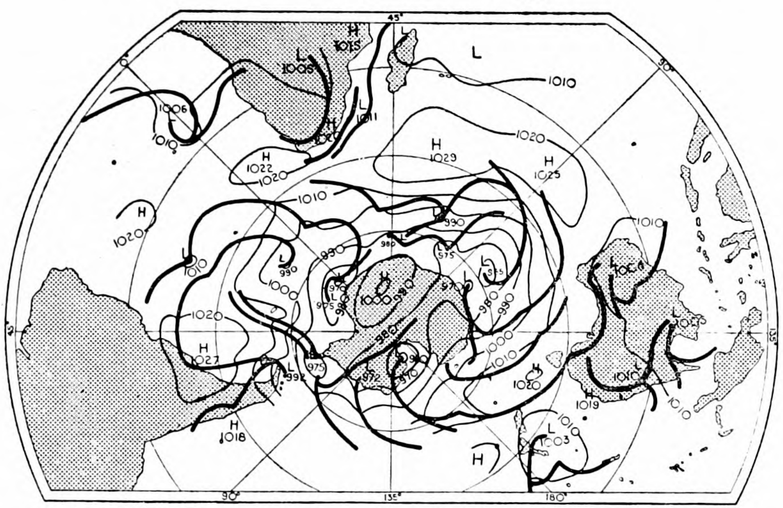

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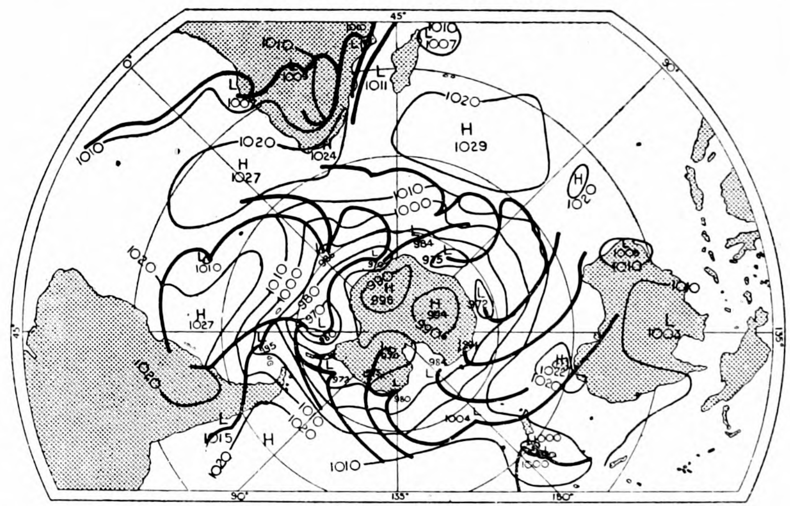


0600 G.M.T., March 25, 1947

FIG. 1—THE 8-DAY SERIES OF RE-ANALYSED CHARTS, MARCH 18–25, 1947

That cyclonic situations occur from time to time over the South Polar regions might be deduced from

(i) occurrences of westerly winds around the coast, sometimes in most sectors simultaneously;

(ii) occurrences of very low pressures (commonly 970 mb. or below) in very high latitudes, particularly in the Ross and Weddell Seas;

(iii) the fact that cloud types over Antarctica are by no means confined to stratus and stratocumulus sheets with indications of subsidence above, but include typical extensive frontal upgliding cloud systems and instability types. The latter were sometimes characterized by marked vertical growth over the coastal mountains. On March 17, 1947, an occlusion, preceded by altostratus in which a wall of cumulonimbus was embedded near the line of the surface front, was observed emerging from the continental interior; its passage over the *Balaena* in 64°S.,105°E. was marked by precipitation of moderate intensity (snow and soft hail), a wind shift, barometer kick and slight rise of temperature.

When anticyclones do occur over Antarctica, the sea-level pressures recorded are low by comparison with northern standards. This is obvious whenever a high-pressure system comes from Antarctica over the observing stations in the Falkland Islands Dependencies (e.g. Graham Land) or over ships off the coast. In these situations pressure maxima of the order of 1010 mb. are common, but values somewhat below 1000 mb. also occur. Kidson[2,3] remarks that the extreme pressure of 1030·5 mb. recorded by Mawson's expedition at Commonwealth Bay, Adélie Land in 1912 was probably quite unusual, and it has never been equalled since in any records of which the author is aware.

The anticyclone which appeared over Antarctica on March 21, 1947, (Fig. 1) was probably associated with dynamic (warm) anticyclogenesis near the tip of the great warm ridge which must have been thrusting south-east aloft ahead of the depressions in the Ross Sea–Australian antarctic sector. Its appearance was forecast on this basis at the time and resulted in a gradual change-over to easterly winds, which became strong in some sectors, around the coast. The origin of this anticyclone may thus be interrelated with the great ridge of high pressure in the South Pacific and with the subtropical anticyclone just east of New Zealand. The connecting ridge between the ice-cap anticyclone and these systems in other latitudes was soon severed by the cool polar-maritime air masses advancing from the west between 50° and 70°S. on March 21–22, 1947, evidently before much meridional transport of air could take place. If this sequence is typical, it may go some way towards explaining the prevailingly low level of pressure in the South Polar regions and the possibility of development of certain chemical peculiarities[4] in air which may be isolated there for some time.

The deduced pressure surge accompanying the formation of the anticyclone over the inland ice on March 20–21, 1947, followed the route described by Simpson[5] save that instead of radiating from 80°S.,120°W. it passed into Antarctica from near this point. If Simpson's pressure surges do indeed follow a preferred route, this case may be typical of the formation of antarctic anticyclones. Nevertheless it seems clear that some of the minor surges Simpson described are merely associated with dumb-bell rotations of depressions in the Ross Sea[6].

On March 20, 1947, another great warm ridge aloft was present in the South Atlantic sector, raising the freezing level to the exceptional height of 2·2 Km. (7,000 ft.) over the *Willem Barendsz* near 64°S.,23°W. This was doubtless associated with the anticyclone shown a little further east in that sector, in an unusual position near 60°S.; but it is not clear that this warm ridge had anything to do with the formation of the ice-cap anticyclone.

The evidence suggests that both these anticyclones in high southern latitudes were warm anticyclones, formed in connexion with other events in the general circulation over the southern hemisphere.

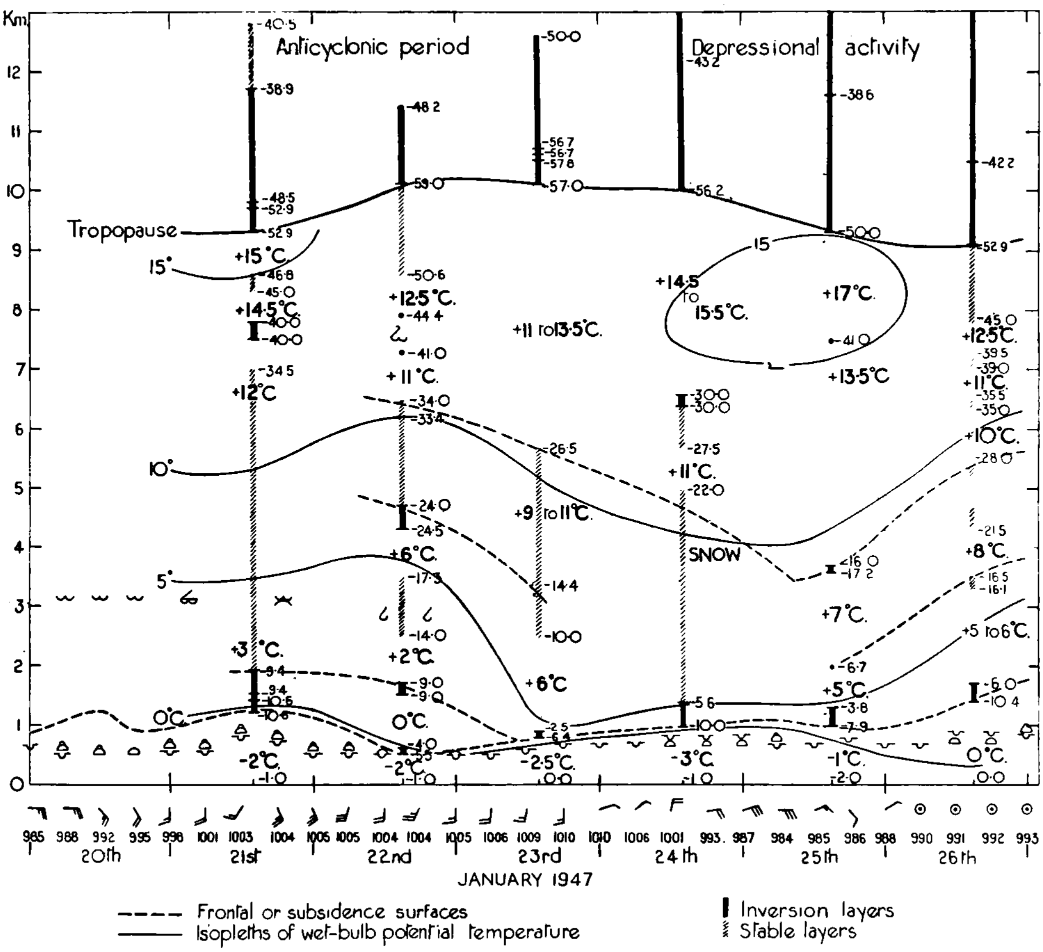


FIG. 2—CROSS-SECTION THROUGH AN ANTICYCLONE OVER THE WEDDELL SEA

Radio-sonde ascents from the *Willem Barendsz* in 62° to 63°S. and 10° to 12° W. The large figures refer to mean wet-bulb potential temperature in various layers. Surface pressure (in millibars) and surface wind are also shown below the diagram for four observations a day.

Indeed the evidence of another occasion, in January 1947 when the *Willem Barendsz* lay near the centre of an anticyclone which had moved out from Antarctica over the Weddell Sea, suggests that polar-plateau anticyclones may even show the relatively high tropopause characteristic of warm anticyclones, exceeding 10 Km. in these regions (see Fig. 2). In the warm ridge on March 20, 1947, the tropopause rose to 11 Km. in 64°S., 23°W.

By March 25, 1947, (Fig. 1) the ice-cap anticyclone was five days old, by which time most warm anticyclones in other parts of the world would have been either dislodged by a deep cold air mass advancing behind the cold front of a depression or rejuvenated by an incursion of shallow cold air behind a weak cold front pushing into the surface layers beneath the subsidence inversion[7]. Neither of these things seems to have happened to this South Polar high. Importance may come to be attached to the lesser probability of break-down of a stable anticyclone here (also in the Arctic basin in summer or in Siberia in early winter) than in most other parts of the world, on account of the unlikelihood of any deep, colder air mass existing outside the anticyclonic area. This may result in long persistence of these highs until progressive shifts of the centre allow room for a cyclonic situation over some part of the cold region, where radiational cooling from the top of the cloud-filled air may produce a really deep cold air mass.

Cyclonic situations and nourishment of the inland ice.—Situations of generally cyclonic character over the continent (e.g. March 18–20, 1947) with westerly winds around the coast in many sectors but with some cols and weak ridges of higher pressure, especially in the higher parts of the interior, are believed to have been rather common during the second half of February and March 1947. At other times, too, large depressions centred off the coast left room for no more than a region of slack circulation and relatively higher pressure near the pole, though anticyclonic situations seem to have predominated over the polar plateau from December till mid February.

Once or twice in various eastern longitudes depressions appeared to emerge from Antarctica and pass on northward tracks rather near the *Balaena*, preceded by westerly and followed by easterly winds. Mostly their circulations were weak, but the medium and upper cloud sequences were always present. Lower cloud masses were often present too, in instances noticed east of 100°E., and appeared to have considerable thickness (or vertical depth); the lows presenting these cloud systems had supposedly passed on recurving tracks mainly close to the coast. On the other hand depressions emerging between 75° and 95°E. on January 19 and April 4–5, 1947, appeared to have come from far in the interior. In the latter case the *Balaena* was lying about 200 miles off the coast, and large cumulus and cumulonimbus and squally showers were soon observed over the open water in the air stream around the depression centre; this was the most vigorous of the depressions which appeared to have come from the interior (winds up to Beaufort force 6 were observed at the ship), and is believed to have been identical with a deep system travelling south-east in the Weddell Sea on April 1, after which it presumably crossed the high ice plateau somewhere south of the mountains of Queen Maud Land. An earlier depression, probably of the same series, had crossed from the Bellingshausen Sea into the southernmost part of the Weddell Sea on March 29–31, passing south of the Falkland Islands Dependencies' observing stations in Graham Land, where westerly winds were observed at 68°S. This followed closely the break-down of the ice-cap anticyclone of March 21–29, 1947.

It seems therefore that the early attempts to solve the problem of moisture supply to the inland ice, in terms of a search for some level aloft at which the mean anticyclonic circulation of the bottom 3 Km. or more is replaced by a mean cyclonic circulation higher up, will be resolved by study of the alternating sequence in time of anticyclonic and cyclonic situations.

The remaining difficulties are that,

(i) the cyclonic situations may be too few, or give too little snowfall, at the present epoch for full maintenance of the ice-cap;

(ii) whatever the frequency of the cyclonic situations at any period the maximum snowfall would probably always be somewhere near the coast, i.e. below the summit of the ice-cap.

The alternations between cyclonic and anticyclonic situations probably occur at all times of the year. Both the highest and lowest pressures so far recorded in Antarctica (respectively 1030·5 mb. at Commonwealth Bay, Adélie Land in 1912 and 932·5 mb. at Little America in 1940) occurred in the late-winter month of September.

Snowfall should be greatest when the uplifted air mass has had a short track from open water. One would thus expect cyclonic situations occurring between late summer and early winter, at the season when sea ice is least extensive, to make the biggest contributions in snowfall to feeding the inland ice. Court's evidence from Little America (78°30′S., 163°50′W.) suggests that this is so[8]. Times of little sea ice, when the main thermal contrast between ice and open water lies close to the coast, might also be expected to give the greatest frequency of "wave" depressions with appreciable snowfall over Antarctica and least opportunity for large anticyclones to form and dominate the region. Such epochs should therefore be most favourable for building up the ice-cap.

Minor wave activity is common even in summer (when the ice-cap is at its warmest and thermal gradients are fairly weak) on the antarctic front; bigger systems form on it in winter[9], though these probably give little snowfall over the continent.

Annual precipitation totals near the coast of Antarctica are believed today to range from about 100 to 430 mm. a year and are surely insufficient for full maintenance of the inland ice. Nevertheless we need not assume the occurrence of abnormal processes such as ice spicules drawn down from cirrus clouds in the heart of a permanent glacial anticyclone[10]. It is now known that the Greenland ice-cap receives normal precipitation at all points, and this seems likely also in the cyclonic situations established as occurring over Antarctica. These cyclonic situations have probably varied in frequency and richness in precipitation at different periods of history. The snowfall would be heaviest at times when air temperatures close to, or slightly above, the freezing point penetrated far into the interior of the continent.

Precipitation may occur orographically, by air-mass instability, from frontal cloud masses, and in cyclonic situations. All these types were observed from the *Balaena* close to the coast of Antarctica and over the coastal mountains. Contributions from the first three causes must be increased in cyclonic situations (defined by cyclonic curvature of the isobars and air trajectories).

Fig. 3 shows the frequency (per mille) of occurrence of fronts per 10,000 square nautical miles taken from the original *Balaena* daily weather maps during March 1947. Fig. 4 shows all the depression tracks noted in the seven weeks between February 23 and April 5, 1947. Both maps are incomplete in much of the Pacific sector. The main features of interest are:—

(i) No region appears to be entirely immune from frontal or cyclonic activity, though the broadest part of the inland ice where the anticyclone was centred from March 21, 1947, onwards (Fig. 1) is most nearly immune. This is also reported to be the highest part of the ice-cap[11]. Undernourishment of this main part of the ice-cap seems to be implied, if this 31–42 day period is typical and if the ice-cap anticyclones habitually or commonly settle down here.

(ii) Certain preferred paths for depressions and frontal systems (where the daily frequencies are boosted by slow-moving systems, trailing fronts and wave disturbances) are evident around the coast of Antarctica and on tracks south-eastward from the principal locations of wave-genesis in temperate latitudes in the South Atlantic, South Indian and South Pacific Oceans.

(iii) Both depressions and fronts appear to have been frequent, at least during March 1947, over the Australian sector of the antarctic continent. These lows were considered (in common with many others during the season) to have crossed the coast and passed inland between 115° and

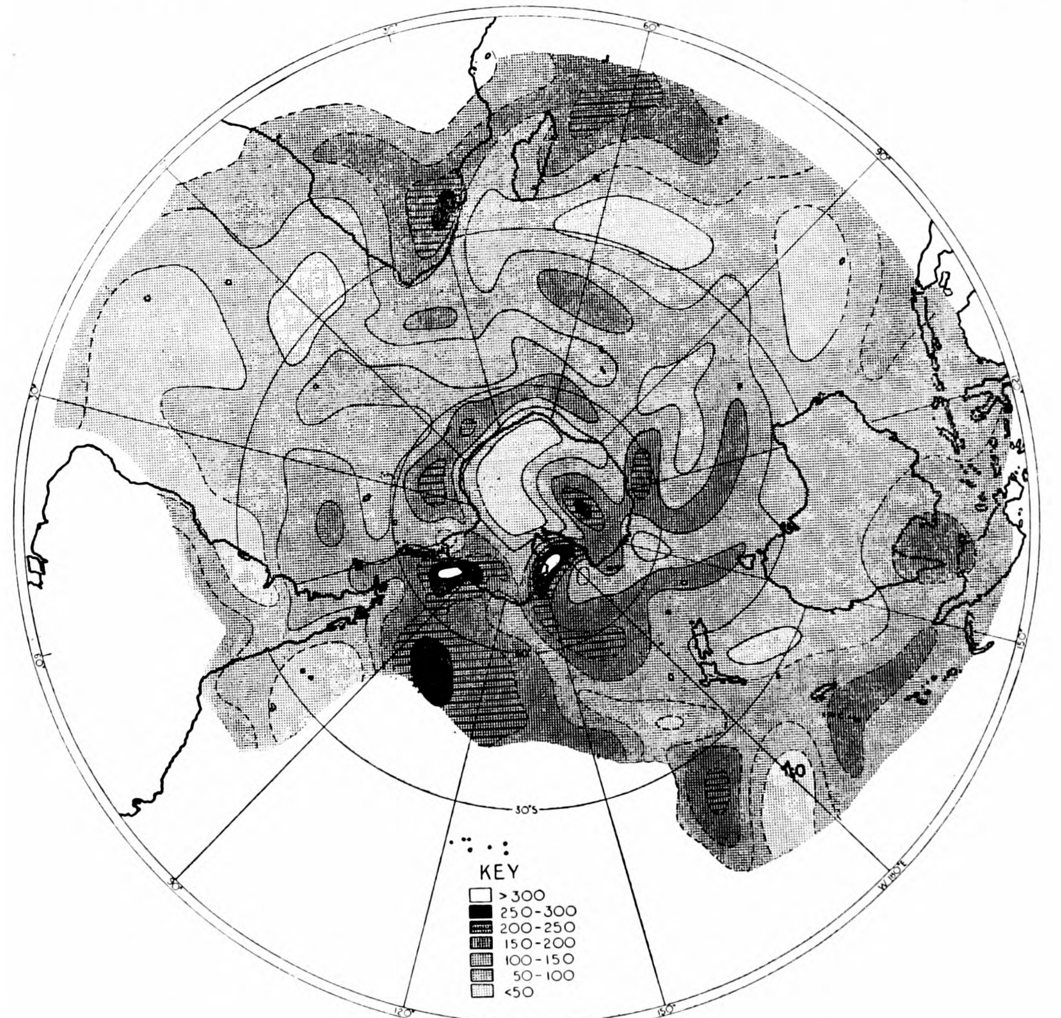
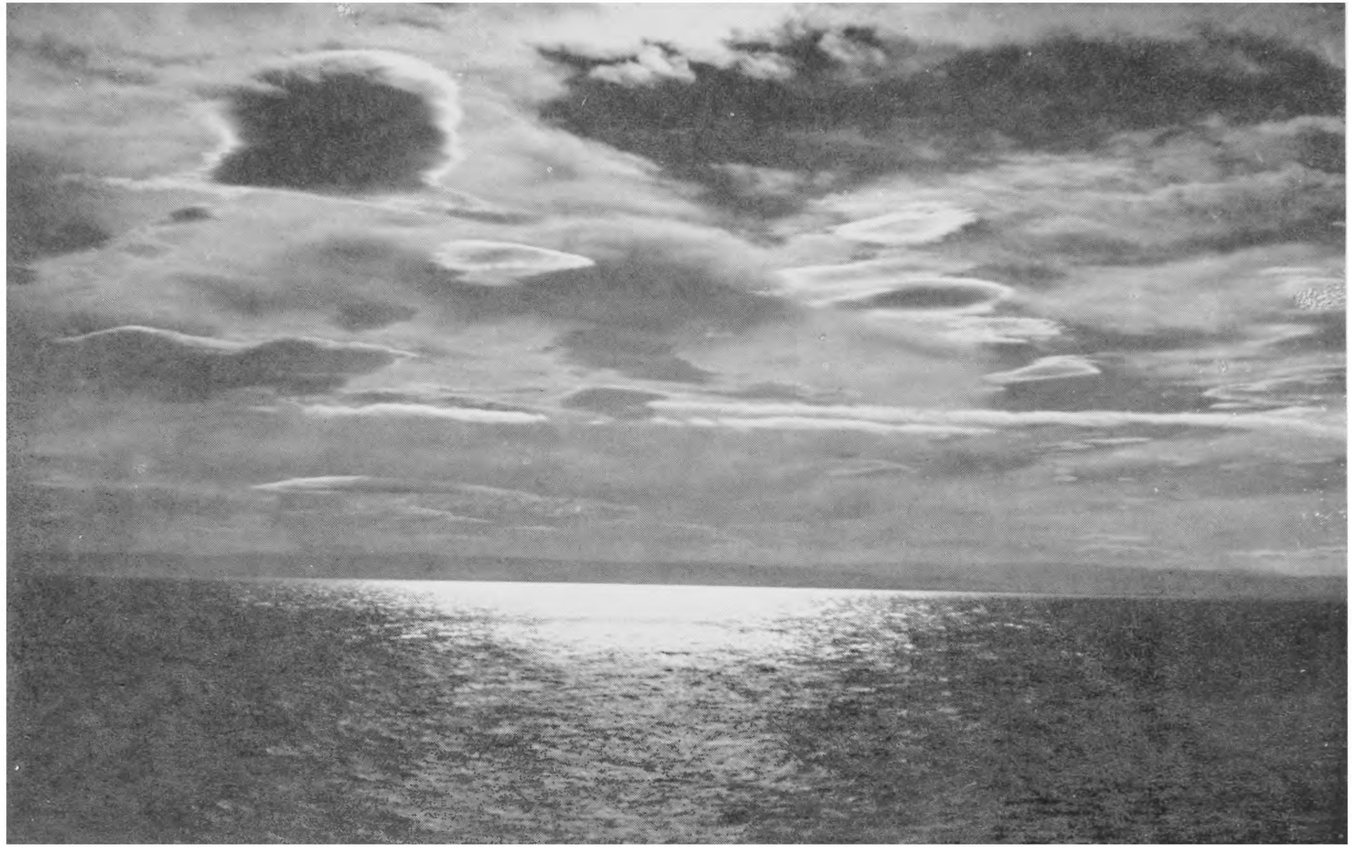


FIG. 3—FRONTAL FREQUENCIES IN THE SOUTHERN HEMISPHERE, MARCH 1947

Mean number of fronts occurring per day within an area 100 × 100 nautical miles (numbers shown in the key should be divided by 1,000).

[To face p. 40



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ALTOCUMULUS LENTICULARIS

This photograph was taken at 1030 on October 24, 1938, at Moray Firth, with the camera pointing south-eastwards.

Reproduced by courtesy of Cdr. E. R. Trendall

CIRRUS IN TUFTS

This photograph was taken on October 5, 1938, at Tarbat Ness (Moray Firth), with the camera pointing eastwards at an elevation of 60°.

140°E.—not far east of the *Balaena*. It did not seem necessary to assume any such common tendency for lows to pass inland elsewhere, except perhaps eastwards near the south-eastern extremities of the Ross and Weddell Seas. We have since learnt from Admiral Byrd's account of his aircraft explorations in 1946–47 in Operation Highjump[12] that the coast between about 115° and 140°E. is low-lying with the ice sloping up imperceptibly inland. This stretch of coast is probably therefore uniquely favourable for depressions to move inland, and the geographical discovery appears to support this feature of our weather-map analysis.

The distribution of precipitation in Antarctica must be related to the longer-period frequency distributions of frontal and cyclonic activity, to the moisture content of the air masses carried inland, and to the unknown orography of the interior. Further exploration and attempts at weather mapping over the hemisphere as a whole should throw light on all these factors.

In the discussion of the paper at Brussels, Prof. T. Bergeron thought that depressions passing over the inland ice might be weakened more than shown on the maps, though this would not affect their indicated position. Amundsen experienced snow from altostratus near the pole, followed by a clearance. Snow should fall mainly with on-shore winds; and, as it drifts most easily when newly fallen, Prof. Bergeron thought this might imply a net drift up-slope towards the

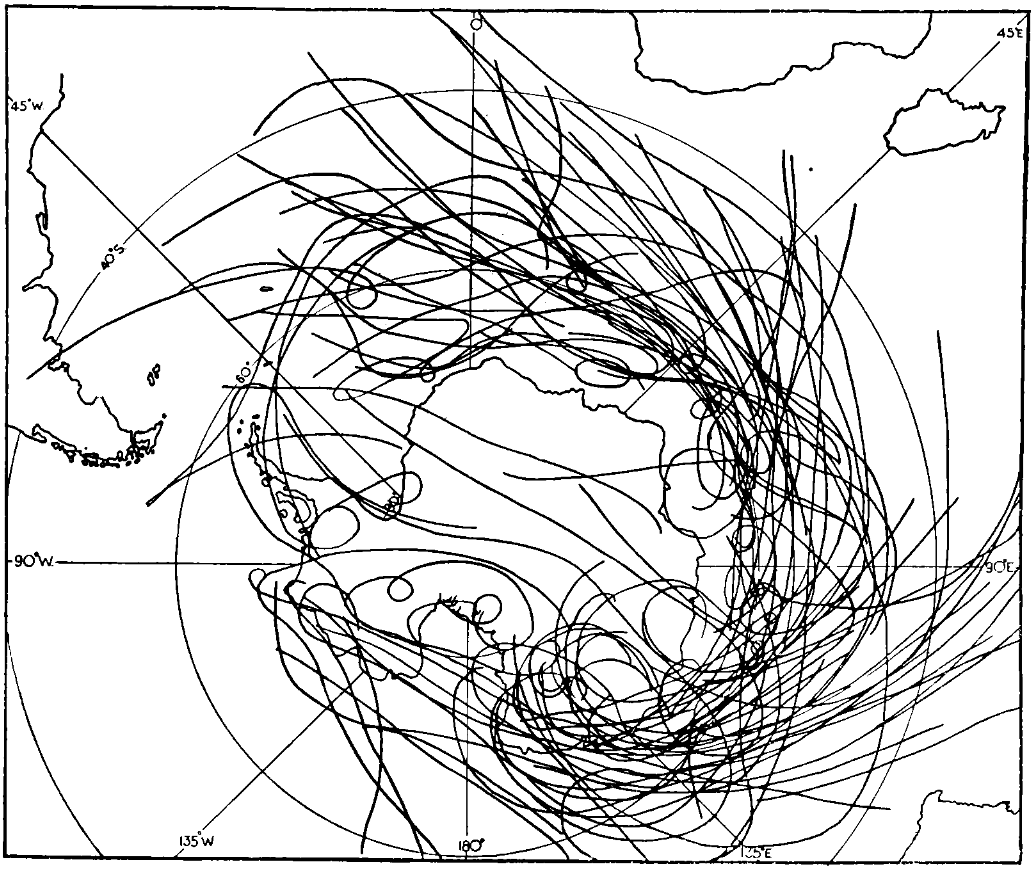

FIG. 4—DEPRESSION TRACKS—FEBRUARY 23–APRIL 5, 1947

The chart is incomplete in the Pacific sector between approximately 180° and 50°W. and everywhere north of 40°S.

interior in spite of the fact that down-slope winds prevail. Prof. Manley also referred to snowfall near the pole, where he estimated the present annual precipitation as being of the order of 40 mm. (equivalent rainfall) a year; presumably its occurrence is to be related to ascending air drawn from the Weddell Sea rather than over the known high mountain barrier between the pole and the Ross Sea.

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PHYSICAL SIGNIFICANCE OF MEAN FLOW CHARTS

By R. W. JAMES, M.Sc.

Summary.—The magnitude of the ageostrophic components of the wind speed meaned over a period is assessed. It is concluded that these components may contain a vector error of the order of 1 kt. if the mean wind is equated to the mean geostrophic wind.

The most important ageostrophic component is found to be the cumulated cyclostrophic wind. A brief period of strongly curved flow may make an appreciable contribution to the mean cyclostrophic component for a period of the order of one month.

Despite this it is found that the mean isobaric or contour chart gives a close approximation to the mean flow, a consideration of the ageostrophic components only being necessary under special circumstances.

Introduction.—An isobaric map gives a geostrophic approximation to the instantaneous horizontal flow pattern in the atmosphere. Under favourable circumstances the ageostrophic components may be assessed, so that a closer approximation to the actual flow may be achieved. In general the geostrophic flow is found to be a close enough approximation for practical use, but this does not mean that closer approximations may not be desirable.

A similar problem arises in the study of mean pressure charts. Does the mean geostrophic wind give a satisfactory approximation to the actual mean wind over a period? Is it possible to arrive at a closer approximation to the mean flow, assuming that only mean isobaric charts are available for analysis?

It is generally assumed that the mean isobaric chart gives a satisfactory approximation to the mean wind field. Indeed, it may be argued that the geostrophic approximation is closer on mean charts, for there is no preferred direction for the ageostrophic components which may therefore be expected to cancel each other out provided a sufficiently long meaning period is taken.

However, although such considerations of plausibility might enhance confidence in the use of mean charts, it is still important to attempt some estimate of the magnitude of the mean ageostrophic terms in order to assess the probable error in equating the mean geostrophic wind to the mean actual wind. This constitutes the purpose of the present paper.

Equation of mean accelerations.—The equations of horizontal motion in vector form are

$$\rho\frac{\partial \mathbf{V}}{\partial t} + \rho\,(\mathbf{V}.\nabla)\,\mathbf{V} + l\mathbf{k}\times\rho\mathbf{V} + \nabla p - \frac{\partial}{\partial z}\left(\mu\frac{\partial V}{\partial z}\right) = 0 \qquad \ldots (1)$$

where ρ is the density, $\mathbf{V}$ is the horizontal velocity, l the Coriolis parameter, $\mathbf{k}$ a vertical unit vector, p the pressure, μ the coefficient of turbulent diffusion, $\times$ the symbol of vector multiplication, and ∇ the vector operator $(\partial/\partial x,\ \partial/\partial y,\ \partial/\partial z)$. Taking mean values of this equation over a given time-interval T (the meaning process being indicated by a suffix m or by a bar over a combination of variables taken together, and dividing by the mean density for the period, ρ_m, we have the equation of accelerations,

$$\frac{1}{\rho_m}\overline{\left(\rho\frac{\partial \mathbf{V}}{\partial t}\right)} + \frac{\overline{\rho\,(\mathbf{V}.\nabla)\,\mathbf{V}}}{\rho_m} + \frac{l\mathbf{k}\times\overline{\rho\mathbf{V}}}{\rho_m} + \frac{\nabla p_m}{\rho_m} - \frac{1}{\rho_m}\frac{\partial}{\partial z}\overline{\left(\mu\frac{\partial \mathbf{V}}{\partial z}\right)} = 0. \qquad \ldots (2)$$

The first term will be referred to as the isallobaric acceleration of the mean map, the second the space-acceleration, the third the Coriolis acceleration, the fourth the pressure-gradient (geostrophic) acceleration, and the last the frictional acceleration.

Let $\rho = \rho_m + \rho'$, $\mathbf{V} = \mathbf{V}_m + \mathbf{V}'$, $\mu = \mu_m + \mu'$, then equation (2) can be expressed as

$$\frac{\partial \mathbf{V}_m}{\partial t} + \frac{1}{\rho_m}\overline{\left(\rho'\frac{\partial \mathbf{V}}{\partial t}\right)} + \overline{[(\mathbf{V}_m+\mathbf{V}').\nabla](\mathbf{V}_m+\mathbf{V}')} + \frac{1}{\rho_m}\overline{[\rho'(\mathbf{V}_m+\mathbf{V}').\nabla](\mathbf{V}_m+\mathbf{V}')}$$
$$+ l\mathbf{k}\times\mathbf{V}_m + \frac{l}{\rho_m}\mathbf{k}\times\overline{\rho'\mathbf{V}}_m + \frac{\nabla p_m}{\rho_m} - \frac{1}{\rho_m}\frac{\partial}{\partial z}\overline{\left(\mu\frac{\partial \mathbf{V}}{\partial z}\right)} = 0. \ldots (3)$$

The second, fourth and sixth terms arise from a possible correlation between the departure from mean density and the wind, or its derivatives. The remaining terms are independent of density variation during the period.

If the mean equations of motion were exactly analogous to the instantaneous equations, they could be written in the form

$$\frac{\partial \mathbf{V}_m}{\partial \tau} + (\mathbf{V}_m.\nabla)\,\mathbf{V}_m + l\mathbf{k}\times\mathbf{V}_m + \frac{\nabla p_m}{\rho_m} - \frac{1}{\rho_m}\frac{\partial}{\partial z}\left(\mu_m\frac{\partial \mathbf{V}_m}{\partial z}\right) = 0 \ \ldots (4)$$

where the time variable τ refers to some agreed epoch (taken for convenience to be the commencement) in the interval over which the mean is taken.

It is obvious that in general equation (4) will not be identical, term by term, with equation (2), and hence from serial mean charts alone it will not be possible to evaluate the individual accelerations arising in the mean equations of motion. It may be, however, that the mean accelerations entering into equation (4) are sufficiently close approximations to the corresponding mean actual accelerations for the mean chart to be used in a way exactly analogous to the use of instantaneous charts.

It may further become apparent that the two most important terms in the mean chart may be the Coriolis acceleration and the pressure-gradient term. If this should prove to be so, the mean flow over a period can be determined as a geostrophic approximation.

Before evaluating the individual accelerations in the mean equations of motion it is appropriate to make a few general remarks about their probable magnitude. The terms containing departure from mean density (ρ') may be expected to be relatively unimportant, as density never departs from its mean by more than a few per cent. Some correlation between ρ' and $\mathbf{V}'$ may be anticipated, the density in southward moving air in general differing from that in northward moving air, so that the term $l\mathbf{k} \times \overline{\rho'\mathbf{V}}/\rho_m$ might be expected to be significant. On the other hand, no immediate connexion between ρ' and $\partial\mathbf{V}/\partial t$ is apparent, so that it would be expected that such terms as $(\overline{\rho'\partial\mathbf{V}/\partial t})/\rho_m$ would be small.

If the wind follows an Ekman spiral, $\mu\partial\mathbf{V}/\partial z$ is a function of the angle between the surface wind and the isobars. Jeffreys's results* seem to show that the angle of surface inflow over the North Sea is different in southerly and northerly air streams, so that the correlation between μ' and wind direction may be appreciable, although there is no information regarding the correlation between μ and the vertical wind shear. It is not certain, therefore, whether the mean frictional acceleration $(1/\rho_m)\partial(\overline{\mu\partial\mathbf{V}/\partial z})/\partial z$ may be represented accurately by $(1/\rho_m)\partial(\mu_m\partial\mathbf{V}_m/\partial z)/\partial z$. If the wind field above the level of frictional influence is being considered, this term may, of course, be neglected.

The term $\overline{(\rho\mathbf{V}.\nabla)\mathbf{V}}/\rho_m$ in equation (2) comprises the vertical velocity (w) term

$$\frac{1}{\rho_m}\left(\overline{\rho w\frac{\partial\mathbf{V}}{\partial z}}\right)$$

as well as terms relating to the horizontal variation of $\mathbf{V}$. Unless something is known of the vertical-velocity field, it will not be possible to assess this term.

It is apparent that with our present knowledge only some of the acceleration terms may be assessed. But while a complete estimate is not possible it is of interest to assess some of the terms in the equation of mean accelerations.

Isallobaric term.—The first acceleration term is the isallobaric term $(\overline{\rho\partial\mathbf{V}/\partial t})/\rho_m$, which may be written

$$\overline{\frac{\partial\mathbf{V}}{\partial t}} + \frac{1}{\rho_m}\left(\overline{\rho'\frac{\partial\mathbf{V}}{\partial t}}\right).$$

*JEFFREYS, H.; On the relation between wind and distribution of pressure. *Proc. roy. Soc., London*, A, **96**, 1919, p. 233.

Now

$$\overline{\frac{\partial \mathbf{V}}{\partial t}} = \frac{1}{T}\int_{\tau}^{\tau+T} \frac{\partial \mathbf{V}}{\partial t}\, dt = \frac{1}{T}\Big[\mathbf{V}(\tau + T) - \mathbf{V}(\tau)\Big] \qquad \ldots (5)$$

provided that there is no real discontinuity of $\mathbf{V}$ in the interval τ to $\tau + T$ of t.

Equation (5) simply states that the mean acceleration over a period is equal to the vector difference of wind at the end and beginning of the period divided by the length of the period.

The mean isallobaric acceleration is likely to be the smaller, the longer the period over which the mean is taken. As an extreme case, for a 30-day mean chart, there might be a vector wind change of 100 kt., giving a mean isallobaric acceleration of 3·3 kt./day, a large value. Since

$$\frac{\partial \mathbf{V}_m}{\partial \tau} = \frac{\partial}{\partial \tau}\left(\frac{1}{T}\int_{\tau}^{\tau+T} \mathbf{V} dt\right) = \frac{\mathbf{V}(\tau + T) - \mathbf{V}(\tau)}{T}$$

$$\frac{\partial \mathbf{V}_m}{\partial \tau} = \overline{\frac{\partial \mathbf{V}}{\partial t}}\,. \qquad \ldots (6)$$

The change in mean wind between serial mean charts gives the mean isallobaric acceleration, just as the wind change between instantaneous charts gives the isallobaric acceleration of the instantaneous wind.

The above results are only valid if there are no true discontinuities of wind. If there is a true frontal discontinuity of wind at time t_1 we have

$$\int_{\tau}^{\tau+T} \frac{\partial \mathbf{V}}{\partial t}\, dt = \mathbf{V}(\tau + T) - \mathbf{V}(t_1 + 0) + \mathbf{V}(t_1 - 0) - \mathbf{V}(\tau).$$

It is a debatable point whether an ideally sharp front is ever encountered. Even the very narrowest transition zone would suffice to validate expression (5). It will be assumed that perfectly sharp fronts do not exist, and that in consequence

$$\overline{\rho\frac{\partial \mathbf{V}}{\partial t}} = \frac{\partial \mathbf{V}_m}{\partial \tau} + \frac{1}{\rho_m}\overline{\left(\rho'\frac{\partial \mathbf{V}}{\partial t}\right)}\,.$$

The value of the second term in the mean isallobaric acceleration has been determined for Aldergrove, Northern Ireland at the 800-mb. level for May 1948. Its numerical value was 0·02 kt./day, density above normal being correlated with W. and N. winds increasing with time.

This acceleration can be neglected in comparison with $\partial \mathbf{V}_m/\partial \tau$, which, in the present instance, was found to be 0·5 kt./day.

For illustrative purposes mean monthly charts have been considered. If the period is shorter than a month the magnitude of the isallobaric acceleration is greater. Thus for the same vector wind change between the beginning and end of a period, $\partial \mathbf{V}_m/\partial \tau$ will be six times as great in a 5-day mean as it is with a 30-day mean, say 3 kt./day as against 0·5 kt./day above. With a wind change of 100 kt. the isallobaric acceleration in a 5-day mean will be 20 kt./day, corresponding to an ageostrophic wind component of 2 kt.

Mean Coriolis acceleration.—The value of the mean Coriolis acceleration is

$$\frac{l}{\rho_m}\mathbf{k} \times \overline{\rho \mathbf{V}} = l\mathbf{k} \times \mathbf{V}_m + \frac{l}{\rho_m}\mathbf{k} \times \overline{\rho' \mathbf{V}_m}.$$

The mean wind at 800 mb. for Aldergrove in May 1947 was 246° 30 kt., so that $l\mathbf{k}\times\mathbf{V} = 28\cdot5$ kt./day. The value found for $l\mathbf{k}\times\overline{\rho'\mathbf{V}}/\rho_m$ was $0\cdot073$ kt./day, or about $\frac{1}{4}$ per cent. of the magnitude of $l\mathbf{k} \times \mathbf{V}_m$.

It is therefore obvious that the mean Coriolis acceleration can be evaluated with the required accuracy on the assumption of a constant density throughout the month.

On comparing the relative magnitudes of the isallobaric acceleration, $0\cdot5$ kt./day, and the Coriolis acceleration, $28\cdot5$ kt./day, the isallobaric wind is seen to be normally small enough to be neglected in comparison with the geostrophic wind.

Evaluation of the space acceleration.—The "spatial" mean acceleration is

$$\frac{1}{\rho_m}\overline{\rho\,(\mathbf{V}.\nabla)\,V} = \overline{(\mathbf{V}.\nabla)\,V} + \frac{1}{\rho_m}\overline{\rho'\,(\mathbf{V}.\nabla)\,\mathbf{V}}.$$

In the case of the isallobaric acceleration and the Coriolis acceleration, it has been shown that density variation accounts for only about 1 per cent. or less of the total, and hence can be effectively neglected. Without actual proof there is a very strong presupposition that a similar result will be valid for the spatial mean acceleration, and hence the ρ'-term in the above expression will be neglected.

The evaluation of $\overline{(\mathbf{V}.\nabla)\mathbf{V}}$ requires a knowledge of the space rates of change of wind velocity. For this purpose a network of three wind-observing stations, Aldergrove, Lerwick and Downham Market, were taken. The value of $(\mathbf{V}.\nabla)\mathbf{V}$ at Aldergrove was taken as

$$(\mathbf{V}_{\mathrm{A}}.\nabla)\left(\mathbf{V}_{\mathrm{A}} - \frac{\mathbf{V}_{\mathrm{L}} + \mathbf{V}_{\mathrm{D}}}{2}\right)$$

where the suffixes A, L and D refer to Aldergrove, Lerwick and Downham Market respectively. The values so computed were $8\cdot5$ kt./day towards the west, and $7\cdot7$ kt./day towards the north.

The magnitudes of the terms are very much affected by the observations for one day, May 5, 1948, when an intense low was centred north-east of Aldergrove. If this day is omitted from the computations we get revised accelerations of $7\cdot1$ and $1\cdot1$ kt./day towards the west and north respectively.

It is not difficult to see how the omission of one day's observations can make this considerable difference amounting to a vector acceleration of 4 kt./day. This corresponds to a mean cyclostrophic wind component of $0\cdot43$ kt. or a component of 13 kt. on one day. This is by no means an unusual value for the cyclostrophic wind component on a day of strongly curved motion.

It will be noticed that the mean "spatial" or cyclostrophic acceleration is of the order of a third of the mean Coriolis acceleration in the above example. Hence a considerable departure from its geostrophic value may be expected in the mean wind.

This, however, does not imply that the geostrophic approximation is less useful when applied to mean charts than when applied to instantaneous charts, for in regions of synoptic charts where the pressure-gradient is so slack as to correspond to a geostrophic wind speed of 3 kt. considerable percentage departures of wind from its geostrophic value are likely.

A further point of interest is to find out whether the mean cyclostrophic acceleration can be inferred from the mean chart itself, that is, whether

$$\overline{(\mathbf{V}.\nabla)\,\mathbf{V}} \simeq (\mathbf{V}_m.\nabla)\,\mathbf{V}_m$$

In the above example, $|(\mathbf{V}_m.\ \nabla)\ \mathbf{V}_m| = 0{\cdot}5$ kt./day or only a twentieth of the magnitude of $\overline{(\mathbf{V}.\nabla)\mathbf{V}}$.

Hence the analogy between mean and instantaneous charts is not perfect, in the same sense that, ignoring friction, it is not possible to write

$$\frac{\partial \mathbf{V}_m}{\partial t} + (\mathbf{V}_m.\nabla)\,\mathbf{V}_m + l\mathbf{k} \times \mathbf{V}_m + \frac{\nabla p_m}{\rho_m} = 0.$$

The proper equation governing mean motion is

$$\overline{(\mathbf{V}.\nabla)\,\mathbf{V}} + l\mathbf{k} \times \mathbf{V}_m + \frac{\nabla p_m}{\rho_m} \simeq 0,$$

for experience with the May 1948 chart suggests that $\partial \mathbf{V}_m/\partial t$ can safely be ignored compared with the remaining accelerations.

The mean geostrophic wind is given by

$$l\mathbf{k} \times \mathbf{V}_{gm} = -\frac{\nabla p_m}{\rho_m}$$

so that the equation of mean motion may be written

$$\overline{(\mathbf{V}.\nabla)\,\mathbf{V}} + l\mathbf{k} \times (\mathbf{V}_m - \mathbf{V}_{gm}) = 0$$

The term $\overline{(\mathbf{V}.\nabla)\mathbf{V}}$ is almost entirely due to the cumulative effect of passing perturbations, that part of it due to the curvature of mean flow $(\mathbf{V}_m.\nabla)\mathbf{V}_m$ being small. In the example chosen $\overline{(\mathbf{V}.\nabla)\mathbf{V}}$ corresponds to an ageostrophic departure in the mean wind of 1 kt. The ageostrophic departures of mean wind are not likely to exceed this figure greatly, so that if the mean geostrophic speed is of the order of 10 kt. the geostrophic approximation may be expected to represent the mean flow to within 10 per cent. If mean winds are light, however, the geostrophic approximation will not be so close proportionately although the absolute departures are likely to be no greater.

It is therefore apparent that the geostrophic approximation is a close indication of mean flow where that flow is strong, as for example at the 300-mb. level, but is not to be relied upon when that flow is weak, as in surface charts.

Contour charts.—In terms of contour height Z for a fixed pressure level the equations of horizontal motion may be written (ignoring friction and writing $\nabla_h = (\partial/\partial x, \partial/\partial y)$)

$$\frac{\partial \mathbf{V}}{\partial t} + (\mathbf{V}.\nabla)\,\mathbf{V} + l\mathbf{k} \times \mathbf{V} + g\nabla_h Z = 0$$

The mean equations can be written

$$\frac{\partial \mathbf{V}_m}{\partial \tau} + \overline{(\mathbf{V}.\nabla)\,\mathbf{V}} + l\mathbf{k} \times \mathbf{V} + g\nabla_h Z = 0.$$

In this particular case the density does not enter into the equations, and hence there are no terms including the density variation. The mean contour chart has, therefore, the advantage of theoretical simplicity over the isobaric chart, but the practical advantage is negligible, since, as seen above, the terms including density departure may safely be neglected.

Except for this slight difference the mean contour chart is in every way equivalent to the mean isobaric chart.

Conclusion.—It is concluded on the basis of one set of monthly data that the mean geostrophic wind represents the mean actual wind with a possible vector error of a knot or so.

A mean ageostrophic departure may arise from the isallobaric term, or from the cumulation of ageostrophic flows due to cyclostrophic components, the vertical velocity term and the frictional departures.

The isallobaric term increases in importance as the period of meaning is reduced; it can safely be neglected for monthly charts, but appreciable ageostrophic mean components may be introduced into 5-day means in special circumstances. If desired, the magnitude of this term may be assessed by "gridding" synoptic charts representing the beginning and end of the meaning interval.

Under some circumstances the cumulation of cyclostrophic components may give an appreciable ageostrophic mean wind component. It is not safe to assume that the cyclostrophic terms will be random as regards magnitude and sign; a low with an accompanying short period of intense curved motion may contribute appreciably to the mean cyclostrophic term. This has particular point with low-level charts where the mean flow is normally weak, and the ageostrophic term may be a substantial fraction of the mean geostrophic speed. At, say, 300 mb. the mean flow is normally strong compared with the perturbed flow, and disturbances are usually characterized by a succession of trough and wedge perturbations. Under such circumstances $\overline{(\mathbf{V}.\nabla)\mathbf{V}}$ may normally be ignored, partly because the signs and amplitudes of the ageostrophic components are more random, and partly because the mean flow itself is stronger. Hence at high levels the mean geostrophic wind is expected to give a close approximation to mean flow.

It is not possible to assess the magnitude of the term $\overline{w\partial\mathbf{V}/\partial z}$ but on general grounds it is expected to be of the same order of magnitude as $\overline{(\mathbf{V}.\nabla)\mathbf{V}}$.

Finally, the ageostrophic component of mean flow due to friction is difficult to assess. This problem arises most acutely with surface charts; it can be ignored in high-level flow.

The mean flow is very closely approximated by the mean geostrophic wind in the free atmosphere, but where the period of meaning is short and the pressure gradient slack, the contribution from ageostrophic components may be significant.

METEOROLOGICAL OFFICE DISCUSSION

Blocking action as a factor in the general circulation

The third Discussion of the 1951–52 series on December 10, 1951, dealt with blocking action as a factor in the general circulation, and was opened by Mr. F. E. Lumb who based his statement on the following papers.

REX, D. F.; Blocking action in the middle troposphere and its effect upon regional climate. I—An aerological study of blocking action, and II—The climatology of blocking action. *Tellus, Stockholm*, **2**, 1950, p. 196 and p. 275.

The normal circulation pattern at 500 mb. in the northern hemisphere is a relatively broad westerly current bounded to the north by the upper low of the polar region and to the south by the subtropical high-pressure belt. Occasionally the development of a pronounced quasi-stationary ridge or anticyclone at the 500-mb. level causes the westerly current to split into two branches. The ridge or anticyclone blocks the westerly current. This is blocking action in terms of the 500-mb. flow pattern.

The surface anticyclone associated with the upper anticyclone or ridge is called the surface blocking anticyclone.

For statistical purposes, an occurrence of blocking action has to satisfy five conditions:—

(i) the basic westerly current must be split into two branches,

(ii) each branch must be clearly defined by the 500-mb. contours,

(iii) the two branches must extend over at least 45° of longitude,

(iv) a sharp transition from zonal type flow upstream to meridional type flow downstream must be observed at the branch point of the two currents,

(v) the pattern must persist with recognizable continuity for at least 10 days.

By way of illustration, the 500-mb. flow pattern on October 9, 1951, was examined.

Blocking action is said to be initiated when the basic westerly current splits into two branches, and to cease when any one of the five conditions is no longer satisfied.

During the periods 1932–40 and 1945–50 covering 13½ years in all, 112 cases of blocking action were found. A statistical analysis shows two characteristics of blocking action of special interest:—

(i) The split of the basic westerly current into two branches, associated with the development of blocking action, occurs in two distinct longitudinal bands, one in the north-east Atlantic (82 cases) centred around 10°W. and one in the north-east Pacific (30 cases) centred around 150°W. In the large majority of cases in the north-east Atlantic the westerly current splits into two branches between 35°W. and 5°E.

(ii) Both for the Atlantic and Pacific cases, blocking action has a maximum frequency in winter and spring, and a minimum frequency in late summer. The percentage number of days characterized by blocking action in the north-east Atlantic averages 36 per cent. for the six months from December to May inclusive as compared with an average of only 16 per cent. for the three months, July, August and September.

Blocking action in winter is usually associated with a quasi-stationary anticyclone whose mean position is over southern Norway giving a spell of cold easterly or south-easterly winds over the British Isles. In summer blocking action is usually associated with a ridge or anticyclone centred over or very near to the British Isles, giving a spell of fine warm weather.

For a simple two-dimensional current of width $2a$ and constant speed u eastward, Rossby[1] has shown that the critical ratio $3u/\beta a^2$, where β is the rate of change of the Coriolis parameter with latitude, is a measure of the susceptibility of the stream to blocking development. However, computed daily values of the critical ratio at the 500-mb. level prior to and during three periods of blocking action show erratic changes from day to day. There is no clear relationship between the critical ratio and blocking development.

An alternative explanation of the development of blocking action was then put forward by the opener, based on the inter-relation between the thickness pattern and the underlying surface-pressure pattern. Sutcliffe and Forsdyke[2] have shown that the development of a baroclinic anticyclone is associated with the growth of anticyclonic distortion of the thickness lines, and that this thermal synoptic system is a self-developing one. The baroclinic anticyclone will normally be subject to thermal steering south-eastward. If this self-developing system finds itself in an environment which is particularly favourable for the growth of anticyclonic distortion, the south-eastward movement of the anticyclone will be retarded; at the same time it will extend north-east. The anticyclone tends to become quasi-stationary and to build up into higher latitudes, in other words to become a blocking anticyclone.

Anticyclonic distortion of the thickness lines is typically associated with a warm ridge extending north-eastwards into relatively high latitudes, and an adjacent cold trough extending south-westwards into relatively low latitudes. If two adjacent regions can be found, one particularly favourable to the north-eastward advection of warm air and the other situated to the south-east particularly favourable to the south-westward advection of cold air, the blocking anticyclone will tend to develop in the strongly baroclinic zone between.

Sutcliffe and Forsdyke[2] have given charts showing the extreme displacements of certain thickness lines for each month of the year. The chart for January suggests that in winter warm air can readily penetrate into high latitudes on a north-north-east track over the north-east Atlantic into the Barents Sea. This would be expected on physical grounds: vigorous cyclonic activity over the western North Atlantic in winter and small gradient of sea temperature from south-south-west to north-north-east over the north-east Atlantic. Also the chart of extreme displacements of thickness lines in January shows that cold air can readily penetrate southwards over European Russia then westwards across the plains of Poland, Germany and France. Scandinavia would be in the strongly baroclinic region between the warm air being advected north-north-east over the north-east Atlantic and the cold air being advected southwards and westwards across Europe. It is therefore over or near Scandinavia that blocking anticyclones would be expected to develop in winter. This is in agreement with the results of Rex's investigation into the mean position of the surface blocking anticyclone in winter.

The chart showing the extreme displacements of certain thickness lines in July suggests that in summer warm air can more readily penetrate into high latitudes over Europe than over the north-east Atlantic, although decreased cyclonic activity in summer will make deep penetrations less likely than in winter. But for the marked growth of anticyclonic distortion of the thickness lines the south-westward advection of deep cold air should give a thickness trough to the south-east of the thickness ridge. Such a trough can at best be only a very temporary feature over a strongly heated continental land mass in summer. Hence blocking action cannot readily develop in summer. This is in agreement with the figures given by Rex for the seasonal variation in blocking action, which was at a minimum in late summer.

As an example, the development of blocking action over north-west Europe between January 17 and 20, 1950, was examined. The development of an anticyclone over the North Sea and southern Norway was shown to be associated with the growth of anticyclonic distortion of the thickness lines, due primarily to the north-eastward penetration of a broad tongue of warm air into the Norwegian Sea.

The Director opened the discussion by suggesting it might be possible to forecast blocking action by forecasting changes in the thickness pattern.

Mr. Peters said that Mr. Clements had looked up the charts prepared in the Forecasting Division at Dunstable for the occasion in January 1950 described by Mr. Lumb. He had found that a remarkably accurate forecast was produced, on the morning of January 16, of the complete and rapid change of type which occurred between January 16 and 17—the crucial point in the weather of the month. Relevant forecast and actual charts for the 17th were shown, and the meeting acclaimed the prebaratic for the morning of the 17th as constructed 24 hours earlier. The further outlook issued on the morning of the 16th foreshadowed the marked change to colder weather which occurred a day or so later.

Mr. Davis showed maps of the mean vector wind $\overline{\mathbf{V}}$ and vector standard deviation σ at the 500-mb. level for the North Atlantic region taken from *Geophysical Memoirs* No. 85[3]. Consideration of the ratio $\sigma/|\overline{\mathbf{V}}|$ showed that the chance of obtaining blocking action was greatest over north-west Europe and greater in winter than in summer. The probable longitudinal distribution of blocking action agreed very well with that given by Rex. Assuming that blocking action leads to the development of winds at 500 mb. at 90° or more to the mean and *vice versa*, the frequency of occurrence can be calculated and is in good agreement with the 112 cases in $13\frac{1}{2}$ years given by Rex. Further consideration of the ratio $\sigma/|\overline{\mathbf{V}}|$ at other levels showed that blocking action was less frequent at 200 mb. with the centre of maximum occurrence further west, indicating that intense blocking action, which reached up to 200 mb., tended to drift westwards as it developed. Blocking action was more frequent at 700 mb., and it was tempting to assume that it was initiated in the lower layers and built upwards through the troposphere. Consideration, however, of the ratio at the 300-mb. level showed that, while this assumption was probably true in regions where blocking action was infrequent, over north-west Europe it was as frequent as at 700 mb. with the centre of maximum probability located in the same place. The conclusion is that blocking action is caused by air descending from 300 mb. through the non-divergent levels at 500 and 600 mb. to the lowest layers and thus causing the formation of a blocking anticyclone. The probable cause of air descending over north-west Europe from the 300-mb. level is to be found in the low tropopause over Russia—especially in winter—which would tend to drive the eastward moving tropospheric air at 300 mb. downward.

Mr. Veryard stressed that the development of blocking action was closely associated with the thermal contrast between ocean and land mass.

Mr. Sawyer stated that Rex's condition that the characteristic 500-mb. flow pattern should last for at least 10 days would greatly restrict the number of cases of blocking action. Many cases have a shorter life, and can develop elsewhere than in the two longitudinal bands found by Rex. Rossby's theoretical explanation of blocking action involved several doubtful assumptions, and its failure to apply in practice should not be attributed solely to his basic assumption of a barotropic atmosphere. Blocking is not necessarily associated with the formation of an anticyclone, it may be due to intensive cyclonic development downstream.

Dr. Sutcliffe did not see the connexion between Mr. Davis's statistics and blocking action. Winds at right angles to the mean flow could be equally well associated with depressions over Scandinavia as with anticyclones. Blocking action is a new term for something known before. In the southern hemisphere zonal flow is much more constant than in the northern hemisphere where every ridge in the surface pressure pattern contains the threat of blocking development. Ridges may start anywhere but have favoured regions for settling down. The cause of ridge development is not local, but the cause of ridge persistence is local. A study is being made in the Forecasting Research Division at Dunstable of flow patterns which have long persistence.

Mr. Jacobs considered that Rex's investigation would have been of more value if he had chosen a shorter period than 10 days as criterion of blocking action. Rex gave a minimum frequency of blocking action in September, but Belasco[4] had found a maximum frequency of anticyclones over the British Isles in September.

Mr. Gold said that for blocking action to develop cold air must come round to the south of the warm air mass. Blocking action is a new name for the "breakthrough" of cold air which concludes the life history of a family of depressions.

Dr. Sutcliffe added that the term blocking action was introduced in order to distinguish clearly between the long-lived blocking anticyclone and the relatively short-lived break-through ridges. It was important that such terms as "jet stream" and "blocking action" should not be allowed to depreciate in value.

The Director in closing the discussion emphasized the value of seeking for features of persistence in the general kaleidoscopic pattern of atmospheric circulation.

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3. BROOKS, C. E. P., DURST, C. S., CARRUTHERS, N., DEWAR, D. and SAWYER, J. S.; Upper winds over the world. *Geophys. Mem., London*, **10**, No. 85, 1950.
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OFFICIAL PUBLICATION

The following publication has recently been issued:—

PROFESSIONAL NOTES

No. 105—Diurnal variation of pressure in the Mediterranean area. By H. Jameson, D.Sc.

This note is a discussion of the harmonic dials representing monthly changes in the 24-hr. and 12-hr. pressure oscillations in various areas of the Mediterranean Sea and in neighbouring land areas. While the dials for the 24-hr.

oscillation differ considerably from one another, even in neighbouring areas, those for the 12-hr. oscillation show in most cases a fairly constant pattern, with changes in amplitude but constant phase, from May to October, and changes in both amplitude and phase during the remainder of the year, causing a counter-clockwise rotation of the dial point.

The mean annual phases of the 12-hr. oscillation in marine areas back appreciably from the values at land stations. A similar phenomenon had previously been noted in the tropics.

Harmonic dials of the 12-hr. oscillation in tropical marine regions are compared with those for the Mediterranean Sea. The marked difference between summer and winter in the Mediterranean dials appears also, in a somewhat modified form, in the northern and even in the southern tropics.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on December 19, 1951, the President, Sir Charles Normand presiding, papers were read on the heating of cold air masses over a warmer sea and on observations with a directional rain-gauge.

*Burbidge, F. E.—The modification of continental polar air over Hudson Bay**

The major topic of this paper by Mr. Burbidge of the Canadian Meteorological Service (read for him by Mr. Craddock) is the change in December in the modification of air passing over Hudson Bay. This change is ascribed to the formation of ice cover over almost the whole of the Bay. Mr. Burbidge points out that until 1948 little was known by direct observation about the central parts of Hudson Bay in winter, but reports by residents and explorers expressed the opinion that open water remained in the central parts throughout the year. This opinion was expressed also in the "Ice atlas of the northern hemisphere" produced by the United States Hydrographic Office in 1946. Mr. Burbidge examined the meteorological data and found a remarkable change in December which could only be ascribed to complete freezing of the Bay.

The data used were mainly comparisons between values of meteorological elements at Churchill on the west shore and Port Harrison on the east shore in about the same latitude. The results are briefly:—

(i) Mean temperature at Port Harrison is over 10°F. higher than at Churchill in November, but from January to June is practically identical at both places though the mean wind remains westerly.

(ii) The mean temperature at Port Harrison with easterly winds is 10°F. lower than with westerly winds in November, but from December to May there is little difference.

(iii) The greatest mean monthly snowfall at Port Harrison occurs in November.

(iv) A double cloud maximum, one in November and one in May, occurs in the Hudson Bay region. The November one is ascribed to heating of very cold air by a water surface and the May one to stratus produced over the ice and cold water of the Bay.

(v) Surface air trajectories from west to east over the Bay were examined for four years, and it was found that in November there was marked

Quart. J. R. met. Soc., London,* **77, 1951, p. 365.

warming of air masses initially at a lower temperature than 30°F. but in December warming was much less. The values for the period January–May indicated negligible modification of air at so low a temperature that it could not have passed over any appreciable area of surface of the Bay at the temperature of about 30°F. appropriate to open water.

(vi) The lapse rates shown by radio-sonde ascents in air which had come over Hudson Bay showed in November a great change from extreme stability on the leeward side to extreme instability on the windward side. In December the change was very variable and from January to May there was little modification.

The conclusion that the whole Bay in midwinter freezes over was confirmed by flights made over the Bay in 1948 and 1949. The general result is that in the autumn Hudson Bay is open and strongly warms air masses originating over the neighbouring continent; in winter it is frozen and effectively a part of the continent; in spring and early summer it is partly frozen and is a source of cold air; in summer it is an area of cold water causing subnormal temperatures with much fog and low stratus in surrounding areas.

Craddock, J. M.—The warming of arctic air masses over the eastern North Atlantic *

Mr. Craddock's own paper dealt with the warming of air masses moving from Iceland to the British Isles. Twenty-eight trajectories in which air moved from Reykjavik over the upper air sounding network in the British Isles were used. He pointed out that a difficulty in the work was that the heating produced a temperature gradient along the direction of motion which lead to shearing so that higher layers moved relatively towards the east. However, if there were a layer of the air mass within which (i) the wind shear at each level was in the direction of the isotherms, (ii) the isotherms and wind shear had the same direction at all levels in the layer, and (iii) the air at some one level in the layer could be directly tracked from the initial to the final sounding then a fair comparison could be made. The trajectories used were carefully selected to satisfy these conditions, and any which showed evidence of a thermal wind changing direction with height were rejected. The gain of heat and water vapour by the air in the selected trajectories was computed. The mean total rate of gain of heat of an Arctic air mass over the sea between Iceland and Britain was found to be 47 cal./cm.^{2}/hr. which is about half the solar constant and exceeds the hourly rate of heating of air over land in the British Isles at noon on a clear summer day. The heating over the sea goes on throughout the 24 hr. so that it is a far more powerful method of heating the air than summer insolation. Part of the heat is derived from the condensation of water vapour evaporated from the sea. An upper limit to the amount of water evaporated can be obtained by supposing that all the heat is obtained in this way and a lower limit is found from the gain in water vapour content. The difference between the two rates of evaporation gives in a typical case an upper limit 0·5 mm./hr. to the precipitation. Mr. Craddock next considered the relation connecting the difference, mean sea temperature over track minus mean surface air temperature over track, with the rate of warming and rate of gain of water vapour for each of the trajectories and found a close connexion which could be expressed in the words "if the difference sea minus air temperature is n°F. and the upper limit of convection is not above 700 mb. then the thickness of the layer from 1000 to 700 mb. will

* *Quart. J. R. met. Soc., London,* **77**, 1951, p. 355.

increase by *n* ft./hr.". Mr. Craddock's paper must be consulted for the application of his results to occasions when the convective limit differs from 700 mb. Finally Mr. Craddock considered all the possibilities of heating an air mass over the sea, namely advection, subsidence, lateral diffusion, radiation, evaporation of water vapour from rain falling from an upper warm front, and direct evaporation from the sea surface. He concluded that in the air masses he had considered evaporation from the sea surface provided the main source of heat with radiative effects producing a small loss.

In the discussion on Mr. Burbidge's and Mr. Craddock's papers, Dr. Robinson pointed out that Craddock's results applied to his and Rider's formula for heat loss corresponded to the reasonable mean wind velocity of 10 m./sec. Dr. Scorer agreed that in Craddock's situations there was little subsidence north-west of the British Isles but considered there was appreciably more in the same air stream south of the British Isles. Cdr. Frankcom was glad to see the Canadian work on the Hudson Bay area which was important for the shipping of grain. Dr. Sutcliffe was concerned as to whether the rising top of the convective layer in air heated by the sea could be confused with a front; Mr. Craddock said it was difficult to distinguish between them over Iceland but easy over Britain. Mr. Sumner asked if convection and subsidence are incompatible, and did not consider the question of the method of heating was settled; Mr. Craddock replied that in all his cases there was vigorous convection in progress on the north-west coasts of Britain, and that he was sure the amount of heating was related to the surface temperature difference which would not be so for subsidence heating.

Lacy, R. E.—Observations with a directional rain-gauge *

Mr. Lacy opened his statement on the observations made with a directional rain-gauge at the Building Research Station, near Watford, Herts., by briefly recounting the importance of meteorological information in connexion with the weathering of building materials, the effect of soil humidity on foundations and the heat loss from buildings. The variation of rainfall with direction was important in studies of the wetting of walls, as wet bricks have twice the heat conductivity of dry bricks. The gauge used had eight apertures, directed to the eight main points of the compass, in its vertical sides and a normal horizontal aperture above them, and was exposed on the flat roof of a building. The results showed that the apertures facing south, south-west and west received more rain than the others with a maximum for the south-west one and a minimum for the north one. The mean ratio between maximum and minimum was about 4:1, with a larger value in winter and smaller in spring. The ratio between the catches in the vertical apertures and in the horizontal gauge varied with season because of the variations in the angle of incidence of the rain, but approximately over a year the rainfall on the wettest wall of a building is about $\frac{1}{4}$ of the rainfall on the ground, and the rainfall on the driest wall of a building is about $\frac{1}{4}$ of the fall on the wettest wall. Calculations of the angle of inclination of rainfall to the vertical showed a mean angle of nearly 30° for winter with its strong winds and 15° in summer. Mr. Lacy described how he had measured the electrical conductivity of walls facing in different directions during recent rain driving from north, and found the north-facing wall had an increase in

* *Quart. J. R. met. Soc., London*, **77**, 1951, p. 283.

conductivity about half that expected from the rain catch. During the discussion Mr. Bonacina pointed out that the amount of rain reaching the ground is the same whether the angle of incidence is zero or nearly 90°. Mr. Craddock questioned whether owing to eddies the conventional gauge caught as much rain as the same area of ground, and Prof. Sheppard said the "collecting efficiency" of a house for raindrops should be about equal to that of the apparatus used for measuring the size of cloud particles.

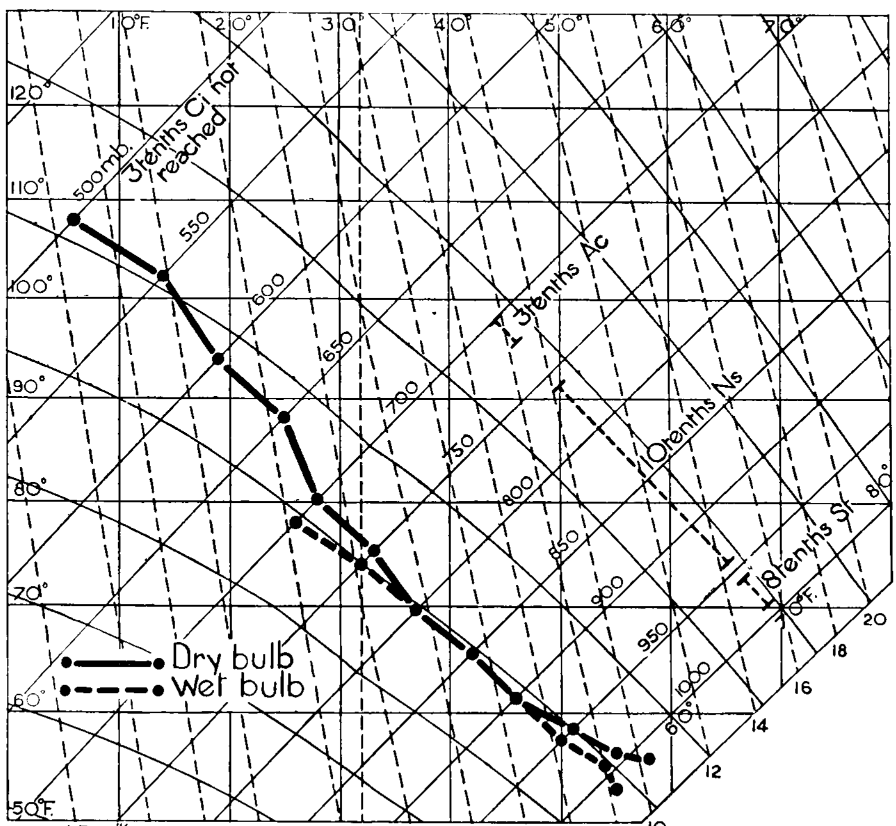
LETTERS TO THE EDITOR

Rain from non-freezing cloud

I well remember whilst flying on the war-time "Epicure" meteorological reconnaisance flight a particular occasion of rain from cloud whose top did not extend above the freezing level. Recently some photographs have come to light with a note of the date. These are reproduced facing this page. The following details have been taken from the log of the flight.

It was on May 22, 1945, at 1425 G.M.T. in 43·1°N., 14·3°W. (the ascent sounding position). There was moderate continuous rain below cloud, which was 10 tenths, apparently thick nimbostratus. The freezing level, at 740 mb., was higher than the tops of the nimbostratus. The mean-sea-level pressure was estimated at 1017 mb.

Photographs of the nimbostratus top were obtained; it was level but gently rippled, and, to all appearances, might have been that of an innocuous layer of stratocumulus. (I think, the amount of the altocumulus layer at 720–700 mb.



ASCENT IN 43·1°N., 14·3°W. AT 1425 G.M.T., MAY 22, 1945

Photograph by R.A.F.

Taken at 1445 from 15,000 ft.

Photograph by R.A.F.

Taken from 10,000 ft.

TOP OF 10 TENTHS NIMBOSTRATUS CLOUD (940–760 MB.) FROM WHICH MODERATE CONTINUOUS RAIN WAS FALLING

Reproduced by courtesy of METPHOTO and Whites Aviation Ltd., New Zealand

LENTICULAR LEE-WAVE CLOUD OVER SOUTH ISLAND, NEW ZEALAND

This photograph was taken by Leo L. White, at a height of approximately 4,000 ft. over Sutton looking north-eastwards at 1330 on May 18, 1951. The aircraft was flying towards Middlemarch on course 20° true.

recorded in the log as 8 tenths was a slip of the pencil for 3 tenths, as the nimbostratus top was photographed without difficulty.)

There is no record of the levels between which rain occurred, but almost certainly the nimbostratus was "wet", i.e. water droplets were impinging on the perspex of the aircraft, from base to top.

Abingdon, November 19, 1951 R. WARD

Lag of wet-bulb thermometer during rising temperature after frost

On the morning of December 12, 1951, after a night with hoar frost (but not rime) the thermometers in my screen read dry bulb $32\frac{1}{2}$°F., wet bulb $31\frac{1}{2}$°F. at 0925. The wet bulb was not wetted by direct application of water. The moisture in the muslin had reached it via the wick.

I had occasion to read the thermometers again at 1100, and was surprised by the large difference between them, dry bulb 37°, wet bulb 33°. Suspecting that this might be due to delay in thawing of the wet bulb I read the thermometers again at intervals. At 1110, the readings were 37°, 34°; at 1130, $37\frac{1}{2}$°, $35\frac{1}{2}$°; and at 1140, 38°, 36°. These readings, I think, confirm my suspicion.

As I can find no reference to this possible source of error in wet-bulb temperature I feel justified in communicating the observations to you so that others may be made aware of it, and take precautions against it when the temperature is rising and the wet bulb goes above 32°, after frost.

E. GOLD

8 *Hurst Close, N.W.11, December 12, 1951*

[The effect reported by Mr. Gold produces a marked false drop in the dew point. The dew points corresponding to Mr. Gold's readings are: 0925, $29\frac{1}{2}$°; 1100, 25°; 1110, 29°; 1120, $32\frac{1}{2}$°; 1140, 33°F.—Ed. *M.M.*]

NOTES AND NEWS

Lenticular lee-wave cloud over New Zealand

The cloud illustrated in the photograph facing this page can best be described as a lenticular lee-wave cloud. It is, however, such an unusual formation that no similar illustration appears in any of the recognized cloud atlases. The physical processes underlying its formation are nevertheless the same as are commonly described in the formation of lenticular cloud.

Lenticular cloud forms are common over Canterbury and Otago provinces where the lower atmosphere is comparatively dry on the east coast of South Island and very moist on the west coast. They most commonly occur with föhn winds which in South Island are associated with the passage of a deep depression across the south Tasman Sea, preceded by very strong north-westerly winds. A well known example is the "Canterbury northwester", a hot dry gusty wind from which most of the moisture has been extracted during its passage across the Southern Alps.

The meteorological situation which produced the cloud form illustrated differed from that normally producing the föhn wind, although the results were rather similar. A deep depression lay far south of New Zealand with a cold front extending northwards from its centre orientated north-west to south-east across South Island moving to the north-east towards Dunedin at midday. An intense anticyclone was centred over the Tasman Sea, and extended to New Zealand, the isobars indicating a strong pressure gradient for SW.–WSW. winds over South Island ahead of the cold front. The air mass was comparatively stable.

At the time the photograph was taken, 1330 on May 18, 1951, the aircraft was approximately 60 miles north of the cold front at a height of 4,000 ft. over Sutton, and it is probable that the northwards movement of this front increased the pressure gradient ahead of it, and at the same time caused the westerlies aloft to veer towards NW. This effect was enhanced by the formation of an orographical low-pressure area on the leeward side of the Southern Alps.

The consequence of these conditions was that an exceptionally strong north-westerly wind blew across the mountain ranges of South Island parallel to the cold front from a direction of 310° true. Correspondingly severe up and down-draughts were produced over the many ranges and individual high mountains. The cloud in question was orientated north-west to south-east parallel to the wind, the front edge of the cloud shown on the left of the photograph lying farthest to the north-west and immediately in the lee of a 4,755-ft. peak of the Rock and Pillar Range. This peak, together with several others approaching the same height, lies off to the left of the photograph.

This particular cloud was caused by the strong north-westerly wind, impinging on the westerly side of the Rock and Pillar Range, being deflected upwards and over the high peaks. At the same time the wind would be increased in velocity over the top of the peaks and would descend on the leeward side, before again carrying out a reflected upward movement. It is apparent from the photograph that a wave motion was commenced in the air by the obstructions, resulting in several billows of increasing wave-length. These show up clearly in the cloud formation. The cloud, in spite of the remarkable impression it gives of ranging across the countryside (from right to left of the illustration), is stationary. This is apparent from the typical lens-shaped structures occurring throughout the cloud, and the generally striated form indicates that the wind is actually blowing at high velocity through it.

The cloud has appeared to the lee of the mountain rather than immediately over it, because the first deflection of air over the summit did not raise the billow of air to a sufficient height to produce the adiabatic cooling necessary for condensation to occur, although the temperature of the air above the summit was brought much closer to its dew point. The downward motion in the wave over the lee side of the mountain would dynamically warm the air slightly, thus removing any chance of condensation above the lee slopes, but the upward deflection has continued and been carried eastwards at higher levels. The next billow or wave crest occurred above the foothills shown in the left of the photograph, and the lifting with adiabatic cooling, has this time been sufficient to reduce a large body of air to its dew point. The front edge of the cloud thus marks part of the crest of the air billow, the coldest temperature in the billow occurring at the crest of the cloud. The crest of a second billow appears at the top right of the photograph where the cloud has the appearance of a false cirrus, and is at a very considerable height. The cloud is most dense in the middle of successive billows because of an increase in condensation there, and it thins out to the rear because of progressive evaporation. Individual droplets are quickly evaporated, and the cloud form is only preserved through continuous condensation from the renewed air deflected over the mountain. The evaporation taking place in the cloud is well shown in the clear space (upper right) where the wave motion is curved downward causing dynamical heating.

WHITES AVIATION LTD., NEW ZEALAND

Angle of deviation between the winds at 50 ft. and 2,000 ft. over the North Atlantic Ocean

In an earlier note* an analysis was made of the distribution of the ratio between observed velocities of the wind at 50 ft. and 2,000 ft. as a function of the lapse rate within this layer. The analysis was based on ocean weather ship observations at stations JIG (53°50′N., 18°40′W.) and ITEM (60°00′N., 20°00′W.). This analysis has now been extended to include the deviation in direction between the observed winds at the same two levels.

Table I shows the mean veer in direction of the wind between the surface and 2,000 ft. as a function of the lapse rate.

TABLE I—MEAN ANGLE OF DEVIATION BETWEEN THE WIND AT 50 FT. AND WIND AT 2,000 FT. AS A FUNCTION OF LAPSE RATE

Lapse rate	Mean angle of deviation	No. of obs.	Notes
°F./2,000 ft.	°		
−9 to 0	17·4	64	Isothermal or inversion
1 to 3	15·9	99	—
4 to 6	11·8	178	Saturated adiabatic, 6°F./2,000 ft.
7 to 9	7·2	237	—
⩾10	7·0	121	Dry adiabatic, 11°F./2,000 ft.
	Mean: 10·5	Total: 699	

The observations have been grouped into five classes of lapse rate ranging from inversion and isothermal to superadiabatic conditions. The number of observations upon which the mean values are based is shown for each class interval together with the mean veer in direction for the whole range of observations. Starting with the negative and isothermal lapse rate class the angle of deviation between the wind at 50 ft. and 2,000 ft. shows a steady decrease up to a lapse rate of 7–9°F./2,000 ft. The decrease appears to level off for lapse rates greater than the dry adiabatic. The general decrease with increasing lapse rate is the result of turbulent transfer of momentum downwards from the upper part of the 2,000-ft. layer where geostrophic flow is approached.

The scatter of the individual observations was large but the figures for standard deviations or extremes are not available for these particular observations.

A. H. GORDON

A proposed regional climatic survey

Dr. K. Knoch†, in an interesting article, sets out the need for a detailed climatic survey of Germany, analogous to the geological survey, primarily for the benefit of agriculture but also to aid in planning new settlements, siting buildings connected with the health service, and similar purposes. Such an idea is not new; Dr. Knoch himself in 1930 proposed a local evaluation of the climates of health resorts, and Dr. Weger has applied it to the Rhine wine-growing region. A parallel survey of the productivity of the soil in Germany has been partly completed on a scale of 1:25,000.

*GORDON, A. H.; The ratio between observed velocities of the wind at 50 feet and 2,000 feet over the North Atlantic Ocean. *Quart. J. R. met. Soc., London,* **76,** 1950, p. 344.

†KNOCH, K.; Über das Wesen einer Landesklimaaufnahme. *Z. Met., Potsdam,* **5,** 1951, p. 173.

Detailed mapping of such a complex entity as climate would present many difficulties. The network of official climatological and rainfall stations must form the basis, but apart from rainfall this is quite insufficient for maps on a larger scale than one in a million. Dr. Knoch proposes that the standard for any locality should be the "normal" climate of the region, derived from the climatological atlas of the country, and that local variations from this standard should be classed as: especially favourable, favourable, unfavourable, especially unfavourable. The charting would be done by specially trained field climatologists surveying the country, and using their own interpretations of the topography and visible signs and the local experience of the inhabitants obtained by questioning. The surveying would not involve actual micro-climatic measurements though such measurements would form part of the training of the surveyors.

Put like this the project does not seem to present any insuperable difficulties, but at once the question arises: favourable for what? Dr. Knoch recognizes that different scales would be desirable for different purposes—agriculture, forestry, settlement, building, etc. However, he thinks one general scale would serve for a first approximation, with special mapping of areas of climatic extremes such as frost pockets, very dry or moist sites, windy places and those subject to flooding or erosion. Some preliminary experiments would be necessary, but of the economic value of such maps there could be no question. It would, however, be much better if the scales could be made absolute, instead of relative to each region, and this would not seem to be impossible.

In Great Britain the potential value of such "meso-climatological" studies has long been recognized, especially in the study of frost pockets. For this country there is a detailed rainfall survey, though on a less open scale than Dr. Knoch envisages—half inch to a mile or 1:126,736. The question of a general meso-climatic survey of the country has been considered by the Agricultural Climatology Branch of the Meteorological Office, and the suggestion was made that a series of maps should be prepared to show the probable distribution of the different elements, including soil moisture, over a standard surface, such as bare soil or short grass, with annotations about the effect of different types of vegetation. This would have to be a long-term programme and much preliminary research would be required. The Ministry of Agriculture has in hand a 25-year plan for a soil survey of Great Britain on 1-inch maps, and the climatic survey could well follow, and be linked up with, the soil survey, on the same scale. Once the details of what is wanted had been settled precisely, it should be possible to enlist a good deal of local help from Farm Institutes, Experimental Farms and Agricultural Colleges. Since the prime need at present is to safeguard and increase the food supply, the emphasis must be on the agricultural side, though the maps would also be of great use for other purposes such as health and housing. It might even be practicable, when experience has been gained, to integrate the climatic factors with the help of local crop records, and so build up maps of indices of favourability for special crops—wheat, potatoes, fruit, beet, hay, etc.—which would show at a glance the best crop to plant to suit the soil in any given locality, and so save much wasted effort in trial and error. Even if the idea should turn out to be impracticable, it seems at least to be worth a thought.

C. E. P. BROOKS

HONOURS

The appointment of Mr. W. A. L. Marshall, Senior Experimental Officer in the Meteorological Office, as a Member of the Order of the British Empire was announced in the New Year Honours List.

METEOROLOGICAL OFFICE NEWS

Retirement.—The retirement of Mr. C. W. Lamb, M.C., on November 22, 1951, from an established post in the Meteorological Office brought to an end a period of rather more than 32 years' service. The first three and a half years were spent in Headquarters Branches with a short interlude at Valentia Observatory, but otherwise he worked throughout with the Royal Air Force. For the last eleven years he has been Senior Meteorological Officer at one or other of the Training Groups of the R.A.F.

At a farewell dinner in Mr. Lamb's honour at Headquarters 21 Group, Morton Hall, at which he was presented with a silver spirit-flask, the Air Officer Commanding and Senior Air Staff Officer paid tribute to him both as a Senior Meteorological Officer and as an associate. Later, at an informal meeting at Headquarters, Mr. J. Durward, Deputy Director, on behalf of the Office staff, presented Mr. Lamb with a gold wristlet watch. Mr. Durward emphasized how much the happy personal relations, which Mr. Lamb established with Royal Air Force officers wherever he went, had helped the Office to understand and meet Service requirements. Mr. Durward added that it was not only in his official capacity that Mr. Lamb had made a mark; as a sportsman he had been welcomed wherever his service commitments, at home or abroad, had taken him; though he had engaged in many sports in his time, cricket had been his real love and the game in which he had excelled.

Mr. Lamb has not yet severed his ties with the Office, since he has accepted a temporary appointment in the Branch dealing with special investigations.

Academic successes.—We congratulate Mr. E. T. Stringer, who has been awarded the degree of Ph.D. by the University of Birmingham, also Messrs. P. B. Bonner, H. J. G. Groom and P. D. de la Mothe who were successful in the Intermediate B.Sc. examination of the London University held in November 1951.

Sports.—*Swimming.*—Mr. S. W. Lewis has added to his achievements during the current season by taking first place in both the Air Ministry 100 yards' free style and back-stroke championships, and places in numerous other events. He represented Fighter Command in the recent R.A.F. championships. He is also a water-polo player and his services are much in demand by local teams. Mr. S. W. Lewis is a younger brother of Mr. A. F. Lewis, at present serving in the Falkland Islands Dependencies, who is also a Civil Service and Air Ministry championship swimmer.

Mr. A. R. Hosker gained third place in the Civil Service plunging championship held in London on November 15.

Cross-country running.—In the Air Ministry cross-country championship held at Chingford on November 24, the Office gained 1st and 3rd places in the team race. In the individual event Mr. D. H. Owers was second, Mr. G. F. Burton third and Mr. B. T. Flatley fourth.

Social events.—More than 200 members of the staff, their families and friends came to the Christmas Party on December 18. The highlights of the evening were a conjuring turn by Mr. J. F. Thornton and Spanish dancing by Miss Désirée Jestico and company. Games organized by Mr. G. F. Tindall and dancing, enlivened by swing music played by Mr. H. D. Hoyle, occupied the rest of the evening.

The Social and Sports Committee announce that the Twentieth evening party (Annual Soirée) is to be held from 7.30–11.00 p.m. on Saturday, March 8, in the North Hall, Victoria Halls, Bloomsbury Square, London, W.C.1, and hope to see a large gathering of the staff with their families and friends.

WEATHER OF DECEMBER 1951

The lowest mean pressure of 984 mb. occurred near south-west Iceland. Mean pressure increased south-eastwards, being 1000 mb. from latitude 55°N. in the North Atlantic to central Scandinavia and 1020 mb. from the Azores to central Europe. Mean pressure in the Mediterranean area and North Africa was generally between 1020 and 1025 mb.

Mean pressure was above normal in Europe and the North Atlantic between latitudes 40°N. and 50°N., the excess being about 5 mb. in the Balkans and central Mediterranean. Mean pressure was below normal north of latitude 55°N., the greatest deficit of 17 mb. occurring south-west of Iceland.

Mean temperature was about 15°F. in northern Scandinavia, 30–35°F. in eastern Europe, 35–40°F. in southern Scandinavia, 40–50°F. in the remainder of Europe, 50–55°F. in the Mediterranean region and 70–80°F. in west Africa. Temperature was mainly above normal, the largest excess being about 9°F. in southern Scandinavia.

In the British Isles the weather was dry in the east and south and wet in the west. It was mainly mild, apart from a cold spell from the 10th to the 13th and sunshine exceeded the average except locally in the north-west. Severe gales occurred at times, notably on the 4th–5th, 27th, 28th and 30th.

In the opening days pressure was low to the north-east and high to the west of the British Isles; north-westerly to westerly winds prevailed with showers and sunny periods. During the night of the 2nd–3rd a deep depression approached south-west Iceland and troughs of low pressure subsequently crossed the British Isles causing rain generally. On the 4th another intense Atlantic depression moved to south-west Iceland and thence east to Norway; more rain occurred in the west and north of the British Isles on the 4th and throughout the country on the 5th, while gales were recorded in the west and north, being severe in the Shetlands where a gust of 78 kt. was registered. On the 6th and 7th a small secondary depression moved from north-west Ireland to north-east France; rain fell in most parts but with appreciable sunshine in England. From the 7th to the 9th a deep depression moved from south-west Iceland to a position off south-west Norway. Showery weather prevailed on the 7th, with long bright periods in England and Wales. On the 8th rain fell generally and was heavy locally (2·30 in. at Borrowdale, Cumberland), with snow or sleet in west and north Scotland and a thunderstorm at Castle Archdale, County Fermanagh. On the 9th there were wintry showers and appreciable snow occurred in parts of Scotland. Gales were registered locally in the west on the 8th and 9th. The northerly winds of Arctic origin behind this system caused a considerable drop in temperature and in the wedge which followed keen frost occurred, notably from the 11th to 13th; screen temperature fell to 13°F. at Eskdalemuir and 14°F. at Dyce on the 11th. During this spell conditions were mainly dry, apart from slight rain in the west and north. Records of bright sunshine were good generally on the 10th and in parts of England and Wales on the 11th, but considerable fog occurred in eastern and midland districts of England on the 12th to the 14th, the fog being dense in places on the evening of the 13th and throughout the night. A period of very mild weather followed with deep Atlantic depressions moving towards south-west Iceland and a mild south-westerly to southerly air stream covering the British Isles. Rain occurred daily in the west and north but in south and east England the rainfall was generally slight, though the skies were mainly cloudy. On the 19th and 20th a shallow secondary depression off south-west Ireland moved north-east across Ireland to Scotland to the west of Norway; rain fell in most places and was heavy locally in the north-west. A very disturbed period ensued which lasted until the end of the month. On the 23rd a deep Atlantic depression moved north-north-east to Iceland and on the 24th a secondary depression moved across Ireland and northern England to the North Sea. Gales occurred locally and rain fell generally, being heavy in some places (2·32 in. at Blaenau Hydfer, Brecon, on the 23rd and 2·72 in. at Dunsop Houses and 2·26 in. at Oughtershaw Hall, both in Yorkshire, on the 24th). On the 25th showery weather prevailed, with local thunderstorms in the west, but the 26th was mainly sunny with scattered showers. On the 27th an intense Atlantic depression moved east-north-east to mid Scotland and later turned north, and on the 28th another deep depression moved east-south-east from south-west Ireland across Cornwall to France. Widespread gales occurred, severe in places in the west; a gust of 85 kt. was registered at Scilly on the 28th. On the 30th another intense depression moved east-north-east along our northern seaboard and an even stronger gale occurred in Scotland, the wind gusting to 94 kt. at Millport, Bute, and 85 kt. at Tiree. Snow fell in west Scotland and Ireland on the 31st and in northern England during the following night.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	59	13	+1·8	100	−1	123
Scotland	58	7	+0·8	123	+3	120
Northern Ireland ...	56	23	+0·9	117	0	95

RAINFALL OF DECEMBER 1951

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·80	75	*Glam.*	Cardiff, Penylan ...	3·51	70
Kent	Folkestone, Cherry Gdn.	2·57	80	*Pemb.*	Tenby	4·25	85
,,	Edenbridge, Falconhurst	3·12	95	*Card.*	Aberdovey (Plas Penhelig)	7·12	150
Sussex	Compton, Compton Ho.	3·98	95	*Radnor*	Tyrmynydd	8·71	106
,,	Worthing, Beach Ho. Pk.	2·74	91	*Mont.*	Lake Vyrnwy	11·96	169
Hants.	Ventnor, Cemetery ...	2·83	84	*Mer.*	Blaenau Festiniog ...	18·34	145
,,	Bournemouth	2·89	74	*Carn.*	Llandudno	5·42	187
,,	Sherborne St. John ...	2·29	70	*Angl.*	Llanerchymedd ...	7·49	171
Herts.	Royston, Therfield Rec.	1·39	60	*I. Man*	Douglas, Borough Cem.	6·77	137
Bucks.	Slough, Upton... ...	1·49	59	*Wigtown*	Port William, Monreith	...	...
Oxford	Oxford, Radcliffe ...	1·56	63	*Dumf.*	Dumfries, Crichton R.I.	7·37	172
N'hants.	Wellingboro', Swanspool	1·75	74	,,	Eskdalemuir Obsy. ...	9·43	135
Essex	Shoeburyness	1·35	73	*Roxb.*	Kelso, Floors	1·64	71
,,	Dovercourt	1·77	82	*Peebles*	Stobo Castle	5·02	132
Suffolk	Lowestoft Sec. School ...	1·50	64	*Berwick*	Marchmont House ...	1·22	43
,,	Bury St. Ed., Westley H.	1·66	69	*E. Loth.*	North Berwick Res. ...	1·33	62
Norfolk	Sandringham Ho. Gdns.	1·40	55	*Midl'n.*	Edinburgh, Blackf'd. H.	2·45	105
Wilts.	Aldbourne	2·81	87	*Lanark*	Hamilton W. W., T'nhill	5·75	133
Dorset	Creech Grange... ...	3·75	85	*Ayr*	Colmonell, Knockdolian	7·46	134
,,	Beaminster, East St. ...	3·68	77	,,	Glen Afton, Ayr San. ...	10·60	166
Devon	Teignmouth, Den Gdns.	2·95	70	*Bute*	Rothesay, Ardencraig ...	9·08	167
,,	Cullompton	3·30	75	*Argyll*	Morvern, Drimnin ...	10·93	139
,,	Ilfracombe	4·98	103	,,	Poltalloch	10·29	171
,,	Okehampton, Uplands	6·12	87	,,	Inveraray Castle ...	14·92	150
Cornwall	Bude, School House ...	3·66	84	,,	Islay, Eallabus	8·26	139
,,	Penzance, Morrab Gdns.	4·97	87	,,	Tiree	7·28	139
,,	St. Austell	5·02	82	*Kinross*	Loch Leven Sluice ...	4·27	108
,,	Scilly, Tresco Abbey ...	4·54	97	*Fife*	Leuchars Airfield ...	2·07	84
Glos.	Cirencester	2·63	79	*Perth*	Loch Dhu	12·79	127
Salop	Church Stretton ...	3·34	95	,,	Crieff, Strathearn Hyd.	4·85	108
,,	Shrewsbury, Monkmoor	2·47	101	,,	Pitlochry, Fincastle ...	4·80	119
Worcs.	Malvern, Free Library	2·66	96	*Angus*	Montrose, Sunnyside ...	1·77	64
Warwick	Birmingham, Edgbaston	2·77	103	*Aberd.*	Braemar	3·48	108
Leics.	Thornton Reservoir ...	1·89	74	,,	Dyce, Craibstone ...	2·27	67
Lincs.	Boston, Skirbeck ...	1·21	56	,,	Fyvie Castle	2·53	74
,,	Skegness, Marine Gdns.	·88	40	*Moray*	Gordon Castle	2·31	86
Notts.	Mansfield, Carr Bank ...	2·29	79	*Nairn*	Nairn, Achareidh ...	2·98	145
Derby	Buxton, Terrace Slopes	7·77	137	*Inverness*	Loch Ness, Garthbeg ...	7·36	160
Ches.	Bidston Observatory ...	3·47	131	,,	Glenquoich	19·67	134
Lancs.	Manchester, Whit. Park	5·50	170	,,	Fort William, Teviot ...	15·26	150
,,	Stonyhurst College ...	12·57	259	,,	Skye, Duntuilm ...	9·18	147
,,	Squires Gate	6·57	211	*R. & C.*	Tain, Tarlogie House ...	3·52	124
Yorks.	Wakefield, Clarence Pk.	1·97	81	,,	Inverbroom, Glackour...	10·71	146
,,	Hull, Pearson Park ...	1·76	73	,,	Applecross Gardens ...	10·29	160
,,	Felixkirk, Mt. St. John	2·48	103	,,	Achnashellach	14·64	154
,,	York Museum	1·98	88	,,	Stornoway Airfield ...	6·19	104
,,	Scarborough	2·01	84	*Suth.*	Loch More, Achfary ...	...	...
,,	Middlesbrough... ...	3·26	168	*Caith.*	Wick Airfield	2·44	79
,,	Baldersdale, Hury Res.	7·98	215	*Shetland*	Lerwick Observatory ...	6·95	145
Norl'd.	Newcastle, Leazes Pk....	1·51	64	*Ferm.*	Crom Castle	4·38	106
,,	Bellingham, High Green	3·76	104	*Armagh*	Armagh Observatory ...	4·30	137
,,	Lilburn Tower Gdns. ...	1·74	66	*Down*	Seaforde	3·58	87
Cumb.	Geltsdale	5·61	147	*Antrim*	Aldergrove Airfield ...	3·88	113
,,	Keswick, High Hill ...	12·27	183	,,	Ballymena, Harryville...	4·98	112
,,	Ravenglass, The Grove	6·82	149	*L'derry*	Garvagh, Moneydig ...	5·70	142
Mon.	Abergavenny, Larchfield	4·89	110	,,	Londonderry, Creggan	5·61	128
Glam.	Ystalyfera, Wern House	7·18	86	*Tyrone*	Omagh, Edenfel ...	4·65	110

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FROST INVESTIGATION

By E. N. LAWRENCE, B.Sc.

Summary.—This investigation is concerned with the incidence and severity of air frosts in the fruit-growing areas in the Fenland district and in the Lower Severn basin. The period covers the months of April and May for the years 1921–50 and standard observations of screen temperature are used. An attempt is made to consider both radiation and wind frosts, and account is also taken of the direction and speed of the wind recorded during both types of frost. A formula is obtained for the frost frequency over flat clay country.

Definitions.—A screen frost is said to occur when the minimum thermometer in a Stevenson screen is reported as 32°F. or less, that is, its reading is less than 32·5°F.

Screen frosts are divided into two types: radiation frosts and wind frosts. Radiation frosts occur on clear nights with little or no wind, the air temperature generally increasing with increasing height above the ground. Wind frosts occur at any time of the day or night, whatever the state of the sky, with a definite wind which brings the air from cold regions. On some occasions a wind frost may be intensified by radiation and the two types of frost occur simultaneously.

The surface wind is the wind at 33 ft. above the ground, and is estimated or measured by anemometers. The wind actually on the surface of the ground is usually considerably less.

A wind frost is said to occur when the surface wind at the time of the minimum temperature is more than 7·5 m.p.h., the value corresponding to the boundary between force 2 and force 3 on the Beaufort scale. A radiation frost is said to occur when the wind is less than this value.

When the air on the slope of a hill is cooled by radiation it tends to flow down hill as a katabatic wind, the direction of flow being dictated by the local orographic features. Local winds are thus sometimes reinforced by katabatic winds. Such flows of air lead to the accumulation of cold air and the formation of frost hollows.

Data.—The stations at which the observations* were made are shown in Fig. 1 which also shows the physical features of the two areas considered. Temperature was measured by alcohol minimum thermometers exposed in a

*To obtain a long period of observations for the Thetford area the data from two nearby stations, Santon Downham and Lynford Hall, were combined but wind roses were not drawn. Frequencies were also computed for each station separately and wind roses drawn.

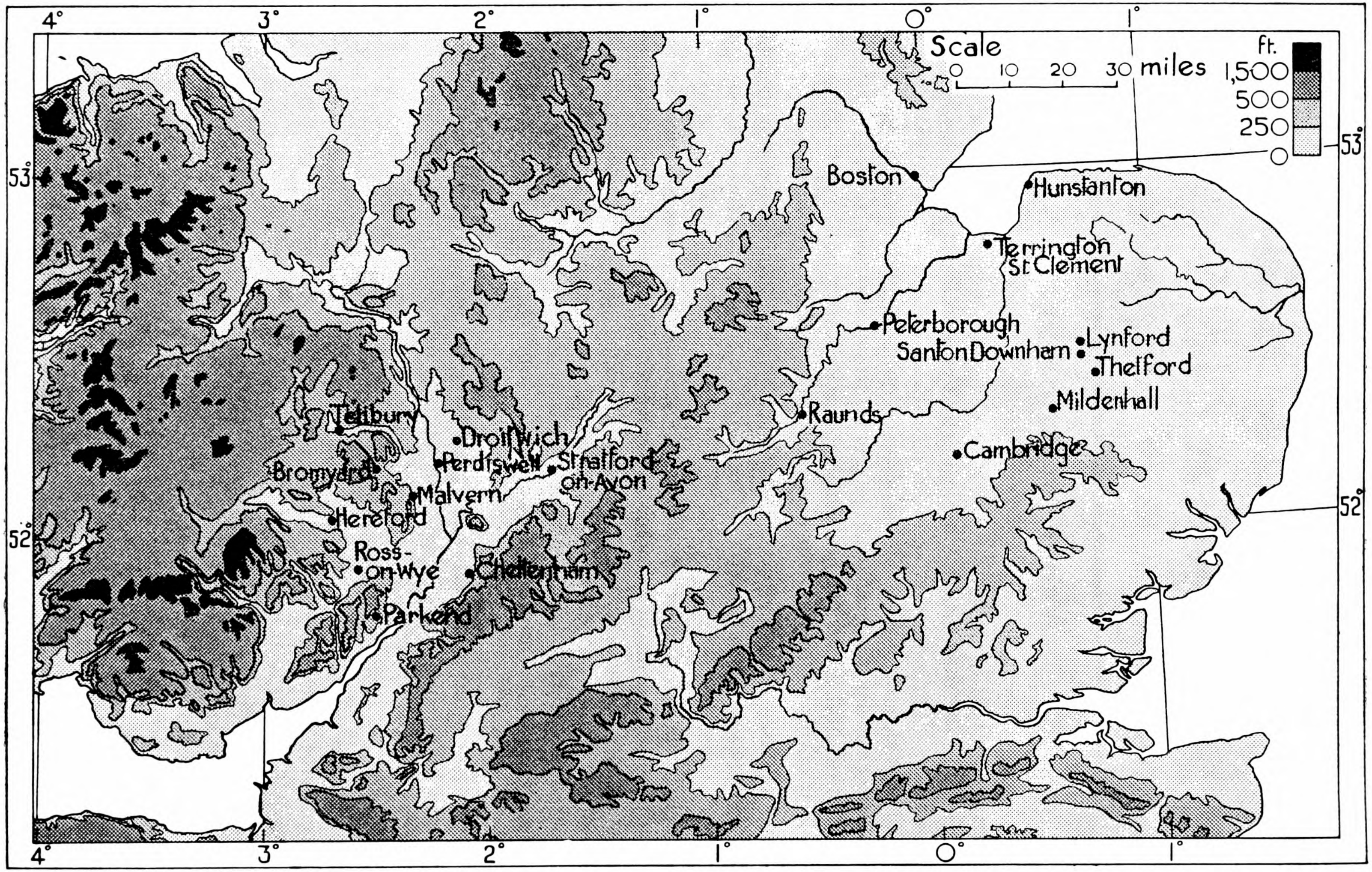


FIG. I—MAP SHOWING THE FENLAND AND LOWER SEVERN AREAS standard screen; the winds were mainly estimated, but in a few cases were measured by anemometer.

The standard period for the investigation was 1921–50, but the whole of this period was not available at all the stations. Table I shows the period available for each station.

TABLE I—PERIODS USED FOR TEMPERATURE AND WIND

	Period	No. of years		Period	No. of years
Raunds	1921–23, 1925–34, 1942–50	22	Cheltenham	1921–50	30
Peterborough	1940–46	7	Hereford	1921–50*	30
Cambridge	1921–50	30	Ross-on-Wye	1921–50	30
Mildenhall	1935–50	16	Malvern	1921–46, 1948–50	29
Boston	1938–41, 1943–50	12	Perdiswell	1926–50	25
Terrington St. Clement	1935–46	12	Bromyard	1921–42	22
Hunstanton	1924–50	27	Parkend	1932–50	19
Lynford	1933–42, 1949–50	12	Stratford-on-Avon	1933–38, 1941–50	16
Santon Downham	1944–48	5	Droitwich	1939–50	12
Thetford, (Lynford and Santon Downham)	1933–42, 1944–50	17	Tenbury	1921–22, 1924–28†	7

*Wind data available only from 1925 to 1950
†Wind data available only for 1921, 1922, and 1928

Relation between screen temperature and frost damage to fruit trees.—In a strong surface inversion, the screen temperature at 4 ft. may be considerably lower than the temperature at tree height. Furthermore the temperature inside the perimeter of the tree may be higher than the temperature on the outside of the tree at the same height because of the blanketing effect of the foliage. The temperature of an exposed bud is not necessarily that of the surrounding air. The critical temperature which causes damage is different for different varieties and for different stages of growth. Because of these complications it is difficult to select a fixed standard of reference in terms of screen minima, and to overcome this difficulty frost frequencies have been calculated with reference to a succession of screen threshold temperatures, namely 32°, 30°, 28° etc.

Effect of the time of observation.—The minimum temperatures considered were observed at times varying between 0600 and 0900 G.M.T. Those observations taken at the earlier hours of 0600 and 0700 were for a period of 12 hr. only. There is thus little chance of the minimum of one night being recorded as two frosts on successive nights, and therefore no correction has been made for the time of observation of temperature.

Wind was not recorded at the stations at the time of occurrence of the minimum temperature, so that to assess the number of wind frosts it had to be assumed that minimum temperature occurred at 0500 in April and 0400 in May. Given a wind at times between 0600 and 0900 the wind at 0400 or 0500 had then to be computed. Use was made of the normal rate of increase of light surface winds at Kew, and factors were determined which gave the proportion of the number of force 3 winds measured at 0600–0900 which were to be considered as force 2 winds at 0400 or 0500. These factors are given in Table II.

TABLE II—CONVERSION FACTORS (WIND)

	Time of observed wind 0600	0700	0800	0900
April	0·26	0·22	0·46	0·70
May	0·12	0·30	0·52	0·68

For example, if 10 frosts were recorded in May at 0700 with a force 3 wind, then 0·30 × 10 or 3 of these were regarded as occurring with a force 2 wind at the time of minimum temperature and were thus classified as radiation frosts and not wind frosts.

Effect of the period of observation.—The standard period was 1921–50, but full sets of records were not available for all stations and a system of qualitative weighting was devised with reference to the standard monthly averages for the 1881–1915 period (the "normal"). This is shown in Table III.

TABLE III—RELATION OF PERIOD AVAILABLE TO STANDARD PERIOD

	Period	APRIL Difference from normal	Effect on frost frequency*	MAY Difference from normal	Effect on frost frequency*
		°F.		°F.	
Cambridge	1921–50	+1·1	=	+0·13	=
Raunds	1921–23, 1925–34, 1942–50	+1·55	=	+0·41	=
Peterborough	1940–46	+0·41	+	0·0	=
Mildenhall	1935–50	+1·8	—	−0·19	=
Lynford	1933–42, 1949–50	+0·83	=	−0·75	+
Boston	1938–41, 1943–50	+2·4	—	+0·08	=
Terrington St. Clement	1935–46	+1·6	—	−0·4	+
Hunstanton	1924–50	+1·3	=	+0·04	=
Standard period, 1921–50		+1·1		+0·13	

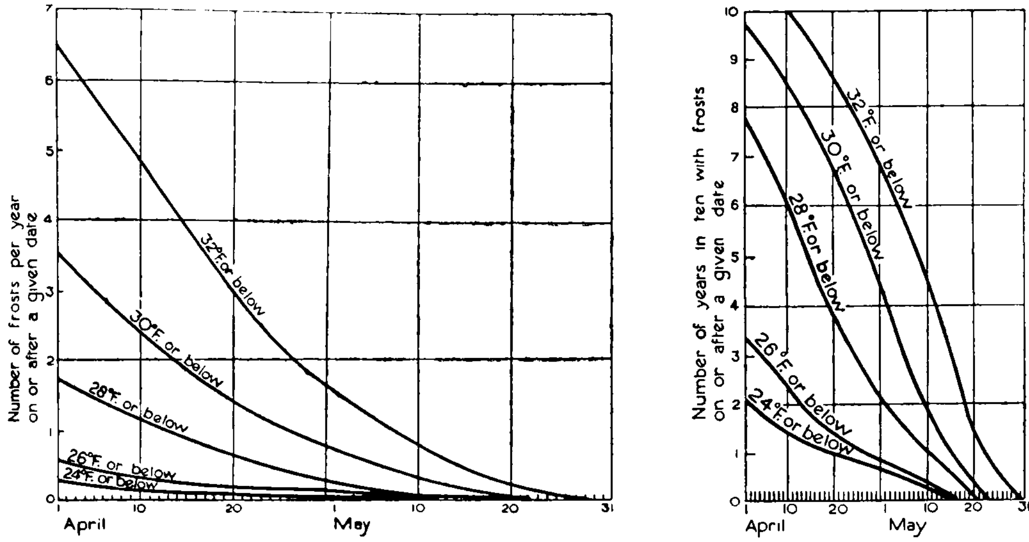
* = Frequency probably close to that for the standard period.
+ Frequency probably higher than that for the standard period.
— Frequency probably lower than that for the standard period.

Orography.—The more regular features of the Fenland area enabled a more detailed analysis to be made of the frost data than did the valleys and neighbouring hills of the Lower Severn area. The land in the east is mainly flat and all sites are below 200 ft. Such a uniformity makes comparison between sites possible, but with valley or hill sites marked differences exist which cannot be treated in a general manner.

Soil.—A simple classification of the soils at the various sites is given in Table IV.

TABLE IV—TYPES OF SOIL

Fenland area Station	Soil	Lower Severn area Station	Soil
Raunds	Clay	Cheltenham	Sand
Peterborough	Mainly clay	Hereford	Clay
Cambridge	Chalk and sand	Ross-on-Wye	Sandstone
Mildenhall	Mainly sand	Malvern	Variable
Lynford	Sand	Perdiswell	Loam
Santon Downham	Sand	Bromyard	Sandstone
Thetford	Sand	Parkend	Loam
Boston	Alluvial loam	Stratford-on-Avon	Clay
Terrington St. Clements	Silt/Loam	Droitwich	Clay
Hunstanton	Sand/Chalk	Tenbury	Red clay and marl



(*a*) (*b*)

FIG. 2—ACCUMULATIVE FROST FREQUENCIES AT CAMBRIDGE

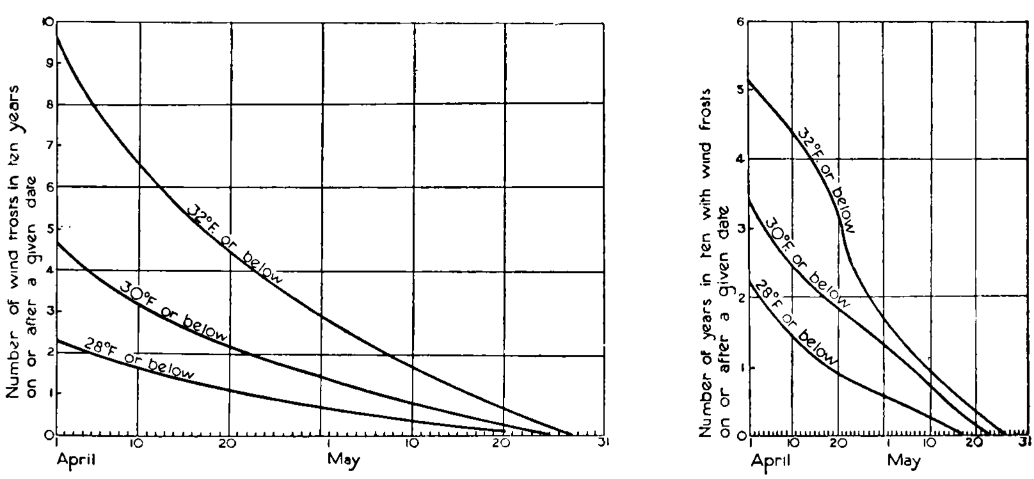
Calculation and representation of frost frequencies.—The average total number of frosts occurring on or after a given date was determined, and was called the "accumulative frost frequency". This was done for the frost "threshold values" of 32°, 30°, 28°, etc. The extracted figures were plotted in the form of a graph against a time base and the curves smoothed, Fig. 2(*a*).

Another set of curves was obtained by noting the date in each year of the latest frost of given severity; then, for each date of the period April 1–May 31, the average number of years in ten with such a frost on or after this date was found, Fig. 2(*b*).

These two sets of graphs were also constructed for wind frosts alone (Fig. 3).

Wind roses were drawn for frosts of varying severity, showing the frequency of wind direction during (i) wind frosts, and (ii) radiation frosts.

Frost frequency and soil type.—The relationship between frost frequency and soil type depends a great deal on the water-holding properties of the soil. Over clay, for example at Peterborough, there was a marked decrease in frost



(*a*) (*b*)

FIG. 3—ACCUMULATIVE WIND FROST FREQUENCIES AT CAMBRIDGE

frequency in the slight-to-medium frost range. Over sand, as at Thetford, the frost frequency was almost a linear function of the threshold temperature. In the west the three stations with clay soil, Droitwich, Stratford-on-Avon and Hereford, showed a greater difference between the frequencies of 32° and below and the frequencies of 30° and below than those between 30° and below and 28° and below. Stations on loam, Perdiswell and Parkend, showed a reverse effect in that the greater difference occurred between the frequencies of 30° and below and the frequencies of 28° and below.

Lower Severn data.—No method of numerical combined analysis was found suitable for use with stations in the irregular terrain of the south-west Midlands. The data were, therefore, considered in a qualitative manner, and for each station the direction of probable katabatic flow was estimated. These estimates were compared with the frost wind roses. At four of the stations, Perdiswell, Bromyard, Parkend and Statford-on-Avon, the predominating winds of the frost wind rose were from the direction of the estimated katabatic flow. These stations were those with the highest frost frequencies, with the sole exception of Droitwich which appeared to have no marked katabatic winds and which probably owed its high frost frequency to its distance inland. The stations with the lower frost frequencies had wind roses dissimilar to the expected katabatic winds, which suggests that they have good cold-air drainage.

The data examined, therefore, confirmed the generally held view that in undulating or hilly country the question of air drainage is of paramount importance in determining frost frequency.

Frost frequency and height.—With the exception of Malvern, Table V shows that the most frosty stations are those below 200 ft. or above 320 ft. The evidence of the wind-frost data is by no means clear-cut. The average height of the stations with the highest wind-frost frequencies is 283 ft. and with the lowest frequencies 274 ft., while the average height of the remainder of the stations is 221 ft., from which no firm conclusions can be drawn.

TABLE V

	Height	Position in decreasing order of frost frequency		
		Total frost	Wind frost	Radiation frost
	ft.			
Perdiswell	94	4	6	3
Droitwich	106	1	4	1
Stratford-on-Avon	210	5	1	6
Cheltenham	214	9	10	9
Ross-on-Wye	226	8	8	8
Hereford	292	6	5	5
Tenbury	313	7	3	7
Parkend	325	2	2	4
Malvern	383	10	9	10
Bromyard	393	3	7	2

Wind and frost.—Many of the sites showed a distinct prevailing wind associated with frost, and some of them showed a prevailing wind direction for radiation frosts and another for wind frosts. These directions could usually be explained with reference to the local orography. In general, radiation frosts were more frequent than wind frosts and gave rise to lower temperatures more frequently. Also the lowest temperature at a particular site usually occurred in the lower wind-force range.

The wind roses are not reproduced here but the frequencies of frosts of 28° or below for ranges of wind force 0–2 and ≥3 for the eight main directions are given in Tables VI and VII.

A formula for the observed frequency of frost.—In selecting a site for fruit, the grower wishes to know the chances of frost after a given date, and with the development of frost-prevention methods he also wishes to know the actual frequency of frosts to assess how many times he needs to use the methods at his disposal.

Frost incidence is essentially local in character and a complete simple formulated solution is not possible. In an attempt to discover a formula, the area with least topographical variations, the Fenland area, was selected for analysis. The frost frequency was linked with the date, the distance from the sea, the severity of the frost (threshold temperature) and the type of soil. The formula was of the form

$$\log F = A + BT + Cx + Dt$$

where F is the average number of frosts after a given date, T is the threshold temperature, x is the distance from the sea in miles, t is the date in weeks after April 1, and A, B, C, and D are constants, A being a soil constant.

TABLE VI—FROST FREQUENCY AND WIND IN THE FENLAND AREA

Temperature ≤28°F.

	Month	Wind force	Calm, or light variable	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Total
				frequency per ten years								
Raunds ...	April	0–2	1·4	0·5	1·2	1·2	0·7	0·7	1·0	1·4	1·0	9·1
		≥3	0·0	1·2	0·8	0·2	0·5	0·0	0·0	0·0	0·7	3·4
	May	0–2	0·5	0·7	1·4	0·3	0·3	0·0	0·0	0·2	1·0	4·3
		≥3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·3	0·3	0·5
Peterborough ...	April	0–2	1·4	0·0	2·1	0·7	0·0	0·0	0·0	0·0	0·0	4·2
		≥3	0·0	0·0	0·0	0·0	0·0	0·0	0·7	0·7	0·0	1·4
	May	0–2	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
		≥3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Cambridge ...	April	0–2	0·7	1·7	2·0	1·3	1·7	0·7	2·2	1·8	1·3	13·3
		≥3	0·0	0·0	0·3	0·0	0·0	0·0	0·7	0·0	0·0	1·0
	May	0–2	0·0	0·5	1·0	0·7	0·3	0·0	0·0	0·0	0·2	2·7
		≥3	0·0	0·0	0·0	0·0	0·0	0·3	0·0	0·0	0·0	0·3
Mildenhall ...	April	0–2	1·9	2·8	1·5	1·2	0·6	1·2	1·2	2·5	0·6	13·5
		≥3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	May	0–2	0·6	1·2	0·0	0·0	0·0	0·0	0·0	0·3	1·5	3·6
		≥3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·3	0·3	0·6
Boston	April	0–2	0·9	0·9	0·0	0·9	0·0	0·0	0·0	0·9	0·9	4·4
		≥3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	May	0–2	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·9	0·9
		≥3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·9	0·9
Terrington St. Clement	April	0–2	0·0	0·9	1·7	0·0	0·0	0·0	0·0	0·0	0·9	3·4
		≥3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	May	0–2	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·9	0·0	0·9
		≥3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Hunstanton ...	April	0–2	0·4	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·4
		≥3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	May	0–2	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
		≥3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Lynford ...	April	0–2	0·0	5·0	10·0	3·3	1·7	2·5	4·2	3·3	3·3	33·4
		≥3	0·0	1·7	5·0	0·9	0·9	0·0	0·9	1·7	0·9	11·9
	May	0–2	0·0	1·7	5·0	1·7	0·9	1·7	0·0	0·9	0·9	12·7
		≥3	0·0	0·9	0·0	0·0	0·0	0·0	0·9	1·7	0·9	4·3
Santon Downham	April	0–2	4·0	2·0	10·0	2·0	4·0	2·0	14·0	0·0	6·0	44·0
		≥3	0·0	0·0	2·0	0·0	0·0	0·0	0·0	0·0	2·0	4·0
	May	0–2	0·0	2·0	4·0	0·0	0·0	0·0	6·0	0·0	2·0	14·0
		≥3	0·0	0·0	2·0	0·0	0·0	0·0	0·0	0·0	2·0	4·0

TABLE VII—FROST FREQUENCY AND WIND IN THE LOWER SEVERN AREA

Temperature $\leqslant 28°$F.

	Month	Wind force	Calm, or light variable	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Total
				frequency per ten years								
Cheltenham ...	April	0–2	0·3	0·5	0·2	0·3	0·0	0·0	0·2	0·8	0·3	2·7
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	May	0–2	0·0	0·3	0·0	0·0	0·2	0·2	0·0	0·0	0·0	0·7
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Hereford ...	April	0–2	0·8	1·8	2·3	1·7	0·6	0·4	0·0	0·0	1·4	9·0
		⩾3	0·0	0·4	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·4
	May	0–2	0·0	0·2	0·4	0·0	0·0	0·0	0·4	0·0	0·6	1·6
		⩾3	0·0	0·4	0·0	0·0	0·0	0·0	0·0	0·4	0·0	0·8
Ross-on-Wye ...	April	0–2	1·7	0·7	0·2	0·2	0·0	0·5	1·0	0·5	0·7	5·3
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	May	0–2	0·0	0·0	0·0	0·0	0·0	0·2	0·5	0·0	0·0	0·7
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Malvern ...	April	0–2	0·3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·3
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	May	0–2	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Perdiswell ...	April	0–2	0·8	2·8	2·4	0·6	1·0	0·8	2·4	1·2	2·4	14·4
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·4	0·0	0·4	0·8
	May	0–2	1·2	1·6	0·0	0·0	0·0	0·4	0·4	0·8	0·4	4·8
		⩾3	0·0	0·0	0·0	0·0	0·4	0·0	0·0	0·0	0·0	0·4
Bromyard ...	April	0–2	1·4	2·7	1·8	0·5	2·3	1·8	0·9	0·9	2·7	15·0
		⩾3	0·0	0·0	0·5	0·5	0·0	0·0	0·0	0·0	0·5	1·5
	May	0–2	0·0	0·0	0·0	0·5	0·5	0·0	0·0	0·5	0·5	2·0
		⩾3	0·0	0·0	0·0	0·5	0·0	0·0	0·0	0·0	0·0	0·5
Parkend ...	April	0–2	0·0	1·1	2·6	0·0	0·5	1·6	1·9	0·7	0·5	8·9
		⩾3	0·0	0·0	0·5	0·0	0·0	0·0	0·5	0·0	0·5	1·5
	May	0–2	0·0	0·0	0·5	0·0	0·0	0·0	0·5	1·1	0·5	2·6
		⩾3	0·0	0·0	0·5	0·0	0·0	0·5	0·5	0·0	1·1	2·6
Stratford-on-Avon	April	0–2	0·6	0·9	0·3	0·0	0·6	1·2	0·6	3·1	1·2	8·5
		⩾3	0·0	0·6	0·0	0·6	0·0	0·0	0·0	0·6	0·0	1·8
	May	0–2	0·6	0·0	1·2	1·2	0·0	0·3	0·9	1·2	0·0	5·4
		⩾3	0·0	0·0	0·6	0·6	0·0	0·3	0·3	0·0	0·0	1·8
Droitwich ...	April	0–2	2·5	0·0	2·5	0·0	0·0	2·5	2·5	0·9	4·2	15·1
		⩾3	0·0	0·0	0·9	0·0	0·9	0·0	0·9	0·0	0·0	2·7
	May	0–2	0.9	0·0	5·0	0·0	1·7	0·9	3·3	1·7	1·7	15·1
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·9	0·0	0·9	1·7
Tenbury ...	April	0–2	0·0	0·0	5·0	5·0	3·3	0·0	0·0	3·3	13·3	30·0
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	May	0–2	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
		⩾3	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0

Sufficient data were available to obtain the complete formula for clay soil. Over sand, with the greater range of frequency of frosts and the more linear relation of frequency with intensity the formula similarly obtained would probably hold true to an even better extent, but an inadequate range of observations made its computation impossible.

Analysis of frequency.—The frequency curves in the Fenland area were found to satisfy an equation of the form:—

$$\log F = a - bt \qquad (F > 1)$$

This equation's closeness of fit with the observed values was statistically acceptable. Values of the constants, a and b, for the various stations are given in Table VIII.

In Table VIII the value of a decreases at the rate of 0·30 (approx.) per 2 degrees fall in threshold temperature. We can therefore write:—

$$a = c + dT$$

where T is the threshold temperature and c and d are constants with respect to t and T. The value of the constant d for Raunds and Peterborough, both on

TABLE VIII—COEFFICIENTS IN THE FROST FREQUENCY FORMULA

	Distance from sea	Threshold temperature 32°F.		Threshold temperature 30°F.		Threshold temperature 28°F.	
	x	a	b	a	b	a	b
	miles						
TOTAL FROST FREQUENCY							
Raunds	45	0·88	0·15	0·52	0·14	0·22	0·12
Peterborough	25	0·59	0·15	0·23	0·15	...	...
Cambridge	42	0·85	0·15	0·57	0·17	0·26	0·16
Mildenhall	30	0·88	0·14	0·64	0·13	0·30	0·14
Lynford	25	1·11	0·16	0·96	0·16	0·86	0·15
Boston	3	0·70	0·15	0·39	0·15	...	...
Terrington St. Clements	3	0·70	0·12	0·33	0·13	...	...
Hunstanton	0	−0·28	0·17	...	...	...	...
WIND-FROST FREQUENCY							
Raunds	45	0·27	0·14	−0·01	0·14	...	...
Peterborough	25	−0·09	0·17	...	...	...	...
Cambridge	42	0·00	0·14	−0·33	0·12	−0·63	0·12

clay soils, was found to be 0·18. The relationship between the values of c and the distance x from the sea in Table V was found to be approximately linear, so that

$$c = A + 0{\cdot}015x$$

where A is a constant depending on the type of soil, and is, for example, the same for Raunds and Peterborough, namely −5·55. Therefore the formula for the total accumulative frost frequency for sites over flat clay soil can be written

$$\text{Log } F = -5{\cdot}55 + 0{\cdot}18T + 0{\cdot}015x - 0{\cdot}15t.$$

Comparison between east and west.—If the ten stations in the west and the eight stations in the east are arranged in descending order of frost frequency the following order is obtained:—

1	Lynford/Santon Downham	(E.)	10	Hereford	(W.)
2	Droitwich	(W.)	11	Tenbury	(W.)
3	Parkend	(W.)	12	Boston	(E.)
4	Bromyard	(W.)	13	Terrington	(E.)
5	Perdiswell	(W.)	14	Peterborough	(E.)
6	Stratford-on-Avon	(W.)	15	Ross-on-Wye	(W.)
7	Mildenhall	(E.)	16	Cheltenham	(W.)
8	Cambridge	(E.)	17	Malvern	(W.)
9	Raunds	(E.)	18	Hunstanton	(E.)

In general, therefore, the western sites are more frosty than the eastern ones, but when wind frosts alone are taken into consideration the eastern sites are frostier.

Mean minimum temperature and frost frequency.—The mean minimum temperature for each of the months April and May for each station was correlated with the average number of frosts of temperature $\leqslant 28°$ during each of these months. The values of the correlation coefficients were found to be −0·94 (April) and −0·82 (May). Thus the mean monthly minimum temperature appears to be a useful indicator of the mean monthly frost frequency (threshold temperature 28°).

Conclusions.—

(*a*) The factors to be taken into consideration in regard to frost frequencies are the date, the intensity, the distance from the sea, the soil and the orographical nature of the country.

(*b*) In hilly country the orographical features are the most important; the frequencies obtained in this investigation can apply only to the sites where the measurements were made.

(*c*) Frosts are more frequent over sandy soils than over clay.

(*d*) The frostiest stations in this investigation are situated in the hilly country of the west with the exception of Thetford. Radiation frosts are generally more common than wind frosts and give rise to lower temperatures. Wind frosts are more common in the flat country of the east.

(*e*) The mean minimum temperature (April or May) is a useful indicator of the frost frequency of a station (threshold temperature 28°).

(*f*) There is no clear-cut relationship between frost frequency and height above sea level.

(*g*) At many stations there was a distinct prevailing wind on occasions of frost, and sometimes a second prevailing wind associated with wind frosts.

(*h*) The frequency of frosts over clay soils in East Anglia can be represented by a formula of the type

$$\log F = A + BT + Cx + Dt$$

where A, B, C, and D are constants and T, x and t are the threshold temperature, distance from the sea and time after April 1, respectively.

A similar formula could probably be extracted for sandy soils.

ELECTRONIC COMPUTING MACHINES AND METEOROLOGY

By J. S. SAWYER, M.A.

During the Second World War 1939–1945 a computing machine, the ENIAC, was completed in America, at Aberdeen, Maryland. It was of revolutionary design employing electronic methods, and it enabled numerical calculations to be performed a thousand times faster than was possible by methods which were available before the war. Further development of electronic computing machines has proceeded rapidly, and three machines have been built in this country for research purposes; at Cambridge, Manchester and at the National Physical Laboratory. These employ basically similar methods although they differ substantially in design; they are still in the experimental stage, but are already capable of undertaking calculations which were previously regarded as impracticable because of the enormous labour expended in manual methods.

It is not suprising that these developments in calculating methods should have stimulated meteorologists to consider whether the new machines can be used to advance the science of meteorology, and whether perhaps they may not ultimately have an application to forecasting. The subject has been discussed at a number of recent meetings and colloquia, and in order to appreciate the ideas which are being put forward it is necessary to recall something of the relevant background of meteorology and mathematics.

It was L. F. Richardson who, during the First World War 1914–1918, visualized the possibility of applying numerical methods to weather forecasting. His calculations in his book "Weather prediction by numerical process"[1] were a failure, whether from lack of initial observations or from incompleteness of knowledge of the atmospheric process we do not know, but his remarkable attempt demonstrated the possibilities and emphasized the difficulties—64,000 computers would be required to keep pace with the weather of the globe according to his estimation.

The new machines make it appear that perhaps L. F. Richardson's "forecast factory" was not so fantastic after all. Since 1945 J. G. Charney in America has given serious attention to the problem and his first calculations on the ENIAC are reported in a recent issue of *Tellus*[2]. Charney's approach differs considerably from that of Richardson. Richardson attempted to compute the future state of the atmosphere from an observed initial state, making very few assumptions about the possible types of motion which could occur in the atmosphere and being guided only by the observations made at his initial time. Charney on the other hand has endeavoured to simplify the problem by considering, not the atmosphere in all its complexity but a simplified "model" of the atmosphere which might be expected to behave according to more simple mathematical relations. For his calculations on ENIAC he considered only the flow of the atmosphere at 500 mb., and assumed that this would proceed as if the atmosphere were of uniform density (without temperature contrasts) and without friction (the barotropic model). Charney did not expect a perfect prediction on this basis—his model was only the first step in the development of a more realistic scheme.

For the purpose of discussing meteorological calculations it is not necessary to understand the inner workings of these remarkable computing machines. Suffice it to say that they operate by counting electronic pulses. EDSAC, the Cambridge machine, can perform an addition in about 1½ thousandths of a second and a multiplication in about 6 thousandths of a second. However, information can only be fed into the machine at the rate of 40 symbols per second, and information can only be read out from the machine at 15 symbols per second. Numbers can be represented in the internal store of a machine by a variety of devices, but only a limited set of numbers can be retained in the machine in this way. The operation of committing these numbers to paper takes far longer than many of the calculations themselves, and thus it is essential for efficient operation that as many relevant numbers as possible should be held within the machine. Otherwise the machine must wait while numbers are fed in or taken out and the advantage of its remarkable speed is lost. Various devices have been developed to extend the capacity of the machines for retaining the numbers within them, their so-called "memory", but it is a feature of problems of meteorological dynamics that many individual numbers are involved, several for every point of the chart, and meteorological problems may well tax the "memory" of even the most modern machines.

A computing machine, whether operated mechanically or electronically, can perform only the simple operations of arithmetic: addition, subtraction, multiplication and division. The numbers with which it operates and the order in which the operations are to be performed must first be decided by the mathematician and set out in a body of rules which the machine can follow.

These rules or instructions to the machine are known as the "programme", and with most of the electronic machines, these, as well as the numbers, have to be stored within the machine in order that it need not wait after performing one operation while instructions as to the next are fed into it.

The problem of applying electronic machines to meteorology therefore contains two important essential stages. First, the meteorological problem must be expressed as a set of mathematical equations, often partial differential equations, of which we require a solution. Secondly, the solution of these equations must be broken down into a series of arithmetical operations which are to be performed upon the initial observed values of the variables; this is the stage of "programming" for the machine.

It was against this background that a colloquium was held at Cambridge on September 6, 1951, on "Numerical methods in meteorology". Opening the discussion, Dr. R. S. Scorer stressed the possible application of electronic computing to meteorology other than the problem of forecasting. He mentioned the problem of recomputing the tephigram on a slightly different basis, the problems of the growth of raindrops and some problems on the dynamics of standing waves in the lee of obstacles. Later speakers, who included Dr. Charney, concentrated on the problem of the dynamics of the synoptic weather systems, an essential to the problem of forecasting. Mr. F. H. Bushby described some preliminary hand computations made at Dunstable which it was hoped would justify the study of a more complicated model than that adopted by Dr. Charney; Mr. Bushby's treatment makes some allowance for horizontal temperature differences, baroclinity. Dr. E. T. Eady described preliminary calculations at Imperial College, London.

The Meteorological Research Committee has shown its interest in the possibilities of electronic computing machines by including in its programme of investigations the "application of computing machinery to forecasting problems", and a member of the scientific staff of the Meteorological Office, Mr. Bushby, attended a recent course on the preparation of programmes for automatic digital computing machines.

Returning from this course in October 1951, Mr. Bushby opened a colloquium at the Central Forecasting Office, Dunstable, at which the possibilities of high-speed computation in meteorology were again discussed. During the discussion emphasis was placed on the probable value of numerical computations in improving our understanding of the dynamics of weather systems. There was a lively discussion of the merits of applying the first calculations to the behaviour of a textbook model cyclone rather than to the irregular disturbances of a real synoptic chart; nevertheless all were agreed that numerical methods had a more immediate application to dynamical research than to forecasting.

Enough has been written above to indicate that numerical meteorology is likely to become a subject of real interest. The number of workers on the subject is small at present, but there is real activity in a number of centres. The difficulties of the subject are considerable. Perhaps the most important is that we do not know if the equations widely used in meteorological dynamics do in fact adequately describe the motion of the atmosphere. Over periods exceeding 24 hours factors such as radiational heating and friction certainly enter, but these are usually neglected. The results of numerical integration over shorter periods will in fact be a crucial test of the theory.

A second difficulty is that little experience has so far been gained by the mathematicians in the integration on the new machines of the type of partial differential equation which is likely to arise in meteorological dynamics. New mathematical methods may need to be devised.

It is tempting to speculate on the future possibilities—perhaps to envisage revolutionary change in forecasting methods. However, there is much research and development to be done, and routine application of the methods to forecasting is therefore unlikely for many years to come. Nevertheless whether success or failure is the end of the attempts at numerical prediction, the experiments should improve our understanding of meteorological dynamics. The basic theory, which will be used in attempts at numerical prediction, is also the foundation of much besides in meteorology, so that if we only learn that the theoretical basis of computation is faulty, the effort will not have been in vain. However, there is reason to hope for better results; a satisfactory explanation of the development, movement and decay of weather systems may well be forthcoming.

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VAPOUR PRESSURE OVER THE SEA

By G. A. TUNNELL, B.Sc.

In an attempt to derive a simple method of estimating average vapour pressure over sea areas a number of interesting correlations were computed using data collected on the voyages of the *Carnegie*[1] during 1928–29 and the *Meteor*[2] during 1925–27.

The *Carnegie* sailed over the Atlantic Ocean between Iceland and about 10°N. and over the Pacific Ocean between the Aleutians and 40°S. The *Meteor* sailed between South America and Africa mainly on east-west and west-east courses ranging from 20°N. to 65°S. approximately. The *Meteor* made three observations a day (0700, 1400 and 2100 local time) while the *Carnegie* made daily observations at noon (G.M.T.).

The data have been classified according to wind force and the following linear equation fitted to each class for each ship,

$$e_h = ae_0 + b\,\Delta T + c \qquad \ldots\ldots (1)$$

where e_h = vapour pressure in millimetres in the screen on the ship

e_0 = saturation vapour pressure in millimetres at sea surface temperature

ΔT = temperature difference in degrees Centigrade between air and sea (positive if air temperature exceeds sea temperature)

a, b, c are coefficients derived from the data.

Table I gives the results of the analysis. Observations taken within 50 miles of land have been removed from the data. All the details of the correlations have been given so that the relationships between differences can be derived by anybody who is interested.

The coefficients of multiple correlations between e_h and the independent variables e_0 and ΔT have been included to give a measure of the closeness of fit of equation (1). It is surprising how good this is and it emphasizes how

TABLE I—ANALYSIS OF VAPOUR PRESSURE AND TEMPERATURE AS OBSERVED OVER THE SEA ON THE VOYAGES OF THE *Carnegie* AND *Meteor*

Beaufort wind force	No. of obs.	Vapour pressure at screen level (e_h) Mean	S.D.*	Range	Saturation vapour pressure at sea temperature (e_o) Mean	S.D.*	Range	Difference between air and sea temperature (ΔT) Mean	S.D.*	Range	Correlation coefficients between e_h and e_o	e_h and ΔT	e_o and ΔT	Coefficients in equation (1) a	b	c	R†
		millimetres			*millimetres*			°C.	°C.	°C.							
Observations on the *Carnegie* (screen height: 3·7 m. above sea level)																	
0, 1, 2	98	17·2	4·7	7·7 to 24·4	22·4	6·5	7·7 to 30·4	−0·4	1·1	−3·1 to +2·2	+0·94	−0·14	−0·32	+0·72	+0·74	+1·40	0·96
3, 4	209	16·4	4·6	7·3 to 24·4	21·0	6·6	7·6 to 30·8	−0·3	1·0	−4·6 to +2·4	+0·95	−0·08	−0·26	+0·70	+0·82	+1·92	0·97
5, 6	55	15·4	5·7	7·4 to 23·8	18·9	7·4	8·0 to 30·4	−0·2	1·2	−4·8 to +2·2	+0·95	−0·14	−0·38	+0·81	+1·25	+0·28	0·98
Observations on the *Meteor* (screen height: 9 m. above sea level)																	
0, 1, 2	120	13·8	5·7	3·6 to 24·4	19·0	7·4	5·0 to 31·7	−1·1	1·3	−5·8 to +2·6	+0·96	+0·08	−0·09	+0·75	+0·77	+0·35	0·98
3, 4	655	14·5	5·5	3·3 to 24·4	19·4	7·1	4·8 to 30·8	−0·6	1·1	−6·4 to +3·2	+0·95	−0·06	−0·24	+0·77	+0·89	+0·12	0·97
5, 6	332	11·6	5·1	3·7 to 23·8	15·4	7·0	4·9 to 30·4	−0·5	1·4	−6·0 to +2·5	+0·94	+0·03	−0·20	+0·72	+0·83	+0·95	0·97
>6	61	8·1	3·4	3·2 to 18·0	11·2	4·2	4·9 to 22·7	−1·7	2·6	−8·0 to +2·6	+0·80	+0·28	−0·25	+0·75	+0·67	+0·82	0·94

* Standard deviation.

† R = multiple correlation coefficient

much the conditions at the surface of the sea control those several metres above.

The coefficient a does not vary much except in the case of the *Carnegie* where there are indications of a discontinuity between forces 3 and 4 and forces 5 and 6. The coefficient b increases with wind force in the *Carnegie* equations, while in the *Meteor* equations there is an increase and a decrease with wind force. The *Carnegie* data again give a discontinuity in b between forces 3 and 4 and forces 5 and 6. The values of c differ so completely that it is thought that they depend on individual peculiarities of each ship.

Although to some extent the data are biased (for example light winds are frequent in the tropics while strong winds are frequent in temperate regions), these results suggest that, with high-quality observations from ships, statistical methods could be used to investigate the general relationships between the meteorological elements of the atmosphere just above the sea.

These analyses have been carried out using individual observations but the relationships derived would give the most satisfactory results when applied to average values of e_0 and ΔT.

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METEOROLOGICAL OFFICE DISCUSSION

Forecasting winds at 30,000–40,000 ft. and above

The discussion on January 14, 1952, dealt with the forecasting of winds at 30,000–40,000 ft. and above. The opening speakers were Mr. R. Murray and Mr. C. S. Durst.

Mr. Murray was concerned with the value and limitations of the conventional method of representing the upper wind flow by constructing the contours of the isobaric surfaces at 300, 200 and 100 mb. and assuming the validity of the geostrophic approximation. The forecasting of the upper wind flow is reduced effectively to forecasting the behaviour of the contour patterns. It is not possible to lay down hard and fast rules for forecasting contour patterns. At the Central Forecasting Office the surface forecast chart (prebaratic) is prepared first, and the upper-level forecast charts (prontours) are constructed by the thickness method on the foundation of the prebaratic so as to ensure mutual consistency between surface and upper air patterns. This procedure does not imply that the prebaratic is drawn independently of the upper air wind and temperature field. The upper air situation is always studied carefully before the prebaratic is prepared. The long-wave pattern, regions of probable cyclonic and anticyclonic development as suggested by Sutcliffe's thermal vorticity theory, extrapolation, and empirical knowledge are some of the considerations which determine the prebaratic as well as the prontour picture.

However, the accuracy with which contour charts can be used in practice to forecast upper winds depends on several factors in addition to the accuracy with which the contour patterns can be forecast.

The apparent geostrophic departure on a set of working charts prepared at the Central Forecasting Office has been found to have a root-mean-square value of 20 kt. at 300 mb. and 18 kt. at 200 mb. These figures appear to place a limit to the accuracy with which working contour charts at 300 and 200 mb. can be used to represent the wind field, assuming the geostrophic approximation. These errors in terms of wind arise from (i) errors due to errors in contour-height observations, (ii) errors due to the measurement of geostrophic wind, (iii) errors due to the personal element in chart construction, (iv) wind errors, (v) small-scale wind fluctuations, and (vi) real geostrophic departures. An assessment of the magnitude of the individual types suggests that (i) and (vi) are most important and that (iv) and (v) are negligible.

In forecasts based on forecast contour charts (prontours) additional errors arise through incorrect forecasting of the contour patterns. If measured geostrophic winds from 24-hr. prontours are compared with the observed winds the vector errors may readily be obtained. For the region of the British Isles a test has given values of 33 kt. at 300 mb. and 25 kt. at 200 mb. for the root-mean-square 24-hr. forecast errors associated with prontour charts prepared at the Central Forecasting Office. Now the root-mean-square apparent geostrophic departure on the working contour charts is about 20 kt. at 300 mb. and 18 kt. at 200 mb. Subtracting these inherent errors in technique from the total forecast errors, we obtain 26 kt. at 300 mb. and 17 kt. at 200 mb. for the root-mean-square errors associated with erroneous forecasting of the contour patterns themselves.

The percentage of the 24-hr. wind variance successfully forecast is 75 per cent. at 300 mb. but only about 40 per cent. at 200 mb. However, if the errors in forecasting the contour gradients (26 kt. at 300 mb. and 17 kt. at 200 mb.) are regarded as the real forecasting errors, then the percentage success improves to 83 per cent. at 300 mb. and 77 per cent. at 200 mb.

Point forecasts are the most difficult to make. For aviation purposes forecasts of the mean wind or of the equivalent headwind over a route are of more practical importance; for such purposes the vector errors of mean wind are substantially less. For instance, for a 1,200-mile route a test has shown that the root-mean-square vector errors in 24-hr. forecasts of mean wind are about 22 kt. at 300 mb. and 17 kt. at 200 mb. (these errors include both the inherent errors in technique and the real errors associated with forecasting the contour gradients).

Since the spring of 1951 100-mb. charts have been drawn at Dunstable. At this high level the wind and temperature observations are less numerous; also the temperature observations are less accurate than at lower levels. Thus really dependable contour charts are very difficult to draw at 100 mb., although the broad, long-wave patterns can be shown clearly.

High-level wind forecasting by means of contour charts for periods up to 24 hours, although not unsatisfactory for some purposes, certainly cannot be said to have reached the optimum standard of accuracy. The main improvement is likely to come from improved methods of forecasting the contour patterns, but at 200 mb. and above there is room for considerable improvement in the quality and number of the observations.

Mr. Durst stated that what he was going to say was intended to be from a practical angle. For research work contours were essential even though they

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SUDDEN DISTURBANCE IN GLORIOUSLY FINE WEATHER

Photograph of rapidly moving cirrus seen from Col Chercrouit, just south of Mont Blanc, at 2.30 p.m., September 1, 1951. The summit of Mont Blanc and the Brouillard Ridge can be seen.

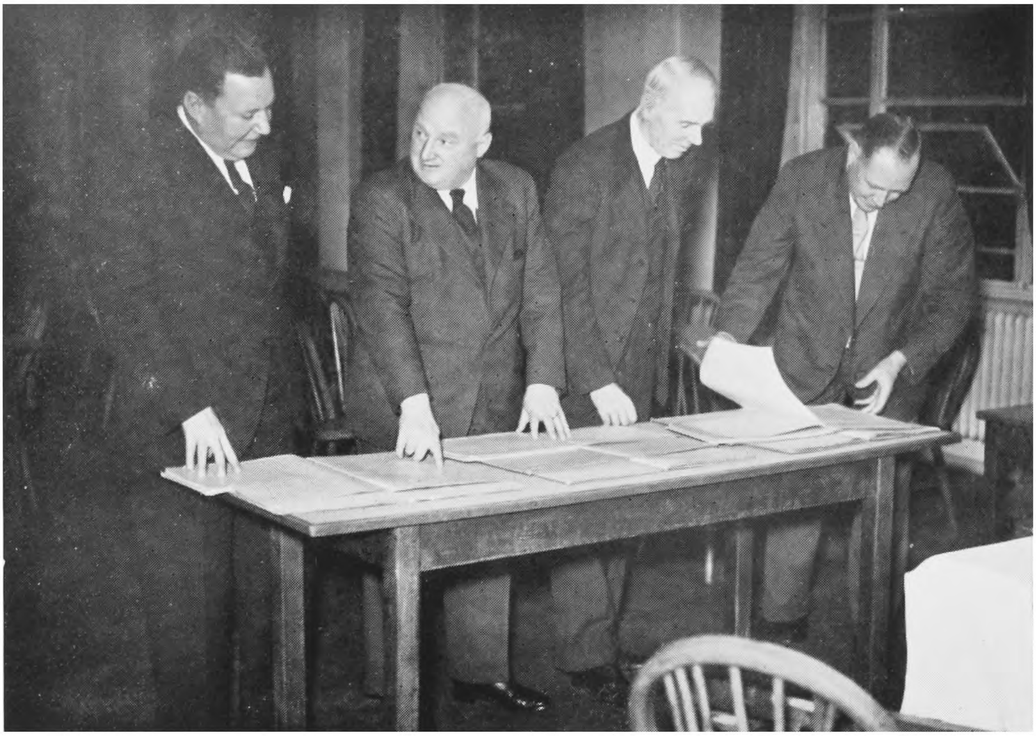
(see p. 91)

Reproduced by courtesy of the Valetta Museum

WATERSPOUTS AT MALTA, 5.0 P.M., OCTOBER 14, 1930
(see p. 91)

Reproduced by courtesy of the Valetta Museum

WATERSPOUTS AT MALTA, 5.45 P.M., OCTOBER 14, 1930
(see p. 91)



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EXAMINING OLD LOGBOOKS

Left to right: Capt. Pilcher, Capt. Fitzgerald, Sir Nelson Johnson, Capt. Whittle

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LUNCHEON PARTY AT THE METEOROLOGICAL OFFICE, HARROW

PRESENTATION OF BAROGRAPHS TO SHIPS' CAPTAINS

(See p. 89)

took long to compile. In practice, time was all important. If an observation of wind were given as a forecast for a later time there was a sharp increase in the error of the forecast in the first six hours or so; after about 30 hr. an observation is so stale that it is less accurate as a forecast than the normal wind of the season. He emphasized that the error in a route forecast was less than that at a point, the longer the route the less the error.

If the stretch vector correlation coefficient (r_{12}) is defined as

$$\frac{\Sigma\, |\mathbf{V}_1|\, |\mathbf{V}_2|\, \cos\theta_{12}}{\{\Sigma\,(\mathbf{V}_1^2)\,\Sigma\,(\mathbf{V}_2^2)\}^{\frac{1}{2}}}$$

where $\mathbf{V}_1$, $\mathbf{V}_2$ are the departures from normal of two series of vectors and θ_{12} is the angle between them, then it is possible to write a vector regression equation of $\mathbf{V}_1$ on, say, $\mathbf{V}_2$ and $\mathbf{V}_3$ in the form:—

$$\mathbf{V}_1 = a\left\{\frac{\Sigma\,(\mathbf{V}_1^2)}{\Sigma\,(\mathbf{V}_2^2)}\right\}^{\frac{1}{2}}\mathbf{V}_2 + b\left\{\frac{\Sigma\,(\mathbf{V}_1^2)}{\Sigma\,(c^2\,\mathbf{V}_3^2)}\right\}^{\frac{1}{2}}(c\,\mathbf{V}_3)$$

Suppose the series $\mathbf{V}_2$ represents winds at a certain time and a certain place, $\mathbf{V}_3$ represents winds at the same time but at a different place and with a weighting factor c appropriate to a circulation index; and suppose $\mathbf{V}_1$ represents wind at the same place as $\mathbf{V}_2$ but at a later time. Then a and b are functions of the partial correlation coefficients between $\mathbf{V}_1$, $\mathbf{V}_2$ and $(c\mathbf{V}_3)$. The regression equation can be used as a means of making a forecast of the wind $\mathbf{V}_1$.

As an example, the values of a and b had been determined from 120 observations made in the months June and July 1948 using winds at Downham Market and Aldergrove at 300 mb. Then, with the help of the resulting equation, forecasts had been made for 24 hr. ahead from observations made in July 1951. A table of errors was exhibited in which these forecasts were compared with those made by prontours, and it was seen that there was little to choose in accuracy between the two methods. Moreover if the two methods were suitably combined by a further regression equation the result showed an improvement of 5 or 10 per cent. on either.

Mr. Durst then showed some charts of stream lines and isotachs (lines of equal speed) drawn for the 300-mb. level which he claimed would avoid some of the principal errors referred to by Mr. Murray, e.g. those under the heading (i), (ii) and (vi). He showed also an isotach chart derived from prontours and for comparison an isotach chart drawn for the same date from statistical forecasts. The latter appeared to be much inferior to the former since the stronger winds were damped down, but when measurements were made at a number of points scattered over the charts it was found that the mean errors were much the same for both charts.

Mr. Durst then went on to give a comparison of the errors in 24-hr. route forecasts from Aldergrove to Berlin, a route selected as giving the greatest cover of accurate observations. The height chosen was 200 mb.; the statistical coefficients were calculated for the season December 1950 to February 1951; and the test was made over the month June 1951. The resulting errors are shown in the table below.

From the combination of prontour values and those derived from the regression equation the maximum error was 17½ kt.

FREQUENCY OF ERRORS IN 24-HR. FORECASTS OF HEADWIND (OR TAILWIND) COMPONENTS FOR A ROUTE ALDERGROVE TO BERLIN AT THE 200-MB. LEVEL, JUNE 1951

	Error less than 5 kt.	10 kt.	15 kt.	20 kt.	25 kt.	>25 kt.
			occasions			
By prontours	15	21	27	29	30	0
By regression equation ...	13	20	24	26	29	1
By the mean of the two methods	14	22	28	30	30	0

Mr. Durst finally mentioned that the technique used in operations of the Comet aircraft was an initial fast climb to 25,000 or 35,000 ft., followed by a slow climb of 5,000 ft. in perhaps 1,000 to 1,200 miles, followed by a steep dive to the terminal airfield. To make forecasts for the various legs of such flights it might prove much simpler and more accurate to devise systems of regression equations than to attempt to interpolate values from charts.

Mr. Briggs summarized the methods at present used by the Forecasting Division, Dunstable. Contour and prontour charts are drawn by a building-up process: adding the "thickness" of each successive layer. Slides were shown to illustrate the marked continuity of thickness pattern at 300 and 100 mb. compared with the poor continuity at 200 mb. The number of observations which reach 100 mb. and can be accepted by the analyst are few, for errors in the basic pressure and temperature observations become very large at 200 and 100 mb. Also wind observations are exceedingly scarce so that the analyst is forced to accept a smoothing process to make the best use of all the observations, both of wind and temperature.

Prontours are deduced from the contours by a technique which is basically one of thickness-pattern extrapolation with a building-up process which starts from the surface prebaratic. In this whole process correspondence of high-level and low-level thickness patterns is maintained in the absence of any expected big development; general synoptic ideas are used, such as keeping the warm pools at 100 mb. in step with the cold troughs at 300 mb.

Winds are deduced directly from the prontours by use of a geostrophic scale. Results obtained during 1951 showed a 70 per cent. success in forecasting the 24-hr. wind variance at 300 mb. over Larkhill. In interpreting such results the effect of strong gradients must be remembered. A good prontour may still show large vector errors in such cases if the forecast and actual winds for a fixed time and place are compared. Geostrophic-scale measurement from a prontour really gives a mean wind for a distance of the order of 200 miles. Also prontours are really forecast flow patterns so that it is doubtful if a system of point checks can indicate the true value of prontours. For the period October–December 1951 results at 200 and 100 mb. showed, respectively, 77 per cent. and 66 per cent. success in forecasting the 24-hr. variance of the mean wind over the route London–Prestwick.

Statistical forecasts had the advantage of not requiring a prontour chart, but work had, practically, to be re-done for each and every route. They were severely limited by the observations available, and, at 100 mb., a statistical forecast would often amount to giving the seasonal mean wind; a wind which, at this level, is itself a very doubtful factor.

Mr. Cummings mentioned the difficulties in forecasting high-level winds for Comet aircraft on the route London to Rome due to the sparse network of observations over the Continent and the Mediterranean. He thought that the accuracy of mean-wind forecasts for east-west routes is likely to be higher than for north-south routes because of the normal west-to-east movement of irregularities of the flow pattern. Mr. Durst, in reply to Mr. Cummings, said that his statistics showed that there is little difference in accuracy between east-west and north-south forecasts of mean wind.

Mr. G. J. W. Oddie showed slides of the 200-mb. charts for 0300 G.M.T., July 9, 1951, constructed at the Central Forecasting Office and at Rome. The two charts were in good agreement near the British Isles but seriously different in the Mediterranean, mainly because the accuracy of the Malta, Tripoli and Benghazi observations was assessed differently by the two meteorological services. He thought that the regression-equation technique avoided really large errors; the prontour method aims at precision but when unsuccessful may introduce extreme errors. In practice it may be desirable to make sure of avoiding excessively large errors rather than attempting to produce correct forecasts.

Mr. Gold pointed out that the statistical method reduces major errors. He asked what period of the year had been examined by Mr. Murray? Also, whether it is possible in deducing winds from prontours to allow for differences between wind and geostrophic wind already in existence on contour charts? Mr. Murray replied that his data were based on April 1950. He did not think that, at the present time, it was possible to allow for pre-existing ageostrophic components in 24-hr. forecast charts—work by Neiburger and others in recent years suggests that the geostrophic approximation can scarcely be improved upon in practice.

Mr. Sawyer pointed out that Mr. Briggs, in checking the accuracy of forecast mean winds over a route at 100 mb., had not made any allowance for the inherent chart errors, so that the real forecasting errors at 100 mb. are likely to be less than he suggested. However, Mr. Sawyer mentioned that there is a good deal of persistence in the wind flow at 100 mb. In constructing 100-mb. contours wind observations 6 hr. or even 12 hr. old could often be used when current observations were not available.

Mr. Zobel said that, at Bawtry, 200-mb. prontours were constructed by gridding the surface prebaratic to the forecast 1000–200-mb. thickness. A test had shown that this method produced a root-mean-square 24-hr. forecast error of about 26 kt. He also mentioned that the apparent geostrophic departure on 200-mb. contour charts had been worked out, and it agreed with the value put forward by Mr. Murray. Comparison of 24-hr. wind forecasts by prontours and by Mr. Durst's simple regression equations showed that the prontour results were more accurate. However, the time required to prepare prontours was very considerable—a 24-hr. prontour was effective for only 12 hr. or so. The statistical technique enabled a 12-hr. forecast to be prepared quickly and simply from the latest wind observation. He also mentioned that the prontours received at outstations contained additional coding and transmission errors.

Miss Carruthers remarked on the rather flat 300–200-mb. thickness patterns shown by Mr. Briggs. She pointed out that the standard deviation of temperature varies with height; it is smallest between 300 and 250 mb. and has a maximum at 170 mb. with a secondary maximum at 500 mb. Miss Carruthers asked Mr. Durst whether the regression equation took account of direction as well as speed. Mr. Durst stated that a vector regression equation did take account of direction, and illustrated on the blackboard how a vector regression equation could be solved graphically in a very short space of time.

Mr. Harley mentioned that flight routes over the Continent from London Airport were fixed, and the pilot of a Comet aircraft was not therefore interested in planning variations in routes according to the wind. He considered that the main cause of the long time required to complete contour charts was the delay in receiving the data and not the actual construction and analysis of the charts.

Mr. J. L. Galloway commented that jet-aircraft flights are of quite short duration, so that the main requirement is to have available really up-to-date wind observations from a few points along the route rather than long-period wind forecasts.

Mr. Holgate said that at Preston he was mainly concerned with short-period wind forecasts for the British Isles. For that purpose the longer-period prontours issued by the Central Forecasting Office were inferior to straightforward extrapolation of the wind field from more recent observations.

Mr. Kirk believed that a large part of the error associated with the prontours was due to errors in the prebaratic. Mr. Murray, in reply to Mr. Kirk, mentioned that, at least at the Central Forecasting Office, the prebaratic chart was not constructed independently of the upper air situation; prebaratic and prontour charts were closely inter-related.

Mr. Buchanan emphasized the collaboration between surface and upper air forecasters in the preparation of both prebaratic and prontour charts. It was of some interest that, after the high-level transatlantic flight of Canberra aircraft last winter, one of the pilots had written to the Central Forecasting Office and had congratulated the upper air analysts on the extremely accurate wind forecasts. However, Mr. Buchanan pleaded for more numerous and more accurate radio-sonde observations, especially in the regions away from the British Isles. He thought that the results of the Payerne trials were difficult to interpret.

Mr. Knighting said that, in ballistics, accurate point forecasts were essential—vector errors of 20–30 kt. were very serious. He considered that much of the apparent definiteness in the pattern of the 200–100-mb. thickness, mentioned by Mr. Briggs, might be illusory owing to the subjective element in constructing 100-mb. charts from such scanty information.

Dr. Harrison stated that the Payerne trials showed the characteristic differences between different types of radio-sondes used by different countries; it was difficult to say which sondes were most accurate. All flights at Payerne were carried out by highly trained personnel not working against time. The accuracy attainable at Payerne might not be reproduced in routine soundings if the organization and training of computers were not up to standard.

Mr. Taylor commented on the performance of British soundings. A test over the past 12 months had shown that wind observations at 100 mb. were obtained on about 45 per cent. of occasions. However, he thought that there was room for improvement in the quality of the balloons used.

The Director, in concluding the discussion, said that the charting and forecasting of very high-level winds was more or less a new problem. The contour chart and statistical method of wind forecasting could develop side by side. In the tropics, charts of mean values and departures of various elements were usually displayed in meteorological offices as a guide and warning to forecasters. He thought that the fine British network of upper air observing stations was a tribute to the planning of six or more years ago, when the need for winds at high levels had been foreseen. At present a new radio-sonde is under development.

METEOROLOGICAL RESEARCH COMMITTEE

The 62nd meeting of the main Meteorological Research Committee was held on November 29. The Committee reviewed the progress made during the past six months. The need for fast, high-flying aircraft for meteorological research was discussed, but it seems unlikely that such an aircraft will be obtained in the near future.

The Committee also considered various staffing matters in the Meteorological Office.

The 18th meeting of the Physical Sub-Committee of the Meteorological Research Committee was held on November 16, 1951. Two papers on visibility statistics were considered, one by Mr. Corby[1] dealing with visibility characteristics of Northolt Airport, and another by Dr. Goldie[2] discussing visibility statistics in general.

Mr. Durst presented a paper[3] dealing with the diurnal and seasonal height of pressure contours and Dr. Goldie read a related paper[4] on the subject of diurnal changes at high levels. Another aspect of the meteorology of the upper levels of the atmosphere was discussed in a paper by Mr. Bannon[5] who has examined the weather systems associated with occasions of severe turbulence at high altitude.

The Committee also discussed the possibility of examining atmospheric turbulence by means of smoke trails laid from aircraft, the variation with pressure of the velocity of sound in gases and some aspects of ice accretion on aircraft.

The 18th meeting of the Synoptic and Dynamical Sub-Committee was held on December 13, 1951. The Committee considered papers by Mr. Bushby on Charney's two-dimensional method of forecasting the instantaneous height tendency[6] and on the computation of the field of mean vertical velocity in the 1000–500-mb. layer of the atmosphere and its effect on the thickness of the layer[7].

A paper by Mr. W. E. Saunders on some further aspects of night cooling under clear skies aroused much interest[8].

Other matters discussed included (*a*) a comparison between rainfall amounts and Sutcliffe's expression for cyclonic development and (*b*) the question of the variability of the winds at 200 mb. in April 1950 at Larkhill.

[1] *Met. Res. Pap., London*, No. 680, 1951
[2] *Met. Res. Pap., London*, No. 691, 1951
[3] *Met. Res. Pap., London*, No. 675, 1951
[4] *Met. Res. Pap., London*, No. 684, 1951
[5] *Met. Res. Pap., London*, No. 669, 1951
[6] *Met. Res. Pap., London*, No. 670, 1951
[7] *Met. Res. Pap., London*, No. 682, 1951
[8] *Met. Res. Pap., London*, No. 687, 1951

OFFICIAL PUBLICATION

The following publication has recently been issued:—

METEOROLOGICAL REPORTS.

No. 10—Memorandum on the intertropical front. Compiled by J. S. Sawyer, M.A.

The area of disturbed weather which separates the wind systems of the northern and southern hemisphere has come to be known as the intertropical front. A considerable increase in knowledge about it was derived from the war-time meteorological organization in the equatorial regions. The present report summarizes the experience then gained for the guidance of both weather forecasters and airmen. The characteristics of the intertropical front are described both as regards oceanic areas where it separates the two trade-wind systems and the continental areas where it forms the limit of a monsoon current.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on January 16, the President, Sir Charles Normand, in the Chair, the following papers were read:—

*Riehl, H., Yeh, T. C., Malkus, J. S., and La Seur, N.E.—The north-east trade of the Pacific Ocean**

Dr. Malkus read the paper written by herself, H. Riehl, T. C. Yeh and N. E. La Seur. In the summer of 1945 three weather ships of the U.S. Navy were stationed north-east of Hawaii, and this, with the station at Honolulu, gave four observing stations very closely along the summer direction of the trade-winds over a distance of 1,500 miles. The weather ships made radio-sonde and pilot-balloon observations as well as surface observations. The data used in the paper were for the months July to October 1945. From these data were calculated vertical cross-sections along the trades, up to a pressure of 700 mb., of wind steadiness, wind speed, temperature and specific and relative humidity.

The vertical structure of the trades was found to be: (*a*) a layer of nearly dry-adiabatic lapse rate from the surface up to the base of the trade-wind cumuli which was at about 950 mb. at the north-east point and 930 mb. at Honolulu, (*b*) cloud layer of lapse rate approximating to the saturated adiabatic but decreasing upwards, and (*c*) a nearly isothermal region, the "trade-wind inversion", of base at about 900 mb. at the north-east point and 800 mb. at Honolulu, and top about 800 mb. at the north-east end and probably at 750 mb. at Honolulu. The wind speed increased upwards to a maximum about 900 mb. and then decreased. The magnitude of the descending air current was calculated from the divergence, and found to be of the order of 195 ft. a day at 700 to 800 mb., so that in the 6 days taken by the air to cover the distance considered the upper air sinks about 1,200 ft. Such a rate of sinking means that the air does not remain throughout in one of the main structural layers. The base of the inversion rises along the wind in spite of the descending air motion because moisture is carried upwards by the cumulus clouds which penetrate into the inversion layer and gradually transform it. The upward fluxes of latent heat and sensible heat from the sea surface were computed, and show that a net amount of latent heat is carried away from the area and is available to balance radiation losses elsewhere. The momentum

**Quart. J. R. met. Soc., London,* 77, 1951, p. 598.

transfer is also computed, and is naturally upwards near the ground but downwards higher up where the wind speed decreases with height so that the trade winds receive westerly momentum from both above and below. Comparison of the intensity of the vertical fluxes of momentum and water vapour showed that the coefficient of turbulent exchange of momentum increased upward, and the corresponding quantity for water vapour decreased upwards at least to the inversion layer; and the ratio of the former to the latter was large above the cloud layer.

In the course of the discussion Dr. Crowe pointed out that the area considered in the paper was the northern half of the trades, and it would be interesting to see what happens further south where further downward motion had taken place. Mr. Bonacina said he had concluded from the very heavy rainfall on the Hawaiian mountains that there must be great instability in the lower levels, and this was confirmed in the paper which showed instability to above the mountain tops. Prof. Sheppard was particularly interested in the vertical flux of momentum which did not conform at all to the conventional ideas of a frictional layer at the base above which there was very little or no friction. Dr. Forsdyke pointed out that the not negligible rainfall in the area, over 1 in. a month, could hardly be considered as coming from the trade-wind cumuli extending only to 700 mb. where temperature was about 50°F.

*Scorer, R. S.—Mountain-gap winds; a study of surface wind at Gibraltar**

The surface wind in the Straits of Gibraltar discussed by Dr. Scorer provides a very interesting field of application of dynamical meteorology.

There is a marked difference between the flow when the lower air is stable and when convection is active. The former flow is the more interesting as the surface wind when convection is active follows the upper wind without any very remarkable features.

When the lower air is stable the flow through the Straits is towards the end where surface pressure is lowest and may depart very greatly from the upper wind. Because of the venturi-like topography the wind is very strong in comparison with that over the sea outside the Straits. Winds of 100 kt. have been observed in the Straits at heights of 100 to 400 ft. when the general wind above the mountains was only 20 to 30 kt. Observations made by aircraft show the air converging towards the Straits does so steadily, but the emerging air blows for a long way in a narrow jet bounded by eddies and does not tend much to spread sideways. On occasions when a shallow pool of cold air is spreading slowly southwards over the area the wind will blow through the Straits towards the side where the lower layers are warmer. On other occasions when there is no marked difference in air mass between the two ends the surface wind will be across the isobars into low pressure. Small changes in pressure gradient may then lead to large changes in surface wind. Even the small gradients associated with the semi-diurnal pressure wave seem to be important. Local katabatic winds also complicate the picture when the general winds are light.

A particularly interesting occurrence is the inversion of the normal diurnal variation of wind velocity which often occurs when a strong easterly wind blows from a shallow cold pool in the Mediterranean. The lowest layers are then in roughly neutral equilibrium but above these there is a very stable layer. If

***Quart. J. R. met. Soc., London,* **78**, 1952, p. 53.

the low-level wind decreases with height, as it may on account of the funnel effect, the increased stability of the lower layers at night means that the surface air will then lose less momentum upwards so that its speed increases.

There was no time for discussion of Dr. Scorer's paper.

LETTER TO THE EDITOR

Triple-walled waterspout

An interesting waterspout was observed from start to finish from the S.S. *Empire Fowey* in the South China Sea at approximately 3°30′N., 106°E. at 0730 G.M.T. (1500 Malayan Standard Time) on May 27, 1951.

It began as a faint tube of cloud particles emerging from a cumulus base estimated to be slightly above 2,000 ft. Directly underneath, the sea was disturbed and throwing up spray to about 100 ft. in a circular area 300 ft. wide. In the second stage the tube, which appeared to be hollow, extended downwards to meet the surface spray. In its third stage, the tube which was about

30 ft. in diameter, apparently formed a second hollow cloud tube inside the first tube for about the middle third of its length. In the fourth stage, a thick cloud sleeve about 400 ft. long and 150 ft. wide grew downwards from the cloud base concealing the original spout and a similar sleeve or annulus grew from the sea at the same time. The spray from the sea surface remained visible outside the sleeve. The reverse processes now took place, and when the spout had reached the second stage again a shower spread from the north, enveloped it and hastened its decay, although it was possible to discern foam on the sea surface five minutes after the spout was no longer visible. No rotation was observable at any time except in the spray which appeared to drift slowly in a clockwise direction.

Weather at the time was cloudy with 7 oktas of large cumulus and cumulonimbus. There were three slight showers to the north and three moderate showers to the south. Surface wind was estimated to be S., 10 kt. Visibility was thirty miles and sea slight. An examination of synoptic charts on return to Changi showed that the area was affected by a south-easterly air stream flowing up the Java Sea and turning to southerly and then south-westerly in the South China Sea north of the equator. There was a convergence zone running east-west about 200 miles to the north of the ship's position and the intertropical front was still further north over French Indo-China. Thus there was nothing abnormal at the time; in fact, waterspouts are a fairly common occurrence in this region.

The spout was very near to where the ship had just passed, and was estimated to be originally three or four miles away, the whole incident lasting twenty minutes while the ship was doing 16 kt.; possibly the spout was initiated by an air eddy set up by the motion of the ship.

P. E. PHILLIPS

Changi, August 23, 1951

NOTES AND NEWS

Maritime occasion at Harrow

A recent ceremony held in the Meteorological Office at Harrow centred around the presentation of suitably inscribed barographs to four Merchant Navy Captains whose long-standing association with the Meteorological Office typifies the invaluable voluntary work carried out at sea by ships of the British "selected" fleet.

Captain Fitzgerald of the Cunard Company's *Vardulia*, Captain Pilcher of the New Zealand Shipping Company's *Haparangi*, and Captain Whittle of the Royal Mail Lines' *Asturias*, were the recipients for the award on November 27. Captains Wood, Anderson and Spriddell, the marine superintendents of the companies concerned were also present. Captain Eckford of the Pacific Steam Navigation Company's *Cuzco*, was at sea at the time, and the presentation to him has since been made at Liverpool on his ship's return there.

Sir Nelson Johnson, in making the presentations, emphasized the importance of maritime observations to meteorological services of the world, both for synoptic and climatological purposes. He said that the ocean weather ships received a good deal of publicity, but the masters and officers of merchant ships, who do such useful meteorological work at sea in all oceans, did not get the same limelight. He was glad to have the opportunity of publicly thanking all voluntary observers in "selected" ships and indeed the entire shipping industry for the fine spirit of co-operation which enabled this vital work to be carried out.

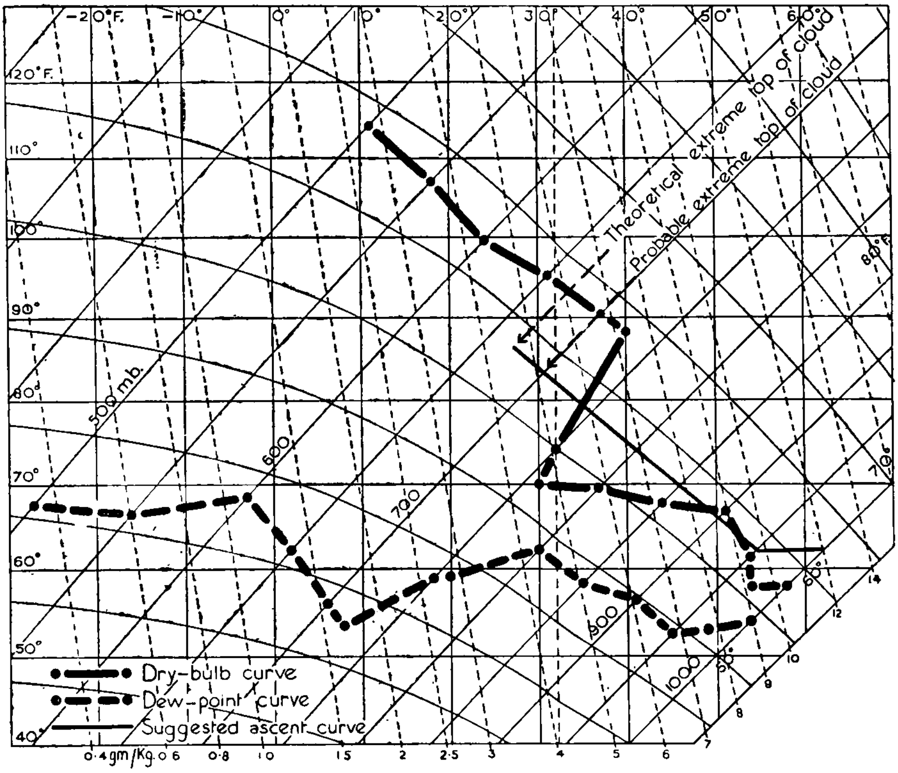
Sir Nelson spoke of the long connexions with the Meteorological Office of each of the three shipping companies represented—connexions dating back to the founding of the Meteorological Office under Admiral Fitzroy nearly a hundred years ago. Before presenting the barographs, he gave some details about the quality of the work done by Captains Fitzgerald, Pilcher and Whittle, during, in each case, more than 15 years of observing and recording the weather at sea.

The presentations followed a luncheon given in the Meteorological Office building at Harrow, which was also attended by Captain Macky Senior Warden, Captain Fisher a Member and Mr. Smith the Clerk of the Honourable Company of Master Mariners, who have been closely associated with such presentations on previous occasions. Captain Quick, the Principal Examiner of Masters and Mates, who is a member of the Meteorological Committee, was also present, together with some senior members of the Meteorological Office Staff. After luncheon the guests had the opportunity of inspecting the work of the Marine Branch.

Unexpected heavy rain

On October 3, 1951, when mainly dry weather was expected, rain or drizzle was reported from several places in south-west England and south Wales. Falls were mostly small in amount, but, in the Plymouth area, heavy rain fell during the late afternoon, 0·28 in. being recorded at Mount Batten between 1530 and 1715 G.M.T.

Anticyclones were centred north-east of the Azores and over Scandinavia with a strong connecting ridge across the British Isles. Over south-west England there was a pressure gradient for light E.–NE. winds and no evidence of any fronts. A study of the situation suggests that the radio-sonde ascent made at Camborne at 1500 G.M.T. gave a broadly correct indication of the temperature distribution over Plymouth at the time the rain fell.



TEPHIGRAM OF RADIO-SONDE ASCENT OVER CAMBORNE, CORNWALL, AT 1500 G.M.T., OCTOBER 3, 1951

Cumuliform cloud was not observed at Mount Batten nor was any reported from neighbouring stations, but, with surface temperature and dew point of 62°F. and 58°F. respectively at Mount Batten during the afternoon, isolated cumulus clouds could have been produced with a wet-bulb potential temperature in the cloud column of about 58°F. Observation and theory indicate that convection clouds may penetrate some distance into an inversion layer. Using the "parcel method" convection may theoretically continue until the "positive" and "negative" areas between the environment curve and the ascent curve on the tephigram are equal. On this occasion, ascent along the 58°F. wet-bulb potential-temperature line might have resulted in the cloud tops penetrating as high as 670 mb. This is the extreme, however, and, allowing for frictional and other damping effects, it is unlikely that the tops reached above 700 mb., at which height the cloud would have had a temperature of 30°F.

The base of the cloud when the rain commenced was 2,000 ft. Heavy rain therefore fell from a cloud of thickness about 8,000 ft. of which only the top 600 ft. or thereabouts could have been at a temperature below freezing point.

Acknowledgement is made to Mr. C. K. M. Douglas for some valuable comments which have been incorporated in this note.

P. F. ILLSLEY

Waterspouts at Malta, October 14, 1930

The waterspouts at Malta illustrated in the centre of this magazine occurred on a cold front which moved slowly south-eastwards across the west and central Mediterranean Sea. The fresh polar air behind the front became very unstable as it moved south-eastwards over the warm sea. The front was associated with a shallow secondary depression, the last of a family, which formed between the Azores and Spain on October 10, and moved steadily towards the Black Sea where it almost completely filled up on the 14th.

The waterspouts were visible to the north and south of the meteorological office at Valetta from 1525 until dark. There were lightning and thunder to the north-east; and again more lightning and thunder between 1900 and 2000. The waterspouts were a remarkable sight, as many as ten being seen at the same time, like so many pillars against a dark background supporting a canopy of yellow, orange and red clouds as the sun began to set.

Cirrus over Mont Blanc

The photograph facing p. 80 was taken by Mr. H. A. Meyer, of the Ministry of Civil Aviation, at 2.30 p.m. on September 1, 1951, from the Col Checrouit looking a little east of north towards Mont Blanc, the summit of which is seen with the Brouillard Ridge.

The fibrous cirrus cloud appeared very suddenly in fine weather and moved at a high speed. It appears to have formed on the upper part of a warm front which at the time extended south-east across France from a small depression whose centre moved along the English Channel during the day. The cloud of this depression blotted out, over most of northern France and southern England, the view of the partial eclipse of the sun which took place on that afternoon.

Obituary Notice of Professor V. F. K. Bjerknes, For.Mem.R.S., by E. Gold, F.R.S.

Mr. Gold has written for the *Obituary Notices of Fellows of the Royal Society* the obituary of Professor V. F. K. Bjerknes.

The Notice is, apart from the interest attaching to the description of V. Bjerknes's own work and personality, a valuable contribution to the history of meteorology. Anyone who wishes to study the development of the application of physics and mathematics to meteorology during the period from 1890 to 1945 would be well advised to begin by reading Mr. Gold's obituary notices of Sir Napier Shaw and Prof. V. F. K. Bjerknes*.

Copies of both Notices are available in the Meteorological Office Library (M.O.20) and in the Technical Libraries of the Special Investigations Branch (M.O.9) and Forecasting Research Branch (M.O.22).

OBITUARY

Edward John Percival, B.A.—It was with deep regret that we learnt of the death of E. J. Percival on November 1, 1951, at the early age of 40 years, following his short, but, often painful, illness—cheerfully borne.

After a brilliant career at Jesus College, Cambridge, during which he obtained 1st class Honours in Parts I and II of the Mathematical Tripos he was engaged by a firm of scientific consultants and remained with them until joining the Meteorological Office as a Forecaster, Grade II, soon after the outbreak of the Second World War 1939–1945. He served in west Africa and in England. Although many war-time entrants to the Meteorological Office returned to their former occupations with their release from the R.A.F.V.R. Percival had become intrigued by the subject of meteorology and expressed a wish to remain in the Office. In consequence, he was appointed Senior Scientific Officer from January 1, 1946.

His special interest was synoptic meteorology although he was well qualified and sufficiently gifted to have undertaken work in, and make contributions to, almost any branch of the science. In June 1942, when in west Africa, he had the vision to see how radar could be used in upper wind observing, and he was the first to organize observations by this means with the co-operation of the Army authorities. His last task, before being stricken by his fatal illness, was a valuable contribution in the field of synoptic climatology.

Percival was able to hide his preoccupations and worries and thus appeared to be always cheerful and bright no matter what difficulties beset him; he retained these qualities even when he must have known that his illness was to prove fatal. He had the capacity to make friends easily and quickly and was very popular in R.A.F. Messes; many of these friendships made by himself and his wife were of an enduring nature, so that when the final blow came Mrs. Percival received a great deal of sympathy, comfort and practical help when she needed it so dearly.

Although he was a man of many interests, Percival did not lean towards sports such as football or cricket. He was, however, a keen equestrian and he and his wife were members of the B.A.F.O. Riding Club during their stay in Germany. As might be expected, Percival was interested in both bridge and chess and was no mean performer of these games which require special mental gifts in order to play them really well. One of his daily recreations which he always enjoyed was to try to complete *The Times* crossword, during the lunch break, in the shortest time possible.

Although his physical deterioration was so awfully apparent to his relatives and friends, he remained until the end alert in mind and managed to continue reading until the last few days. Only ten days before his death he said how

* *Obit. Not. Fellows roy. Soc., London,* **5**, 1945, p. 203, and **7**, 1951, p. 303.

anxious he was to resume and complete the work he had begun at Headquarters, Bomber Command.

The Meteorological Office has lost a gifted and good companion, and our very deep sympathy is extended to Mrs. Eileen Percival and her son Andrew in their grievous loss.

BOOK RECEIVED

Indian Journal of Meteorology and Geophysics, **2**, 1951, No. 3, India Meteorological Department. $9\frac{1}{2}$ in. × $7\frac{1}{4}$ in., pp. ii+165–242. Manager of Publications, Delhi, 1951. Price: *Rs.* 2/8 or 4*s*.

ERRATUM

December 1951, PAGE 345, Fig. 3; The isopleth in the bottom right-hand corner should be labelled 5 and not 10.

METEOROLOGICAL OFFICE NEWS

Birmingham's water supply.—The film "Birmingham's water supply" kindly lent by the Birmingham Water Department, was shown at the Meteorological Office, Harrow, on January 23, 1952. Although the film contained only a passing reference to rainfall observing—there was a brief shot of an observer reading a gauge—the importance of rainfall recording to a water scheme was frequently implied. It brought added meaning to the work of the hydrological and rainfall sections of the Office.

Training course for crop weather observers.—Twenty-one observers from crop weather stations attended a course of lectures in meteorology and in observational and recording technique given at the Meteorological Office Training School, from November 19 to November 22. The observers visited the Climatology and Instrument Divisions of the Office at Harrow on November 23 and saw something of the application of their records to agricultural meteorology. The observers expressed appreciation of the lectures and of the thorough way in which light had been thrown on their meteorological work. They made suggestions for future lectures, including more advanced work. The next course, which will be adapted to suit observers from both crop weather and health resort stations, is planned for October 1952.

Ocean weather ships.—O.W.S. *Weather Observer* spent Christmas on station JIG. Mail and parcels, including a large Christmas tree, the gift of the R.A.F. Kinloss, were dropped by an aircraft of R.A.F. Coastal Command. It had been hoped to obtain some interesting photographs of the arrival of the mail, but a very heavy swell and moderate SW. gale precluded boat work and a grappling iron had to be used instead for retrieving it. Messages of seasonal greetings and thanks were exchanged by the aircraft and the ship.

The weather on Christmas Day was not so bad as to preclude enjoyment of Christmas dinner and a party, but on December 26 the barometer fell steeply. In four hours (1800 to 2200) the wind increased from force 6 to a force greater than force 12. In this hour the sea, which was ordinarily rough, became a boiling mass of white with continuous driving spray at mast height.

Commenting upon the voyage in general, Captain Israel, Master of the *Weather Observer*, from whose report the above condensed notes have been made, writes:

"The whole voyage has been one of excessive bad weather . . . The storms of the 26th/27th December were the worst I have seen in the North Atlantic and simulated a compact West Indian hurricane . . . Always having a great deal of faith in Corvettes, I have never before had the chance of this supreme test for one. They are without doubt the finest sea ships in commission and their fortunate length (which fits between waves) has a great deal to do with it. One cannot help but mark that within three hundred miles 10,000-ton cargo steamers were in trouble, one being the famous *Flying Enterprise.*"

In view of the extraordinarily severe weather on this voyage, the continuous maintenance of the meteorological routine reflects great credit on all staff concerned.

Transfer of staff to Colonial Meteorological Services.—Two more Assistants left in January for the Colonies, Mr. D. R. Walker to Nyasaland and Mr. V. J. Wooller to Bermuda.

Social and sporting activites.—The Meteorological Office, Croydon, held an enjoyable party on January 11, when some past members of the staff joined other present members and their friends for a social evening which concluded with a visit to "King's Rhapsody". Staff who have served at the Meteorological Office, Croydon, and who are interested in any similar gatherings in the future are invited to forward their names and addresses to that office.

Miss B. Edwards, of M.O.20 (Editing), Harrow, played for the Civil Service in a netball match against the Women's Royal Air Force team on January 14. The Civil Service team won by 11 goals to 8.

WEATHER OF JANUARY 1952

Mean pressure was abnormally low off the west coast of Norway, falling below 1000 mb. and as low as 994 mb. in places. Over Scandinavia generally mean pressure was 5–10 mb. below normal. Low mean pressure extended also over Europe and the Mediterranean; it was 1005 mb. in Denmark, nearly 10 mb. below normal, increasing to 1015 mb. in the Mediterranean, about 2 or 3 mb. below normal. Mean pressure in the North Atlantic was high, with the Azores anticyclone well established. Mean pressure was about 1008 mb. in latitude 55°N., 5 mb. above normal, and increased to 1030 mb. in the Azores, which was about 10 mb. above normal.

Mean temperature was 15–30°F. in Scandinavia, 30–40°F. in Europe and 50°F. in the Mediterranean. Departures from normal were generally small, being slightly above normal in Europe and below in the Mediterranean.

In the British Isles the weather was mainly sunny for the time of year with a very cold spell during the latter half of the month. Snow or sleet fell frequently and lay in some places in the west and north from the 16th or 17th onwards. A widespread gale occurred on the 15th, the wind reaching hurricane force in the Orkneys.

In the opening days a complex depression was situated over Scandinavia, while a secondary disturbance crossed the British Isles; rather cold W.–N. winds prevailed with wintry showers and long bright periods in the south and east on the 1st and 2nd and sunny spells over a wider area on the 3rd. On the 4th a trough of low pressure crossed the country giving precipitation generally, mainly in the form of rain. From the 4th to the 6th a very deep depression moved from mid Atlantic to the north-east of Greenland and a milder south-westerly air stream prevailed over the British Isles, with rain in the west and north and fog and slight drizzle in the south. Meanwhile pressure became high in a belt from the Azores across France to Germany. On the 8th a deep depression over Iceland moved east and turned north-east, while an associated trough moved east over the British Isles causing general rain, but conditions continued mild. Colder westerly winds brought a fall in temperature on the 9th, with wintry showers, the snow being heavy locally in the north of Scotland; snow lay to a depth of 1 ft. at Dalwhinnie on the 10th. These colder conditions persisted in the north but a trough of low pressure, moving south-east across the southern half of the country, was associated with a temporary rise in temperature in this area, the 10th being the mildest day of the month in parts of England. Rainfall was heavy in some areas on the 9th and 10th (2·14 in. at Gam, Montgomeryshire, on the 10th). During the next few days rather cold, northerly winds prevailed, with showers and bright periods but on the 14th–15th a deep depression moved east-north-east along our northern seaboard and associated troughs moved south-east across the country. Temperature rose and widespread strong winds and gales occurred, the gale being very severe in the north of Scotland; hurricane force was reached in the Orkneys causing immense damage. Subsequently a depression moved from west of Iceland to Germany. Cold northerly or north-westerly winds prevailed, reaching gale force on the 17th and 18th; widespread snow occurred on the 17th and 18th. Thereafter a belt of high pressure lay across the British Isles joining anticyclones over Scandinavia and the Azores. Cold dry weather prevailed in most parts from the 19th to the 21st, with long sunny periods on the 19th and 20th. On the 22nd and 23rd a small disturbance moved from the Hebrides across Ireland to the Bay of Biscay. Temperature continued low and the weather was dull, with some precipitation. Subsequently pressure was low eastward of the British Isles and high to the westward and a spell of very cold weather ensued with widespread sleet or snow, though the snow cover was thin over a wide area in the south-east. Air temperature fell to 6°F. at Silloth and 2°F. at Shawbury on the 27th. On the 28th a trough of low pressure moved rather quickly north-east over the country and was followed by a ridge; more snow occurred on the 28th and temperature fell to 2°F. at Glentress that morning. In the closing days a deep trough moved east giving further precipitation. Snow lay locally on high ground in the west and north from the 16th or 17th until the end of the month; at Bwlchgwyn (1,267 ft.) in Denbighshire, for example, level snow lay 10 in. deep on the morning of the 27th and increased to 14 in. on the 31st, with drifts up to 4 ft. on the 27th. At Eskdalemuir air temperature remained continuously below 32°F. from the 22nd to the 28th inclusive.

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	2	−2·2	113	+2	144
Scotland	55	2	−4·8	110	0	134
Northern Ireland ...	53	18	−4·1	147	+5	102

RAINFALL OF JANUARY 1952

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·64	88	*Glam.*	Cardiff, Penylan ...	3·26	88
Kent	Folkestone, Cherry Gdn.	3·22	143	*Pemb.*	Tenby	4·29	114
”	Edenbridge, Falconhurst	2·88	118	*Mer.*	Aberdovey	3·78	97
Sussex	Compton, Compton Ho.	3·09	97	*Radnor*	Tyrmynydd	9·16	145
”	Worthing, Beach Ho. Pk.	2·70	116	*Mont.*	Lake Vyrnwy	9·65	167
Hants.	Ventnor Cemetery ...	2·90	111	*Mer.*	Blaenau Festiniog ...	12·37	121
”	Bournemouth	2·00	74	*Carn.*	Llandudno	3·40	141
”	Sherborne St. John ...	2·40	103	*Angl.*	Llanerchymedd ...	4·39	139
Herts.	Royston, Therfield Rec.	1·44	83	*I. Man*	Douglas, Borough Cem.	3·80	113
Bucks.	Slough, Upton	1·80	97	*Wigtown*	Newton Stewart ...	4·49	109
Oxford	Oxford, Radcliffe ...	1·82	101	*Dumf.*	Dumfries, Crichton R.I.	3·90	121
N'hants.	Wellingboro' Swanspool	1·52	82	”	Eskdalemuir Obsy. ...	7·61	141
Essex	Shoeburyness	1·48	110	*Roxb.*	Kelso, Floors	2·00	114
”	Dovercourt	2·48	155	*Peebles*	Stobo Castle	4·56	152
Suffolk	Lowestoft Sec. School ...	2·52	151	*Berwick*	Marchmont House ...	1·86	83
”	Bury St. Ed., Westley H.	2·47	138	*E. Loth.*	North Berwick Res. ...	0·88	51
Norfolk	Sandringham Ho. Gdns.	2·57	132	*Midl'n.*	Edinburgh, Blackf'd. H.	2·45	139
Wilts.	Aldbourne	2·68	116	*Lanark*	Hamilton W. W., T'nhill	3·60	109
Dorset	Creech Grange... ...	2·75	84	*Ayr*	Colmonell, Knockdolian	5·04	116
”	Beaminster, East St. ...	3·34	96	”	Glen Afton, Ayr San. ...	8·08	158
Devon	Teignmouth, Den Gdns.	3·11	107	*Renfrew.*	Greenock, Prospect Hill	7·75	120
”	Cullompton	4·19	129	*Bute*	Rothesay, Ardencraig ...	5·66	126
”	Ilfracombe	4·58	139	*Argyll*	Morven (Drimnin) ...	6·02	95
”	Okehampton Uplands...	7·51	147	”	Poltalloch	7·60	150
Cornwall	Bude, School House ...	3·40	112	”	Inveraray Castle ...	8·83	107
”	Penzance, Morrab Gdns.	6·10	161	”	Islay, Eallabus	...	...
”	St. Austell	5·46	128	”	Tiree	5·27	124
”	Scilly, Tresco Abbey ...	3·64	116	*Kinross*	Loch Leven Sluice ...	3·00	95
Glos.	Cirencester	2·21	88	*Fife*	Leuchars Airfield ...	0·94	52
Salop	Church Stretton ...	3·47	133	*Perth*	Loch Dhu	...	...
”	Shrewsbury	2·43	125	”	Crieff, Strathearn Hyd.	2·75	68
Worcs.	Malvern, Free Library...	2·22	100	”	Pitlochry, Fincastle ...	3·35	96
Warwick	Birmingham, Edgbaston	2·72	135	*Angus*	Montrose, Sunnyside ...	1·34	67
Leics.	Thornton Reservoir ...	1·93	97	*Aberd.*	Braemar	2·73	86
Lincs.	Boston, Skirbeck ...	1·52	94	”	Dyce, Craibstone ...	2·66	113
”	Skegness, Marine Gdns.	1·57	91	”	New Deer School House	3·67	158
Notts.	Mansfield, Carr Bank ...	1·80	84	*Moray*	Gordon Castle	2·93	145
Derby	Buxton, Terrace Slopes	6·61	148	*Nairn*	Nairn, Achareidh ...	1·73	96
Ches.	Bidston Observatory ...	2·64	125	*Inverness*	Loch Ness, Garthbeg ...	4·67	106
Lancs.	Manchester, Whit. Park	3·29	131	”	Glenquoich	11·54	84
”	Stonyhurst College ...	5·43	127	”	Fort William, Teviot ...	7·79	80
”	Squires Gate	2·82	108	”	Skye, Duntuilm ...	5·63	106
Yorks.	Wakefield, Clarence Pk.	1·92	100	”	Skye, Broadford ...	7·54	100
”	Hull, Pearson Park ...	1·53	85	*R. & C.*	Tain, Tarlogie House ...	2·17	89
”	Felixkirk, Mt. St. John...	1·73	87	”	Inverbroom, Glackour...	9·77	182
”	York Museum	1·58	89	”	Achnashellach	8·67	95
”	Scarborough	2·72	136	*Suth.*	Loch More, Achfary ...	7·54	104
”	Middlesbrough... ...	1·62	101	*Caith.*	Wick Airfield	3·67	149
”	Baldersdale, Hury Res.	3·14	97	*Shetland*	Lerwick Observatory ...	4·64	109
Norl'd.	Newcastle, Leazes Pk....	1·54	78	*Ferm.*	Crom Castle	4·35	131
”	Bellingham, High Green	3·20	112	*Armagh*	Armagh Observatory ...	4·60	183
”	Lilburn Tower Gdns. ...	2·59	125	*Down*	Seaforde	3·44	109
Cumb.	Geltsdale	3·77	135	*Antrim*	Aldergrove Airfield ...	3·10	113
”	Keswick, High Hill ...	5·79	115	”	Ballymena, Harryville...	4·89	132
”	Ravenglass, The Grove	2·94	88	*L'derry*	Garvagh, Moneydig ...	6·57	191
Mon.	Abergavenny, Larchfield	3·67	109	”	Londonderry, Creggan	6·10	169
Glam.	Ystalyfera, Wern House	8·48	134	*Tyrone*	Omagh, Edenfel ...	5·37	152

M.O. 559 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

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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.

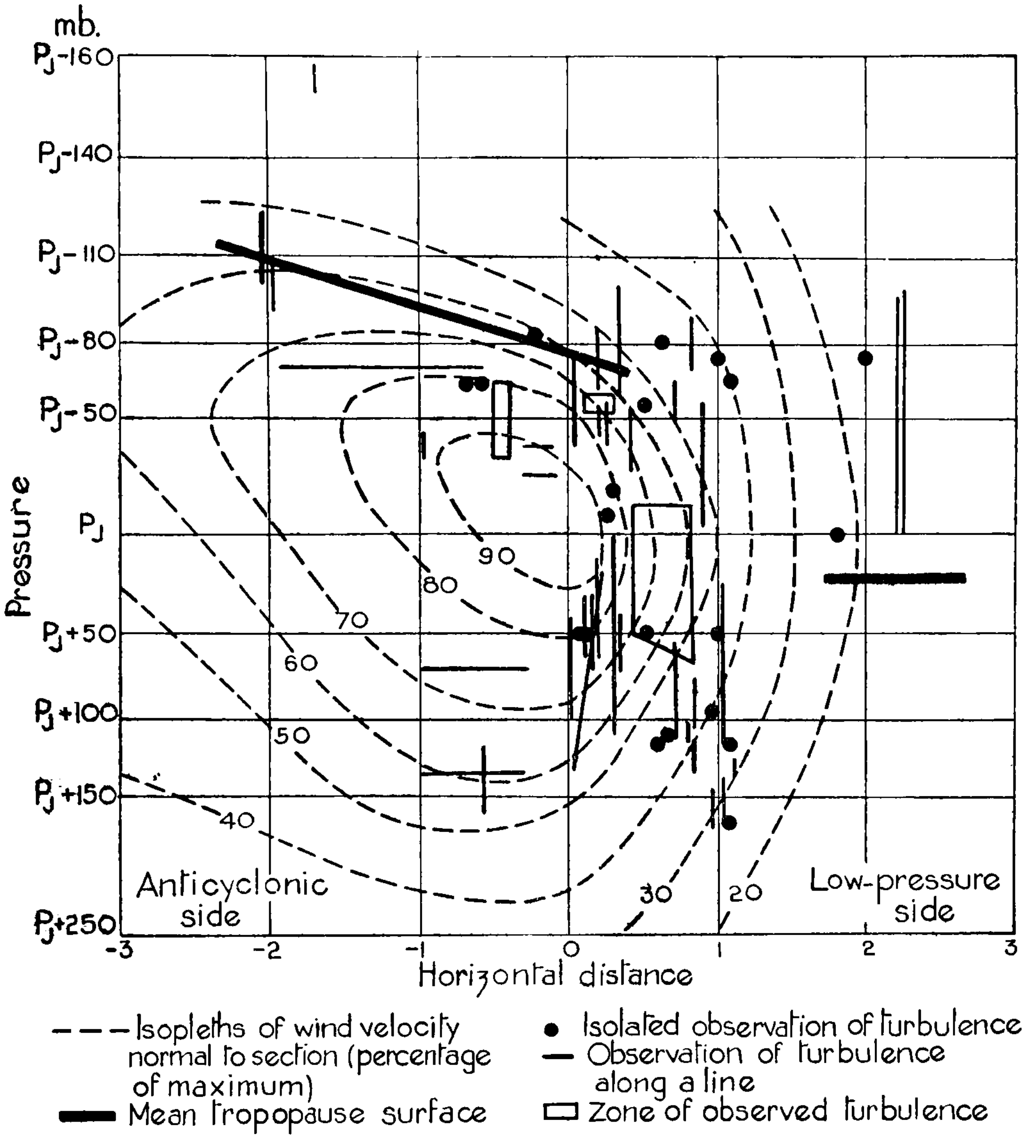

FIG. I—POSITIONS OF OCCURRENCES OF SEVERE TURBULENCE RELATIVE TO A JET-STREAM AXIS

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.

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

	Difference in dry-bulb temperature						Difference in relative humidity at 0900			Ratios of vapour pressures at 0900			
	$T_1 - T_2$			$T_2 - T_3$									
	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.)

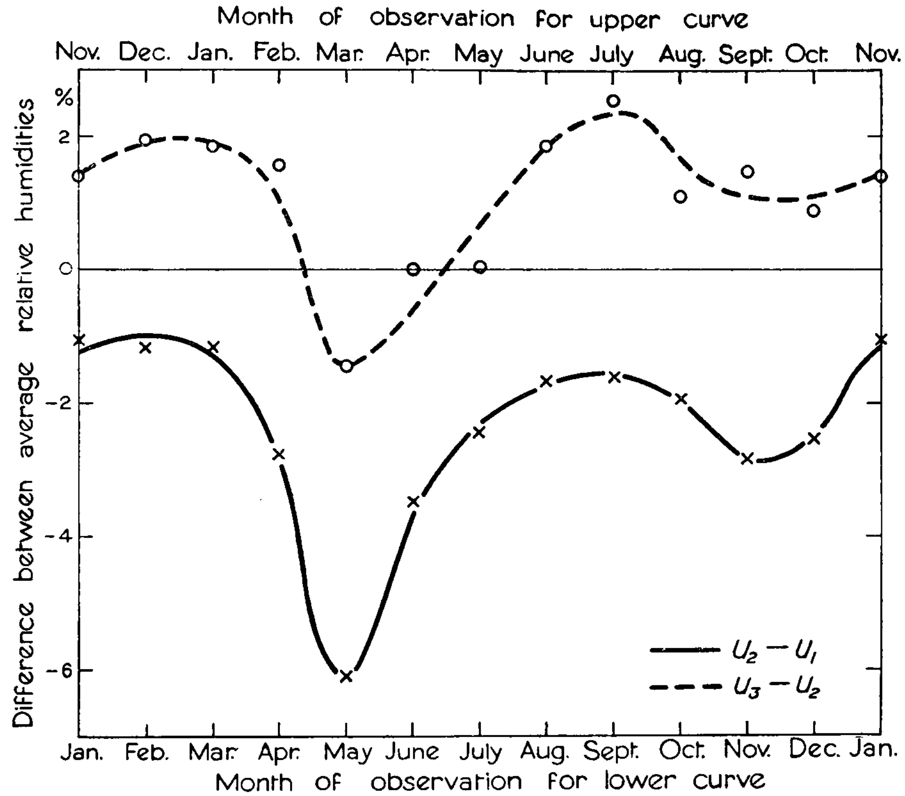
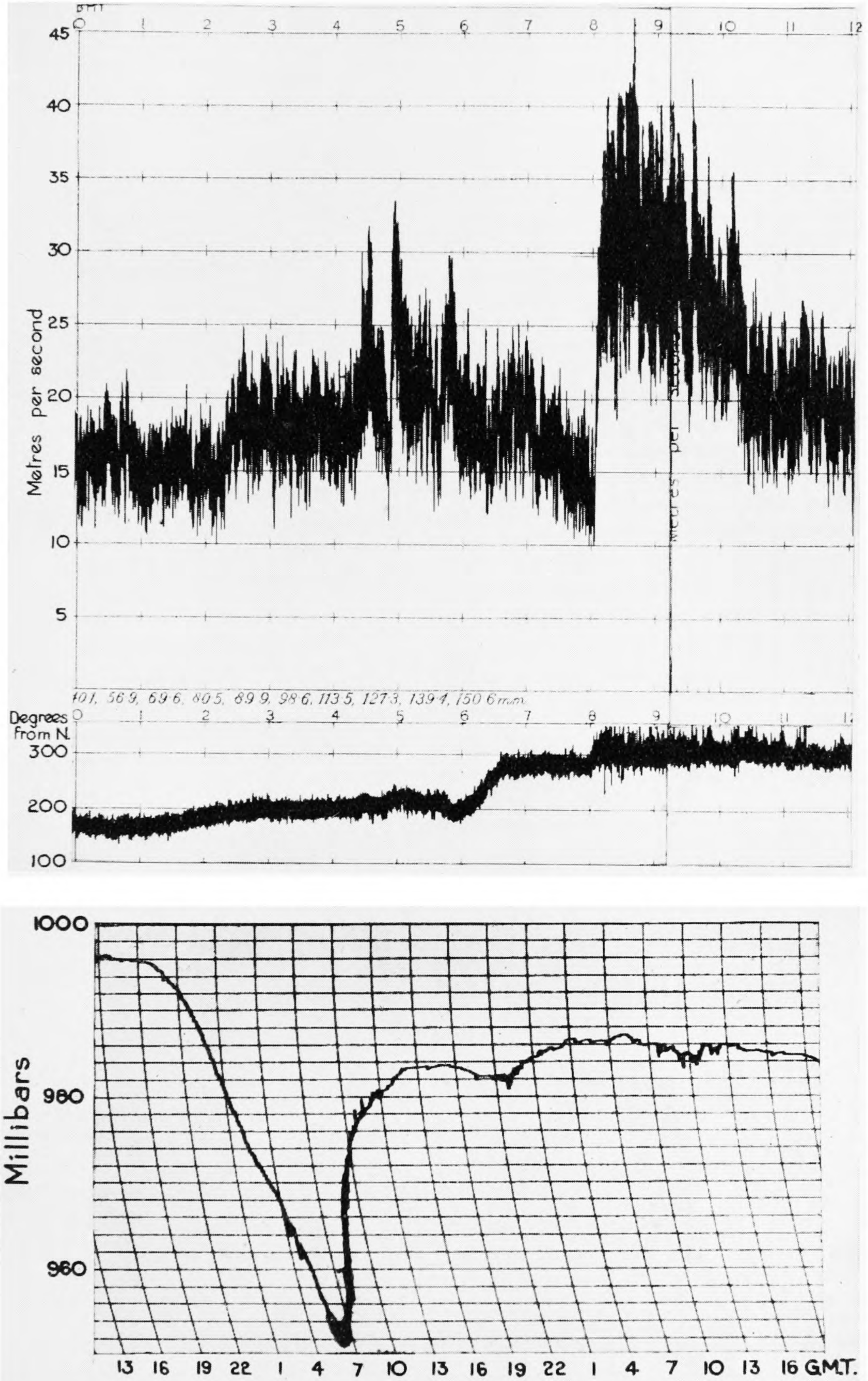


FIG. 1—ANNUAL VARIATION OF HILL-SIDE HUMIDITY DIFFERENCES (see p. 102).

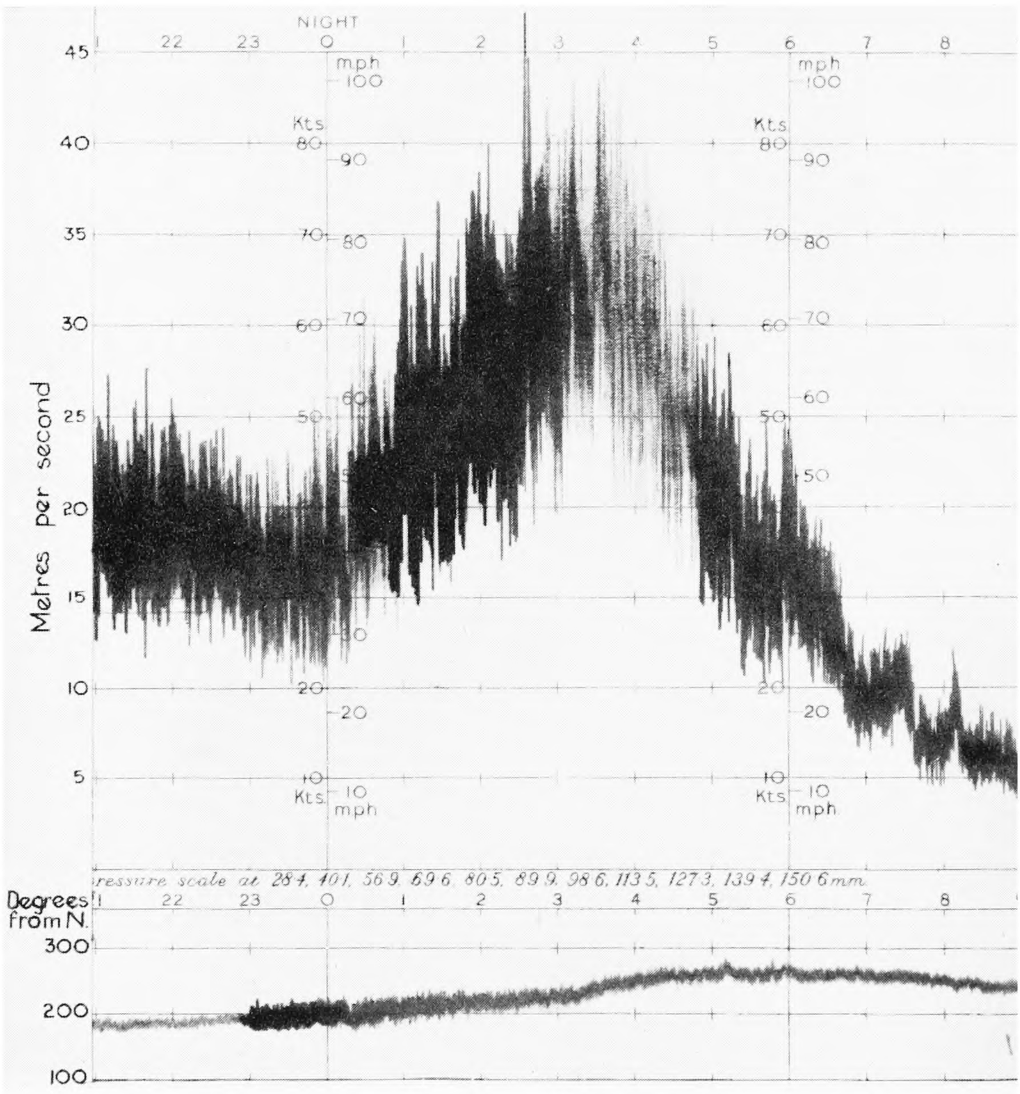
SYNOPTIC ASPECTS OF THE STORM OVER NORTH SCOTLAND ON JANUARY 15, 1952

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

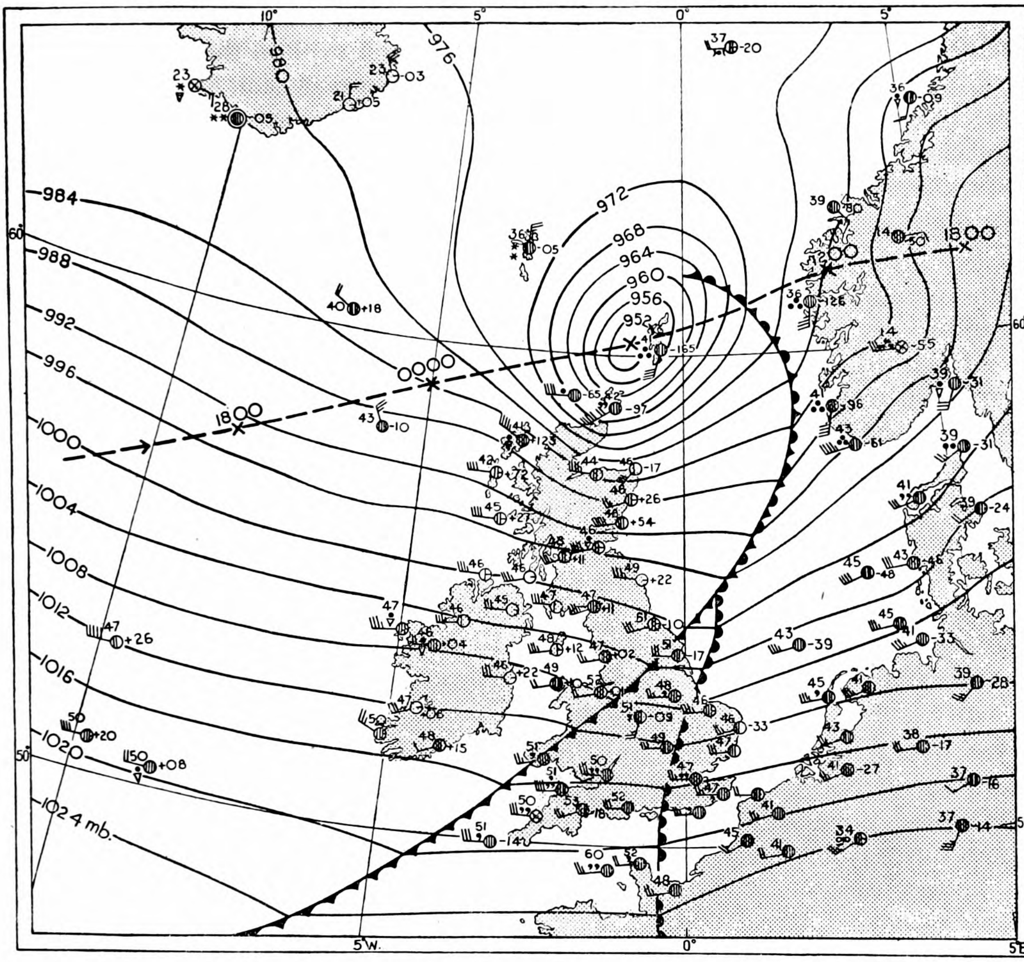


ANEMOGRAM FROM STORNOWAY SHOWING THE PASSAGE OF THE HURRICANE OF JANUARY 15, 1952

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.

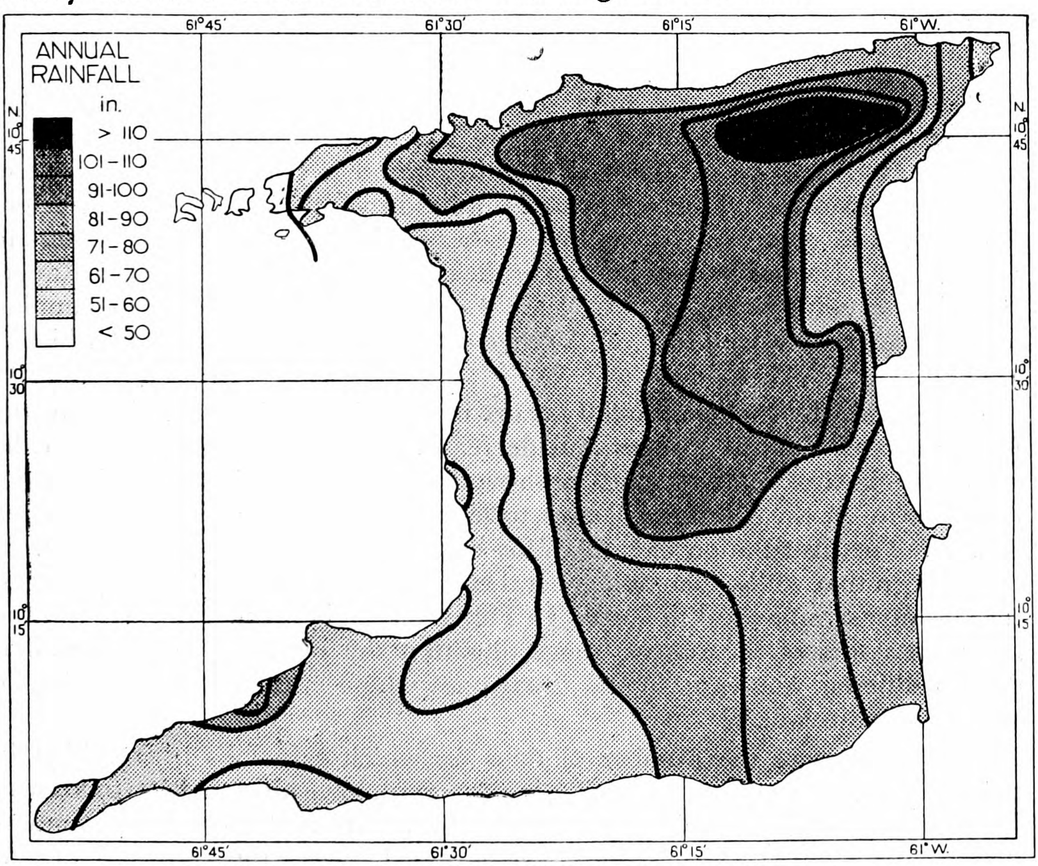


FIG. 1—ANNUAL RAINFALL DISTRIBUTION OVER TRINIDAD

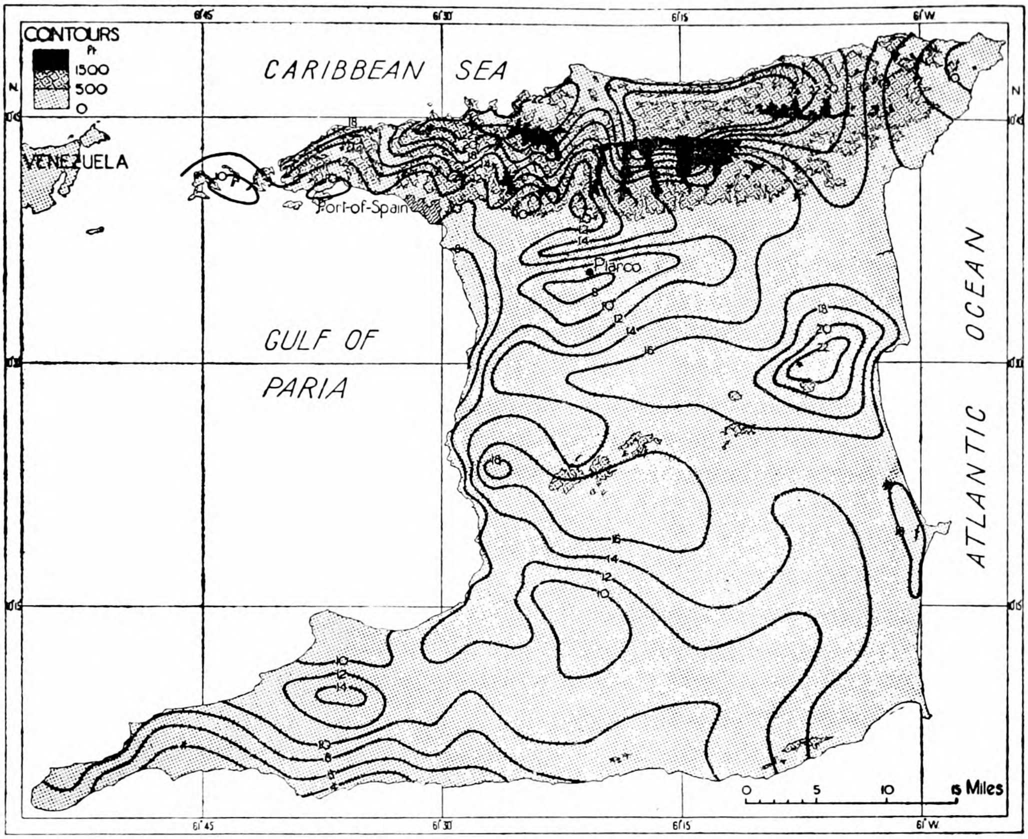


FIG. 2—RAINFALL DISTRIBUTION OVER TRINIDAD IN FEBRUARY 1951
The isohyets are in inches

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

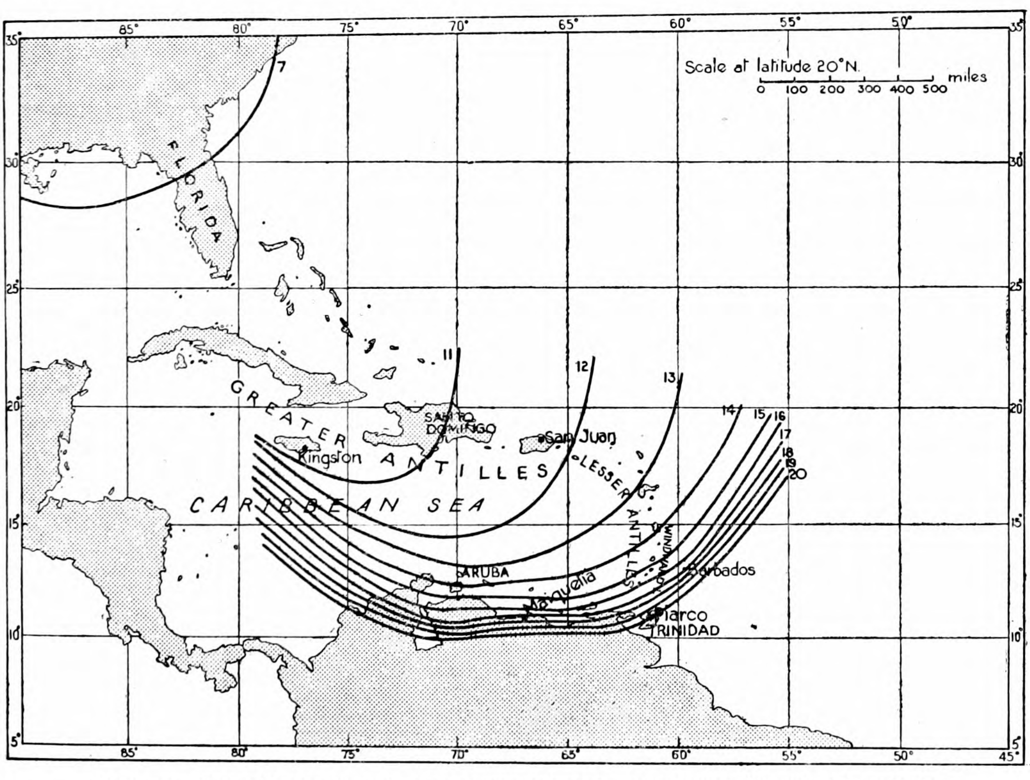


FIG. 3—ISOCHRONES OF THE COLD FRONT, FEBRUARY 11–20, 1951

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

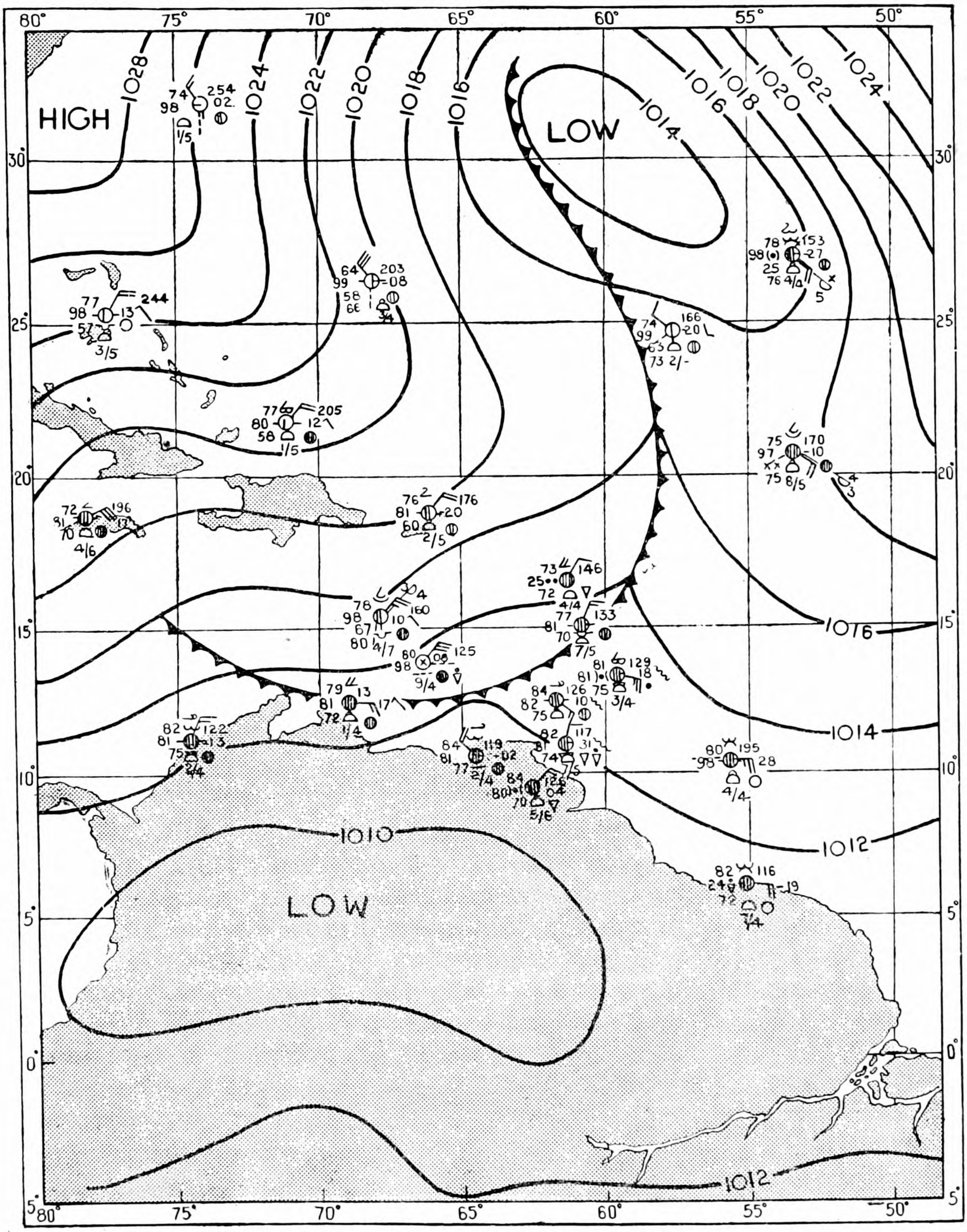


FIG. 4—SYNOPTIC WEATHER MAP, 1800 G.M.T., FEBRUARY 14, 1951

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

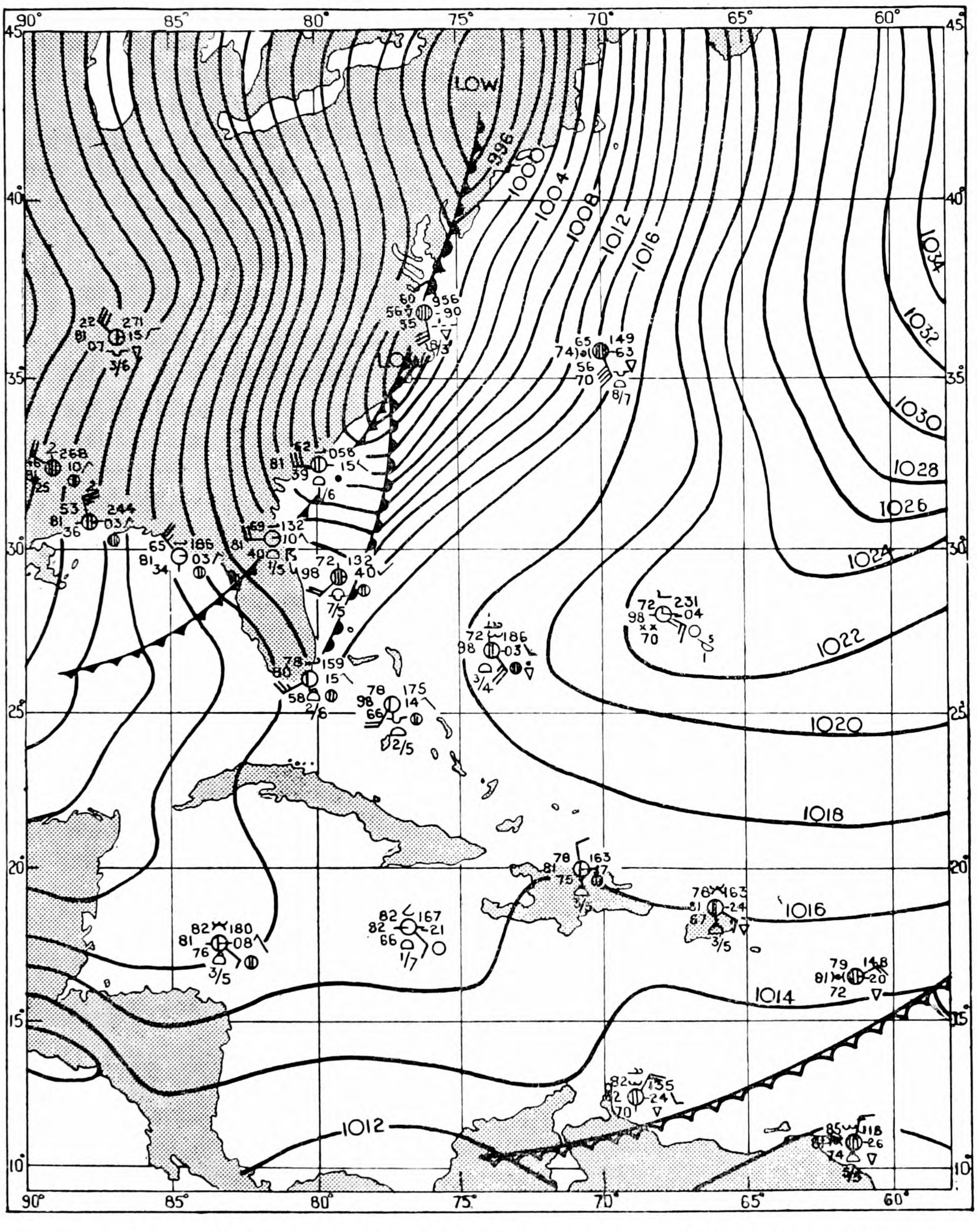


FIG. 5—SYNOPTIC WEATHER MAP, 1800 G.M.T., FEBRUARY 7, 1951

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",

for "+18 +08 +09" *read* "+1·8 +0·8 +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

Reproduced by courtesy of W. C. Glander

SNOW DRIFTS AT WICK AIRPORT, JANUARY 10, 1952

Reproduced by courtesy of W. C. Glander

SNOW DRIFTS AT WICK AIRPORT, JANUARY 28, 1952

Reproduced by courtesy of K. E. Woodley

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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:—

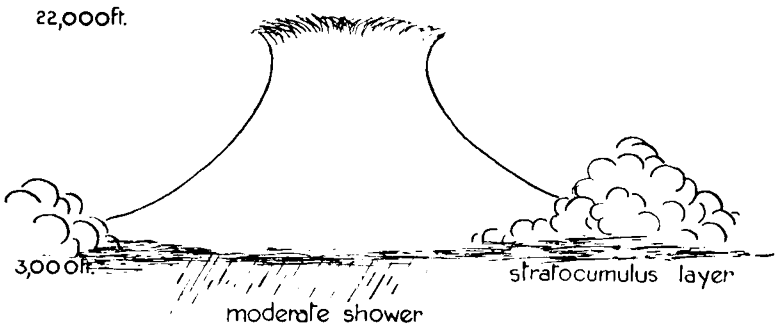
(i) From the co-pilot's seat, the flash appeared to be between himself and the pilot, near the instrument panel and the aircraft controls, and appeared as a white floating ball of fire. Its disappearance and the bang were simultaneous.

(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 0·2g to 0·3g; 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

M.O. 559 AIR MINISTRY

METEOROLOGICAL OFFICE

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TRAINING IN THE METEOROLOGICAL OFFICE

By P. J. MEADE, B.Sc.

Training has always formed a lively subject for controversy. While some regard it as an essential preparation for efficient work, others believe that systematic training merely postpones the day when the individual can begin to learn his job properly in the exacting school of experience. Sympathy can be felt with the latter point of view, and indeed there are many qualities of a good workman which can only be acquired in the responsible performance of his duty—by becoming operational as it were—and which formal training can make little attempt to provide. As far as the Meteorological Office is concerned, however, the question hardly arises. In nearly all the educational institutions of Great Britain meteorology is either excluded or an intruder. Most of the staff on joining the Office are therefore confronted with meteorology as a separate subject for the first time, and it is thus imperative to provide courses of instruction for them.

Although it is regrettable that meteorology is not more widely taught at schools and colleges, it must be conceded that the subject would be an awkward one to fit into the general curriculum. The trouble is that a number of other subjects have to be mastered first. Meteorology is the science of the atmosphere, and the task of the meteorologist is to observe and describe as accurately as possible the many different phenomena that occur. He therefore applies the methods of physics and mathematics to account for the various elements which in their aggregate constitute the weather, and he also uses the summaries and speculations of geography to supply a background of average conditions. The student, therefore, who wishes to understand even the elementary processes of the atmosphere will find himself severely handicapped if he has neglected physics, mathematics and, perhaps in a less degree, geography. The importance of these subjects as a stepping stone to the study of the atmosphere illustrates the practical difficulty in schools of devoting more attention to meteorology. It could hardly be expected that progress in fundamental studies should be arrested so that the large amount of time necessary could be spent on their application to the weather.

The preceding remarks have been made in the full knowledge that for some years past some elementary meteorology has been included in practically every geography syllabus. This development, though welcome in many respects, gives rise to a tendency for meteorology to be treated from the wrong angle. The analysis of past weather from the climatological standpoint—average rainfall, the world distribution of temperature from season to season, the identification of prevailing winds—falls conveniently within the scope of geography, but it is to physics and mathematics that we must look for the explanation of how these elements occur or how they vary—the formation of rain, changes in temperature caused by the ascent or descent of air, why the wind blows and so on. In case this statement may appear to magnify the difficulties of meteorology, it should be stated at once that, although there is still a lot to be learnt about every atmospheric process, much of what goes on may be described in a general way in quite straightforward terms. But the explanation will be a physical one, and, however simple, not readily grasped by those with no knowledge of physics.

To many this insistence on the importance of the application of physics and mathematics to meteorology may seem rather unnecessary, but it is not made without good reason. A number of young people while still at school become fired with an intense interest in meteorology and assume that if they concentrate on geography they will be taking the best possible steps to fit themselves for careers as meteorologists. Since meteorology has appeared only in their geography lessons, the assumption is a reasonable one. Some of these enthusiasts, however, proceed to neglect mathematics and physics if not to give them up altogether. Eventually they discover that their preparations for a meteorological career have been ill planned, and that much time has been wasted at a period of their lives when the study of physics and mathematics might have presented least difficulty.

Historical.—Systematic centralized training did not begin in the Meteorological Office until late in 1935. Before that time the Office was comparatively small, and new staff were engaged at irregular intervals as and when vacancies arose. These recruits were posted immediately to the offices where they were required to serve, and there they were regarded as under training until, after a few months as a general rule, they were declared to be efficient in their grade by their Officers-in-Charge. This type of training, although apparently of an *ad hoc* nature, had a number of advantages. The new member of staff received personal tuition over a lengthy period from an officer of many years' experience of the work; the latter had a vested interest in the successful outcome of the training because the future efficiency of his own office was involved.

Towards the end of 1935 the rate of recruitment to the Meteorological Office increased suddenly, and a number of Technical Officers were appointed within a short space of time. It is interesting to recall that this increase in strength was made necessary not by military expansion but by the ripening of plans for the development of civil air routes overseas. The Short "C" class flying boats, forerunners of the R.A.F. Sunderlands, were under construction and were to be used for speeding-up the Empire Air Mail Service and for transatlantic flights. The latter were to be experimental at first because in those days the idea of regular commercial flights across the Atlantic Ocean was little more than an act of faith.

The weather was naturally one of the most important factors to be taken into account, and, as a preliminary to the flights, the Meteorological Office undertook an intensive examination of the weather that might be encountered from season to season over the 2,000-mile flight from Foynes to Newfoundland. Accordingly a special section in the Overseas Division of the Meteorological

Office was formed at Croydon airport with a Senior Technical Officer, Mr. S. P. Peters, in charge. The new batch of Technical Officers was posted to the section, and Mr. Peters was given the dual responsibility of training them as forecasters and then of carrying out, with their assistance, the Atlantic investigations.

While this work was proceeding the level of recruitment rose once again, this time because the meteorological requirements of the R.A.F. were beginning to increase as the effects of the expansion programme were seen in the opening of new airfields. There was then every indication that for some time to come more and more staff would be needed by the Office. It was therefore decided to centralize the training of forecasters as much as possible. The special section of the Overseas Division formed the obvious foundation for such a project, and, until its transfer to Foynes in the summer of 1937, it received and trained all newly appointed Technical Officers. The move did not, however, disturb the continuity of training. As an additional measure to the appointment of staff from outside, steps had been taken within the Office to increase the number of forecasters available, and suitable Technical Assistants with long experience had been selected to attend a forecast course. A new training element, working in close association with the Overseas Division, was formed at Croydon, and it was able, when the necessity arose, to take over the responsibility for all forecasting courses including those for Technical Officers.

A further aspect of training had to be considered in 1939 when the formation of a Meteorological Branch of the R.A.F.V.R. was sanctioned, and the recruiting of officers and airmen began. It was originally intended that the volunteers should be trained by means of evening classes arranged at various centres throughout the United Kingdom, but the war started before these proposals could be carried out, and the problem then became one of providing full-time instruction for officers and airmen who had been mobilized.

The airmen were required for assistants' duties, and they were posted in small parties to Royal Air Force stations where the local meteorological offices could provide the training.

For the officers more elaborate arrangements were necessary, and a school was opened for them at Berkeley Square House, London. Professor (now Sir David) Brunt was released temporarily by the Imperial College of Science to take charge of the training programme, and about 40 officers who were awaiting courses were posted to the new school. At the same time the training classes for civilian forecasters were moved into Berkeley Square House, and so Professor Brunt became responsible for the training of all forecasters, service and civilian, for the Meteorological Office. These arrangements came into existence on September 15, 1939. The date is an important one for the record because it marks the official opening of the Meteorological Office Training School. Thus, although training courses had been quite a normal activity of the Office for the preceding four years, the organization under which they flourished had never been given a separate title.

With the formal setting up of a training school on a more or less permanent basis, the advantage of centralizing the instruction of assistants as well as forecasters was soon appreciated, and classes for synoptic assistants, airmen and civilians, were arranged.

Recruitment to the Meteorological Office was stopped for a few months in the summer of 1940, and the Training School accommodation at Berkeley Square House was released for other purposes. Towards the end of the year it became necessary to resume training and the School was re-opened at Barnwood, Gloucester, Mr. C. J. Boyden, a Senior Technical Officer being appointed Chief Instructor. After about a year it was found more convenient to hold the assistants' classes which then contained civilians, airmen and airwomen, in the London area. The School was therefore divided, the forecast classes remaining at Gloucester, but, in August 1943, accommodation difficulties also forced their removal to London and the two sections were reunited at Kilburn. Since then the Training School has had several moves within the London area, the final one taking place on August 22, 1951, when it was moved to Stanmore, its permanent location.

At Stanmore the School is accommodated in a plain, single-storey building. Apart from the usual classrooms and administrative offices, an instrument display room and a cinema are provided and there is also a suitable exposure for the Stevenson screens and other outdoor equipment. The surroundings are quite pleasant, and from the technical point of view Stanmore is a very suitable place for a meteorological training school compared with, for example, central London with its smoke-laden atmosphere. The photographs between pp. 144 and 145 show the type of classroom provided, the instrument enclosure and the space available for pilot-balloon work.

Present training organization.—In 1948 when the general reorganization of the Meteorological Office took place the training of staff became the responsibility of a separate branch which was created for the purpose. This Branch is responsible not only for imparting the knowledge and skill which staff need to carry out their meteorological duties but also for supervising external training, that is studies taken outside the Office in order to improve scientific qualifications. External studies are important because they enable staff to keep abreast of modern developments in meteorology and also help to fit them for more responsible work. Concessions are made to staff taking approved courses externally.

Before a description is given of the various types of course provided at the Training School, it might be useful to refer to the principles on which the recruitment of staff are based. Owing to the nature of its work the Meteorological Office forms a part of the Scientific Civil Service and its personnel consists almost entirely of scientific staff. These are divided into three classes—Scientific Assistants, Experimental Officers and Scientific Officers—and entry to a class is largely determined by the standard of qualification attained in physics and mathematics. Assistants must normally have reached the ordinary level of the General Certificate of Education in these subjects. Experimental Officers require at least Intermediate B.Sc. or its equivalent, and for Scientific Officers a good honours degree in either physics or mathematics is essential.

On joining the Meteorological Office the new member of the staff is first of all posted to a station for a week or two so that he may at first hand obtain a general impression of the work that has to be done. After this brief but useful introduction he is sent to the Training School and formal instruction begins.

Since the large majority of the staff of the Meteorological Office are employed in some way or other on synoptic meteorology, the basis of weather forecasting, this aspect of meteorology receives most attention during training. In the courses arranged for each class a primary objective is to do more than merely impart to each trainee the ability to carry out his duties in a routine manner. A fair proportion of the time in every course is therefore devoted to the theory of meteorology, and in this way staff acquire a good understanding of the scientific background to their work and an appreciation of its importance in relation to the general international arrangements for promoting the efficiency of meteorological services. While the amount of theory and the detail of its treatment in each type of course must naturally take account of the academic qualifications of the trainees, the scope of each course is made as wide as possible, and an underlying motive is to encourage further reading in meteorology so that each trainee will maintain a lively interest in the subject throughout his career.

Courses for Scientific-Assistant Class.—The courses provided for assistants at the Training School last for eight weeks. A revision of basic physics, especially heat and properties of matter, prepares the way for some meteorological theory, and the assistant is then introduced to ideas on air masses and fronts, the life histories of depressions and anticyclones, the meaning of Buys Ballot's Law and the formation of cloud and rain through the ascent of air. In addition to these lectures, instruction and practice are given in technical procedures in force at outstations such as the making of weather observations, both visually and with instruments, the use of meteorological codes and the plotting and drawing of synoptic charts.

The main syllabus of the course is completed in six weeks, and the final fortnight is spent on intensive practical work in which conditions at outstations are reproduced as closely as possible. By the end of his course the new assistant should have a good grasp of all his duties but naturally he would not have the facility, or speed, in carrying them out that is the hallmark of an experienced assistant. However, speed is acquired with long practice and at the Training School the main emphasis is upon accuracy and neatness. The importance of these two qualities is repeatedly stressed because the observations made by an assistant are transmitted far and wide and therefore must be absolutely reliable, and the charts which he plots are the first and perhaps the most vital steps in the preparation of forecasts.

When the course at the Training School ends the assistant is posted to a station, and there, working under the guidance of an expert colleague, he develops in proficiency and confidence until he is fully competent to fill a vacancy on the establishment. This period of further training varies in duration between one assistant and another, but on the average it last about 2 months and seldom exceeds 3 months.

After his initial training is completed the assistant has not finally severed his connexion with the Training School. It is intended that after several years spent on routine duties at stations, he should return to the School for a three-week refresher course during which he would be able to revise and extend his knowledge of the basic theory of meteorology. The first of these courses was held in February 1950, and six more have taken place since then; in fact, they are arranged whenever it is possible to obtain the release of assistants from their offices in sufficient numbers. The courses so far held have been most successful, and there is no doubt that they have served a useful purpose.

Courses for Experimental-Officer Class.—In the past four years new entrants to the Experimental-Officer Class have been drawn largely from assistants who, by means of further studies as well as general efficiency, have qualified for promotion. As such staff are already conversant with the fundamental duties of observing and plotting they go straight to a forecasting course which lasts for 12 weeks. Staff who are recruited externally to the Experimental-Officer Class and who have had no previous experience of meteorology, are first of all given three weeks' preliminary training, mainly on assistants' duties, before their forecasting course begins.

The syllabus of the course includes a study of the dynamics and thermodynamics of the atmosphere, including a detailed consideration of the tephigram, and of the application of radiation principles to special phenomena such as fogs and frosts. Lectures are also given on upper air analysis, general climatology and on the forecasting techniques used in tropical areas. Among other subjects treated are ice formation, thunderstorms and turbulence cloud.

The practical work of the forecasting course is based first of all on the analysis of simple situations, and the trainees then pass on to a study of selected sequences of past weather. These have been chosen for their instructive features, and are useful examples of weather situations frequently encountered. Each sequence contains from 4 to 7 consecutive charts which are printed with the basic data already plotted. Trainees are provided with the charts of a sequence one at a time, and they analyse and draw up each chart and forecast from it before receiving the following one. The main advantage of using sequences in this way is that they contribute to completeness, whereas a reliance on current weather throughout a course would entail the risk of experiencing too few interesting situations, and the slow trainee would find his answers by gazing out of the window as the actual weather overtook his pedestrian efforts.

Current weather is not scorned, however, and the final 3 weeks of a course are occupied with forecasting as nearly as possible in accordance with an office routine and, when practicable, in conjunction with a class of assistants. Groups of forecasters and assistants then become responsible for the operation of "stations" with a working programme which includes written forecasts, telephone and personal inquiries and routine observations.

On completing their course the forecasters go to offices where, for the following 3 months, their practical training is continued with the object of developing those qualities, such as briefing ability, which cannot be fully imparted at a training school.

The initial training of a forecaster is thus spread over six or seven months at the outset of his career. He then spends several years on routine forecasting duties working under the direction of senior and far more experienced forecasters. During this period he inevitably extends his practical knowledge of the weather and its ways, and this, combined with his understanding of the physical processes that take place in the atmosphere, helps him to become a reliable forecaster with the confidence that results from the scientific application of accumulated experience. At this stage he will be regarded as ready to return to the Training School for a course in preparation for more responsible forecasting duties.

Advanced forecasting courses for members of the Experimental-Officer Class were started in March 1949. Before that time the officers to be trained were sent to major forecasting offices where instruction and operational experience in higher duties were provided simultaneously. The scheme worked very well, but it was considered that greater benefit would accrue if the technical instruction were given by means of organized courses at the Training School to be followed immediately by practical training at a major forecasting office.

The syllabus of the advanced forecasting courses, which last for four weeks, is concerned mainly with the application of upper air data. A study is made of Sutcliffe's development patterns, of Rossby's theory of waves in a barotropic atmosphere, and lectures are also given on jet streams.

Courses for Scientific-Officer Class.—A scientific officer is regarded as under training during the first two years of his career, although during much of that period he is in fact doing useful and responsible work. Since high qualifications in mathematics or physics are an essential condition of entry to the Scientific-Officer Class, its members are recruited with the intention that they should undertake original research in order to extend existing knowledge in one or more branches of meteorology. Their training is therefore planned so that they may acquire a wide knowledge of the subject, and also a keenness to investigate some of the many problems that still remain to be solved.

The first part of the two-year training period is spent on a course at the Training School which lasts for 18 weeks. The annual intake of scientific officers is small—not more than 10—and, as they all join at about the same time shortly after they leave the University, only one course is required each year. This is concerned primarily with synoptic meteorology, the ground covered being similar to that for the initial and advanced courses for members of the Experimental-Officer Class except that the treatment is more theoretical, and original papers, such as those of Sutcliffe, Petterssen and Rossby, are discussed in detail.

Following this course at the Training School a scientific officer is given two main attachments for the balance of the two years, one to an important forecasting unit and the other to a meteorological centre which is not engaged in forecasting work. During the former attachment, besides gaining a great deal of practice in the technique of forecasting, he is also given time to read research papers and may take part in any investigations which are in progress. The second attachment, for which account is taken of the individual's special aptitudes, may be to an observatory or to Harrow where the Instrument Development and Climatology Divisions are situated, or to a centre established for a particular project such as the Meteorological Research Flight.

To supplement this training programme, short visits of a few days or a week are made to other centres whenever convenient. Thus, by the end of the two-year training period, the young scientific officer should have become well acquainted with the work of the Office as a whole, and will have acquired a good knowledge of forecasting and of at least one other branch of meteorology.

Miscellaneous courses.—At intervals during each year the normal routine of the Training School is pleasantly varied by the arrangement of a special course. About twice a year, normally in the late autumn or early spring, short courses lasting four days are provided for observers from climatological and crop weather stations. The former are maintained by private observers or by municipal and other local authorities, while the latter are situated at agricultural colleges and research institutions for the study of the relation between the weather and growing crops. These stations make valuable contributions to the weather records from which statistics and summaries are compiled for the benefit of the community generally. The courses are arranged in conjunction with the Climatology Division of the Meteorological Office, and the primary objects are to perfect the observers' technique in reporting the weather and in the maintenance of their equipment, and to give them an opportunity to raise questions of technical procedure with experienced instructors. Since they were first started in March 1950, six very stimulating courses have been held.

Another interesting course was held early in 1950 for instructors at nautical schools, whose duties include the teaching of meteorology to officers of the Merchant Navy studying for their Master's and Extra-Master's Certificates. This course was arranged at the request of the Ministry of Education, and it is probable that it will be repeated in a few years' time.

With the re-forming of the Meteorological Branch of the Royal Air Force Volunteer Reserve some special problems arose in connexion with the training of officers. Many of them had been forecasters during the war, and this experience, together with that obtained in post-war reserve training, had qualified them to receive training for higher duties. Short courses, on the lines of the advanced forecasting courses provided for officers of the Experimental Class, were therefore arranged and were given during the period of 15 days' continuous training for which reserve officers are liable. Two of these courses were held in 1951 and three more have been arranged for the summer of 1952.

Among others for whom courses are arranged whenever necessary are Merchant Navy Officers recruited to the Marine Branch of the Meteorological Office for duty at Headquarters, at port meteorological offices or on ocean weather ships.

Students from overseas.—Since the war a number of overseas meteorological services have asked for vacancies on forecasting courses at the Training School to be reserved for selected members of their staffs. Such requests have always been complied with, and in consequence there have been few forecasting courses in the past few years which have not included among their members at least one student from abroad. Within the Empire, Ceylon, Nigeria, Hongkong and the Sudan have sent locally recruited staff to England for training, and other countries that have been represented on forecast courses include Belgium, Greece, Iraq, Persia, Siam and Peru.

After their forecasting courses these visitors from overseas spend two or three months at offices adding to their practical experience, and some also continue their training by going to centres such as Eskdalemuir Observatory where they learn about terrestrial magnetism or to Hemsby where the operation of radio-sonde and radar wind equipment is taught.

Although not strictly under the present heading, it should be mentioned that the Colonial Office and the Crown Agents for the Colonies recruit a number of staff within the United Kingdom for duty in colonial meteorological services. Such staff are invariably sent to the Training School for a course before they go abroad.

External training.—In 1944 the Assheton Committee published its report on the training of civil servants. One of its recommendations was that Departments should encourage their staff to obtain external qualifications in subjects related to their official work. Accordingly shortly after the end of the war, the Treasury circulated a memorandum laying down the general principles on which the further studies of staff should be approved and specifying the material help that should be given.

The application of the scheme in the Meteorological Office is concerned with the study of physics, mathematics and geography, and staff are encouraged to study these subjects in order to obtain qualifications above the basic minimum required for entrance to their particular class. Thus the objective of Scientific Assistants would be Intermediate B.Sc., and members of the Experimental Officer Class who wished to participate in the arrangements would study for a full science degree. Facilities granted to those whose course of study is approved include the payment of fees and time-off with pay to attend classes and sit for examinations.

Since its inception the scheme has proved very popular among the staff of the Office and the numbers availing themselves of its provisions are usually in the neighbourhood of 200 or nearly 10 per cent. of the total. The scheme is also proving worth while in that a satisfactory number of examination successes have been gained and, a point of particular importance, assistants taking external studies have presented a fruitful field for recruitment to the Experimental-Officer Class.

ESTIMATION OF WEEKLY FROST RISK USING WEEKLY MINIMUM TEMPERATURES

By E. N. LAWRENCE, B.Sc.

Summary.—The following note describes a method of estimating the weekly frost risk in spring, and may be used for sites with only a short period of observations providing there is a meteorological station of long standing in the same climatic region.

It is necessary to find the average weekly mean daily minimum temperature of the site, and also either the average weekly absolute minimum temperature or the value of the "spread coefficient". The latter is a measure of the scatter of minima about the average minimum temperature and may be calculated from the two minima mentioned or estimated from an examination of the site characteristics. For flat country, it is possible to construct maps showing the lines of equal spread coefficients, which may be used to obtain the spread coefficients of any site within the area.

It is shown how the two minima mentioned may be obtained graphically from brief records of observations.

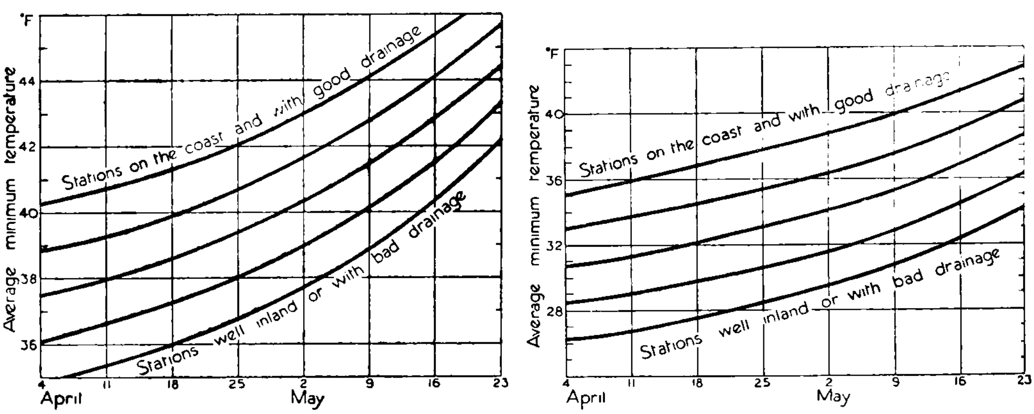
Finally, using the resulting values of the average weekly mean daily minimum temperature and the spread coefficient, the frequency of frosts for threshold temperatures 32°, 30° and 28°F. may be read from the graphs of Fig. 3.

Assumptions.—It has been found[1] that the curve of distribution of minimum temperature exhibits a negative skew in winter, and that of maximum temperature shows a positive skew in summer. For the spring months considered in this note, it is assumed that minimum temperature follows the normal distribution curve. Thus the frequency of minimum temperature below a given value depends on the average minimum temperature and a measure of the spread of minimum temperature about the average.

Generally, with normal distributions, spread is measured in terms of the standard deviation, which may be expressed as the quotient of the range and a range parameter[2]. The latter depends on the number of independent minima, and may be expected to be approximately constant for all stations within a limited area of similar climate. Hence the standard deviation is proportional to the range, which therefore also represents a comparable measure of the scatter. The spread is here conveniently calculated in the form of the average half range or spread coefficient (S), expressed as the difference between the weekly mean minimum temperature and the weekly absolute minimum temperature.

Stations on exposed coasts are greatly susceptible to the moderating influence of the sea and may be expected to show some tendency towards a negative skew distribution of minima. This phenomenon may be the cause of disagreement between observed and calculated values of the very low frost frequencies.

Method.—As an aid to the estimation of the weekly mean minimum temperature at a site for which long-term measurements are not available, graphs showing its mean rates of increase with time have been constructed [see Fig. 1 (*a*)]. The top curve is typical of a coastal station and the lowest curve corresponds to a station well inland. Curves for stations with good drainage lie towards the top of the chart and curves for sites with bad drainage tend to lie near the bottom.



(*a*) Weekly mean minimum (*b*) Weekly absolute minimum

FIG. 1—RATE OF INCREASE DURING APRIL AND MAY OF AVERAGE WEEKLY MINIMUM TEMPERATURE

When estimating the weekly mean minimum temperature, Fig. 1 (*a*) may be used as follows:—

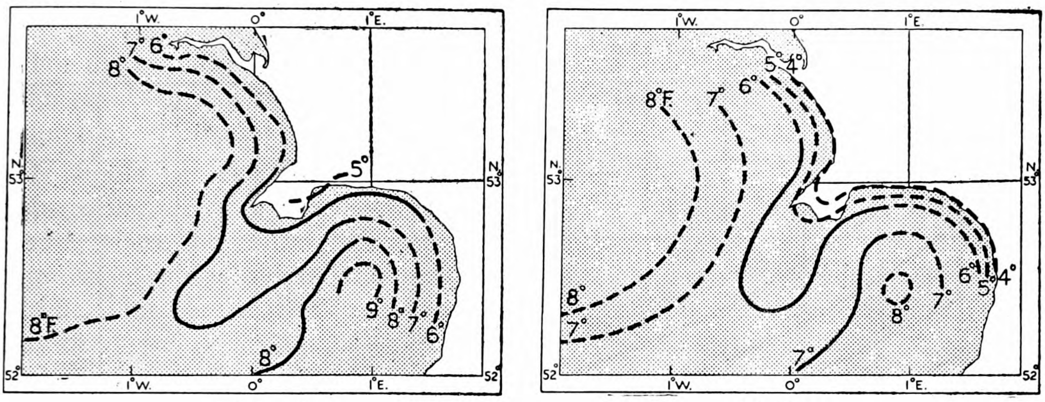
(i) Obtain a series of weekly mean minimum temperatures for a period of at least one spring.

(ii) Examine the observations for this period of the nearest meteorological site of long standing and calculate the differences of the latter from their long-term averages.

(iii) Correct the weekly mean minimum temperatures of (i) using the differences calculated in (ii), plot the results on Fig. 1 (*a*) and draw the curve which best fits these points and lies parallel to the adjacent curves. This curve gives the average minimum temperature of the site during April and May.

A further set of curves [Fig. 1(*b*)] has been constructed for weekly absolute minimum temperature and is similar to that of Fig. 1(*a*) regarding topography and use.

For flat country, a good estimate of the spread coefficient may be simply computed from a map based on the network of meteorological stations. Fig. 2 shows the lines of equal spread coefficients for the northern part of eastern England for April and May respectively. Unfortunately, the spread coefficients of sites in hilly country cannot be obtained by reference to a chart, because orographic features would make a chart over-complex. In order to calculate such spread coefficients, it is necessary to know or estimate (by the method above) the average weekly absolute minimum temperature in addition to the average weekly mean minimum temperature. The difference between these two values is the spread coefficient.



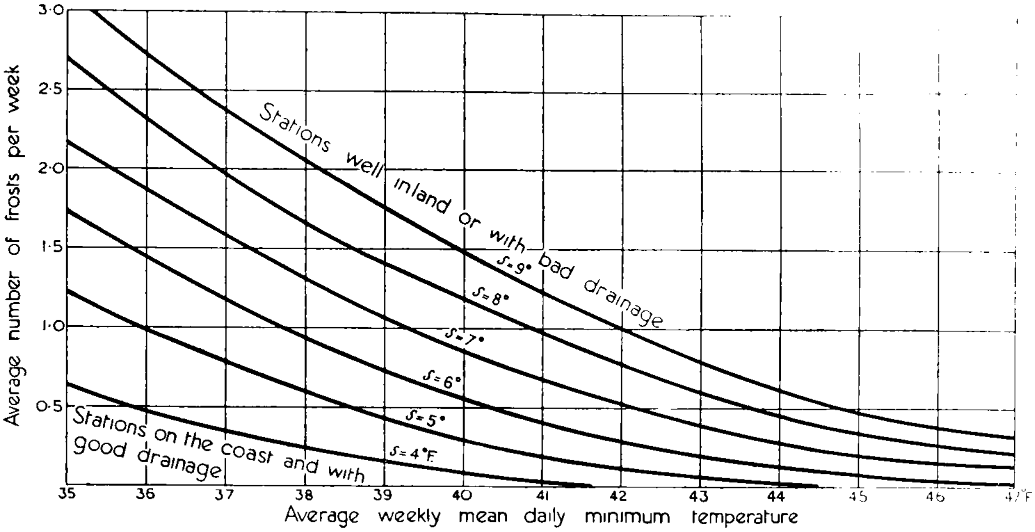
(*a*) April (*b*) May

FIG. 2—LINES OF EQUAL SPREAD COEFFICIENT OF MINIMUM TEMPERATURE

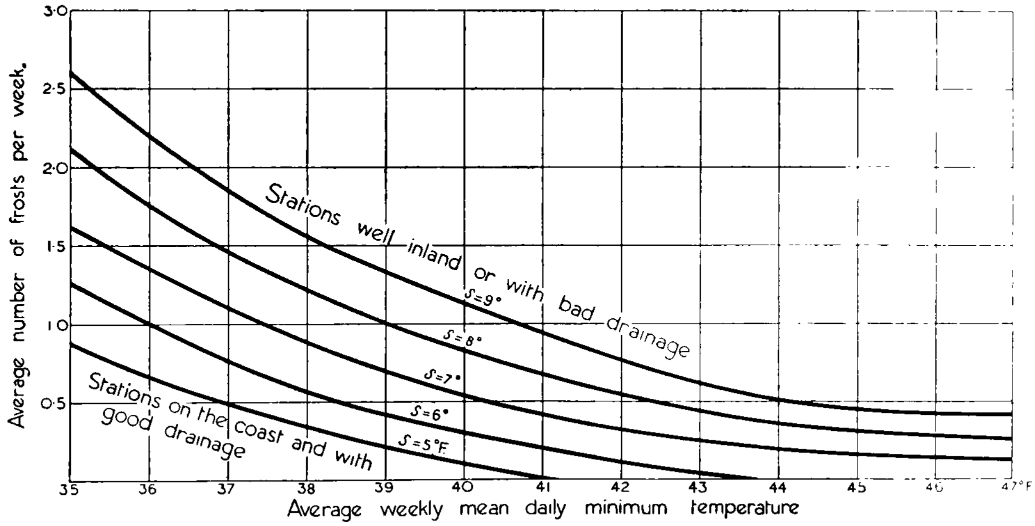
Having found the value of the average minimum temperature of any particular week during April or May, and the corresponding spread coefficient of a particular site, by reference to a chart or otherwise, the weekly frost risk may be read from the graph of Fig. 3(*a*). The closeness of fit of the spread-coefficient lines of Fig. 3(*a*) is acceptable statistically, and the agreement between observed and forecast frost frequencies is satisfactory for all stations with periods of observation exceeding fifteen years. Stations with shorter periods exhibit strong sampling errors. It should be emphasized that estimates of frost frequencies cannot be expected to agree with observed frequencies over periods of less than fifteen years.

So far this note has dealt with frequencies of frosts with temperature of 32°F. or below. Figs. 3(*b*) and 3(*c*) give forecast frequency graphs for threshold temperature of 30° and 28°F. respectively. In these cases to obtain reasonable agreement between the estimated frost risk and observed frequencies, it was found necessary to take a period of the order of at least 20 years. In all cases good agreement is not obtainable for frequencies of the order of one per month or less.

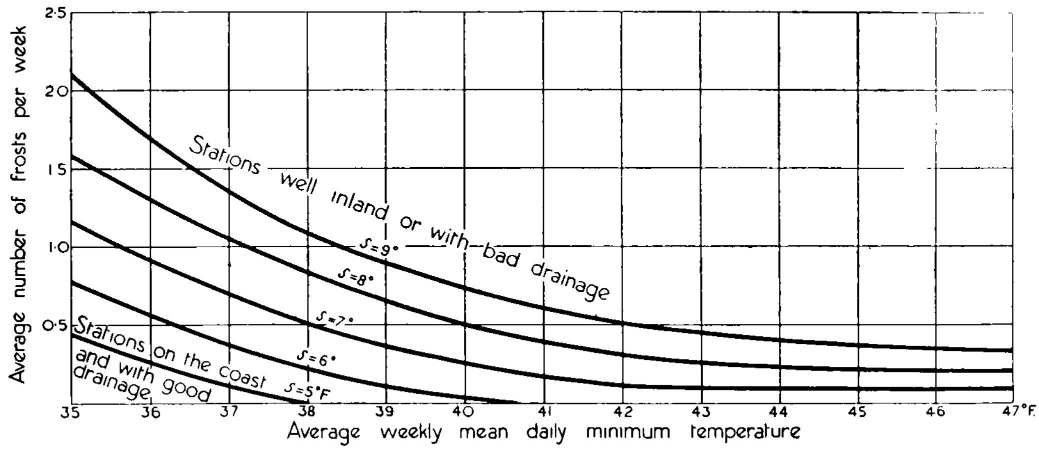
It may be seen from the graphs of frost frequencies (Fig. 3) that for high average minimum temperature (e.g. the Wash district in May) the weekly



(*a*) Threshold temperature 32°F.



(*b*) Threshold temperature 30°F.



(*c*) Threshold temperature 28°F.

FIG. 3—RELATION OF FREQUENCY OF TEMPERATURE AT OR BELOW VARIOUS THRESHOLD VALUES TO THE AVERAGE WEEKLY MEAN DAILY MINIMUM TEMPERATURE AND THE SPREAD COEFFICIENT (S)

frost frequency changes slowly with change of temperature, so that a very rough estimate of the average minimum temperature will give an approximation to the frequency, provided that the country is flat and that spread-coefficient charts are available for the area.

Distribution of spread coefficients in relation to topography and soil.—The value of the spread coefficients is usually about 5°F. in April and of the order 4–5°F. in May for coastal sites and stations with extremely good drainage of cold air, i.e. stations on steep slopes well above valley floors. Malvern, Worcestershire, is situated on a steep slope well inland and has an average value of 5·0°F. for the April–May period.

The value of the spread coefficient is about 8°F. in April and 7–8°F. in May for stations well inland (about 40–70 miles from the open sea), though stations less than about 40 miles inland with some impediment to free drainage of cold air may have high spread coefficients. Parkend, Gloucestershire, where woodlands impede the drainage, has values of 7·4° and 6·8°F. respectively.

For the remaining stations, i.e. those less than about 40 miles inland but not near coasts and without major orographical features, the spread-coefficient value is about 7° in April and about 6–7°F. in May.

It should be noted here that all these values for the spread coefficient are approximations and that they are influenced by soil type, as may be seen from Fig. 2, where the values appear to be lower along the belt of lias (clay), oolites (limestone) and alluvium which extends roughly from the Cotswolds to near the Wash. This means that frost frequencies tend to be lower for example over clay than over sandy soil, a fact borne out by a previous investigation[3].

Owing to paucity of data, the spread-coefficient lines of Fig. 2 were estimated in places (shown by broken lines) by extending the exhibited tendency of these lines to lie parallel to coasts and their less marked tendency to be parallel to certain soil boundaries.

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METEOROLOGICAL RESEARCH COMMITTEE

The 19th and 20th meetings of the Physical Sub-Committee of the Meteorological Research Committee were held on February 22 and 29, 1952, respectively.

The technical papers discussed at these two meetings included one by Mr. Durst and Mr. Gordon[1] on the distribution of humidity at sea. Miss Carruthers[2] presented a paper dealing with the use of probability paper in upper air climatology, the use of this type of graph being illustrated with data regarding tropopause heights. Upper air climatology was also considered in a paper by Mr. Frost[3] entitled "The upper air circulation in low latitudes and its relation to certain climatological discontinuities".

The influence of the size of condensation nuclei on the development of radiation fog was considered in a paper by Mr. Best[4].

Cloud physics was represented by two papers, one by Mr. Jones[5] dealt with aircraft observations of the nature of cloud particles above the freezing level in cloud from which a radar response is obtained. The other paper described some laboratory experiments by Mr. Palmer[6] on the reproduction of ice crystals by splintering.

The Committee also considered recommendations regarding changes in Part III of the research programme for the forthcoming twelve months.

ABSTRACTS

1. DURST, C. S., and GORDON, A. H.; The distribution of humidity at sea. *Met. Res. Pap., London,* No. 665, S.C.III/106, 1951.

At ocean weather station JIG (53°50′N., 18°40′W.) October–December, 1947, vapour pressure differences, sea surface (assumed saturated at sea temperature) to 28–30 ft., were compared with wind direction and force. Decrease greatest with N.–E. winds and force 2–3, least with S.–SW. winds. Relative humidities at bridge height from all data at JIG and ITEM were expressed as mode, 10 and 80 percentiles against wind direction and force, showing a minimum at force 2.

2. CARRUTHERS, N.; Probability paper—an application in upper air climatology. *Met. Res. Pap., London,* No. 711, S.C.III/124, 1952.

The use of probability paper for examining frequency distributions is described. The results of combining two normal distributions differing in mean or standard deviation and of plotting platykurtic and leptokurtic distributions are illustrated. The method is then applied to tropopause pressures at Habbaniya (Iraq), giving (except in July) combinations of two distributions. From discontinuities in upper air temperatures it appears that the total frequency distribution of tropopause pressure is made up of 10 normal distributions.

3. FROST, R.; The upper air circulation in low latitudes and its relation to certain climatological discontinuities. *Met. Res. Pap., London,* No. 706, S.C.III/122, 1952.

The author discusses the abrupt changes of tropopause in Iraq in late May and October, and corresponding discontinuities in surface temperature. Sections of temperature and east-west component in 40°E., 0–60°N., up to 130 mb. in January, April, July and October show a westerly jet stream in 26°N. (January) to 40°N. (July), crossing Iraq at time of tropopause change, and an easterly jet stream in July in 15°N. at 100 mb. Causes of the jet streams and relation to surface conditions and sudden onset of Indian monsoon are discussed.

4. BEST, A. C.; Condensation nuclei and the development of radiation fog. *Met. Res. Pap., London,* No. 698, S.C.III/118, 1952.

The paper traces the effect of condensation on hygroscopic nuclei (sea salt) on visibility as humidity increases. Opacity (extinction coefficient) is discussed as a function of drop size and the latter as a function of mass of nucleus and relative humidity. With assumed distributions of nucleus size, opacity and liquid water are calculated for humidities 80–99·9–100 per cent. Assuming all nuclei of same size, equations are solved for growth of droplets and decrease of visibility in cooling air after saturation; visibility is found to depend on water content, total salt content and size of nuclei.

5. JONES, R. F.; Aircraft observations of radar reflecting particles above the freezing level. *Met. Res. Pap., London,* No. 683, S.C.III/113, 1951.

Observations of character of precipitation, temperature and icing on 8 flights in cloud in and above freezing level, in conjunction with ground radar, are discussed. Echoes from above freezing level are associated with numerous ice crystals 0·5 mm. or more long, the bright band occurring at the change to raindrops. Other observations describe flights through cumulus and cumulonimbus above freezing level, with columnar echoes from supercooled water and usually icing.

6. PALMER, H. P.; The reproduction of ice crystals by 'splintering'. *Met. Res. Pap., London,* No. 702, S.C.III/120, 1952.

A layer of hoar frost was formed by sublimation on under surface of a cooled block at 0° to −25°C. from an air stream in a cloud chamber. When surface was 6° colder than air, hoar frost grew dendritically and ice splinters were released (10/min./cm.^{2}) probably by fracture of dendrites. With difference less than 6°, tabular plates were formed without splintering. Release of splinters during freezing of deposited water is also discussed; it occurs only with contaminated water.

ROYAL METEOROLOGICAL SOCIETY

Meteorology and the operation of jet aircraft

At the meeting of the Society held on February 20, the President, Sir Charles Normand, in the chair, there was a discussion on meteorology and the operation of jet aircraft.

The proceedings opened with statements by Air Cmdre G. Silyn Roberts (Ministry of Supply), Capt. A. M. Majendie (B.O.A.C.). Gp. Capt. C. G. Lott (H.Q., Fighter Command R.A.F.), Mr. G. J. W. Oddie (Meteorological Office) and Mr. C. S. Durst (Meteorological Office).

Air Cmdre Roberts gave an outline of meteorological phenomena of significant interest in the flying and design of jet aircraft. He pointed out that the thrust of jet engines decreased more rapidly with increasing temperature than that of piston engines and that jet-fuel consumption was very high at low levels. Jet aircraft could fly at greater heights and speeds and climb more rapidly than piston-engined aircraft. While low-level meteorology was as important as ever, the operation of jet aircraft called for consideration of meteorological conditions at greater heights than before.

Turning to individual meteorological elements he pointed out first that forecasts of visibility for landing were very important because the jet aircraft uses a great deal of fuel if it has to loiter at low levels waiting to land.

Turbulence was probably the most important meteorological phenomenon for jet aircraft because their higher speed made its effects more violent. The gustiness which can occur in clear air at great heights was serious for transport and bomber aircraft, for the risk of stalling it brings. Much more information was needed about the structure of gusts at all heights for use in aircraft design, and ability to forecast occurrence of clear-air turbulence was highly desirable if not essential for the comfort of airline passengers.

As regards ice accretion, the higher speed of jet aircraft caused the rate of accretion to be more rapid, but this effect was mitigated by the temperature rise associated with the higher speed and the fact that their high cruising altitude enabled jet aircraft to spend more of the flight above clouds. Jet engines very quickly lost power if the air intake was throttled by ice accretion. Accurate forecasting of icing regions was very important. Hail might cause severe damage because of the high speed, and hail drawn inside the jet engine might be serious for axial compressor engines though centrifugal compressor engines have been unaffected by quite large lumps of ice. It was difficult to protect the intake against hail without making it more liable to throttling by ice accretion.

Temperature was very important because of the loss of thrust as temperature increased, and it was a critical factor in taking off from tropical airfields. Air Cmdre Roberts concluded by stating that he considered the advent of jet aircraft had made flying safer, and it was particularly to assist in more economical operation that further meteorological information was required.

Capt. Majendie, who had piloted a Comet aircraft on several proving flights to the tropics, discussed the operation of jet air liners. He pointed out that to obtain maximum range for the fuel carried the jet air liner climbed rapidly to the operating height of 30,000–40,000 ft. and descended rapidly at the destination. The major meteorological requirements in flight planning were airfield temperature for deciding maximum load at take-off, cloud, mean wind and temperature for climb, wind and temperature at operating height and the landing forecast. The elements for which the most improvement in forecasting was necessary were wind at operational height and the areas in which turbulence was likely to occur. He quoted instances of departure of wind at operational height from the forecast value. The landing forecast was very important because it was essential for a jet pilot to decide, while still at operating height, to fly to an alternative airfield if the intended destination were unfit. This was because of the high rate of fuel consumption at low levels. Capt. Majendie also considered more information was needed about the heights to which cumulonimbus cloud reached in the tropics because of the serious risks of turbulence and ice accretion associated with these clouds.

Gp Capt. Lott said the problems of military jet aircraft were similar to those encountered in civil operation, but were more acute or different because military aircraft were necessarily operated to the limits of endurance and because attainment of the aim was more important than safety.

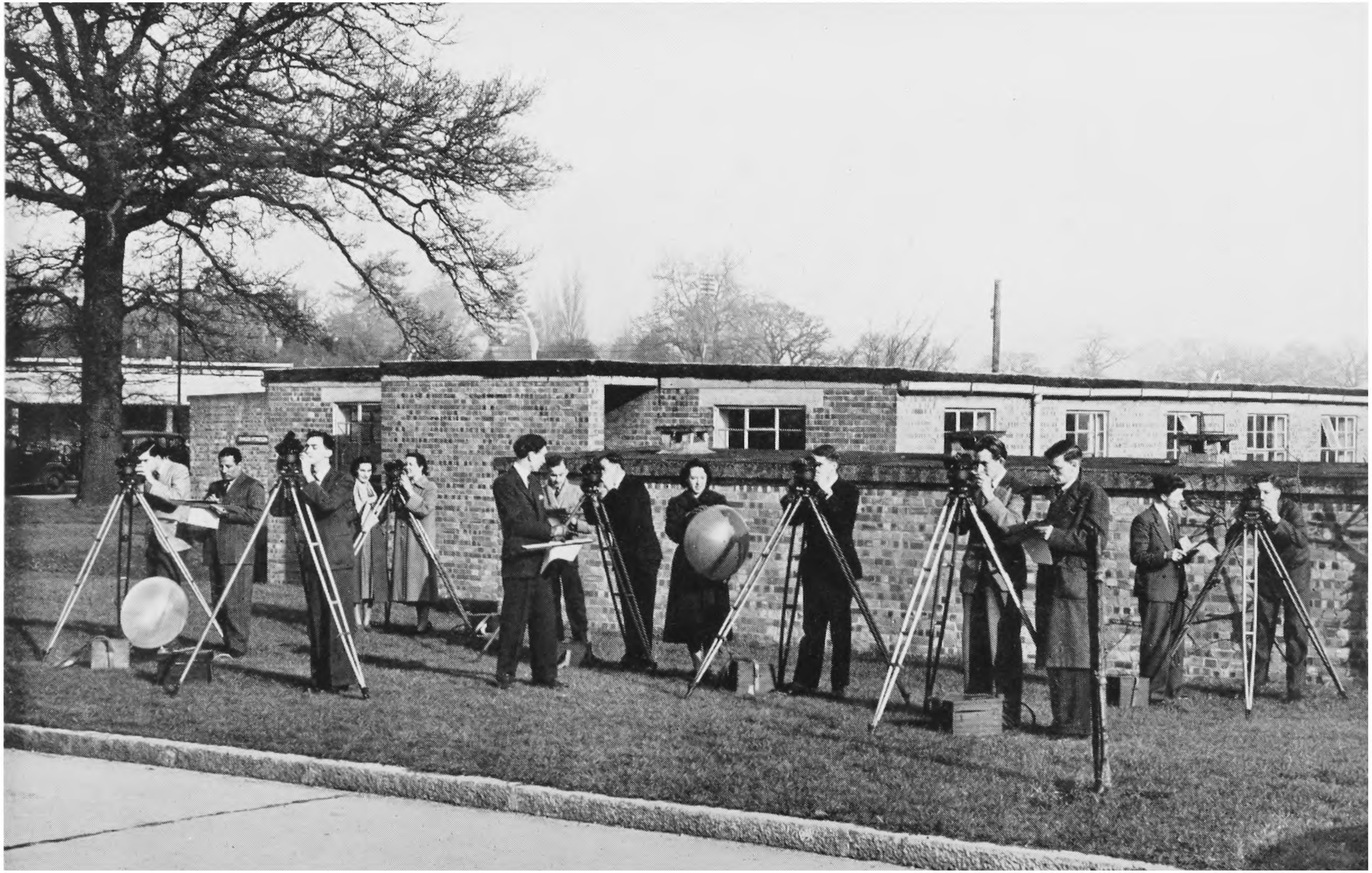
First, in poor visibility there would be a very serious air-traffic-control problem in landing large numbers of jet aircraft in a short time. This was especially acute for fighters. Another point about visibility was that at heights of the order of 40,000 ft. it was more difficult to sight other aircraft than it was at lower levels unless the other aircraft were making condensation trails. As regards condensation trails, there was now evidence that they could form at greater heights than thought likely in the past and the sighting problem increased the importance of trail formation. Temperature was important in bomber and fighter operations because of its relation to range and rate of climb respectively; the director of fighter operations was thus much concerned with the height of the tropopause. The strong winds at great heights were of obvious importance for the range of bomber aircraft and for fighter interception because the higher the ground speed of bombers the less time there was for interception. Turbulence was important in Service flying for its effects on bombing accuracy and on the manœvrability of fighters.

Mr. G. J. W. Oddie outlined the forecasting of winds at 30,000–40,000 ft. by contour and isotach analysis, and discussed with the aid of a diagram due to Mr. J. K. Bannon[1] the distribution of turbulent areas around a jet stream. Mr. Oddie called for more reports from pilots of jet aircraft about the winds and meteorological phenomena encountered at great heights.

Mr. C. S. Durst described the correlation method of predicting wind at great heights developed in the Meteorological Office since 1945. For fuller information on the forecasting of winds at 30,000–40,000 ft. dealt with by Mr. Durst and Mr. Oddie reference should be made to the report of the Meteorological Office Discussion of January 14 in the *Meteorological Magazine*[2].

Capt. S. W. C. Pack and Lt-Com. F. G. Christie of the Naval Weather Service described the Navy's problem in forecasting for the operation of jet aircraft from aircraft carriers as no diversion at all was possible. The forecaster on a carrier in mid ocean had little information, and Captain Pack observed that Mr. Durst's charts of the standard deviation of wind showed highest values over the oceans. Lt-Com. Christie said that at a naval shore station he had been able to forecast sufficiently accurately to enable jet fighters to fly when cloud base was as low as 300 ft., and he had found that condensation trails did not form at a temperature above −55°F.

METEOROLOGICAL OFFICE TRAINING SCHOOL
Assistants taking the readings in the instrument enclosure

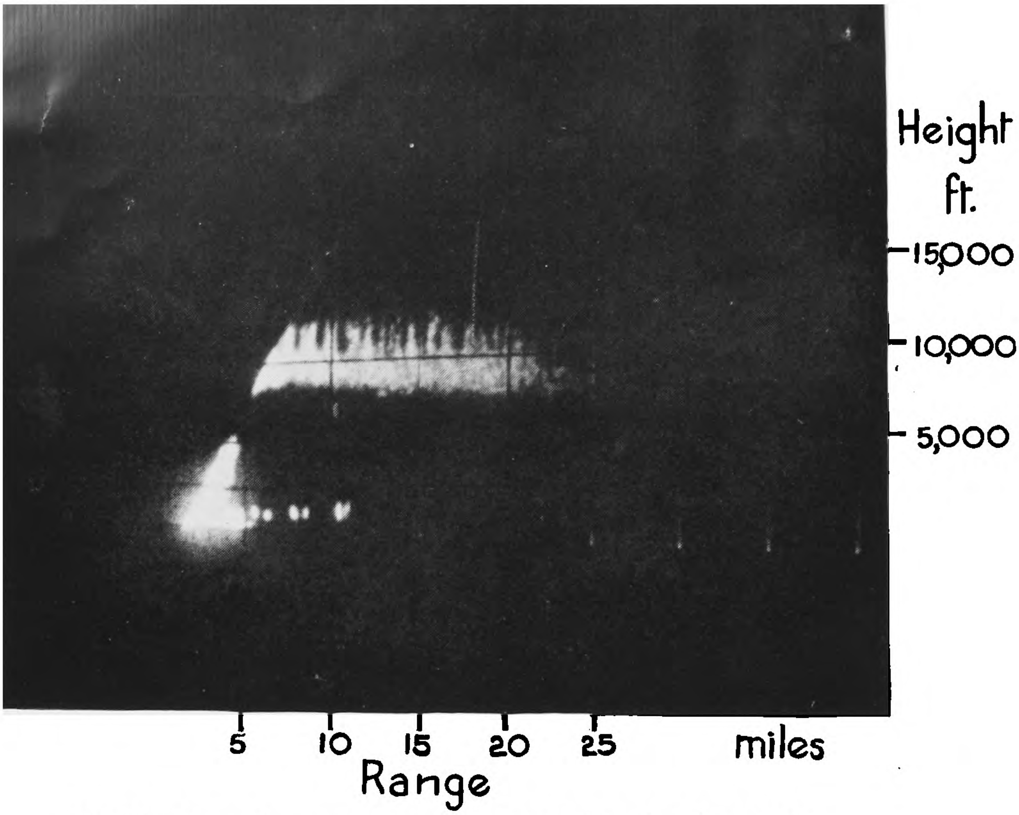


METEOROLOGICAL OFFICE TRAINING SCHOOL
A class of forecasters measuring upper wind by pilot balloon

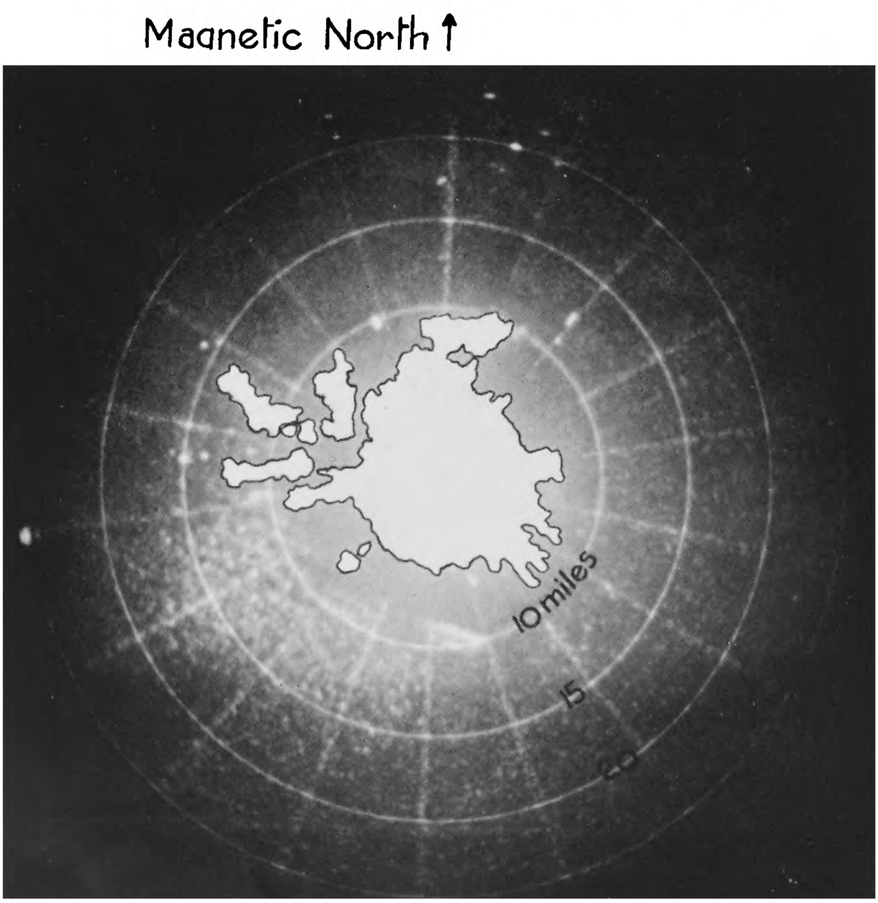
METEOROLOGICAL OFFICE TRAINING SCHOOL

A class of Scientific Officers analysing a weather map in one of the class rooms

To face p. 145]



H.R.T. Photograph at 17h. 00m. 00s. on a bearing of 240° magnetic



P.P.I. photograph at 17h. 28 m. 15s. The permanent echoes are surrounded by firm lines

RADAR PHOTOGRAPHS FROM EAST HILL, BEDFORDSHIRE, ILLUSTRATING BÉNARD-CELL CLOUD ECHOES, DECEMBER 31, 1951

See p. 152

Mr. J. Durward pointed out that the requirements of jet aircraft had not outstripped information over areas for which the British Meteorological Office was responsible. He thought Capt. Majendie's example of a wind of 50 kt. from west when it was forecast to blow from east referred to a change expected on the Cairo–Nairobi route which did not take place precisely at the latitude indicated in the forecast. He stressed the need for in-flight reports of measured winds.

Dr. R. S. Scorer said the requirements of jet aircraft had outstripped the theory of turbulence and high-level cloud formation. He suggested high-level turbulence might be partly explained by orographically produced vertical currents.

Mr. J. D. Hastings said he had five years' experience of forecasting for jet aircraft. First, he queried the seriousness of icing damage to jet engines on the basis of flight trials with a sprayer ring whereby cones of ice 6 in. long and 2 or 3 in. in diameter went into the air intake but caused no damage. He doubted the importance of the V^2 law for rise of temperature in reducing icing risk because a Meteor aircraft flown at 40,000 ft. at an external temperature of −60°C. for three-quarters of an hour at presumably maximum cruising speed had an external panel temperature only 16°C. above air temperature. No instances of ice accretion on the airframe of jet fighters had however been reported to him. He was not surprised at the observations made from jet aircraft of cloud above 30,000 ft. because the tropopause can be at a greater height than 40,000 ft. even over Great Britain. With regard to tropical clouds Spitfire aircraft sometimes reported cumulus cloud extending up to 50,000 ft. during the monsoon over Burma, and he thought monsoon cloud could be quite extensive at the Comet's operating level. Finally he had found that for forecasting condensation trails critical temperatures of −51°F. for polar air and −61°F. for tropical air worked well in practice.

Dr. J. S. Farquharson referred to the successful forecasting by the Central Forecasting Office of winds for the flight of Canberra aircraft across the Atlantic, and claimed that this Office's forecast of high-level turbulence for research flights at South Farnborough had been successful on 22 occasions out of 24. He said that isotach charts were being drawn experimentally at the Central Forecasting Office for study.

Dr. A. W. Brewer confirmed the difficulty of sighting other aircraft, even at an agreed rendezvous, in the bright sun and dark sky of great heights. His experience was that condensation trails do not form in the stratosphere unless the air is exceptionally cold and more than 15°C. below MINTRA value*, when they were inevitable.

Mr. J. K. Bannon did not consider high-level turbulence could be set up by orographic effects alone as it had been observed with no high ground up-wind for hundreds of miles and very few instances had been noted of turbulence in conjunction with general up- and down-currents. He gave instances of the relation of turbulence to the jet stream of which the main feature is the small frequency of turbulence below the level of the jet axis and on the anticyclonic side[1]. With regard to condensation trails he strongly advised caution in the use

*The MINTRA temperature is that above which for a given pressure condensation trails are not likely, on the basis of the theory in "Condensation trails from aircraft"[3], to occur.

of the temperature criteria given by previous speakers as he knew of observations which contradicted all of them.

Flt-Lt Allen, of the Royal Aircraft Establishment, Farnborough, confirmed Dr. Farquharson's statement of forecasting for flights to examine high-level turbulence, but added that on a number of other occasions when turbulence was forecast it had not been possible to fly to investigate it.

Gp Capt. S. W. R. Hughes considered forecasting in all areas was not yet good enough. An unexpected difficulty, which had recently occurred with jet fighters, was icing on the cockpit canopy in clear air during descent which seriously impaired the pilot's vision. He was not satisfied that there was little risk of internal damage by ice to jet engines.

Capt. Majendie, replying to the discussion, said he was grateful to know meteorologists were putting so much effort into these problems. It was difficult for jet-air-liner crews to measure and report winds accurately as yet because of inadequate navigational aids, but as regards forecasting accuracy there had certainly been occasions, even over Europe, when there had been a large drift angle in the opposite direction to the forecast one. He reiterated the need to know when clear-air turbulence was likely, to enable precautions to be taken, and his concern at the possible dangers of climbing through ice-forming cloud in the tropics.

Professor P. A. Sheppard concluded the proceedings with a general summing up of the discussion.

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3. London, Meteorological Office. Condensation trails from aircraft. London, 1943.

ROYAL ASTRONOMICAL SOCIETY

Thunderbolts: The electric phenomena of thunderstorms

Mr. E. Gold took the chair at the geophysical discussion held at the Royal Astronomical Society on January 25, 1952, on the subject of "Thunderbolts: the electric phenomena of thunderstorms".

Mr. Gold opened the proceedings with an interesting and amusing statement on literary references to "thunderbolts" from Lucretius to the *Meteorologische Zeitschrift* which emphasized the unexpectedness and violence of the electric discharges of thunderstorms, their tendency to strike the higher places, and the appearance on rare occasions of ball lightning.

Dr. Wormell indicated the major results of past research employing the two techniques of direct photography of the lightning stroke, and instrumental measurement of the field-changes at ground level associated with lightning flashes. After describing the well known stepped-leader picture of the lightning stroke due to Schonland, he showed that recent field-change studies at Cambridge by Dr. Pierce revealed the time-scale of Schonland's picture to be characteristic of only very few discharges. The majority of flashes had a leader which came down to earth much more slowly than Schonland's stepped leaders. In between successive discharges along a given channel a new leader developed. Sudden changes in the electric field occurred with the return stroke up the channel and between successive such strokes the changes were, in comparison, slow or zero. When the field-change intervening between return strokes was zero the charged leader in the cloud was progressing towards another cloud charge at the same level, because field-change was a measure of change in the electric moment; if there was an appreciable positive change the new charge tapped was at a greater height. Intervening zero field-changes were three times as frequent as intervening positive field-changes; intervening negative field-changes were very rare. Dr. Wormell gave figures, derived from the Cambridge field-change records, which showed that 90 per cent. of flashes to earth brought down negative electricity.

Finally, Dr. Wormell spoke of the work at Cambridge by Mr. Browne on reflection of a vertical radar beam in thunderstorms and especially of the very intense low-level echo changing rapidly in intensity with height found to occur in very heavy thunderstorm rain. The intense concentration of raindrops producing this echo could only be explained by supposing that there was a violent updraught in the cloud at the level in question. Attempts to interpret the effect, however, in terms of the breaking-drop hypothesis and the consequent generation of the lower positive charge found by Simpson and Scrase in the Kew altielectrograph results, encountered considerable difficulties in connexion with the observed rate of rainfall, size of the charge produced, etc.

Dr. R. H. Golde spoke of the topographical, geophysical and geological conditions which have been claimed to determine points where lightning flashes may be concentrated. There were some areas, often quite small, called lightning nests which received more than their share of strokes, and it had been suggested that these might be associated with regions of high gradients of soil conductivity. Here Dr. Golde turned to consider what might cause a lightning leader stroke coming down from the cloud actually to strike a particular point of the ground. He pointed out that the leader stroke constituted a "self-propagating" or "incomplete" discharge, and that, even for the most intense stroke, the field strength below the leader required for complete breakdown would not be reached until the tip was within about 100 m. of the ground and, for an average stroke, within about 15 m. This was supported by photographic evidence of upward streamers developing from the earth to meet the down-coming leader. It had been suggested that geological faults of high conductivity or underground water courses surrounded by high-resistivity soil would be liable to attract lightning because of the local field concentration produced at the earth's surface. Calculations of the attractive effects of buried metal cables or lightning conductors showed, however, that the attractive effects extended only to distances of under 200 m., so that the presence of a highly conducting feature in high-resistivity soil would explain the concentration of discharges in small "nest" areas only.

Mr. J. Durward described two instances when he saw what appeared to be ball lightning. The first was in Scotland in 1934, when a ball of fire came out of an adjacent wood in a thunderstorm to strike an iron gate over a road, and the second was in an aeroplane over southern France when a ball of light exploded with a loud bang in a doorway after causing damage in the pilot's cabin.

Mr. Logan defended the existence of ball lightning because of the large common measure of agreement in the observations made by rural people having little or no knowledge of it before seeing it. He suggested the ball was a volume of little pressure containing a number of charged particles moving at very high speed.

Capt. Brown, an airline pilot, described his observation of a ball of blue fire which struck his aeroplane over India in a thunderstorm and damaged the wireless system.

Dr. Pierce, of Cambridge, discussed the development of leader strokes. He said it seemed most likely that they originated in the main negative charge in the cloud. An arc régime existed within the leader channel, and, as the leader moved out into areas differing in potential, corona discharge occurred from the sides. From the Cambridge field-change records, a value of the corona constant had been derived which appeared to be characteristic of the gaseous channels involved; using this value, the calculated currents for upward leaders from the Empire State Building were in excellent agreement with those measured experimentally by McEachron.

Dr. Allibone referred to a photograph showing lightning striking a beach very close to the sea, which was against the theory of attraction by high conductivity areas. Mr. Shipley described seeing, when a schoolboy, from a bus top in London, a ball of fire during a thunderstorm. He suggested ball lightning might be an incandescent volume produced at the end of a lightning streamer which remained more or less stationary for a time. Dr. Allibone said that suggestion had already been made, and described laboratory observation of long sparks which supported it.

Dr. F. J. Scrase described the thundercloud charge distribution found before the war in the Kew alti-electrograph soundings which revealed a positive charge in the highest part of the cloud at a temperature below $-15°$C., a negative charge just above the freezing level, and a positive charge in the base of the cloud. The existence of the lower positive charge had since been confirmed by observations from aircraft and on the Zugspitze, as well as by the increase in frequency of positive fields below the centre of an active thunder cell. Dr. Scrase said he regarded the essential difference between thunderclouds and shower clouds was that in the latter the lower positive charge was absent or less well developed. This idea was supported by the field-changes which take place as the clouds pass over and by the fact that thunderstorm rain is predominantly positively charged and shower rain predominantly negatively charged. The Kew alti-electrograph data and the Zugspitze observations show that thunderstorms have their bases well below freezing level, where conditions are most favourable for breaking drops while shower clouds do not. The Kew data show that the negative charge extends over a greater depth in thunderclouds than in shower clouds, and recent radar-echo observations show a much bigger echo in thunderclouds which is probably due to the increase in drop size.

BOOK RECEIVED

Jaarboek A. Meteorologie (*Yearbook, A. Meteorology*) *1949*, Koninklijk Nederlands Meteorologisch Instituut. $13\frac{1}{4}$ in. × $9\frac{1}{2}$ in., pp. xii + 96, Staatsdrukkerij-en Uitgeverijbedrijf, 's-Gravenhage, 1951. Price: *fl.* 5.00.

LETTERS TO THE EDITOR

Abrupt seasonal temperature changes at the tropopause and at the surface at Habbaniya

In the *Meteorological Magazine* for November 1951, Mr. Dewar describes the abrupt change which occurs in the temperature of the stratosphere in June and October at Habbaniya. I do not know whether it has ever been pointed out, though it must be well known to those who have served in Iraq, that similar changes occur at the surface in May–June and September–October. Thus a curve of maximum temperature is not "smooth" because of an abrupt rise at the beginning of the summer and an abrupt fall at the end. The latter was of course the change which one noticed most because it provided a welcome relief from the heat of the summer.

Mr. Dewar considers three years, 1948–1950. He gives the date of change in 1948 as October 9, in 1949 as October 23, and in 1950 as October 20. In 1948 and 1950 the fall in surface maximum temperature was marked about one day later than the fall at the tropopause. Thus the mean maximum for the period October 6–10, 1948, was 99°F., and for the five days October 11–15, 79°F. In 1950 the mean for the period October 17–21 was 93°F., and for the five days October 22–26, 81°F.

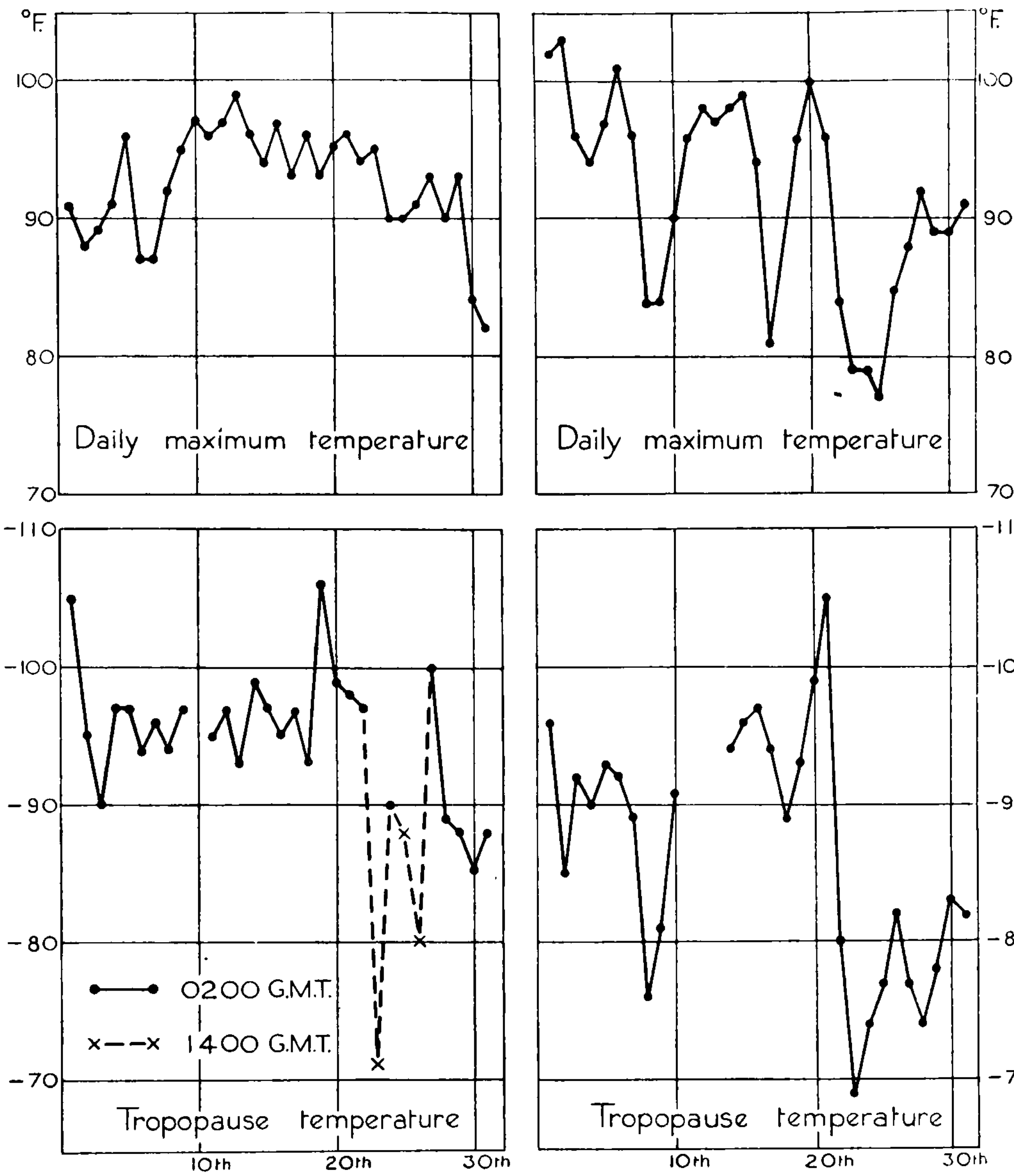
The fall in surface maximum temperature in 1949 was not so pronounced on the date given by Mr. Dewar. Thus the five-day mean October 19–23 was 95°F. and for October 24–28, 91°F. A pronounced fall did not take place until October 30 (93° to 84°F.). October 1949 was in fact rather different from other months. The maximum temperature was much more constant and lower at the beginning of the month than in 1948 or 1950; the mean maximum for the first ten days of 1949 being 91°F. compared with 99·5°F. in 1948 and 95°F. in 1950.

January 14, 1952 J. DURWARD

[Mr. Durward's letter drawing attention to the connexion between the seasonal change in tropopause temperature over Habbaniya and the change in surface daily maximum temperature is very interesting, and, in order to examine the changes more closely, graphs have been drawn for each transition period during the years 1948–50. Those for October 1949 and October 1950 are reproduced in Fig. 1. In order to simplify the comparison only the 0200 G.M.T. values* for the tropopause temperature have been plotted (apart from some 1400 G.M.T. values around October 24, 1949, where 0200 G.M.T. values were not available) and the appearance of the graphs differs somewhat from those published before.

From Fig. 1 (*b*) it will be seen that the most pronounced change of temperature in both graphs occurs between the 21st and the 22nd. The reason why they do not show the 24-hr. lag referred to by Mr. Durward is that the dates May 19 to October 20 given in the previous article refer to the period for which the tropical régime persisted; the transition started on the following day after a tropical régime value at 0200 G.M.T. The same relation holds for the change in October 1948. It is, indeed, sometimes difficult to say precisely when the change occurs, and it would be unwise to regard them as well defined changes which might be used to forecast changes in the surface maximum temperature.

*It would probably have been better to use 1400 G.M.T. temperature readings but these were not as complete as the 0200 G.M.T. readings.



(*a*) October 1949 (*b*) October 1950

FIG. I—DAILY MAXIMUM SURFACE TEMPERATURE AND TROPOPAUSE TEMPERATURE AT HABBANIYA

Except where otherwise stated the time of observation is 0200 G.M.T. (0500 L.T.)

This is well illustrated in Fig. 1(*a*) by the graphs for October 1949. As Mr. Durward remarks, this year was rather different from the others, and the fall in the surface maximum temperature did not occur until October 30 though the change in tropopause temperature began on October 23.

In addition to the main fall of temperature referred to by Mr. Durward there is also, on many occasions, a marked similarity between large fluctuations of surface maximum temperature and of tropopause temperature around the transition period. In Fig. 1(*b*) these fluctuations are most evident during the tropical régime but the other graphs show, in general, the reverse. The resemblance appears to be most marked when the seasonal change is well defined.—D. DEWAR].

Föhn effect over Scotland

Every meteorologist knows the theory of the föhn effect, but probably very few meteorologists, at any rate in this country, have seen an example actually worked out from data for the British Isles.

On January 23, 1952, the gradient wind over central Scotland was south-south-easterly and about 15 kt.; it remained so sufficiently long for air from Leuchars to travel up to Kinloss. The distance between the two places, as the crow flies, is about 90 miles so that it would take about six hours for a parcel of air to make the journey.

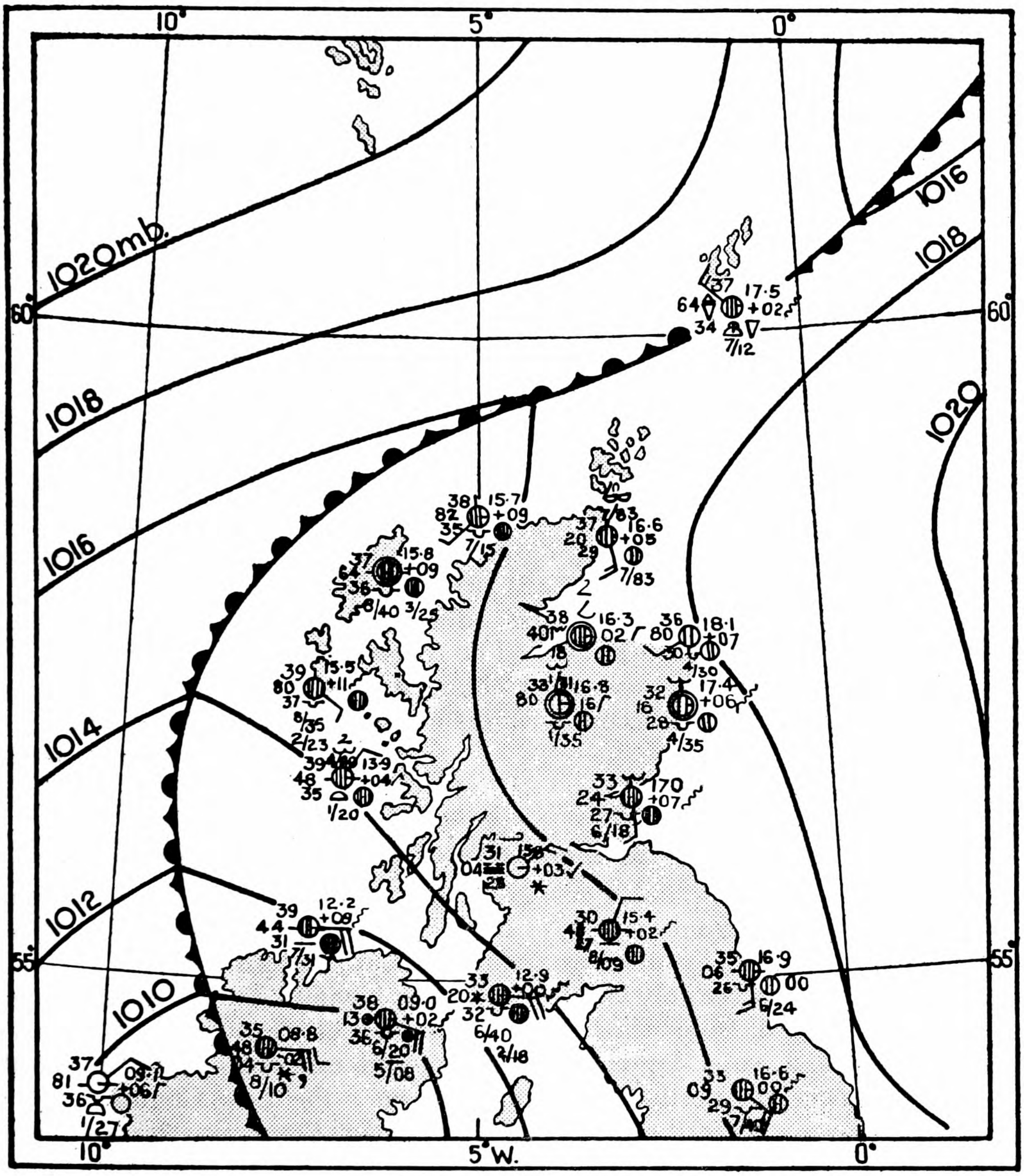


FIG. 1—SYNOPTIC WEATHER MAP, 1200 G.M.T. JANUARY 23, 1952

At Leuchars at 0600 G.M.T. temperature and dew point were 33°F. and 28°F. respectively, and they remained practically constant throughout the morning. At Kinloss at 1200 G.M.T. temperature and dew point were 38°F. and

18°F. respectively. The cloud cover over the track was sufficient to preclude the difference between these figures being explained by insolation at this time of the year. The only possible explanation is therefore föhn effect over the Cairngorms, the peaks of which rise above 4,000 ft.

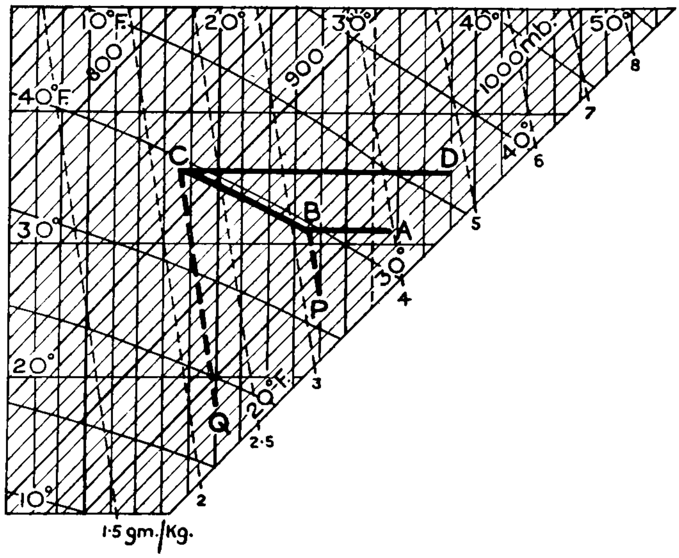


FIG. 2—TEPHIGRAM SHOWING ASCENT OF AIR AT LEUCHARS AND DESCENT AT KINLOSS

It is reasonable to assume that, in crossing the Cairngorms, the air was lifted mechanically an average of 3,500 ft., or about 135 mb., and that, after saturation was reached, further lifting resulted in precipitation. The tephigram shows that air at Leuchars at a surface pressure of 1017 mb. would ascend via the path represented by ABC, and descend to Kinloss via the path represented by CD; the dew point at Kinloss would be represented by Q. The theoretical values of temperature and dew point obtained by this process are 37°F. and 20°F. respectively, in close accord with the actual observations at Kinloss.

W. D. S. McCAFFERY

Pitreavie, January 23, 1952

Radar evidence of the formation of Bénard convection cells

On December 31, 1951, radar echoes from medium-level precipitation were received at East Hill from 1100–1730 G.M.T. For most of the period the echoes took the form of a band centred at about 10,000 ft., and generally some 2,000–4,000 ft. thick, and were only visible on bearings having a southerly component. The medium cloud, from which the precipitation echoes were received, was associated with a wave depression which moved eastwards along the north coast of France into north-east France and later the Low Countries. The centre of the wave, according to the *Daily Weather Report*, was on a bearing of about 225° magnetic from East Hill at 1200 and about 155° magnetic at 1800. The radar echoes were strong in the late morning and early afternoon but became very weak and diffuse in mid-afternoon (about 1430–1530). About dusk (sunset 1600 G.M.T.) the echo intensity increased rapidly, and, as seen in the H.R.T. photograph (opposite p. 145) taken at 1700, the echo showed a marked cellular structure. The P.P.I. photograph (opposite p. 145) taken at 1728 suggests the presence of very many tiny cells which had a tendency to form into lines with an orientation of about 290–110° magnetic (280–100° true). The winds in this layer appear to have been somewhat variable about this time (Larkhill, 1500, 208° 14 kt. at 700 mb. to 289° 14 kt. at 600 mb.), but the probability is that the lines of cells were parallel to the wind direction in the top of the layer. Overhead at 1730 the cloud appeared to have broken to a cellular type of high stratocumulus but appeared thicker to the south and south-west.

It is thought that this intensification of echo and tendency for cellular structure were brought about by the cooling of the top of the cloud layer by radiation after sunset at this level, producing cells of the Bénard type. If this were the case the distance apart of the individual echo columns (if one column indicates the up-current of one cell) should give the diameter of the cells, and hence, approximately, the depth of cloud affected by the cells*. The spacing of the individual columns on the H.R.T. photograph and of the lines of echo columns on the P.P.I. photograph averaged about 4,500 ft., suggesting a depth of air taking part in the cell movement of about 1,100–1,500 ft. The distance suggested by the H.R.T. photographs—the vertical extent of the columns—is 1,750 ft. The Larkhill upper air ascent at 1500 showed that a very small cooling effect (less than 1°F.) at 12,700 ft., supposing this echo-top height to be the cloud top, would be sufficient to make the 1,300-ft. layer beneath unstable for saturated air, while a cooling of 2°F. would make this layer unstable even if unsaturated.

Presumably this effect of layer cloud breaking into cellular cloud may occur quite frequently around dusk, the present case being unique only in the accident of having large naturally formed ice crystals present already as radar "tracers" for the cellular motion.

It is also of interest to note that, although ice crystals of considerable size must have been present in this layer, the base of the echo did not fall over several hours, implying that as the ice crystals fell from the layer their reflectivity decreased very rapidly. This decrease was probably occasioned by rapid evaporation, since the air at 750 mb. (8,000 ft.—the echo base was about 8,250 ft.) was very dry (dry bulb 17°F., dew point −7°F. at Larkhill) at 0900 and still far from saturated (dry bulb 17°F., dew point 11°F.) at 1500. On the other hand the upper air ascents at Larkhill do not indicate saturation at any time or any height, even in the layer from which echo was received. Only a trace of precipitation was recorded between 0900 and 2100 at Kew, London Airport and Boscombe Down.

East Hill, near Dunstable, Bedfordshire, January 14, 1952 R. F. JONES

NOTES AND NEWS

Vertical air motion over northern England and southern Scotland November 27, 1951

Strong vertical air motion was experienced by three Wellington aircraft flying at 13,000 ft. over northern England and southern Scotland between 1700 and 1900 G.M.T. on November 27, 1951. Their route was from southern England to Newcastle, north to Berwick, west across southern Scotland to near Stranraer, and finally southwards.

*See BRUNT, D.; Physical and dynamical meteorology. London, 2nd edn, 1939, p. 219.

One of the pilots, Flt-Lt Stansfield, reports that near Newcastle rising air currents of the order of 750 ft./min. were encountered, and persisted for between 10 and 15 min. The speed of the aircraft was 140 kt. which indicates the rising current was encountered from Newcastle to a point off the north-east end of the Cheviot Hills. From that point to the turning point near Stranraer a series of up- and down-currents, mostly down ones, was encountered. The down-currents had a speed of 400–500 ft./min. The aircraft were flying in clear air in a wind of about 270° 70 kt. and did not experience any bumpiness.

A well marked jet stream, with its axis at about 300 mb. and axial speed of at least 120 kt., was situated at the time just to the north of the line Berwick to Stranraer. During the occurrence of the strong up-currents the aircraft were flying roughly at right angles to the axis of the jet stream, and during the period of variable but mainly down-currents were flying roughly parallel to it. It is however doubtful if the vertical currents encountered were associated with the jet stream.

It seems more probable that they were vertical currents produced by the strong winds over the mountains. It is known that, notably to the lee of mountains, up- and down-currents can occur at considerably greater heights than the top of the mountains. The theory of these currents, the so-called "lee-wave" phenomena, has been discussed by Queney[1] and Scorer[2,3] amongst others. The available upper air information shows that, at the level of flight, the wind was increasing with height and the lapse-rate of temperature was large—about 4°F./1,000 ft.—and larger than at lower levels; these conditions are favourable, according to Scorer, for the formation of lee-waves though his theory does not seem definitely to allow for them at a height so great in proportion to the height of the mountain tops.

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3. SCORER, R. S.; Forecasting the occurrence of lee waves. *Weather, London*, **6**, 1951, p. 99.

Extreme tropopause pressure

The values of extreme tropopause pressure and corresponding heights given in the table below were extracted for an inquiry. It has been suggested that they are of sufficient interest to be published in spite of the reservations appended to them as far more conservative values are usually quoted.

The outstandingly low maximum pressure over Larkhill in March has been critically examined and it appears that the tropopause is usually high over southern England during this month. The next lowest pressure for 1948–50 was 350 mb. and in March 1951 the lowest pressure was 358 mb.; tropopause pressures below 200 mb. were frequently recorded.

These extremes have been obtained by taking the extreme tropopause pressures given on returns to the Upper Air Climatology Branch and then obtaining the heights from the *Upper Air Section* of the *Daily Weather Report* or *Daily Aerological Record* (as the corresponding heights were not entered on the forms used in 1948–50). These forms gave the station's assessments of the tropopause, and these do not always agree with the assessments published by

EXTREME TROPOPAUSE PRESSURE AND CORRESPONDING HEIGHTS AT LARKHILL AND LERWICK, 1948–50

	Larkhill (51°11′N., 1°48′W.)				Lerwick (60°08′N., 1°11′W.)			
	Maximum pressure	Corresponding height	Minimum pressure	Corresponding height	Maximum pressure	Corresponding height	Minimum pressure	Corresponding height
	mb.	ft.	mb.	ft.	mb.	ft.	mb.	ft.
Jan.	392	22,500	150	45,600	457	18,700	143	46,000
Feb.	450	19,400	145	45,800	440	19,800	161	43,100
Mar.	357	25,500	152	45,400	490	17,800	147	44,800
Apr.	**494**	17,700	164	43,300	**550**	14,500	187	40,200
May	370	25,100	167	43,700	386	23,400	187	40,800
June	400	22,800	142	47,300	400	22,900	164	43,800
July	340	27,400	130	49,100	350	26,300	170	43,700
Aug.	380	24,300	150	46,700	350	26,200	177	42,400
Sept.	350	26,200	**115**	51,800	470	18,900	119	49,800
Oct.	379	23,700	**115**	51,300	400	21,900	**109**	50,300
Nov.	414	24,500	130	47,700	455	18,500	138	46,100
Dec.	448	19,700	154	44,100	450	19,300	158	43,800

the Central Forecasting Office. When it appeared that the station's value was doubtful the next highest (or lowest) value was adopted. The values given may not be extreme heights, but this is not considered to be of practical significance in view of the uncertainty attached to these extreme values. They should be treated with reserve.

D. DEWAR

REVIEWS

General astronomy. By Sir Harold Spencer Jones. 8½ in. × 5½ in., pp. x + 458, *Illus.*, Edward Arnold & Co., London, 3rd edn, 1951. Price 30*s.* 0*d.*

"General astronomy" is written for the elementary student of astronomy knowing simple algebra and trigonometry and Intermediate B.Sc. physics. It deals with the observations and the inferences that can be directly drawn from them and avoids the more speculative parts of recent astronomical theory. For a meteorologist wishing to acquire a broad knowledge of astronomy it is quite the best book. It is, however, regrettable that no references are provided to more specialized books for further reading in any part of the subject in which the reader may be particularly interested.

The book has been revised throughout for this third edition. Subjects of very recent discovery such as the solar radiation in the radio part of the spectrum and the use of radar for the detection of meteors are described.

The book is particularly recommended to meteorologists for the account of sun-spots and bright solar eruptions, and the associated radiations of great importance in terrestrial magnetism, radio propagation, and the production of auroræ.

In discussing the maintenance of the sun's radiation the author says the existence of ice ages in the past makes it reasonably certain there have been variations in the radiation, without mentioning that there are serious theories of ice ages which do not require any change in the radiation emitted by the sun.

The reproduction of the photographs is excellent. There is a very good index.

G. A. BULL

The Egyptian climate: an historical outline. By G. W. Murray. *Geogr. J., London,* **117**, 1951, pp. 422–434.

The December 1951 number of the *Geographical Journal* contains an interesting article by Mr. G. W. Murray, "The Egyptian climate: an historical outline". Mr. Murray's data are the rate of erosion of softer rocks of the Sahara, the rate of growth of the western dunes and the flint implements and remains of tree trunks on the surface. He concludes that, except during two brief rainy interludes, the Egyptian deserts have been dry for three-quarters of a million years. The rainy interludes occurred about 20,000 years ago and again from about 8000 to 4000 B.C. His paper includes evidence of a fall in the level of the subterranean water of the Sahara which is supplied from the Sudan rainfall.

G. A. BULL

On the microclimatic properties of sheltered areas: the oak-coppice sheltered area. By R. J. Van der Linde and J. P. M. Woudenberg. *Meded. ned. met. Inst., De Bilt, A*, No. 56, 1950, pp. 151. Staatsdrukkerij-en Uitgeverijbedrijf 's-Gravenhage. Price: *fl.* 3.00.

This book is a welcome addition to the growing number of studies of climate experienced in the first two metres or so over natural surfaces of the type actually encountered in agriculture. The first 40 pages consist of an excellent critical review of existing knowledge on the subject in the course of which most, but not all, of the various sources have been tapped. Particular attention is drawn to the work of the Russian, Bodrov, who, in a paper in 1936, stressed that, especially when temperature is being investigated, separate consideration should be given to observations from sunrise to early afternoon (when there is a net gain of heat at the surface) and to those obtained during the rest of the day.

The body of the work (some 70 pages) is a detailed account of experimental studies during some ten periods, each covering from two to five days, scattered over the months April to November (inclusive) in 1943–47. The experiments were carried out in a flat area near Oldebroek—some 6 Km. from the east bank of the IJssel Lake (the Zuider Zee)—which had been divided, by strips of oak coppice 4 to 5 m. high, into a series of long narrow fields rarely more than 50 m. wide running approximately south-east to north-west. There were also a number of secondary barriers perpendicular to the main system. In most of the ten series of observations, frequent readings were recorded from shielded thermometers 2 cm. from the surface, at a number of points 10 m. or less apart in a line perpendicular to the belt, but in one case the heights were 10 cm. and 25 cm., and in another the vertical temperature profile to $1\frac{1}{2}$ m. was examined at two points supplemented by readings in a standard screen 40 cm. above the surface. In general the surface was one of bare soil. Other observations were a series of readings of soil temperature at 10 cm. depth, twice daily readings of water loss as indicated by Piché evaporimeters with the evaporating surface 10 cm. from the ground and some observations of humidity (at 30 cm.). The observations in each series, which are set out graphically, are prefaced by a detailed account of the weather prevailing at the time—an essential procedure when considering phenomena whose interrelationships vary significantly between different types of weather. To estimate the extent of the shadow thrown by the barrier a diagram from an earlier paper by the same authors is reproduced.

The experimental data are analysed and appraised in the light of similar studies by other workers, in particular C. G. Bates of the U.S.A. and Bodrov, in a section of 20 pages. A 7-page summary and bibliography complete the book.

One novel result is the specification of four different temperature zones within the protected area which become most evident on sunny days with light or moderate winds (i.e. Beaufort force 3 or less). These are

(i) a narrow shaded strip on the north-east side of the barrier with temperatures lower than anywhere else in the area

(ii) a zone a few metres wide with high temperatures

(iii) a zone some 20–30 m. wide where temperatures are noticeably lower than in zone (ii) and fairly uniform

(iv) a final zone, again 20–30 m. wide, where the temperature gradually increases towards the next barrier.

Some of the highest early-afternoon temperatures were recorded in zone (iv) and would be sufficient to cause "sun-scald" to many types of crop. In contrast to the generally accepted ideas, the zone of maximum temperature (i.e. zone (ii)) did not coincide with the region of greatest air stagnation, but appeared to move as the position of the edge of the midday shadow varied from month to month. Nor did the temperature maximum by day coincide in position with that of lowest minimum at night, as is usually stated. A partial explanation of some of these findings is suggested in terms of local circulations within the protected area. Other interesting results are the evidence that the effect of these barriers on temperature extended up to $1\frac{1}{2}$ m., and the statement that in the conditions of intermittent sunshine, so characteristic of the climate in western Europe, temperature by day will generally be higher in the protected zone than in the open.

It is essential when studying the results to bear in mind that successive belts followed each other so closely that cumulative effects must have been operative, and to note the authors' conclusion that the oak coppice when in full leaf must be regarded as a "dense" barrier. It is not clear to what extent the writers consider their findings influenced by the peculiarities of the shelter-belt network and of its orientation, and it would perhaps have been an advantage if they could have provided rough numerical values for the temperature differences to be expected in given conditions—if only to prevent the reader drawing his own, possibly unsound, conclusions from the diagrams.

It is unfortunate that the number of occasions of sunny weather with moderate or fairly strong winds perpendicular to the main belts were very few, and hence the influence of such barriers whilst acting in their most characteristic fashion cannot be assessed. It would have been helpful if horizontal distances had been expressed, as customary, in multiples of barrier height as well as in absolute measures.

In conclusion, this volume is of considerable value and interest—the critical review with which it begins would alone commend it to a wide public—and we look forward to those further related studies which the authors hint at more than once.

R. W. GLOYNE

METEOROLOGICAL OFFICE NEWS

Gale damage at Bristol.—On the night of Friday, March 28, during a gale with gusts of 50–60 m.p.h., a large beech tree was uprooted and fell on to the meteorological office at the National Agricultural Advisory Service Headquarters, Bristol. The office, which was a one-storey prefabricated hut, was completely wrecked, the centre branches of the tree falling in the middle of the building. A night-watchman and a postman, who were sheltering in the small store-room on the side of the office furthest away from the tree, were trapped and hurt but escaped serious injury. Display material, papers and furniture were destroyed but the instruments held in stock were in a steel cupboard and remained intact. Luckily an oil-stove in the storeroom was extinguished by the crash.

Award.—We congratulate Mr. J. M. Craddock on the award to him by the Royal Meteorological Society of the First Darton Prize for 1951, an annual prize for the most meritorious paper on instrumental meteorology published by the Society during the year. The paper dealt with "An apparatus for measuring dewfall" and it was published in *Weather* for October 1951.

Sports.—The Air Ministry Harriers held a 3½-mile cross-country race at Cranford on March 15, 1952. Mr. P. D. Dench was first man home, with Mr. M. D. Dobson third. A sealed handicap was won by Mr. Dobson.

Mr. S. W. Lewis has been selected to represent the Civil Service at water polo against Cambridge University.

Marriage.—We offer our best wishes to Dr. A. H. R. Goldie, Deputy Director of Research, and Miss N. Carruthers, known for her statistical work in the Office, on the occasion of their marriage on April 5, 1952.

WEATHER OF MARCH 1952

Pressure was generally low in the North Atlantic, west Europe and the Mediterranean, and high in Scandinavia and the Arctic Ocean. The lowest mean pressure of 999 mb., about 10 mb. below normal, occurred in the North Atlantic about 50°N., 25°W.; mean pressure in the Azores, about 1009 mb., was 14 mb. below normal. Mean pressure in west Europe and the Mediterranean was mainly between 1010 and 1015 mb. generally 3–6 mb. below normal. In Scandinavia and to the northwards, mean pressure was between 1014 and 1019 mb., generally 4–8 mb. above normal.

Temperature was generally high for March in south-west Europe and low in Scandinavia and central Europe. Mean temperature in France, Spain and the western Mediterranean was generally between 50° and 60°F., about 5°F. above normal. In Scandinavia and central Europe mean temperature was well below freezing in most places, the lowest being in Finland and Lapland, where it was between 7° and 14°F., which was 5–10°F. below normal.

In the British Isles the weather was very mild until the 25th apart from a temporary cold spell from the 13th to the 15th. The last week was cold, particularly from the 27th onwards. An unusually severe snowstorm occurred in south-east and east England and the Midlands on the 29th.

During the opening days a depression south-westward of the British Isles moved north-east and caused rain in the west and north. On the 2nd another depression developed on the Atlantic and moved to a position north-westward of Ireland, where it remained, with little movement but becoming less deep, for several days. Meanwhile troughs of low pressure moved north-east or north over the British Isles giving rain at times. On the 6th another depression approached our south-west coasts and associated troughs of low pressure moved north over the country; rain fell generally on the 6th and 7th and was heavy locally (2·61 in. at Maesteg Park, Glamorgan, and 2·08 in. at Ulpha, Cumberland on the 6th). In the early hours of the 9th a small secondary depression moved north-east along the English Channel giving considerable rainfall in southern England. More settled sunny weather, apart from local fog, set in on the 10th when a ridge of high pressure crossed the British Isles. Between the 12th and the 15th an anticyclone moved from a position north-east of Iceland to central Europe and maintained fair weather over most of the British Isles, with variable amounts of sunshine but long bright periods in many places. On the 15th and 16th a depression off the south of Ireland moved north and filled; scattered rain occurred in England and southern Ireland. Except in south-west England and west Ireland, good records of bright sunshine were obtained in most areas on the 15th and in the Hebrides on the 16th (10·7 hr. at Waddington and 10·6 hr. at Finningley on the 15th and 10·5 hr. at Stornoway on the 16th). The period 13th–15th was rather cold (maximum temperature 39°F. at Elmdon on the 13th and minimum 20°F. at Eskdalemuir on the 15th) but temperature rose considerably on the 16th. A very mild unsettled spell ensued, with relatively high pressure over Scandinavia and troughs of low pressure crossing the British Isles. Scattered rain or showers occurred on the 17th and 18th and local thunderstorms were recorded in the south-east of England. On the 19th and 21st rain fell generally, and was heavy locally, but on the intervening days, the 20th and 22nd, it was mainly very slight and scattered. On the 17th–19th there was much morning fog, which persisted locally on the coasts. A depression approached south-west Ireland on the 23rd and a trough crossed southern England causing rain generally in England and Wales. On the 24th the depression moved a little south-east and a trough lay over southern England and was associated with more rain. Thereafter a wedge of high pressure extending south from an anti-cyclone centred east of Iceland lay over the British Isles and cold north-easterly winds prevailed. The anticyclone subsequently moved slowly south-westward, while pressure became very low west of Portugal and later over the Bay of Biscay also. In consequence the north-easterly winds strengthened and very cold air spread from Russia to the British Isles giving an exceptionally cold spell for late March. Snow fell widely from the 27th onwards, the fall being substantial with severe drifting in the southern and midland districts of England on the 29th.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	°F.	°F.	°F.	%		%
England and Wales ...	63	16	+1·9	115	0	78
Scotland	61	15	+1·5	94	−2	97
Northern Ireland ...	59	27	+2·2	61	−7	101

RAINFALL OF MARCH 1952

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·97	162	*Glam.*	Cardiff, Penylan ...	2·66	84
Kent	Folkestone, Cherry Gdn.	3·96	182	*Pemb.*	Tenby	2·72	88
,,	Edenbridge, Falconhurst	3·32	134	*Mer.*	Aberdovey	2·72	82
Sussex	Compton, Compton Ho.	3·67	132	*Radnor*	Tyrmynydd	3·04	57
,,	Worthing, Beach Ho. Pk.	2·71	141	*Mont.*	Lake Vyrnwy	3·40	76
Hants.	Ventnor Cemetery ...	4·15	198	*Mer.*	Blaenau Festiniog ...	12·21	141
,,	Bournemouth	...	...	*Carn.*	Llandudno	0·86	42
,,	Sherborne St. John ...	2·76	123	*Angl.*	Llanerchymedd ...	2·25	76
Herts.	Royston, Therfield Rec.	3·13	171	*I. Man*	Douglas, Borough Cem.	2·85	96
Bucks.	Slough, Upton	2·55	145	*Wigtown*	Newton Stewart ...	2·96	86
Oxford	Oxford, Radcliffe ...	2·40	145	*Dumf.*	Dumfries, Crichton R.I.	2·52	84
N'hants.	Wellingboro' Swanspool	2·93	164	,,	Eskdalemuir Obsy. ...	3·91	80
Essex	Shoeburyness	2·76	204	*Roxb.*	Kelso, Floors	0·82	42
,,	Dovercourt	2·87	186	*Peebles*	Stobo Castle	1·34	46
Suffolk	Lowestoft Sec. School ...	2·38	148	*Berwick*	Marchmont House ...	1·58	60
,,	Bury St. Ed., Westley H.	3·10	164	*E. Loth.*	North Berwick Res. ...	1·33	71
Norfolk	Sandringham Ho. Gdns.	2·72	143	*Midl'n.*	Edinburgh, Blackf'd. H.	0·95	48
Wilts.	Aldbourne	3·00	135	*Lanark*	Hamilton W. W., T'nhill	2·15	77
Dorset	Creech Grange	3·96	140	*Ayr*	Colmonell, Knockdolian	2·15	64
,,	Beaminster, East St. ...	4·02	137	,,	Glen Afton, Ayr San. ...	3·23	77
Devon	Teignmouth, Den Gdns.	2·77	107	*Renfrew*	Greenock, Prospect Hill	4·61	99
,,	Cullompton	3·65	133	*Bute*	Rothesay, Ardencraig ...	4·10	114
,,	Ilfracombe	3·71	129	*Argyll*	Morven (Drimnin) ...	5·71	118
,,	Okehampton Uplands ...	4·85	117	,,	Poltalloch	4·04	105
Cornwall	Bude, School House ...	3·18	130	,,	Inveraray Castle ...	6·82	108
,,	Penzance, Morrab Gdns.	3·98	124	,,	Islay, Eallabus	3·62	95
,,	St. Austell	4·30	125	,,	Tiree	4·71	141
,,	Scilly, Tresco Abbey ...	3·25	124	*Kinross*	Loch Leven Sluice ...	3·58	120
Glos.	Cirencester	3·19	138	*Fife*	Leuchars Airfield ...	1·78	91
Salop	Church Stretton ...	2·06	85	*Perth*	Loch Dhu	...	...
,,	Shrewsbury	1·25	75	,,	Crieff, Strathearn Hyd.	3·63	113
Worcs.	Malvern, Free Library ...	2·24	115	,,	Pitlochry, Fincastle ...	2·35	85
Warwick	Birmingham, Edgbaston	2·49	130	*Angus*	Montrose, Sunnyside ...	3·33	160
Leics.	Thornton Reservoir ...	2·87	156	*Aberd.*	Braemar	1·93	65
Lincs.	Boston, Skirbeck ...	2·35	151	,,	Dyce, Craibstone ...	3·86	146
,,	Skegness, Marine Gdns.	2·55	154	,,	New Deer School House	2·03	78
Notts.	Mansfield, Carr Bank ...	2·00	96	*Moray*	Gordon Castle	1·84	79
Derby	Buxton, Terrace Slopes	3·16	77	*Nairn*	Nairn, Achareidh ...	1·38	75
Ches.	Bidston Observatory ...	1·63	86	*Inverness*	Loch Ness, Garthbeg ...	·78	53
Lancs.	Manchester, Whit. Park	2·40	106	,,	Glenquoich	9·00	93
,,	Stonyhurst College ...	2·22	60	,,	Fort William, Teviot ...	5·86	87
,,	Squires Gate	1·71	76	,,	Skye, Duntuilm ...	4·37	99
Yorks.	Wakefield, Clarence Pk.	1·58	88	,,	Skye, Broadford ...	6·68	110
,,	Hull, Pearson Park ...	2·53	139	*R. & C.*	Tain, Tarlogie House ...	2·66	48
,,	Felixkirk, Mt. St. John ...	1·90	96	,,	Inverbroom, Glackour ...	3·13	63
,,	York Museum	2·24	133	,,	Achnashellach	5·06	75
,,	Scarborough	1·70	94	*Suth.*	Loch More, Achfary ...	...	...
,,	Middlesbrough	1·20	76	*Caith.*	Wick Airfield	2·80	123
,,	Baldersdale, Hury Res.	1·61	56	*Shetland*	Lerwick Observatory ...	6·15	195
Norl'd.	Newcastle, Leazes Pk....	1·05	51	*Ferm.*	Crom Castle	2·24	72
,,	Bellingham, High Green	2·46	84	*Armagh*	Armagh Observatory ...	1·42	60
,,	Lilburn Tower Gdns. ...	1·57	59	*Down*	Seaforde	1·41	48
Cumb.	Geltsdale	1·26	45	*Antrim*	Aldergrove Airfield ...	1·42	57
,,	Keswick, High Hill ...	2·38	53	,,	Ballymena, Harryville ...	2·08	66
,,	Ravenglass, The Grove	2·45	79	*L'derry*	Garvagh, Moneydig ...	2·09	67
Mon.	Abergavenny, Larchfield	2·06	68	,,	Londonderry, Creggan	2·00	63
Glam.	Ystalyfera, Wern House	5·65	105	*Tyrone*	Omagh, Edenfel ...	2·05	65

M.O. 559 AIR MINISTRY

METEOROLOGICAL OFFICE

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FORECASTING FOR THE D DAY LANDINGS*

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

The following account of the D day forecast has been written from the point of view of one of the forecasters at the British Central Forecasting Office, which along with its counterparts in the Admiralty and in the Weather Service of the U.S. Air Forces then in this country, took part by telephone in the meteorological conferences which invariably preceded the formulation of the weather forecasts given to the Supreme Commander. The account draws largely on the report to the Supreme Commander made by Group-Captain J. M. Stagg, Chief Meteorological Officer, SHAEF.

The wind and weather are vital factors in all modern operations of war. The demands of all the Services for forecasts really require a much higher standard than is at present attainable, or is likely in any near future. This refers more especially to the length of the time interval, but in the case of some operations, particularly air operations, the degree of precision required is sometimes difficult to attain even for short periods ahead. Nevertheless the Service Chiefs have always been grateful for anything they can get in the way of forecasts. Meteorology was quite important in the first World War, and still more important in the second, and in spite of the difficulties of forecasting the relations between the meteorologists and the Service Chiefs have been on the whole very good.

A sea-borne invasion of a strongly defended area is an exceptionally difficult operation, and in a region like the northern French coast it is by no means free from major weather hazards at any season of the year. It is only from May to September that it could seriously be contemplated. It is not only necessary to secure a footing in enemy-held territory, but also to build up rapidly a properly equipped force, large enough to withstand the concentrated attacks of the enemy which can be brought to bear within a few days. It was considered important to have 10 days of reasonably quiet weather after the first landings. The probability of this can only be deduced from climatological statistics, but synoptic forecasting can be helpful for the vital first few days. The task of the meteorologists would have been greatly eased if the date of the assault could have been decided at short notice when the weather conditions were really settled, but that was impossible owing to the special tidal conditions required for an invasion of Normandy. In any case there was no settled spell during June or July 1944 and it would have been impossible to keep a large invading force waiting indefinitely for suitable weather. The carrying out of the operation in unsettled weather involved a

* This article is reprinted from the Marine Observer Vol. XXIII. No. 155, January, 1952, in view of its exceptional interest to all meteorologists.

small but definite element of serious risk. Though the chances of two or three successive days of very adverse weather in summer are small, they are not negligible. Such a development did in fact occur on June 19–21, when there was a spell of NE. wind of force 6–7, unpredecented at such an advanced period in the summer. Had this occurred immediately after D day the result might well have been catastrophic. Owing to the tidal factor D day would have been on June 17 or 18, had it not been for the courage of General Eisenhower in issuing orders to go ahead in a marginal situation in the early morning of June 5. In the event the result was satisfactory from the standpoint of meteorology. The date of the assault was postponed from June 5 until June 6 as the result of meteorological advice, to the great advantage of the operation, and the forecasts for June 6 enabled the assault to proceed. The actual conditions on D day were good on the western beaches sheltered by the Cherbourg Peninsula, and though further east the sea was distinctly rough, this was unavoidable and the difficulties were successfully overcome.

Period of preparation.—The synoptic climatology of the area was studied well in advance by the meteorological services who would be jointly responsible for the forecasts, namely, the Meteorological Office, the Naval Meteorological Service and the Weather Service of the U.S. Army Air Force. Statistics showed that June was the best month, but the postponement from the date originally planned in early May was due entirely to the fact that more time was required for the military preparations. In 1944 May was a much better month than June, so that the postponement was very regrettable, though unavoidable. The fine weather was not wholly wasted as there was heavy bombing of railway targets in France. Past records showed that a combination of the good weather wanted for the whole period of the landings, and at one time thought necessary, along with suitable tidal conditions was unlikely to occur, and it became necessary to define a set of minimum meteorological conditions which could be accepted by all arms as being the worst conditions in which the operation could be launched. These were never wholly accepted by all the forces, but they represented the conditions which the meteorological section at SHAEF (General Eisenhower's Headquarters) kept in mind. These minimum conditions included a wind of not more than force 3 on shore or force 4 off shore from D day to D day plus 2. The actual conditions on the eastern beaches on D day and the following day were slightly worse than this, which shows how very marginal the position was. It was also necessary to have cloud conditions in which our bombers could operate successfully, and this included suitable weather in the base area.

In February 1944 telephone conferences were instituted between the three Central Forecasting Centres at Dunstable, the Admiralty and Widewing. The last mentioned was the Headquarters of the U.S. Army Air Force and was in the same set of buildings as SHAEF. The Chief Meteorological Officer at SHAEF (Group-Captain J. M. Stagg) or his deputy (Colonel Yates of the U.S. Army Air Force) acted as chairman of the conference. The early conferences were held two or three times a week with the idea of producing an agreed five-day forecast. This attempt was made in reponse to strong pressure from the Services, but the experiment soon showed, as one would expect, that except in settled weather the forecasts of the three centres differed widely, so that an agreed forecast had low confidence and meant very little. As the time of the operation approached there was an increasing concentration on the first 48 hours, and though some sort of outlook for the following three days was given it was nearly always with low confidence, and it is unlikely that it had much practical application. From mid April onwards the conferences were held twice daily, and during much of May, when operational forecasts were required for preliminary manoeuvres in the Channel, they were held three times daily. The Meteorological Staff Officer of the Naval Commander-in-Chief and the Chief Meteorological Officer at Headquarters, Allied Expeditionary Air Force, also took part in these conferences. On the days immediately preceding D day a further conference was held at 0300 (double summer time) each morning, on which to base the final advice given to the Supreme Commander's meetings at 0415.

The important forecasts of sea and swell were made throughout the period by the Forecasting Office at the Admiralty. They had carried out extensive research into this subject, particularly the swell from Atlantic depressions. The disadvantage of swell diminished as larger landing craft became available, but nevertheless a heavy swell had to be avoided.

Operational period.—Shortly before D day observations became available from meteorological ships in the Atlantic. During most of the war the lack of information from the Atlantic was a serious handicap. Reconnaissance flights were of immense value, but they could not be made frequently enough or go far enough to west to enable the forecaster to obtain an accurate picture of the Atlantic situation. The charts accompanying this article show that by D day there was a very considerable amount of information available. Lack of information from certain areas gave rise to some difficulties during the D day period, but the information actually obtained was vital and indeed indispensable to the 48-hr. forecasts. Radio soundings of upper air temperature were also carried out, and there was enough information to determine the main features of the distribution of upper air pressure and therefore of wind across the Atlantic.

A fine quiet spell in late May 1944 was followed by a change to an unsettled westerly type of weather. A few days before June 5, the date originally fixed for the landings, it looked as if the weather in the Channel area would be marginal in type, in the intermediate region between a belt of high pressure over France and depressions to northward. It was impossible to hold out a favourable prospect, but until the evening of June 3 the outlook was too doubtful to justify a definite postponement of the landings, a contingency to be avoided if possible. The provisional decision to postpone the assault for 24 hr. was made at the Supreme Commander's meeting at 2130 on June 3, after the evening meteorological conference, and this decision was made final after the meeting at 0415 (double summer time) on the 4th, following another meteorological conference. The 1800 chart on the 3rd is shown in Fig. 1. Two depressions on the Atlantic were moving east-north-east toward the Orkney-Shetland area, and the rate of fall of pressure in the north-west part of the British Isles was in itself sufficient to ensure that the wind in the English Channel would freshen from SW., bringing in low clouds from the Atlantic. This happened next day, as can be seen in Fig. 2, the 1800 chart for the 4th. A cold front went through the Channel area during the early hours of the 5th, and behind it the wind moderated, but around dawn the sea must still have been rough and the cloud conditions were quite unsuitable for the airborne landings or for bombing. Thus the decision to postpone the landings on meteorological grounds was fully justified by the event.

Provisional instructions to launch the assault at 0630 on the morning of Tuesday, June 6, were issued after the Supreme Commander's meeting at 2100 (double summer time) on Sunday, June 4, following the evening meteorological conference. During the morning of the 4th it became clear that the cold front which reached the Irish coast soon after 1000 G.M.T. would go well south of the French coast and that a relatively fair interval would follow.

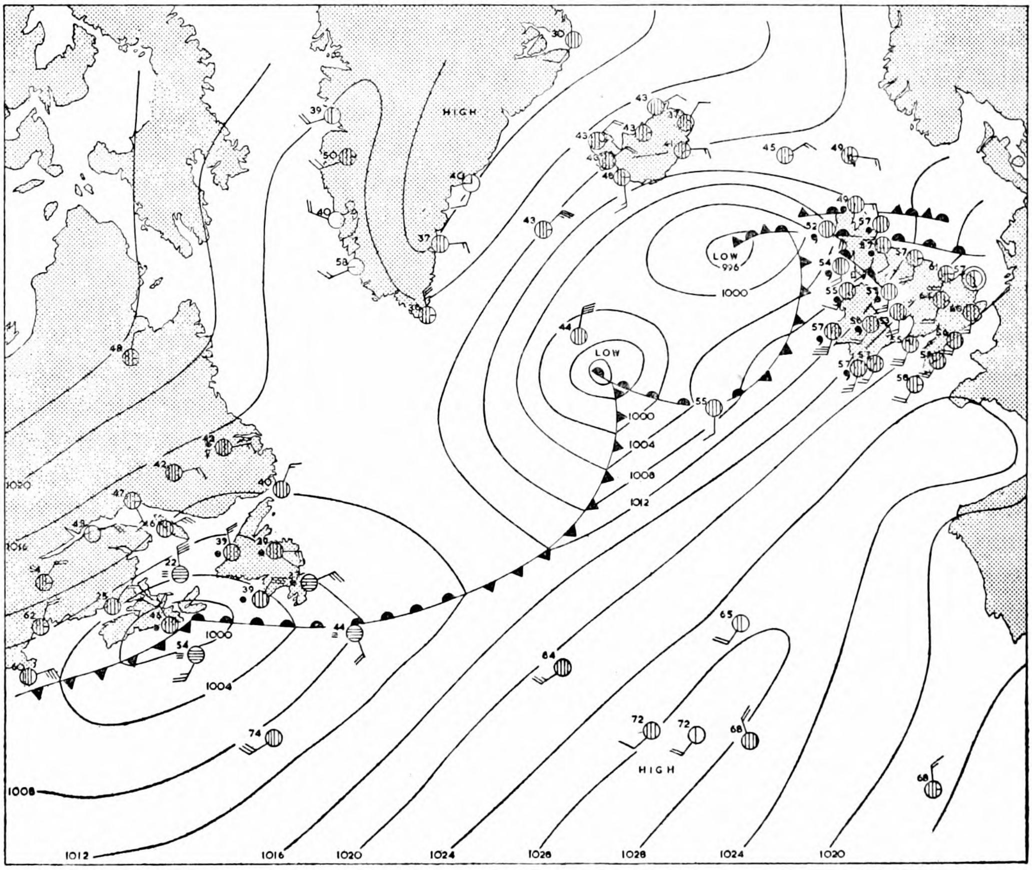

FIG. 1—WEATHER MAP FOR 1800 G.M.T., JUNE 3, 1944

This weather map is broadly the one on which the decision to postpone the assault from June 5 until June 6 was made.

The final and irrevocable decision to launch the assault was made after the meeting at 0415 (double summer time) on Monday the 5th, which was preceded by another meteorological conference. Fig. 2 shows the last main chart available at the time of the conference. The advice given at the Supreme Commander's meeting was as follows.:

> The fair to fine interval which by 0415 had begun at Portsmouth will probably last into the forenoon of Tuesday. During this interval, cloud will be mainly less than 5 tenths, with base at 2,500–3,000 ft.
>
> Wind on the beaches in the assault area will probably not exceed force 3 in this interval and will be westerly. Visibility will be good.
>
> During Tuesday cloud will very probably increase again from the west, giving a period of overcast sky with cloud base at about 1,000 ft. in the assault area later in the day; these cloud conditions will continue overnight Tuesday to Wednesday. Winds will be westerly force 4 on the English coasts and mainly force 3 on the French coasts.

Conditions will probably continue unsettled after Tuesday and it is difficult to time further changes. But it is likely that after another front has passed on Wednesday, when the 10 tenths cloud at 1,000 ft. lasting over Tuesday night becomes broken, the cloud base will increase to 2,000–3,000 ft., though the average amount will probably remain at about 7 tenths. In this period from the passage of Wednesday's front till about Friday, beyond which no useful forecast can be given, there will be intervals of completely overcast sky with cloud base down to 1,000 ft. Considerable fair intervals of broken cloud can reasonably be expected between the overcast intervals. Visibility will be good throughout.

The chart on which the forecast was based (Fig. 2) was an unusual one for the time of the year, with a very deep depression off north-west Scotland and another off Labrador, and the situation was difficult from the point of

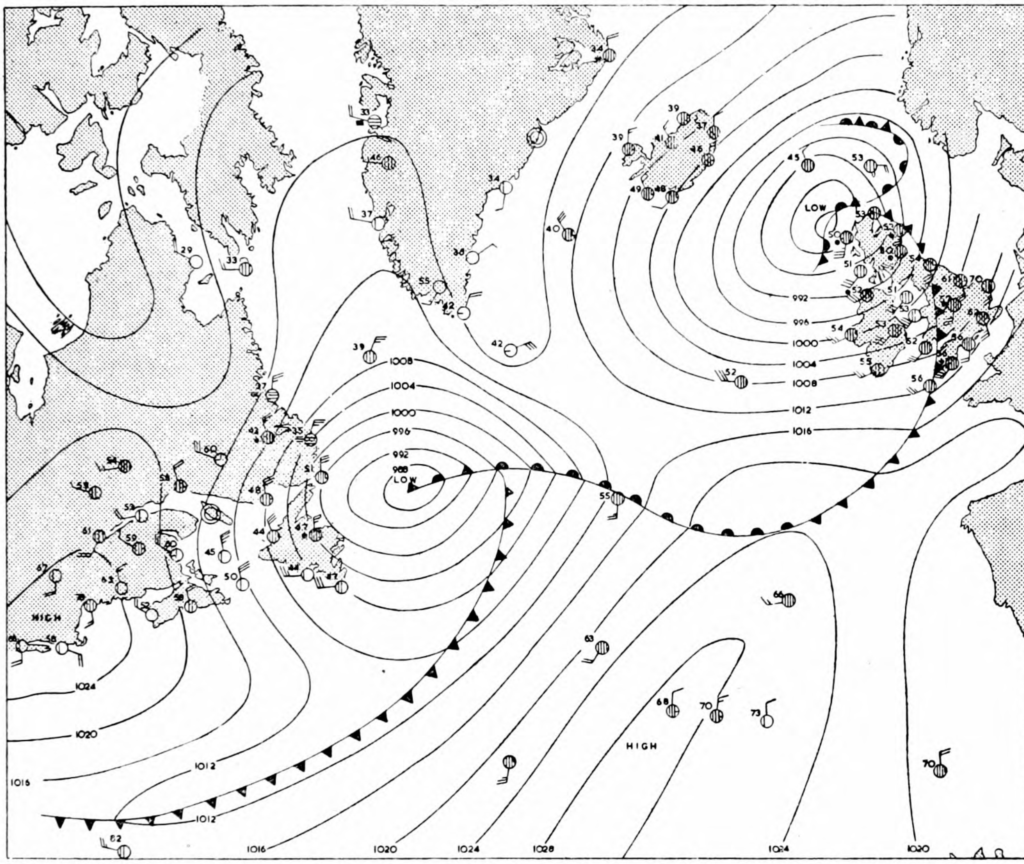

FIG. 2—WEATHER MAP FOR 1800 G.M.T., JUNE 4, 1944
The weather map on which the decision was made to launch the assault on June 6.

view of extended forecasting. The depression moving along the north Scottish coast was the more westerly one on the Atlantic in Fig. 1, which had absorbed the one further east, and it became still deeper during the night until at 0400 on the 5th pressure fell to 976·8 mb. at Wick. This was the lowest June pressure of this century in the British Isles up till then, though curiously enough there was a lower reading, also at Wick, exactly two years later, on June 5, 1946, when 975·8 mb. was recorded. Such a deep depression obviously precluded the possibility of a quiet spell, but, in the conditions prevailing, a very vigorous depression was needed to bring the cold front to southward of the coast of Normandy. If there had been a prolongation of the warm south-westerly air stream, as had at one time appeared likely, there would have been more low cloud, especially in the mornings, and weather would have been worse for air operations than it actually was.

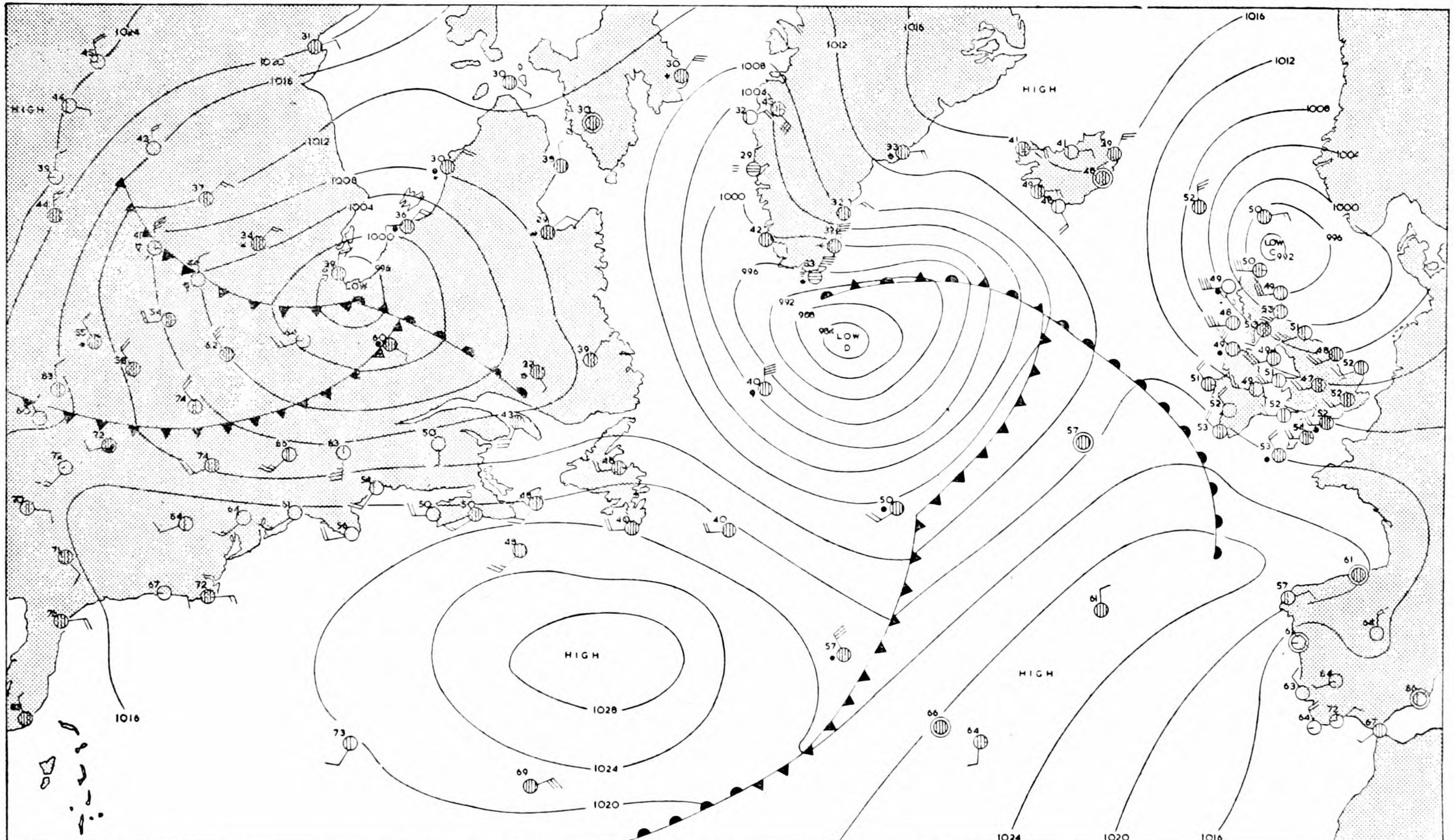

FIG. 3—WEATHER MAP FOR 0700 G.M.T., JUNE 6, 1944
This shows the weather on the morning of the assault.

On the morning of June 6, when the first and most important landings were made, the weather was quite good (see Fig. 3). The wind at the beach-head was WNW. force 3, becoming 3–4. The clouds cleared temporarily over the beach-head at a critical time when our bombers were over in force. The cloud amount during the day was half to three-quarters cover between 3,000 and 7,000 ft., and visibility was excellent. The depression off north-east Scotland moved south-eastward during the day, becoming less deep. A small trough of low pressure moved south-east over Great Britain and this increased the wind in the beach-head area, which reached force 5 at times later in the day.

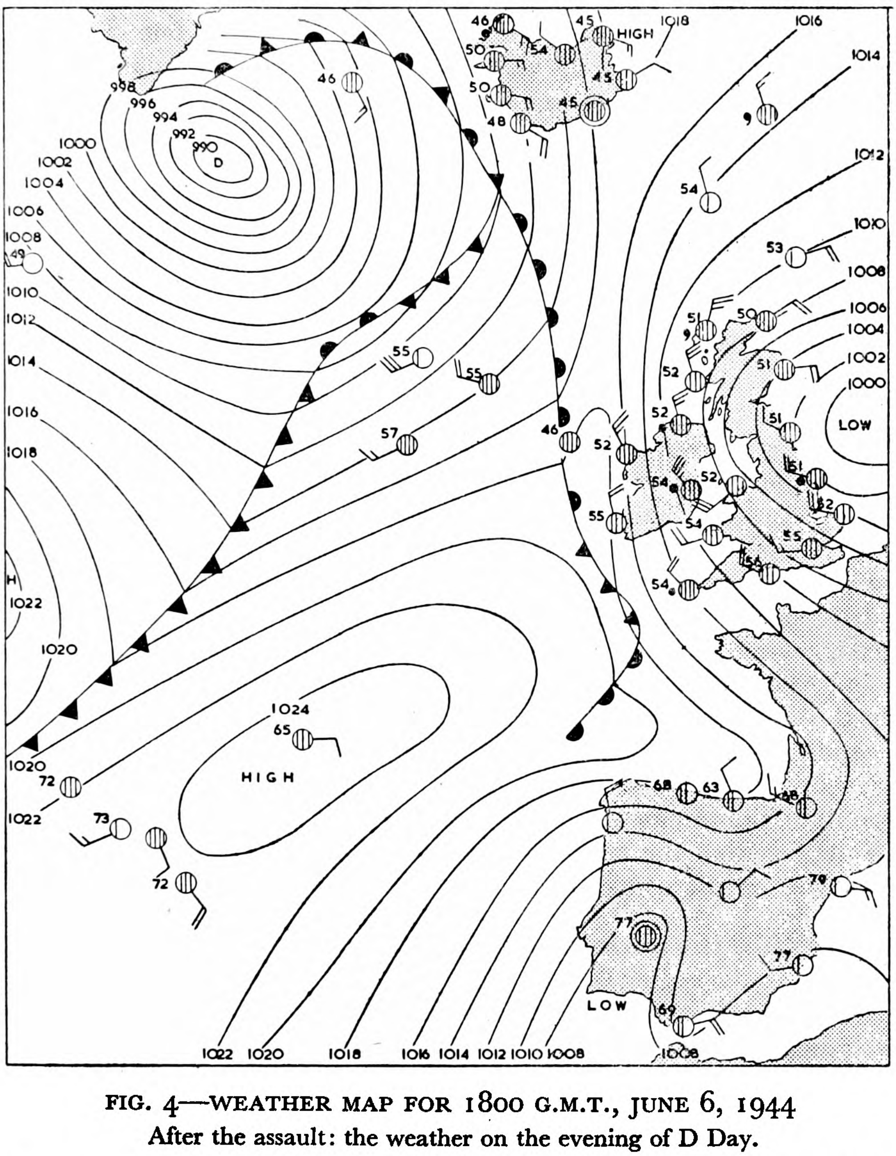

FIG. 4—WEATHER MAP FOR 1800 G.M.T., JUNE 6, 1944
After the assault: the weather on the evening of D Day.

The 1800 chart is shown in Fig. 4. This freshening of the wind caused difficulties on the more easterly part of the beach-head which was exposed to a WNW. wind, and even the force 4 wind during the morning was too strong. This was an unavoidable trouble, as a landing on that day was essential if at all possible. Additional casualties due to the rough seas were probably more than offset by the advantages of obtaining tactical surprise, which was due largely, if not entirely, to the very unsettled weather. The enemy made regular daily reconnaissance flights to northward of Scotland and to westward of Ireland, and undoubtedly knew about the exceptionally deep depression off north-east Scotland. There is definite evidence that they thought that we could not attack in such weather, and that they were taken completely by surprise. They failed to allow for the technical advances that had been made in landing craft. Another vital factor was the courage of General Eisenhower in going ahead in such dubious weather, with no prospect of the settled fair spell that had been hoped for. The only alternative was a postponement until the tides were again favourable. As we shall see shortly, the weather played one of its unkindest tricks at precisely that time, and in fact there was one of the very few possible summer developments that could have led to disaster. Quite apart from this unknown factor, there were obviously very strong reasons against postponement, which would have been bad for morale and would have involved a serious risk of leakage. But this does not alter the fact that the supreme responsibility for making the decision fell on General Eisenhower, a man to whom the entire civilized world is in debt.

A point of interest in Fig. 4 is the small warm-front wave which was moving south-south-east off the Scilly Isles. This produced some light rain from medium cloud in south-west Ireland and at Scilly, and the medium cloud was seen to westward from aircraft over the beach-head. Behind the small wave the warm front retreated slightly. Though the unexpected south-east movement of the depression freshened the wind in the Channel it also resulted in the advance of the warm front being delayed for 36 hours if not longer. If the Shetlands depression had filled up *in situ* or drifted away north-east or east, there can be no doubt that the warm front would have affected the beach-head area much earlier than it actually did. By June 8 the North-Sea depression had partly filled up and moved away eastward and the warm front then advanced, giving a period of moderate rain over the beach-head area in the afternoon. The effect of the south-east movement of the depression was to impede the landings on the eastern beaches on D day, but it also improved cloud conditions and thus facilitated air operations from the evening or night of D day until the afternoon of June 8. It would require a close knowledge of the military problems to decide which effect was most important, but in view of the fact that the landing difficulties were overcome it is probable that the result was on the whole beneficial.

Weather after the initial landings.—An unsettled westerly type of weather prevailed for 10 days after D day. There were some fair intervals with very good visibility, but on the whole the weather was worse than is normal in June. Poor weather predominated for the whole summer and autumn, and the only prolonged good weather was in the first half of August. This fair spell was beneficial to the series of operations which culminated in the victory at Falaise.

On June 17 there was a wedge of high pressure moving slowly over Ireland and Scotland, and on the 18th its crest was in the Irish Sea area. The prospect certainly looked better than it had at any time since May, though that is saying very little. If the landings had been postponed from June 6 they would almost certainly have been carried out at this time, probably on the morning of the 18th. Then followed one of those unique and unpredictable developments to which the atmosphere is prone. A cold front which at 0700 on the 17th

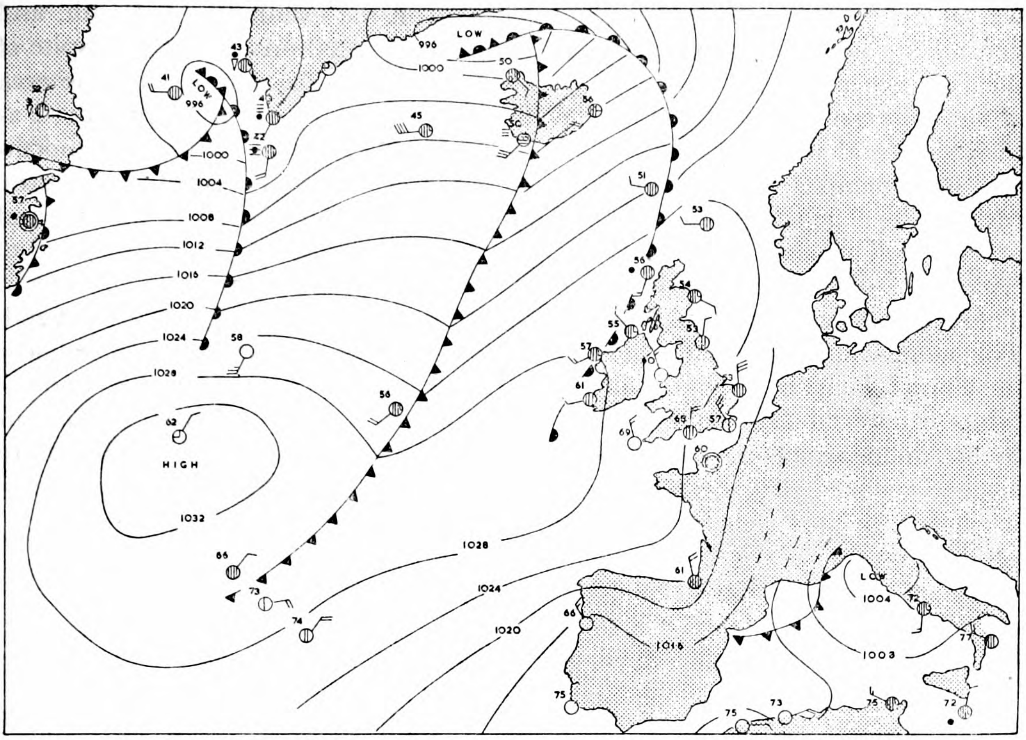

FIG. 5—WEATHER MAP FOR 1800 G.M.T., JUNE 17, 1944

If D Day had been posponed the assault would have been launched soon after this date. This then shows the weather map on which the decision to carry out the operation might have been made.

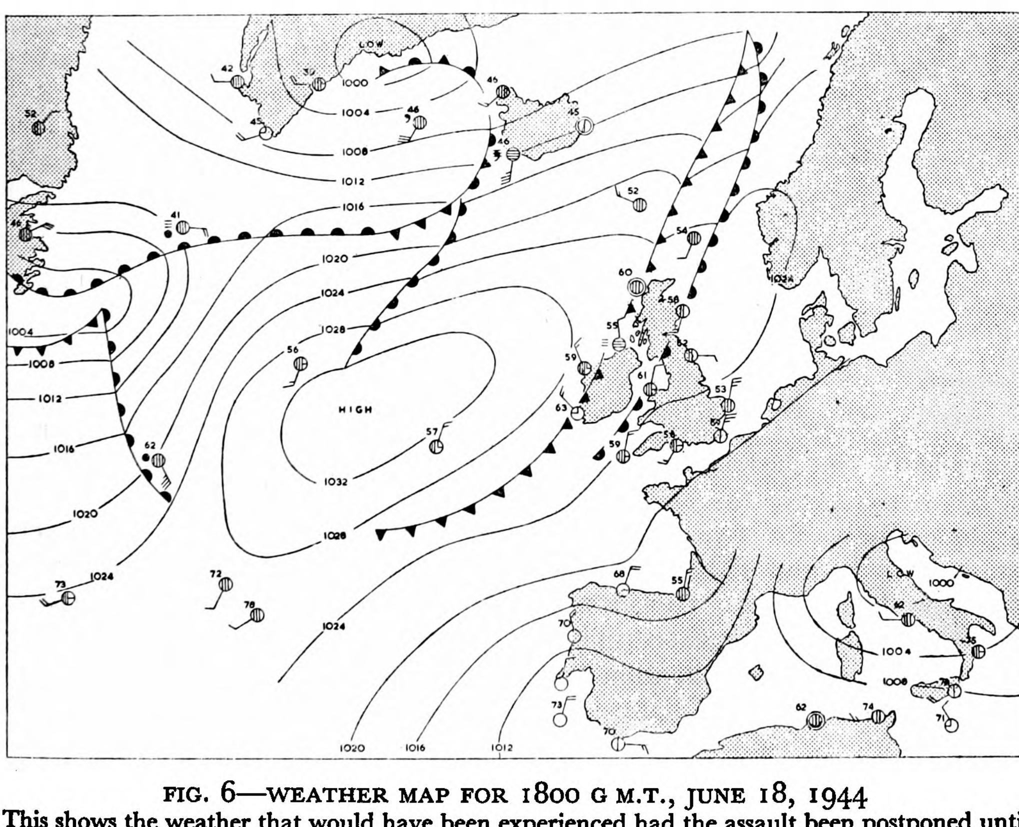

FIG. 6—WEATHER MAP FOR 1800 G M.T., JUNE 18, 1944

This shows the weather that would have been experienced had the assault been postponed until the next period of favourable tides.

was at 29°W. reached our north-west coasts on the evening of the 18th, and behind it a large rise of pressure set in which persisted on the 19th, in spite of the advance of a warm front and then another cold front right into the area of rising pressure. The 1800 G.M.T. charts for June 17–19 are reproduced as Figs. 5–7, and they show this development which had the nature of a north-east movement of an anticyclone from the area to north-west of the Azores. Meanwhile a depression in the Mediterranean deepened and spread north, and pressure fell in south and south-west Europe. During the 19th a NE. wind of force 6–7 developed in the Channel and this continued over the 20th. There was only a slight decrease on the 21st but a large decrease by the 22nd. The wind was only slightly below its geostrophic value and was intensified near the French coast by topographical influence. It caused some loss of life and enormous material damage, including the destruction of the "Mulberry" harbour in the American sector. Fortunately the Americans were able to seize Cherbourg

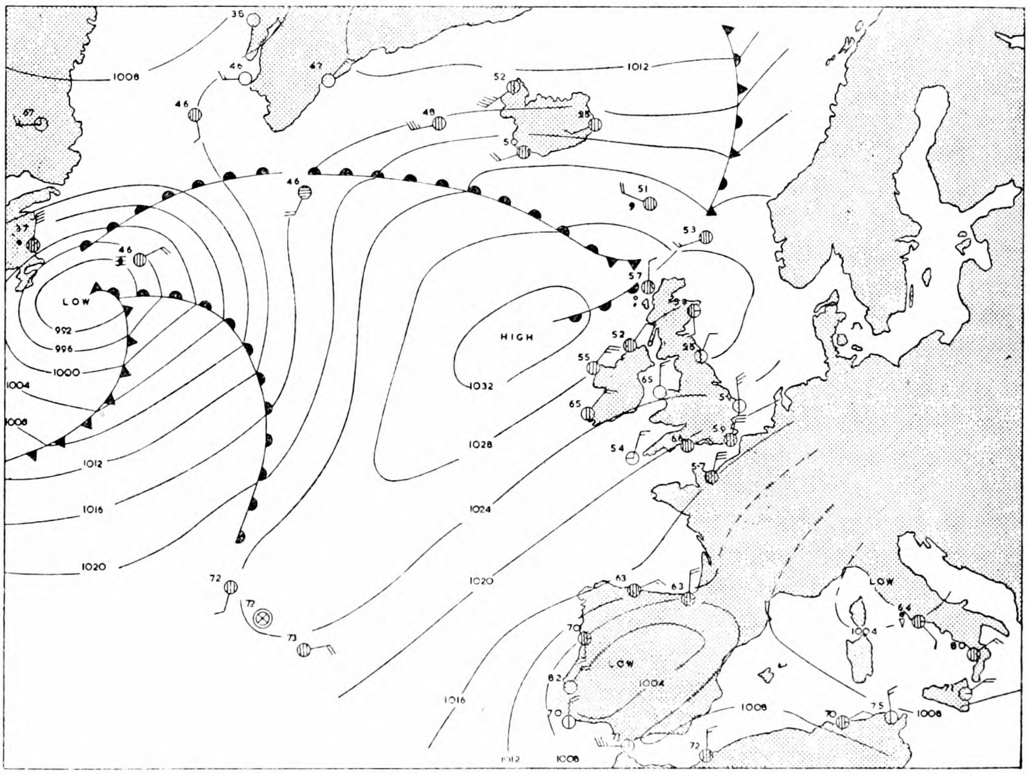

FIG. 7—WEATHER MAP FOR 1800 G.M.T., JUNE 19, 1944

This is the situation producing the wind that caused enormous material damage to the Allied landing forces. Had the winds occurred immediately after D Day the results might well have been catastrophic.

not long afterwards. Even a fortnight after D day the high winds were a very serious episode, and if they had occurred immediately after D day the results might well have been catastrophic. Thanks to the courage of General Eisenhower this possible catastrophe was avoided.

Long before D day attention had been called to the potential danger of strong NE. winds in the Channel, with special reference to the case of May 8, 1935, when there had been an unexpected development of force 6–7 winds, but the development in 1944 was different, and analogies of this kind have almost no forecasting value. The ease with which a NE.–E. gale develops in the

Channel in winter and spring has long been recognized, but the frequency decreases rapidly as the season advances, and after mid June prolonged NE.–E. winds of force 6 or over are almost unknown. There were strong NE. winds in early June 1939, but their onset was not sudden and there has been no other such spell in June during the present century. A development which only occurs about once in a century and which develops out of a situation which is common in its broad features, is not one which can be predicted on the basis of past experience. The development of June 19–20 was not forecast on the 18th, and it is difficult to see in retrospect how it could have been. Still less would it have been possible to foresee it in the early morning of the 17th, when the decision to start the assault would have been made if it had been postponed on the 6th.

As events actually worked out the result was satisfactory from the point of view of the meteorologist. The time taken for the operation and its restriction to a limited number of possible dates made some degree of weather hazard quite probable, and it was a great relief that everything went so well. The vital forecasts were good for an interval of rather more than 36 hr. from the chart on which they were based, and though there were some errors in the outlook beyond that time they were certainly no greater than can normally be expected in a time interval of such length in changeable weather, and were probably less. General Eisenhower expressed his satisfaction with the meteorological advice he received. He sent a personal letter of thanks to the forecasters who took part in the telephone conferences, a remarkable act of courtesy considering the immense burden of work and responsibility which he was carrying. He regarded the meteorological advice received as supplying adequate grounds for going ahead, having regard to all the other factors. If the forecasters had played for safety too much and introduced a pessimistic bias into their forecasts, the vital decision of the Supreme Commander would have been made more difficult, or even prevented altogether.

WORLD METEOROLOGICAL ORGANIZATION

Third Telecommunications Sub-Commission Meeting, Paris, February 1952

By C. V. OCKENDEN, B.Sc.

Short accounts of the first and second meetings of the International Meteorological Organization European Sub-Commission for the Transmission of Weather Information were published in the *Meteorological Magazine* for October 1948 and August 1949. The third meeting, the first one to be held since the formation of the World Meteorological Organization, took place in Paris on February 11–23, 1952.

The sessions were held in the Palais d'Orsay, and representatives were present from Belgium, Denmark, Egypt, France, Ireland, Italy, Netherlands, Norway, Portugal, Poland, Sweden, Switzerland, United Kingdom, Yugoslavia, the Allied Meteorological Board, the Bad Eilsen Centre, the U.S. Air Force and Rhine Main Centre, the International Air Transport Association, the International Civil Aviation Organization and the World Meteorological Organization.

Many countries in Region VI (Europe) of the World Meteorological Organization are now becoming largely independent of radio broadcasts for the reception of synoptic data since they are served by teleprinter broadcasts.

Further connexions to these broadcasts have been established in the last few years with the result that certain circuits now extend in the north to Helsinki and in the south to Rome. The basis of the network will also undergo a change in the relatively near future; instead of this being in the nature of a quadrilateral with main centres at Dunstable, Paris, Bad Eilsen and Rhine Main, circuits will be re-arranged to form a triangle based on Dunstable, Frankfurt and Paris. Paris will originate two broadcasts on independent circuits, one for European data and the other for North American and selected northern-hemisphere data.

The possibility of replacing W/T morse broadcasts by radio-teleprinter broadcasts in the future was raised; this would enable data to be transmitted at nearly three times the present speed and would permit rediffusion by simple tape-relay. The Sub-Commission felt, however, that several years must elapse before sufficient necessary apparatus is likely to be available; accordingly it set up a small working panel to give the matter further study.

The rapidly growing demand for data to facilitate the construction of charts of the whole of the northern hemisphere was reflected in many documents produced at the meeting, and considerable discussion took place on the means by which surface and upper air data for twice-daily charts could best be collected and disseminated. A recommendation was made that the President of Region IV (North and Central America) should be asked if a limited amount of such data could be transmitted on the transatlantic radio-teleprinter circuit.

The development of facsimile apparatus to enable weather maps to be exchanged was dealt with by a special working group, and animated discussion evidenced the growing interest taken by many countries in this method of disseminating meteorological information. The meeting fully appreciated the great importance of securing that facsimile apparatus which is being developed in several different European countries should be standardized to the maximum extent possible, and it was also generally agreed that the scanning density of 5·3 lines per millimetre agreed at the last meeting of the Sub-Commission is unnecessarily high. In order that machines shall work into each other it is necessary that they shall have the same index of co-operation* and the same speed of rotation of the drum. The sub-commission considered that a rotation speed of 60 rev./min. with multiples or submultiples should be adopted, and recommended that 576 be considered by the International Telecommunications Union as one of the indices of co-operation which might be standardized for meteorological purposes. British apparatus which is being developed will conform to the proposed specification; it is continuously recording, the scanning density is 96 lines/in. and the drum of the transmitter is 6 in. in diameter and 22 in. in length. The Sub-Commission felt that it would be premature to frame any recommendation concerning plans for international facsimile exchanges until countries are able to make some statement as to their intentions based upon the results of experimental national transmissions.

Delegates were invited to a reception given by the French Ministry of Foreign Affairs at the Hotel Crillon before the close of the Session. The French broad-

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*The international index of co-operation is defined by the formula

$$M = \frac{D}{P} = DF$$

where D = diameter of drum, P = scanning pitch (in the same units), and F = number of lines per unit length of drum.

casting service included an account of the work of the Conference in one of its programmes and invited the United Kingdom delegate to speak on the British point of view.

CLOUD PHOTOGRAPHS TAKEN FROM COMET AIRCRAFT

By G. W. HURST, B.Sc.

Development flights from the United Kingdom to the Far East have recently been undertaken by B.O.A.C. Comet aircraft, and it proved possible for arrangements to be made for some photographs to be obtained of the appearance of Middle-East and Far-East weather from above. Notable photographs have been taken of monsoon activity over India, Burma and Malaya. On the third (and last) of this particular series of flights (from which many of these photographs have been chosen) Mr. E. Chambers of B.O.A.C. and Mr. D. G. Harley of the Meteorological Office actually flew and took the photographs. The Captains of the aircraft were Captain Majendie on the first and third trips and Captain Rodley on the second; it is due to their most helpful co-operation and assistance together with that of Mr. Chambers, with whom plans were originally made, that the photographs were possible at all.

The equipment used was a normal R.A.F. type F.24 camera with a focal length of 8 in. and a format size of 5 in. × 5 in. A red filter was used throughout, the exposure was 1/500 sec., and aperture varied in the range *f* 5·6–8. Photographs were mostly taken from 35,000 ft. or above (in some cases well above) and the camera was mounted as a side (port) oblique with an angle of depression of about 10° below the true horizontal. The photographs were taken from a rear passenger window and in all those reproduced in the centre of this magazine the tip of the port wing can be seen.

Fig. 1 was taken from 38,500 ft. over the toe of Italy at 1410 local time on September 4, looking south-west. Part of an extensive cirrostratus sheet is seen. This sheet was almost unbroken for several hundred miles, and was associated with a shallow (thundery) surface low to the south-east of Italy. The pilot stated that cloud of this nature (on this occassion at 36,000 ft.) was quite frequent in the central Mediterranean, and was often thin, non-frontal and was not forecast. It was however thick enough, as this photograph shows, to mask any cloud which might have been below the aircraft. There is a break in this cloud sheet in the top right of the print, and some cumulus heads are visible, probably associated with the thundery activity, and centred over Sicily or near the Strait of Messina.

Fig. 2 was taken about five minutes later than Fig. 1 and shows the cirrostratus layer breaking up. On the horizon is a massive cumulonimbus which may well have been associated with Etna. The cloudscape revealed by the clearance of the cirrostratus is complex, and well developed cumulus to over 30,000 ft. and much rather chaotic altocumulus at 15,000–20,000 ft. are seen.

Figs. 3–6 (in the centre of the Magazine) were taken on October 1 from the Comet when it was flying from Karachi to Bombay at a height of 33,000 ft. at about 1420 local time. The aircraft was flying over the peninsula of Kathiawar which is on the whole fairly flat, though there are a few hills to about 2,000 ft. and one to 3,600 ft. The peninsula is 150 miles wide from north-west to south-east. It happened that the track of the aircraft carried it to within five miles or so of a massive cumulonimbus so the pilot took a sequence of four shots over a period of about three minutes to try to record it photographically. In Fig. 3 is seen the type of cloud which was typical of that flown over in the north earlier and over low ground—well broken fair-weather cumulus at a few thousand feet with little vertical development. The details on the right-hand side of the print are practically lost in the cirrus cloud. In Fig. 4 the anvil has largely spread over the print; the greater horizontal extent of the cloud at its top will be noted. Fig. 5 is to the south-west of the cumulonimbus, and other cloud formations can be seen in the lower right-hand side of the photograph. It will be noted that the upper sloping line of the cumulonimbus is much harder than the corresponding line in Fig. 4; this is probably due in part to the cloud being more distant. In Fig. 6 is seen the edge of the anvil (which extended up to well over 40,000 ft.) and a massive cumulus which had already attained a height of about 40,000 ft. and was still building as there is no evidence of spreading out into anvil form. It is interesting to note how isolated these two clouds are; it seems that if the building cumulus can break through to above 15,000–20,000 ft., instability above those levels is sufficient to maintain convection. Possibly the higher ground of Kathiawar was sufficient to cause the necessary trigger action. Also to be seen in Fig. 6 are a thin layer of altocumulus at about 15,000 ft. and the southern coastline of Kathiawar, in the vicinity of Jafarabad.

Fig. 7 was taken near Ujjain in the west of the Central Provinces, India, from 36,000 ft. at about 1245 local time on September 3. The flight was from Calcutta to Karachi, and the direction of the view was south or south-south-west. The photograph shows the top of an altocumulus layer at about 17,000 ft. through which a still developing cumulus has built up. The top of the cloud is already well over 40,000 ft. A similar cloud will be noted in the left foreground. Banded cirrus is visible in the distance.

Fig. 8 was taken over eastern Malaya (at about 5°N.) at 0940 local time on October 14 when the aircraft was flying in a north-north-westerly direction towards Bangkok. The height of the aircraft when the photographs were taken was 34,000 ft. and a very varied cloudscape is seen. The lowest cloud is cumulus over the land. This is mainly small, fair-weather cumulus with an apparent tendency to spread out into stratocumulus; there is however an occasional cloud of rather greater vertical development with a thickness of a few thousand feet. Over this layer is a contrasting, apparently darker, layer of cirrocumulus at a height of about 25,000 ft. This is obviously not a thick cloud but it is sufficiently dense to block out completely all the lower cloud. This high cloud layer was fairly short-lived and only lasted a few miles, but the low cumulus cloud persisted over the entire mainland of Malaya. Also visible is cirrostratus at 40,000 ft. or so—well above the height of the aircraft.

METEOROLOGICAL OFFICE DISCUSSION

Diurnal and seasonal variation of visibility

The subject for discussion on Monday, March 10, 1952, was "Visibility—its diurnal and seasonal variation and its dependence upon atmospheric pollution as determined by wind speed and direction". The openers were Mr. L. Sugden and Mr. H. L. Wright.

Mr. Sugden, in his introductory remarks, said that the material of his opening statement was derived largely from the following papers:—

CORBY, G. A.; The visibility characteristics of Northolt Airport[1]

SAUNDERS, W. E. and SUMMERSBY, W. D.; Fog at Northolt Airport[2]

DAVIS, N. E.; Fog at London Airport[3].

For localities other than Northolt and London Airports use was made of tabulated data and remarks provided by local meteorological officers.

The most important factors in the diurnal and seasonal variation of visibility were:—

(i) Ratio of incoming to outgoing radiation, broadly resolving itself into the ratio of the length of day to night together with the elevation of the sun.

(ii) General synoptic situation prevailing which determined the amount of air movement, the prevailing humidity, the likelihood of restriction of visibility by precipitation, more particularly by snow, and to some extent the likelihood of fogs due to the mixing of air masses with critical humidities.

(iii) Geographical location, e.g. coastal stations liable to be affected by sea fog at certain seasons, high-level stations liable to hill fog under certain situations, and localities such as Tangmere on the south coast where the occurrence of katabatic winds on radiation nights decreased the frequency of fog.

(iv) Smoke pollution which was frequently of paramount importance because of the siting of large airports convenient for large centres of population.

Location was also a factor in smoke pollution and one of the conclusions of the Leicester survey of 1937–39 was that the smoke concentration in a town was proportional to the square root of the population[4]. On this basis alone it would be expected that smoke pollution at Northolt and London Airports, under conditions favouring the accumulation of smoke, would be a particular menace. It was noted that whereas it was unusual for smoke alone to reduce visibility below 1,000 yd. occasions were known of visibility about 200 yd. at Northolt with relative humidity of 60–70 per cent. The general synoptic situation also played its part in determining the degree of smoke pollution for it embraced the factors of wind and stability of the air. Since turbulence was a potent factor in dispersing smoke, stability, either inherent in an air mass such as that brought by the easterlies frequently experienced in east and south-east England from December to February or produced by evening and night cooling, acted to concentrate the pollution and worsen visibility. Pollution was subject to yearly, daily and to some extent weekly cycles. The two main sources of smoke could be classed as domestic and industrial, and, referring to the relative proportions over Great Britain, it was stated that half the smoke was of domestic origin, and that Shaw and Owens had found for London that two-thirds was such[5]. It was the larger smoke particles rather than the small combustion nuclei which restricted visibility, and these large smoke particles were the products of inefficient combustion such as that in domestic grates, particularly for an hour or so after fires had been lit or stoked. During the summer half year domestic smoke was slight in amount though industrial smoke continued. There was a reduction in the latter at the week-ends compensated to some extent in winter by a slight increase in domestic smoke.

Progressing to the diurnal and seasonal variation of visibility at particular stations, isopleths of percentage frequency of visibility less than 2,200 yd. at Northolt Airport were shown, the diagram being Fig. 1 of the paper by Corby[1]. Significant features of the diagram commented on included:—

(i) Minimum mist and fog frequency in July.

(ii) Gradually increasing mist and fog frequency in August and September.

(iii) Rapidly increasing mist and fog frequency in October reflecting the factors of increasing length of night, continued high humidity of the air, and the bringing into use of more domestic fires in the evenings and mornings.

There was generally at this time still sufficient convection to clear the fog and mist by mid morning.

(iv) High incidence of mist and fog (30–35 per cent.) from an hour or so before sunrise to about 1100 in October and November because of the predominance at this time of moist, maritime air masses with a fog point of 35–40°F., together with nights sufficiently long to form radiation mist and fog which thickened shortly after dawn, as fires were lit and increasing turbulence caused more complete mixing.

(v) High mist and fog frequency (30 per cent.) between 0900 and 1100 in December and January with a maximum of over 40 per cent. about 1000 in the latter month owing to the increasing frequency of drier, easterly air masses at this season in which the liability to radiation fog was reduced, whilst smoke pollution from London and domestic sources near Northolt (at this time at its winter maximum) increased.

The shift of the maximum to a time after sunrise was explained as due to the increase in smoke pollution taking place around the airfield as domestic fires were lit and furnaces stoked in the morning, together with a time lag for the subsequent pollution to reach the airfield.

(vi) Minimum frequency of less than 15 per cent. shortly before sunrise agreeing well with the experience of forecasters dealing with smoky areas that visibility usually improves during the night as smoke is carried away or settles out.

(vii) Tendency for fog and mist to persist in winter owing to the strong night inversions produced, the low elevation of the sun and the liability for insolation to be largely reflected from the upper surface of a fog layer.

(viii) Rapid decrease of fog and mist frequency from March to April and the increasing tendency to clear during the day, though a 30 per cent. maximum shortly after sunrise in March probably reflected the onset of moister air masses whilst there was still a cold ground and appreciable night cooling.

During the period of the diagram this maximum was emphasized by a high frequency of calms and also a high frequency of winds between ENE. and ESE.

(ix) Weekly smoke-pollution cycle masked in the diagram, for during the period when smoke pollution predominates it was frequently found that the morning smoke maximum was delayed by about an hour on Sundays due to the later lighting of domestic fires.

London Airport was considered next and a diagram of the percentage frequency of visibility less than 1,100 yd., Fig. 1 of the paper by Davis[3], showed broadly the same features as the previous diagram for Northolt.

[To face p. 176

FIG. 1—CIRROSTRATUS FROM 38,500 FT.

This photograph was taken from a Comet aircraft at 1410 L.T., September 4, 1951, over the toe of Italy.

FIG. 2—EDGE OF CIRROSTRATUS SHEET

This photograph was taken five minutes after Fig. 1 from about the same height.

FIG. 3

FIG. 4

FIG. 5

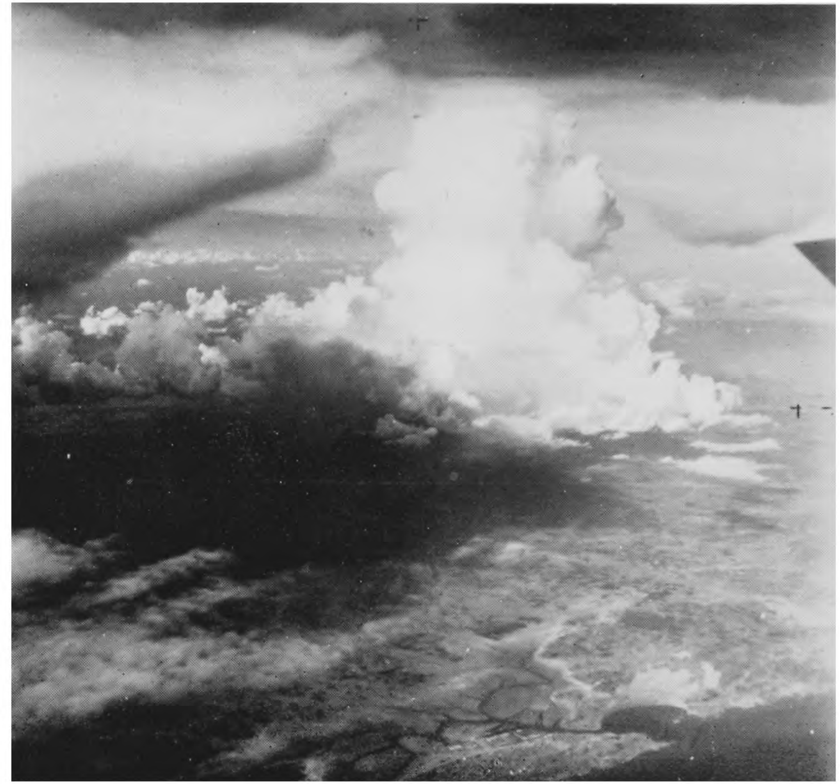

FIG. 6

PHOTOGRAPHS FROM 33,000 FT. OF A CUMULONIMBUS OVER THE KATHIAWAR PENINSULA

All these photographs were taken from a Comet aircraft within about three minutes as it flew to the right of the cumulonimbus, the camera being in a fixed position in the aircraft (see p. 173).

To face p. 177]

FIG. 7—DEVELOPMENT OF A LARGE CUMULUS FROM 36,000 FT.
The top of the altocumulus layer is at 17,000 ft. and the protruding cumulus has already reached 40,000 ft.

FIG. 8—CLOUDS OVER MALAYA FROM 34,000 FT.
This photograph was taken about 0940 L.T. at about 5°N. on October, 14, 1951. Clouds visible are cumulus, a thin layer of cirrocumulus at 25,000 ft. and cirrostratus at about 40,000 ft.

The two diagrams indicated that, from an aircraft operator's point of view, the worst time to plan operations into or out of these two airports was one to two hours after sunrise throughout the year and two to three hours after sunset in winter. The best times were the middle of the day and, in winter, a few hours before sunrise except in October and November.

Isopleths of the percentage frequency of visibility less than 2,200 yd. for Ringway demonstrated visibility characteristics very similar to those for Northolt Airport and London Airport, though the pronounced maximum shortly after sunrise in January, seen at Northolt, did not appear. This was thought to be due partly to the absence at Ringway of the circumstances, peculiar to the two southern airports, of increasing frequency of stable air masses from a predominantly smoky direction at this time of year.

The variation of visibility less than 2,200 yd. at Renfrew for the winter half year was seen to reproduce the now familiar feature of the daily smoke-pollution cycle. It was interesting and illuminating to note that the early morning minimum frequency in this visibility range was considerably smaller than the early afternoon minimum at Renfrew, and this was also characteristic of many polluted localities at seasons when smoke pollution was dominant. The variation of visibility less than 440 yd. for the same period revealed only a small night variation and a morning maximum frequency some two hours later than that for the previous visibility range, a reflection on the predominance of water fog in this range of visibility.

As a contrast to the polluted areas, the isopleths of frequency of visibility less than 2,200 yd. for a rural area free from any immediate source of large-scale pollution were examined, the station chosen being Mildenhall, the diagram that due to Durst[6]. Points of contrast were:—

(i) Simpler and more regular pattern of the isopleths.

(ii) Early afternoon clearance of fog and mist beginning earlier in the year and persisting later into the year.

(iii) No pronounced minimum occurring in the early hours of the morning in December, January and February, nor an increase in frequency an hour or so after sunrise in these months.

(iv) Though the March maximum around dawn was evident, the night period was marked by a gradual deterioration of visibility instead of the rapid fall shortly after dusk associated with smoke pollution.

As an interesting example of a locality where visibility characteristics are complicated by sea fog, the isopleths of percentage frequency of visibility less than 880 yd. for Dyce showed clearly the incidence of the sea fog from May to August with maxima of 7–9 per cent. during the night. Winter, by contrast, had remarkably low frequencies of 1–2 per cent.

Turning to the question of the dependence of visibility on atmospheric pollution as determined by wind speed and direction, several diagrams depicting the percentage frequency of visibility at Northolt less than stated values through the range 1,100 yd. to 12½ miles plotted on a wind-rose grid were shown. The first (Fig. 2 of the paper by Corby[1]) referred to the winter half year and embraced all wind speeds, calms excluded. Marked asymmetry about a north-south axis showed the high pollution of easterly winds. The next two diagrams (Figs. 4 and 6 of the same paper) were similarly constructed but restricted to winds in the ranges 1–6 kt. and 11 kt. or over. The attenuation of pollution with increasing wind speed was at once apparent and considering easterlies, 55 per cent. of the occasions had visibility less than 2,200 yd. with winds 1–6 kt. but only 25 per cent. with winds in the higher speed range. Fog was shown to be rare with winds of speed of 11 kt. or over. A further striking feature was the increasing canalization of pollution into a narrow sector, defined by the location of the major sources of smoke pollution, as wind speed increased. Consideration of a similarly constructed diagram for the summer half year for all wind speeds, calms being again excluded, showed an overall improvement in visibility, with fog relatively rare. The maximum of pollution from easterly directions was still maintained, but now there was a further maximum from a northerly point, probably associated with industrial pollution from Watford which, during winter, was masked by more local sources of domestic smoke.

Finally the variation of visibility less than 2,200 yd. with wind direction at Ringway was examined. Maximum frequencies were found to lie in directions which could largely be explained in terms of pollution. A northerly maximum showed the effect of Manchester smoke and, to a lesser extent, that of the industrial areas of Lancashire and Yorkshire on either side of Manchester. A north-westerly peak could be associated with pollution from Lancashire, but also with deteriorations due to heavy showers in unstable north-westerly winds and, to that extent, did give a false impression of visibilities in north-westerly winds since, except in the showers, visibility would be good with these air.masses. A south-easterly peak was due to several factors, such as pollution from the Midlands and from the Potteries and to the precipitation of fronts moving from the west and south-west.

Mr. Wright dealt with the separate contributions to the extinction coefficient (normally equal to 3·91 ÷ visibility) made by gaseous molecules, liquid nuclei, and solid particles. The size of a nucleus depends on the mass of hygroscopic substance in solution and increases with relative humidity, rapidly at high humidities. There appear to be two classes of nuclei, one produced in combustion processes and having radii of the order of 5×10^{-6}cm., and the other found in air remote from sources of combustion and presumed to be solutions of sodium chloride having radii some ten times greater—about equal to that of smoke particles and the wave-length of light. In industrial areas combustion nuclei are much more numerous than salt nuclei, and the total cross-sectional area of the two classes may be of the same order of magnitude; but since the effective cross-sectional area of nuclei whose radius is small compared with the wave-length of light is only a small fraction of the physical area, the contribution of combustion nuclei to the extinction coefficient is much less than that of salt nuclei, being about the same order as the contribution from molecules, 0·016 per kilometre, corresponding with a visibility of 150 miles. Thus the important contributions are salt nuclei and, in industrial areas, smoke particles.

Futhermore, since the supersaturation required for condensation on nuclei depends on their size, being about 100·2 per cent. for combustion nuclei but only 100·02 per cent. for salt nuclei, excess water vapour will be deposited on the latter first and so the higher supersaturation will not be attained. This deposition on the fewer but larger salt nuclei will produce droplets having a radius about 10^{-3}cm., and will be manifested as fog.

From observations at Kew Observatory, it is found[7] that the number of nuclei and particles in unit volume varies with wind direction and is subject to marked annual variation, particles more so than nuclei. As wind speed increases the number of particles falls off but the number of nuclei shows signs of increasing; as relative humidity falls so does the number of particles but there is no marked systematic change in the number of nuclei. These results are supported by an analysis[8] of extinction coefficients derived from visibility observations at Valentia, Scilly, Tiree, Aberdeen, Spurn Head and Lympne. Observations at the first three places with winds from the Atlantic were assumed to represent conditions in air containing nuclei of salt only; and the additional contribution to the extinction coefficient found at the other places, and with land winds at the first three, was attributed to smoke. It was found that in winds from the Atlantic the extinction coefficient increases with relative humidity (reflecting the increase in size of salt nuclei) and with wind speed (possibly attributable to increased production of spindrift). In places affected by smoke the extinction coefficient is increased when the wind is in the direction of a smoke source, even 150 miles away. The increase is greater in light winds and with high relative humidity, reflecting atmospheric stability, and appears to be roughly inversely proportional to the distance of the smoke source.

The Director opened the meeting for general discussion.

Mr. W. A. L. Marshall demonstrated graphically the diurnal and seasonal variation of visibility on the Air Ministry roof, Kingsway. A series of four graphs of the average number of days a month with fog plotted against the time of day for the months of December, March, September and June for the period 1941–46 showed largely similar features to those demonstrated for other polluted areas in Mr. Sugden's opening statement. However, it appeared that the fog frequency at Kingsway was generally double that at London and Northolt Airports at 0900 and 1500. A further diagram of the percentage frequency of fogs at Kingsway plotted against wind direction showed a maximum frequency with NE. winds and a lesser peak with SE. winds. A comparison of the average number of days with fog at Kingsway at 0900, 1200 and 1800 compared with Kew and Croydon revealed that there was not so much thick fog in the morning in central London as in the suburbs. Maximum fog frequencies at 0900 occurred in March and November with a minimum in February and a more pronounced minimum during the summer. The hours of 1200 and 1800 showed maximum frequencies in December and January. An interesting commentary on the decrease of pollution in central London during the past 50 years was to be found in the report of the "London fog inquiry 1901–02". At that time the average visibility from St. Paul's and Westminster was one mile and the maximum visibility one and a half miles in winter. Nowadays the winter visibility in Kingsway at midday is often four and a half miles and the average visibility from the roof of Victory House one and a half miles.

Mr. W. C. Muir dealt in detail with the variation of visibility at Renfrew Airport. He pointed out the frequent rapid deterioration of visibility at sunrise, and that the evening maximum of poor visibility was not so great as at Northolt. Most of the pollution at Renfrew appeared to be of domestic origin, and the effect of Sunday morning on the time of the morning deterioration was most marked. December was found to be the worst month for dense fogs. Renfrew lies in a natural basin, and in winter a pool of air stagnates there, persisting long after a general circulation has become established. A maximum frequency of fog was found with winds between NE. and E. and a secondary maximum with W. winds. Mr. Muir thought that the greatest difficulty in forecasting fog at Renfrew was to know the relation between the surface and the gradient wind.

Mr. C. J. Boyden referred to a paper dealing with fog forecasting by Saunders[9]. He stated that, ignoring wind direction and using relative humidity and screen temperature, Saunders found that fog occurred on 90 per cent. of the occasions when the fog point was reached. Was it not remarkable that one could forecast so accurately with these factors when there was, apparently, such a great directional effect? Presumably there was a correlation between temperature, relative humidity and wind direction. At Renfrew errors in forecasting fog were mainly due to errors in forecasting wind direction. Mr. Boyden observed that, since smoke rises and travels with the wind at varying heights before falling again to the surface, it was remarkable that Northolt should show such a close correlation between visibility and wind direction and that the time of maximum smoke pollution should appear to be independent of wind speed. On these grounds it seemed likely that quite nearby local sources of smoke were mainly significant in the control of visibility and the diurnal effect was one of the production and dissipation of surface inversions. The dominant control of local smoke sources seemed to be borne out by the sharp maxima indicated in the Ringway diagram depicting variation of visibility with wind direction. Regarding the relation of the concentration of smoke and wind speed, this was an inverse linear one and agreed well with Table I in the paper by Corby[1]. This led to the point that, with light winds, speed within a knot ot two was critical in forecasting fog.

Mr. C. S. Durst commented on the various theories of the sunrise decrease of visibility which had been suggested since the 1920's. At one time it was explained in terms of the interaction of ultra-violet light and hygroscopic nuclei; later Entwistle ascribed it to the mixing, by dawn turbulence, of thermally stratified layers which were practically saturated. The theory that the morning lighting of fires was partly responsible had been advanced by himself. Mr. Wright, in reply, said that he could not comment on the effect of ultra-violet light but thought that the lighting of fires was a sufficient explanation of much of the dawn deterioration.

Mr. F. H. Dight, after commenting on the observed effect of smoke haze at Croydon, made the point that during January and February frost was a controlling factor in the increase of visibility observed in the early morning.

Mr. C. E. Wallington, describing the approach to fog dispersal problems at Northolt, stressed the importance of the details of the vertical temperature distribution from the surface to 1,000–2,000 ft. and gave a few practical hints on how to determine it. Diurnal changes in the assumed local temperature change with height as plotted on the tephigram were made according to detailed insolation data at Northolt with the simplifying assumptions that an area representing fog on the tephigram needed twice as much heating as a dry area and that a complete cloud cover cut out 75 per cent. of the potential insolation. No method of forecasting the fog dispersal temperature was completely satisfactory, but an estimation could be made. Usually when the water fog had dispersed visibility was still limited by smoke. Although the vertical distribution of smoke within the haze layer was not normally uniform it was reasonable to suppose that the visibility depended mainly on the wind direction and the depth of smoke. Limited data collected showed that, as haze tops rose from about 1,000 to 5,000 ft., general air-mass characteristics took over control of visibility from the local smoke sources, thus ruling out the application of simple mathematical relationships between visibility, haze tops and wind direction. However, knowledge of the probable visibility for any wind direction and a standard haze top, say 1,000 ft., would be useful and efforts were being made to assemble appropriate data. Mentioning some of the problems to be solved, Mr. Wallington told how differential heating in the London area could cause smoke to drift to initially clear districts when the pressure gradient was slack. Such occurrences could be explained but not forecast accurately.

Mr. R. J. Ogden considered in some detail the Leicester Atmospheric Pollution Survey[4] in the light of local forecasting at London Airport. He stressed the domestic origin of smoke pollution at London Airport, this being borne out by the observation that there is little significant reduction of smoke on Sundays in winter, in fact often it seemed much worse. The daily cycle of smoke pollution at London Airport was confirmed statistically in the Survey as also was the one to two hours' delay in the Sunday morning deterioration and subsequent improvement of visibility. Experience at London Airport also confirmed the correlation between pollution and lapse rate mentioned in the Survey, and Mr. Ogden thought that lapse-rate changes were some of the most important criteria in forecasting pollution. Referring to the effect of wind direction and distance from source of pollution, Mr. Ogden thought that immediate sources of smoke were much more important than more distant ones, even though those might be larger. Mere wind direction, however, was not sufficient and always the air trajectory must be estimated in determining possible sources of smoke.

Mr. G. H. Robins made the observation that smoke, even when it reduced visibility to fog limits, was often thin vertically, and airfield lighting could be seen from approaching aircraft from distances far exceeding the reported meteorological visibility. Mr. Marshall's figures suggested that fog cleared in central London in winter before it did so at London Airport. This confirmed Mr. Robins's view that, when easterly winds were blowing, the clearance started in east London and spread westwards. With light winds it might not reach London Airport until mid afternoon where a deterioration often immediately preceded the improvement which was sometimes very rapid.

Mr. D. D. Clark, referring to attempts to clear fog by heating, questioned Mr. Wright as to the comparative sizes of water droplets and smoke particles in fogs. If the smoke particles were much larger than the water droplets and were preponderant in a fog then mere heating was a waste of time and money. Mr. Wright, in reply, stated that the water droplets in these fogs were much larger than the smoke particles. A further question from Mr. Clark as to how much fog would be left behind after FIDO* heating elicited the reply that the effect of the smoke particles compared with water droplets would be small but that some further pollution could be expected if FIDO was operated with a smoky fuel.

Miss Meiklejohn observed that the sunrise deterioration of visibility occurred even in rural areas, such as Lincolnshire, away from large sources of smoke.

*Fog, intensive, dispersal of.

Mr. Sugden, in reply, explained that the dawn deterioration in rural areas, where fogs are almost entirely water fogs, was a relatively rapid occurrence soon after dawn turbulence became effective. In the case of deteriorations due to smoke there was a time lag corresponding with the time taken for the smoke, consequent on the lighting of fires, to drift across the airfield.

Mr. E. Gold inquired whether there had been any individual examination of the sequences of better visibilities in the early morning, for it was possible that causes other than the settling out of smoke particles entered into this improvement of visibility. A further query was what comparison was there between night visibility observations with lights and daylight observations, since it appeared that dawn visibility deteriorations could not be completely explained by the lighting of fires, the time of morning fire lighting having no close correlation with sunrise. Mr. Sudgen, in reply, said that no individual investigation of the observations had been made.

Mr. E. T. Tunstall, in outlining some of the variations of visibility at Speke, made a plea for more observations of temperature and humidity in the lower layers.

Mr. J. S. Sawyer said he was impressed at so much investigation into visibility problems being undertaken and referred to the difficulty of understanding the several problems without local knowledge. The need for constantly bearing in mind relative humidity even when dealing with occasions of smoke pollution was stressed. Mr. Wright agreed, but pointed out the difficulty that if one began segregating observations according to this or that effect very few observations would be left on which to work.

Mr. T. Marshall, in reply to Mr. Boyden's point, said that Saunders, in assessing the accuracy of his method for forecasting fog, had only used occasions when the fog could strictly be called water fog. He had excluded cases when fog was due to smoke, defining water fog as when visibility was below 1,000 yd. and relative humidity greater than 95 per cent. Mr. Marshall also stated that in October, and possibly also in March, sharp night cooling and the setting up of a steep surface inversion could be expected. In support of this view he drew attention to a curve given by Bilham[10].

Mr. J. M. Waldram (General Electric Company) recalled experiments made during the war in which it had been possible to distinguish between scattering aerosols and absorbing particles in the atmosphere up to heights of about 1,000 ft. from manned balloons. It was found that the scattering and absorbing particles were apparently independent of one another and either might occur in layers. On some occasions scatter was found without absorption and on others a strongly absorptive layer with very little scatter. An interesting pair of ascents was made over Coventry. On the first occasion it was a week-night and the wind was blowing from the direction of Coventry. Marked absorption was found. On the second occasion it was a Sunday night and the wind was blowing away from Coventry, but Birmingham was almost directly downwind. Nevertheless, no absorption was detected. This isolated observation was inconclusive but lent support to the suggestion that strong absorption might be associated more with close than with distant sources of pollution.

Mr. A. . W. Berry described the situation of Elmdon Airport, open to the west to a large source of domestic and industrial smoke in Birmingham and built on reclaimed marshland. One of their difficulties was in deciding the change in smoke concentration with variation of wind associated with fronts moving from the west and north-west across the smoke belt. The pollution was generally considerably attenuated by the time the front reached the airport.

Mr. J. McGregor quoted the synoptic situation of December 31, 1951, as an example of the close correlation existing between wind direction and visibility at London Airport and also of the effect of precipitation in improving visibility by washing out some of the smoke. He further explained that it had become necessary to measure visibility, or more accurately "visual range", on the runways at London Airport, since this, due to local areas of water, was often lower than the reported meteorological visibility. In reply to a query from Mr. McGregor as to the attenuation of smoke pollution with distance, Mr. Sugden pointed out that the Leicester Report[1] concluded that the concentration of smoke diminished as the distance for places between about four and ten miles downwind from a large source, and as the square of the distance for places between ten and one hundred miles, reverting to the linear relationship beyond that.

Mr. E. Chambers thought that compilation of visibility frequencies for other airports, such as had been done for Northolt and London Airports, would be very useful to aircraft operators. In stressing the variability of visibility in the stagnant conditions attendant on fog situations, Mr. Chambers thought there was a need for ultra-short-period changes in visibility to be known by pilots attempting landings in minimum conditions. He was pessimistic, however, as to the progress that could be expected in this direction.

The Director, in closing the discussion, said it had been shown there was considerable interest and activity at outstations in tackling the problem of visibility. He pointed out the dangers of reading too much into annual isopleths which are only a first approximation, and emphasized Mr. Gold's plea for an individual examination of observations. Mr. Boyden's observation that concentration of smoke pollution was inversely proportional to wind velocity was approximately correct but the difficulty lay in deciding what was the appropriate wind velocity to use. Because of the varying rate of travel of pollution at different levels and diffusion downwards, it was dangerous to rely merely on surface velocity. The patchiness of the visibility conditions associated with low wind gradients referred to by Messrs. Boyden and Chambers would probably prove a limiting factor in attempts at forecasting in these conditions. The Director concluded by referring to the work at present being undertaken by Dr. Stewart on the physics of fog.

Further contribution by Mr. Summersby communicated later

I wondered if more might have been made of the differences which came to light from the comparison between London Airport and Northolt Airport.

It appeared that there was a tendency for water-fog formation $\frac{1}{2}$–1 hr. earlier at Northolt than at London Airport. This is attributable to several factors of which the main ones are the following:—

(i) Northolt lies in a hollow.

(ii) London Airport has up to 15 ft. of drainage soil on top of the underlying London clay, whereas Northolt has very little. More surface water is often therefore available at Northolt than at London Airport to aid in fog formation.

As a result of (i) it seems there is a mean difference in minimum temperature of the order of 3–4°F. so that the fog-point temperature is reached earlier at Northolt than at London Airport—and in some critical circumstances Northolt can have water fog on some nights, while London Airport does not. I can remember a few occasions when this difference has successfully been recognized and different figures maintained in the Civil Aviation Conference Summary for the two airports, in spite of their close proximity.

Turning to the wider aspect of comparing the north-western and south-south-western sides of London, I have the personal feeling that the smoke deteriorations we experience at Northolt and London Airport in times of south-easterly surface winds are worse than those I used to see when I was working at Croydon during a northerly régime. A further fact came to light when my home followed me to the Northolt area. It was quite obvious that much more dust was deposited on furniture and more housework resulted. This in itself may be trivial but the important point is that there is more dust. May this not be attributable to the tendency for northerly air streams to be unstable as compared with southerly and south-easterly ones? The resulting advice we might offer on the siting of airfields in relation to the position of sources of smoke is obvious. A set of figures and diagrams for Croydon, similar to those for Northolt and London Airport would give an interesting comparison in this connexion.

In connexion with the forecasting aspect of the visibility problem at the evening period, the following points come to mind:—

(i) The degree of obscurity due to smoke is dependent on the wind direction and speed (source and horizontal distribution), and the height to which surface turbulence can carry smoke particles (vertical distribution).

(ii) The improvement after dark is probably due to smoke particles dropping out (a phrase which covers a multitude of possible theories some or all of which may have some truth in them—but as I have already mentioned it obviously happens), and a tendency for local sources to supply less pollution later in the evening.

Dense fog may result if the fog-point temperature is reached prior to the smoke dropping out, but the fog is not so dense if the reduction in density of smoke has occurred first. It is often possible to see that the fog point will not be reached until well on in the night.

With regard to water fog the surface temperature is the main consideration though fog is not impossible in unsaturated conditions from smoke alone.

At Northolt we attempt to time the formation of water fog in the following way:—

From a representative tephigram (upwind) of the air in which fog is to form, or a reasonable construction of one where no suitable ascent has been made we formulate values for the fog-point temperature[9], and calculate values for the temperature at which the change of rate in decrease of temperature[11] is expected to occur from representative values (upwind again) of the maximum temperature and the dew-point temperature at the time of maximum temperature. The time of reaching the maximum is known on an annual basis, but can be verified during the evening. Thus the rate of reduction of temperature up to this point is known. At the time of change of rate dew starts to deposit on the ground and the rate of reduction in temperature is approximately halved because of the release of the latent heat of evaporation of the dew, so that the new rate of loss of temperature is approximately known. Hence the time of the fog point can be calculated.

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LETTER TO THE EDITOR

Heating requirements of a house

In the interesting article on the heating requirements of a house in the *Meteorological Magazine* for June 1951, Mr. R. E. Lacy gives an equation for computing the full requirement H, in kilowatt-hours, from the temperature, wind and sunshine,

$$H = -13{\cdot}87 + 3{\cdot}02\Delta t + 0{\cdot}098v\Delta t - 1{\cdot}01S$$

This equation implies that if the mean outside temperature of the air were the same as the temperature inside your house, you would be able both to boil your kettle and to provide the family with hot baths without any consumption of fuel—you would get 14 kilowatt-hours of energy free plus a few more if the sun were shining. The paradox arises from the application of the equation to conditions differing greatly from those of the trials from which the equation was derived, and Mr. Lacy has included in his paper a clause debarring such an application.

It is however worth while to inquire into the source of the paradox. It appears to be due to the assumption that the relation between H and Δt is linear. This is probably justifiable for only a relatively small range of Δt. It seems likely that for a larger range $H = b(\Delta t)^n$ where $n > 1$, implying that that more heat is required to raise the inside temperature 1°F. when Δt is large than when Δt is small. Such a result might, I suggest, be expected because the convection currents set up when Δt is large will introduce a factor of heat loss which is negligible for small values of Δt. It would be interesting if Mr. Lacy could indicate the character of the curve showing the relation between H and Δt for days of no sunshine. On such days some heat would still be required to maintain the inside temperature even when the outside temperature was the the same, because the house would be losing heat by radiation. This implies that the constant on the right-hand side of the equation must be positive.

Wind is assumed in the equation to have no effect when $\Delta t = 0$. Actually it would supply a little heat, about 0·7, for a wind of 20 kt. and an effective area of 10m. × 5m. (across the wind).

E. GOLD

8 Hurst Close, N.W.11, December 13, 1951

[Mr. Gold suggests that equation (2) implies that if the house temperature is the same as the outside air temperature one is getting something for nothing. Actually the constant term (−13·87) expresses, in part at any rate, the fact that the house is normally at a higher temperature than the surrounding air, even when no heat is supplied by the heating plant. Measurements in this particular house, over a period of several days with no artificial heating, showed that in winter, with a mean daily duration of sunshine of 1·5 hr., the house was about 5°F. warmer than the outside air over a 24-hr. period, this excess increasing as the sunshine duration increased. Although there is no heat gain at night under these conditions, the thermal lag of the structure prevents the loss of the whole of the stored heat gained from solar radiation during the day, and the 24-hr. mean temperature of the house is therefore almost always higher than that of the surrounding air.

As Mr. Gold surmises, the relationship between the heat requirement H and the temperature difference Δt is not linear for all values of Δt. However, as long as Δt lies within the range 10° to 40°F., i.e. the air temperature t_0 is less than about 55°F., the relationship appears to be linear or very nearly so. At lower values of Δt the outside air temperature will often exceed the desired house temperature for a part of each day. As Δt approaches zero and the outside air temperature exceeds the inside temperature for a longer period each day, the relationship between H and Δt departs from the linear one, and an equation of the form $H = 6(\Delta t)^n$ may then be more appropriate. In this experiment we were not considering these "end-of-season" conditions, although at least one gas authority has found a non-linear relationship of this form valuable for estimating gas consumption.

The other points that Mr. Gold mentions are being dealt with in a paper which it is hoped to publish in due course.—R. E. LACY]

REVIEWS

Compendium of meteorology. Edited by T. F. Malone under the direction of the American Meteorological Society. 11¼ in. × 8½ in., pp. x + 1334, *Illus.*, American Meteorological Society, Boston Mass., 1951. Price: $12.

The avowed purpose of this magnificent volume "is to take stock of the present position of meteorology, to summarize and appraise the knowledge which untiring research has been able to wrest from nature during past years, and to indicate the avenues of further study and research which need to be explored in order to extend the frontiers of our knowledge." The idea originated in 1948, and during 1949 the general plan took shape and the Editor justified the title by commissioning no fewer than 102 authors to prepare a total of 108 articles covering nearly all branches of meteorology. At first glance the only subjects not included are earth temperature, barometer reduction and air density. Hail is dealt with only briefly and superficially, and one would have liked the application of statistical methods to be treated in its own right and not merely as an adjunct of forecasting, but these small details count for nothing amid the general abundance. The authors are, naturally, predominantly

American, 77 of the contributions emanating from the United States and two from Canada. Great Britain is represented by eleven papers, Germany by eight, Belgium and Norway by two each and Austria, Finland, India, Japan, Sweden and Switzerland by one each. Thus the volume can almost be regarded as a world effort, especially when one considers that several of the authors, such as Lettau (Diffusion in the upper atmosphere), Gutenberg (Sound propagation) and J. Bjerknes (Extratropical cyclones) are American only by comparatively recent adoption. The whole catalogue of authors is most impressive, though too long to include here, but we may mention that the continental list includes such well known names as A. Ångström, van Mieghem, Götz, Sverdrup, Palmén and Defant, and the Asiatic contributors Mitra and Nakaya.

Obviously all the articles cannot be mentioned individually, but it may be of interest to list the 25 sections into which the work is divided: Composition of the atmosphere, Radiation, Meteorological optics, Atmospheric electricity, Cloud physics, The upper atmosphere, Cosmical meteorology, Dynamics of the atmosphere, The general circulation, Mechanics of pressure systems, Local circulations, Observations and analysis, Weather forecasting, Tropical meteorology, Polar meteorology, Climatology, Hydrometeorology, Marine meteorology, Biological and chemical meteorology, Atmospheric pollution, Clouds, fog and aircraft icing, Meteorological instruments, Laboratory investigations, Radio-meteorology, and Microseisms. The lengths, both of the sections and of the individual papers, vary widely: Dynamics of the atmosphere with 138 pages, The upper atmosphere with 131, and Weather forecasting with 125 take pride of place and reflect the attention being devoted to these subjects at present, but the seven papers on Cloud physics and four on Radio-meteorology (radar and sferics) also cover research of great present-day importance.

Not much of the book is easy reading. The weight alone (over 7 lb.) precludes an easy chair by the fire. Then, although the total length is well over half a million words, this works out at an average of only about 5,000 words per article, into which the author has had to condense not only a comprehensive documented survey of the history of his subject and its present position, but also his ideas of future development. Some of these latter suggestions are of great interest and should be an inspiration for much future research. Several of the articles, especially those on the dynamics of the atmosphere, are highly mathematical, and give the impression that modern meteorology is well on the way to becoming an exact science in spite of the numerous approximations and simplifying assumptions which are necessary to make the atmosphere tractable. It has been the reviewer's lot to abstract about a third of the book for the American Meteorological Society's monthly journal "Meteorological abstracts and bibliography", and he found that to deal satisfactorily with a single article was, in most cases, occupation for a whole engrossed morning. But anyone who does succeed in working his way steadily through the whole series will certainly learn a lot of meteorology. Should he wish to acquire even more, or amplify points of detail, he will find the carefully selected bibliographies, some of which are of considerable length, a great help. As an authoritative source of material for future consultation, the book is unique in meteorology.

The production reaches a very high level of excellence. The type is dignified and readable without eyestrain, the numerous diagrams and maps clear and beautifully reproduced (a few in two colours), the text and—still more wonderful—even the mathematics singularly free from misprints. The editorial staff and proof readers well deserve the credit awarded to them in the Preface.

To conclude—in the manner of the articles—with suggestions for the future. In 1934 the Royal Meteorological Society collected a series of essays into a volume "Some problems of modern meteorology". Though far more modest than the present work, it is still a valuable work of reference, but a comparison of the two brings out the giant strides which meteorology has made in the intervening period. With the continued intensification of research, especially by team work, progress is certain to be even more rapid in the future. Dare one hope that the "Compendium" will not be an isolated phenomenon, but that some means will be found, by revisions, addenda, progress reports or what you will, to bring it up-to-date at not too infrequent intervals?

C. E. P. BROOKS

Weather. By A. O. Chesters. E.S.A. Information book: What causes things. $8\frac{1}{4}$ in. × $6\frac{1}{2}$ in., pp. viii + 96, *Illus.*, Educational Supply Association, Ltd., London, 1951. Price: 5*s*.

There are, at present, a fair number of elementary books on meteorology; but few indeed are those written specially for the young, and the present volume does much to fill a far too prominent gap in meteorological literature. The author, a grammar school headmaster, has succeeded in doing what one hardly expects from one in his station, i.e. descending to the level of young people of 10–12 years and producing an attractive book on weather science which will appeal to the youngest class in his school, or even to the scholarship class in the Junior School.

The introduction has a touch of artistry, which is evident again later on. Then almost immediately, the invisible vapour near a kettle-spout is called "steam" and the white cloud of drops is called "vapour"—sound enough for the engineer, but very confusing to the embryo meteorologist who, later on, tries to understand the formation and dissolution of clouds. However, this book excites much more admiration than criticism. With great skill in the avoidance of technical terms the author explains in an effortless manner such physical principles as Boyle's Law, latent heat and dynamical heating. In an equally easy style come explanations of meteorological principles, such as instability, and a number of topics which often present difficulty are dealt with, for instance, why polar maritime air is dry. Towards the end the book leads up to more difficult things, such as the polar-front theory.

There is no particular sequence between the chapters; according to the author this is intentional, and indeed it has the advantage of leaving the reader desiring to find out what the book has obviously not dealt with, and to refer to the more advanced works mentioned in the bibliography. The volume is up-to-date, and one finds references to the work of Schonland and his team, to Bergeron's theory, and to artificial nucleation of clouds. The author has enlisted the help of an artist well versed in the production of sketches which appeal to children, and there are some good cloud photographs (including two of the rare standard cumulus photographs known to the reviewer not containing a factory chimney).

Criticisms are few. "Nimbus" is a term long out-of-date. Diagrams containing lightning flashes would have been better had the old zig-zag representation been replaced by something more like a real flash. And the young reader will probably conclude that the breaking-drop mechanism is the only one of any importance in the production of thunderstorm electrification.

The price of the book in limp covers is 5*s*., rather high, perhaps, for a children's book, but it is hoped that the volume will have the large circulation it thoroughly deserves.

S. E. ASHMORE

OBITUARY

Dr. Alexander Crichton Mitchell—Dr. Crichton Mitchell died in Edinburgh on April 15, 1952, at the age of 87, 27 years after his retirement. He was appointed Superintendent of Eskdalemuir Observatory in 1916, taking over from L. F. Richardson. Previously he had been Director of Instruction at Travancore, India. In 1922 he became the first Superintendent of the Edinburgh Office after the reorganization of meteorological work in Scotland consequent to the ending of the Scottish Meteorological Society.

All who worked with him will remember the tireless energy he devoted to setting up the new Observatory at Lerwick and to reorganizing the work at Edinburgh, while at the same time carrying out his laborious magnetic research. Retirement from his official duties merely meant to him more time to be spent on his many other interests and in the service of the Royal Society of Edinburgh. He was elected a Fellow in 1889, was Curator of the Library for many years and Vice-President from 1926 to 1929. He was awarded the Keith Prize 1931–33 for his work on the diurnal incidence of disturbance in the terrestrial magnetic field. He served on the Advisory Committee on Meteorology for Scotland for ten years until 1937.

He lived a full life almost to the end, throwing himself vigorously into all the occupations of the moment. His chief relaxation from hard work was good conversation with fanciful but informed speculation on scientific matters and anecdotes about scientists and leading figures in the academic world. Increasing deafness in his later years was a great trial but he was full of plans for further research to within a short time of his death.

Although he published various papers on the diurnal variation of temperature and pressure, these were by-products of his main interest of terrestrial magnetism and on this he published surprisingly little. His passion for research led him from one investigation to another, and he had not always the patience to collect his work into presentable form before starting his next step. In his later years he went deeply into the history of terrestrial magnetism and his articles published in the *Journal of Terrestrial Magnetism* are a useful summary of the subject from the times of Chinese legend to Halley. In collaboration with J. J. Shaw he wrote the article on seismometry in the "Dictionary of applied physics".

It was the good fortune of the writer of this note to start his Office career under Crichton Mitchell at Eskdalemuir, and his pleasure to be able to repay his debt, in small measure, during the last few years by occasional evening visits for discussion of geophysical subjects. For the span of life to exceed four-score years is not always an enviable thing but in this case it was.

R. A. WATSON

METEOROLOGICAL OFFICE NEWS

Weather forecasts by telephone.—So much adverse criticism of our forecasts receives publicity that evidence of appreciation is always welcome. Mildenhall, one of the local meteorological offices listed in the Post Office Guide, recently received the following letter:—

I write to congratulate you on the accuracy of your weather forecasting. I am a farmer and from time to time during the past two years I have been ringing you, and have only once found you giving wrong advice. In particular, I value the way in which you frankly state the probabilities of fine (or bad) weather in circumstances when accurate forecasting is impossible . . . . This letter is really inspired by your very accurate forecasting yesterday, which was of immense value to me.

This must be only one instance, among many, of the help which the Office renders in the vital problem of food production.

Awards of the Royal Meteorological Society.—The Buchan Prize, founded in memory of Dr. Alexander Buchan, Secretary of the Scottish Meteorological Society from 1861–1907, has been awarded to Dr. G. D. Robinson for his outstanding contributions to the study of atmospheric radiation and for his contribution (in collaboration) to problems of turbulent transfer near the ground. This award of the prize covered the period 1947–51.

The 1952 award of the Hugh Robert Mill Medal and Prize, awarded in memory of Hugh Robert Mill, Director of the British Rainfall Organization from 1901–1919, has been made to Dr. J. Glasspoole for his outstanding contributions to meteorology with particular reference to rainfall.

Sport.—*Football.*—The Meteorological Office team won the Air Ministry football cup for the tenth time when they beat Finance 4—0 in the final at Northolt on May 2. Goal-scorers were Pike and Wellard (3).

Athletics.—The Harrow Meteorological Office Sports will be held at Alperton on Wednesday, June 25.

Bishop Shield.—With successes in the football competition, swimming and cross-country running, the Office has made a good start in the competition, which will terminate at the end of the Air Ministry Sports to be held at the White City on July 2.

WEATHER OF APRIL 1952

Mean pressure was low over the North Atlantic Ocean north of latitude 50°N. and over the Arctic Ocean, and high over Europe. In the areas south of Iceland and Greenland, mean pressure fell below 1005 mb., and was about 5 mb. below normal. Mean pressure at the Azores was 1023 mb., slightly above normal. Over Europe generally mean pressure was very uniform between 1015 and 1020 mb., and about 2–6 mb. above normal.

Mean temperature was above normal, the excess being generally about 5°F. Over southern Scandinavia it was 45°F., increasing to 50–55°F. over west Europe and 60–65°F. in the Mediterranean region.

In the British Isles the weather was mainly warm after the first few days. The month was dry in Northern Ireland, most of Scotland and much of the eastern half of England but wet on the whole in western and midland districts of England and Wales. In most parts sunshine appreciably exceeded the average.

On the 1st a small depression north of the Hebrides moved south and cold northerly winds prevailed in the British Isles, with wintry showers in places and keen night frosts locally. On the 4th and 5th a trough of low pressure moved east across the country giving considerable rain. Thereafter a depression off north-west Scotland moved slowly east, while a secondary off our south-west coasts moved east-north-east and turned north-east across England; local gales were recorded in England, and rather heavy rain occurred in the south but in the north precipitation was scattered with some sleet or snow in places. On the 7th a trough of low pressure lay over southern England causing rain in this area. On the 9th and 10th a trough of low pressure associated with an Atlantic depression moved east over the British Isles; a sharp temporary rise in temperature occurred over England, Wales and Ireland on the 9th and thunderstorms developed locally in England during the day and the following night. Temperature rose to 65°F. or somewhat above at many inland stations in England and reached 69°F. at Kensington Palace. On the 12th and 13th a depression over the Bay of Biscay spread slowly north and some rain occurred in the south-west of England and Wales. On the 14th a weak trough lay over the English Channel and north France; rain occurred at most places in England and Wales, with rather widespread thunderstorms (2·08 in. of rain fell at Stanley Moor, Buxton). On the 15th an anticyclone over Iceland moved south-east to a position north-east of Scotland and subsequently moved south; this system maintained mainly fair, warm weather over most of the country until the 18th, but thunderstorms, with heavy rain and flooding, occurred locally in south-west England and Wales on the 16th. On the 18th a trough of low pressure associated with a depression near Iceland approached our western seaboard; some rain occurred in north-west Ireland and the Hebrides during the night but most places experienced a warm sunny day, temperature rising to 75°F. at Kensington Palace and at Chivenor, north Devon. On the 20th a depression south of Iceland moved a little eastwards and on the 21st associated secondary depressions crossed the British Isles. Rain fell widely on the 20th and 21st and showers occurred on the 22nd and 23rd, while local thunderstorms were recorded on the 21st–23rd. Temperature fell considerably in the cooler air stream behind the depressions. Subsequently a ridge of high pressure developed over the British Isles and maintained mainly fair weather, with varying amounts of sunshine, until the 28th, though there was some local rain at times, particularly on the 27th. Among good records of bright sunshine during this period were 13·5 hr. at Renfrew and Prestwick Airport on the 24th and at St. Eval on the 25th. On the closing day of the month troughs associated with a deep depression centred off the south-west of Ireland moved north-east across the British Isles; showers occurred in many places and thunderstorms were recorded at a number of stations in England. Temperature rose to 70°F. at many places in England and touched 79°F. at Camden Square, London, and 77°F. at Kensington Palace.

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 ...	79	21	+3·1	107	−1	110
Scotland	73	22	+3·2	79	−3	116
Northern Ireland ...	68	28	+3·3	60	−2	98

RAINFALL OF APRIL 1952

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·25	81	*Glam.*	Cardiff, Penylan ...	3·32	133
Kent	Folkestone, Cherry Gdn.	1·08	65	*Pemb.*	Tenby	4·11	179
,,	Edenbridge, Falconhurst	1·97	105	*Mer.*	Aberdovey	2·57	99
Sussex	Compton, Compton Ho.	2·43	121	*Radnor*	Tyrmynydd	3·29	89
,,	Worthing, Beach Ho. Pk.	1·35	87	*Mont.*	Lake Vyrnwy	3·36	106
Hants.	Ventnor Cemetery ...	1·57	92	*Mer.*	Blaenau Festiniog ...	4·42	72
,,	Southampton (East Pk.)	2·00	108	*Carn.*	Llandudno	1·44	85
,,	Sherborne St. John ...	1·56	88	*Angl.*	Llanerchymedd ...	2·24	101
Herts.	Royston, Therfield Rec.	1·32	84	*I. Man*	Douglas, Borough Cem.	1·43	59
Bucks.	Slough, Upton... ...	1·78	124	*Wigtown*	Newton Stewart ...	1·73	68
Oxford	Oxford, Radcliffe ...	1·61	101	*Dumf.*	Dumfries, Crichton R.I.	2·73	116
N'hants.	Wellingboro' Swanspool	1·99	134	,,	Eskdalemuir Obsy. ...	3·67	108
Essex	Shoeburyness	0·73	60	*Roxb.*	Kelso, Floors	1·39	89
,,	Dovercourt	0·67	54	*Peebles*	Stobo Castle	1·83	88
Suffolk	Lowestoft Sec. School...	0·84	57	*Berwick*	Marchmont House ...	1·65	82
,,	Bury St. Ed., Westley H.	1·73	113	*E. Loth.*	North Berwick Res. ...	1·35	97
Norfolk	Sandringham Ho. Gdns.	1·39	91	*Midl'n.*	Edinburgh, Blackf'd. H.	1·50	102
Wilts.	Aldbourne	2·04	110	*Lanark*	Hamilton W. W., T'nhill	2·56	137
Dorset	Creech Grange... ...	2·02	94	*Ayr*	Colmonell, Knockdolian	1·67	66
,,	Beaminster, East St. ...	3·03	128	,,	Glen Afton, Ayr San. ...	3·00	100
Devon	Teignmouth, Den Gdns.	2·66	132	*Renfrew.*	Greenock, Prospect Hill	3·01	87
,,	Cullompton	2·91	128	*Bute*	Rothesay, Ardencraig...	2·26	76
,,	Ilfracombe	4·01	192	*Argyll*	Morven (Drimnin) ...	2·75	75
,,	Okehampton Uplands...	4·16	130	,,	Poltalloch	1·85	61
Cornwall	Bude, School House ...	2·65	140	,,	Inveraray Castle ...	3·47	75
,,	Penzance, Morrab Gdns.	3·76	155	,,	Islay, Eallabus... ...	1·83	64
,,	St. Austell	3·60	128	,,	Tiree	2·03	83
,,	Scilly, Tresco Abbey ...	2·93	149	*Kinross*	Loch Leven Sluice ...	1·65	86
Glos.	Cirencester	2·05	110	*Fife*	Leuchars Airfield ...	0·87	55
Salop	Church Stretton ...	1·84	84	*Perth*	Loch Dhu	...	...
,,	Shrewsbury	1·83	124	,,	Crieff, Strathearn Hyd.	1·70	78
Worcs.	Malvern, Free Library...	2·40	133	,,	Pitlochry, Fincastle ...	1·43	64
Warwick	Birmingham, Edgbaston	2·86	164	*Angus*	Montrose, Sunnyside ...	0·89	49
Leics.	Thornton Reservoir ...	2·21	130	*Aberd.*	Braemar	1·63	69
Lincs.	Boston, Skirbeck ...	1·09	81	,,	Dyce, Craibstone ...	1·51	75
,,	Skegness, Marine Gdns.	1·01	75	,,	New Deer School House	1·38	69
Notts.	Mansfield, Carr Bank...	1·77	102	*Moray*	Gordon Castle	1·36	78
Derby	Buxton, Terrace Slopes	4·33	147	*Nairn*	Nairn, Achareidh ...	0·67	48
Ches.	Bidston Observatory ...	1·54	94	*Inverness*	Loch Ness, Garthbeg ...	1·29	57
,,	Manchester, Ringway...	3·17	176	,,	Glenquoich	5·34	82
Lancs.	Stonyhurst College ...	3·66	135	,,	Fort William, Teviot ...	4·39	98
,,	Squires Gate	2·25	126	,,	Skye, Duntuilm ...	2·97	91
Yorks.	Wakefield, Clarence Pk.	1·23	73	,,	Skye, Broadford ...	4·61	102
,,	Hull, Pearson Park ...	1·16	74	*R. & C.*	Tain, Tarlogie House ...	0·63	34
,,	Felixkirk, Mt. St. John...	1·47	88	,,	Inverbroom, Glackour...	2·16	58
,,	York Museum	1·19	74	,,	Achnashellach	4·13	77
,,	Scarborough	1·01	65	*Suth.*	Lochinver, Bank Ho. ...	1·79	63
,,	Middlesbrough... ...	1·59	116	*Caith.*	Wick Airfield	0·49	25
,,	Baldersdale, Hury Res.	1·60	66	*Shetland*	Lerwick Observatory ...	1·78	78
Norl'd.	Newcastle, Leazes Pk....	0·94	59	*Ferm.*	Crom Castle	1·30	51
,,	Bellingham, High Green	2·14	99	*Armagh*	Armagh Observatory ...	1·58	75
,,	Lilburn Tower Gdns. ...	1·74	88	*Down*	Seaforde	1·88	72
Cumb.	Geltsdale	2·49	117	*Antrim*	Aldergrove Airfield ...	1·20	57
,,	Keswick, High Hill ...	3·18	104	,,	Ballymena, Harryville...	1·61	61
,,	Ravenglass, The Grove	3·19	129	*L'derry*	Garvagh, Moneydig ...	1·29	53
Mon.	Abergavenny, Larchfield	3·00	119	,,	Londonderry, Creggan	1·39	54
Glam.	Ystalyfera, Wern House	4·42	116	*Tyrone*	Omagh, Edenfel ...	1·51	57

M.O. 559 AIR MINISTRY

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USEFULNESS OF FORECASTS

By A. F. CROSSLEY, M.A.

Useful effort.—The following scheme of assessing the usefulness of a certain type of forecast has been put forward by Mr. H. Dawes of the Scientific Adviser's Department of the Air Ministry.

The type of forecast concerned is of the "black or white" type, and may relate, for example, to the suitability as regards weather of any day for carrying out a specific operation; any one day is therefore forecast as suitable or unsuitable. Dawes defines the forecast accuracy c as the proportion of all occasions which are correctly forecast ($0 \leqslant c \leqslant 1$). The "useful effort" is defined as the proportion of occasions forecast as suitable which in fact turn out to be so. If operations are conducted in accordance with the forecasts, the useful effort represents the proportion of operations which turn out successful as regards weather.

If the proportion of suitable days in a given period is denoted by b, then the proportion bc of suitable days will be correctly forecast and the proportion $(1 - b)(1 - c)$ of unsuitable days will be incorrectly forecast as suitable. Therefore the proportion of occasions forecast (rightly or wrongly) as suitable will be $bc + (1 - b)(1 - c)$, and the useful effort is given as

$$E = \frac{bc}{2bc - b - c + 1} \cdot \qquad \qquad \text{.........(1)}$$

This formula indicates that the useful effort depends not only on the forecast accuracy, but also on the frequency of occurrence of the element being forecast. Since one requires $E > b$ to make forecasting worth while, this necessitates $c > \frac{1}{2}$, i.e. the forecast accuracy must exceed 50 per cent.

This argument, however, assumes that the forecast accuracy is the same for suitable as for unsuitable days, and this is not in general the case. Consider an event about which little is known except that it occurs on 1 per cent. of occasions, $b = 0 \cdot 01$. It might then with some justification be regularly forecast as not occurring, and its forecast accuracy would be zero. On the other hand, forecasts of non-occurrence of the event would have an accuracy of 98/99, while the overall forecast accuracy is 98/100. Then let c denote the forecast accuracy of suitable days, and c' that of unsuitable days. The proportions of correct and incorrect forecasts in the two categories may then be set out as in Table I.

TABLE I—FORECAST CONTINGENCY TABLE

	Forecast	Not forecast	Total
Suitable	bc	$b(1 - c)$	b
Unsuitable	$(1 - b)c'$	$(1 - b)(1 - c')$	$1 - b$
Total	$bc + (1 - b)c'$	$b(1 - c) + (1 - b)(1 - c')$	1

From this, the useful effort (in regard to suitable days) is given by

$$E = \frac{bc}{bc + (1 - b)(1 - c')} \cdot \qquad \text{.........(2)}$$

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

$$c + c' > 1, \qquad \text{.........(3)}$$

so that the sum of the two forecast accuracies must exceed unity. It is not therefore essential for the forecast accuracy c to exceed 50 per cent. in order to make forecasting of some particular event worth while; the accuracy can fall short of 50 per cent. provided this is counterbalanced by an accuracy above 50 per cent. for forecasts of non-appearance of the event.

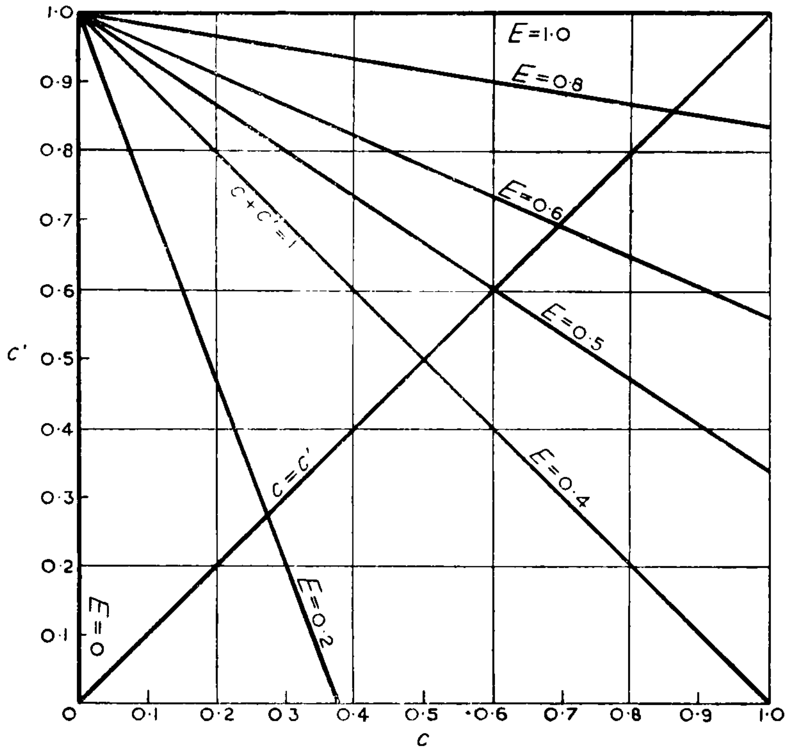

FIG. 1—USEFUL EFFORT (E) IN RELATION TO FORECAST ACCURACIES (c, c') FOR FREQUENCY OF OCCURRENCE $b = 0 \cdot 4$

Fig. 1 illustrates the relationship between useful effort and the forecast accuracies when $b = 0 \cdot 4$. In this and similar diagrams (not reproduced) for other values of b, the diagonal line $c + c' = 1$ is identical with the isopleth $E = b$. Hence for a useful effort greater than b, the point (c, c') must lie above and to the right of this diagonal. The other diagonal is the line $c = c'$, which refers to the simple case considered by Dawes. It is seen that to achieve a useful effort of 0·5 it is necessary to have one or other of c and c' more than 0·6. However, c may be for example as low as 0·3 provided c' is at least 0·8. A similar point was made by Dawes in remarking that a useful effort of 0·48 with $b = 0 \cdot 2$ requires a forecast accuracy of nearly 0·8 (i.e. with $c = c'$).

Varying the useful effort.—The useful effort is a function of the frequency b of the event forecast and of the accuracies c and c' with which both the event and its non-occurrence can be forecast. If b can be varied without invalidating the purpose for which the forecast is required, the value of the useful effort will in general be altered. It is a matter for consideration whether the useful effort can be improved. For example, suppose the event for which forecasts are required is that of "cloud base not below 13,000 ft.". This is included in "cloud base not below 15,000 ft.", and it is conceivable that the useful effort in regard to the latter event is greater than the useful effort in regard to the former. On the other hand, the operations for which the forecasts are required might well be still practicable provided the cloud base is not below 10,000 ft., and again it may be found that the useful effort is in consequence increased. In such cases—where economy of effort is the main consideration and time of less importance—the limiting situation requires to be selected not only from the point of view of feasibility of a particular operation, but also with regard to the resulting useful effort. What at first might appear to be a loss, due to restriction or extension of conditions, may be more than compensated by an increase of useful effort.

Consider again the forecasting of an event of which the frequency distribution consists of a curve with a single hump centred near (but not in general coincident with) the average value, while on either side it tails off towards zero for low and high values. Wind speed, for example, has this type of frequency distribution. Let us suppose that forecasts are required of speed greater (or less) than some value V. If V is near the average value, speeds in this neighbourhood will occur with high frequency and it will often be difficult to predict whether the speed will or will not exceed V; on the other hand, occasions of both very strong winds and very light winds will be more readily forecast successfully, since both, being infrequent, depend on exceptional conditions which will be readily recognized in advance. Thus while b decreases, the accuracy of forecasting increases. However, if variations in c' are ignored, the useful effort increases with bc and may be expected to attain its maximum values in the neighbourhood of the two points of inflexion of the frequency curve, i.e. at moderately low and moderately high values of the wind speed.

By varying expression (2) for the useful effort, it may be seen that for small variations in b, c and c' the useful effort is increased provided

$$\frac{\delta c}{c} + \frac{\delta c'}{1 - c'} + \frac{\delta b}{b\,(1 - b)} > 0. \qquad \ldots\ldots\ldots(4)$$

If the forecast accuracies remain unchanged while b is increased, then the useful effort is increased; this increase will be still greater if either or both of c and c' are increased; but some increase in useful effort may still occur even if one or both of c and c' are reduced. On the other hand if b is reduced, there may be increases in c or c' sufficient to ensure an increase of useful effort.

Examples.—Some of the above ideas may be illustrated by actual results for certain forecasts. Consider first, a series of trial 4-day forecasts of weather over Great Britain made by the Forecast Research Division at Dunstable over the period February 1949 to March 1950. The series included definite forecasts of a change of weather type; such a forecast, to be correct, has to predict a change occurring on the right day of the four. Not more than one change of type occurred, or was forecast, in any one of the 4-day periods concerned.

The following table shows the results of an analysis of these forecasts, each 4-day forecast period constituting one occasion.

TABLE II—FORECASTS OF CHANGE OF TYPE, FEBRUARY 1949–MARCH 1950

Number of cases	Forecast	Not forecast	Total
Change of type	19	17	36
No change...	59	13	72
Total	78	30	108

From these figures we have the following:—

(i) Frequency of occurrence of "change", $b = 36/108 = 0{\cdot}33$*

(ii) Accuracy of forecasts of change, $c = 19/36 = 0{\cdot}53$

(iii) Accuracy of forecasts of no change, $c' = 59/72 = 0{\cdot}82$

(iv) Useful effort, or proportion of forecasts of change which are correct, $E = 19/(19 + 13) \doteq 0{\cdot}59$.

All these figures indicate that forecasts of a change of type constitute a definite improvement on a wait-and-see policy, according to which, on average, a change of type would be expected one occasion in three. At the same time, as might have been expected, there is a much higher forecast accuracy in regard to forecasts of "no change" than there is for forecasts of "change" (82 per cent. against 53 per cent.). Depending on the "operations" concerned, which may of course include the use of the forecasts by the public, forecasts of "no change" may be of as much, or more, importance as forecasts of "change". It is equally appropriate therefore to consider the useful effort in regard to forecasts of "no change", which is $59/(59 + 17) = 0{\cdot}78$. Thus 78 per cent. of the forecasts of "no change" are correct. This compares with the earlier statement that 82 per cent. of the occasions of "no change" are correctly forecast. From the point of view of reliability of the forecasts, the lower figure (the useful effort) is, in this case, the more pertinent.

Another example is provided by the results of an investigation by Sawyer[1] into the application of certain criteria for the formation of secondary depressions at points of occlusion. When his results for both warm-occlusion and cold-occlusion secondaries are combined, Table III is obtained.

TABLE III—FORMATION OF SECONDARY DEPRESSIONS, OCTOBER 1947 TO SEPTEMBER 1948

Number of cases	Criteria correct	Criteria incorrect	Total
Secondary formed... ...	63	14	77
Not formed	137	23	160
Total	200	37	237

Using the same notation as before, we have

$b = 0{\cdot}32$, $c = 0{\cdot}82$, $c' = 0{\cdot}86$.

$E = 0{\cdot}73$ in regard to secondary forming,

$E = 0{\cdot}91$ in regard to no secondary forming.

These figures show that the criteria have a high degree of validity, especially in regard to non-development of a secondary, in which case 91 per cent. of the expectations are correct.

*This number refers only to changes occurring within the 4-day forecast periods; these did not cover the whole of the period mentioned.

Economic importance.—The economic value of forecasts has been discussed by Bilham[2] and more recently by Bijvoet and Bleeker[3]. The latter authors emphasize the economic importance by considering, as an example, the cost of taking precautions against frost damage, and the losses incurred on account of damage if no precautions are taken. Suppose that without preventive measures the average loss on a frost night is L, and that the daily cost of preventive measures is P. Two cases arise according as P is greater or less than bL, i.e. according as the cost of prevention is greater or less than the cost of damage in the absence of preventive measures. If preventive measures are applied only when frost is forecast, it is seen by reference to Table I that the average daily cost C, is given by

$$C = \{bc + (1 - b)(1 - c')\} P + b(1 - c) L.$$

Hence if $P > bL$, the average daily saving obtained by use of the forecasts is

$$B_1 = bL - C = bcL - \{bc + (1 - b)(1 - c')\}P.$$

Similarly if $P < bL$, the average daily saving is

$$B_2 = P - C = (b + c' - bc - bc') P - b(1 - c)L.$$

From these relationships, Bijvoet and Bleeker give two diagrams showing the relationship between P/L and B_1/L or B_2/L for $b = 1/10$.

Conclusion.—Such instances as that just discussed, together with the earlier considerations, show that there is little direct relationship between the value and the accuracy of a given type of forecast. The accuracy is a matter depending on the personal ability of the forecaster, the quality of his technique and the meteorological circumstances, while the value of the forecast to the user depends also on the particular circumstances in which it is applied. If the user is unwilling to risk losing an opportunity on account of a bad forecast, then forecasts (for that purpose) are of no use to him, however accurate they may be, short of perfection. Nevertheless it is desirable to have an estimate of the reliability of any given type of forecast, and expression (2) given above for the useful effort, which is also the chance that a forecast has of being correct, appears to meet this need satisfactorily.

Acknowledgement.—I am indebted to Mr. C. S. Durst for discussions which led to the writing of this note.

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HURRICANE OF AUGUST 17–18, 1951, IN JAMAICA

By W. J. FOWLER

The area of formation of West Indian hurricanes during the months of August and September lies mainly to the eastward of the Lesser Antilles between latitudes 5° and 15°N. Observations show that during the early stages of hurricane development, unsettled and squally weather sets in over a considerable area of ocean. In the later stages the squalls appear to amalgamate and a depression centre forms. Once there is a centre of low pressure the hurricane usually develops rapidly and within 24 hours there may be winds of hurricane force (75 m.p.h.) near the centre. The diameter of the storm area increases to about 75 miles in the case of the small intense ones and to 500 miles for larger ones. Intense convection occurs producing cloud to over 30,000 ft. and torrential rain.

The forecasting of development and movement of these storms and the issuing of the necessary warnings is carried out under international arrangements made by the Caribbean Commission in collaboration with Regional Commission IV of the World Meteorological Organization. The Caribbean Commission is a specialized organization of the United Nations, financed by the British, United States, French and Dutch Governments. Under these arrangements the United States Weather Bureau office at San Juan, Puerto Rico, is the official central hurricane warning centre for the eastern Caribbean Sea. The British, French, Dutch and other United States meteorological offices maintain close contact with each other and with San Juan. Each office can issue a local hurricane warning but no general hurricane warning is, however, issued except in agreement with San Juan. The San Juan office controls the United States squadron of hurricane-reconnaissance aircraft, and any meteorological office can ask San Juan to arrange a reconnaissance flight if a storm centre is located from ship or aircraft reports or if there is a suspicious departure from the normal seasonal weather. The reconnaissance aircraft which then search for the eye of the storm seldom abandon the attempt to find the centre even in the dangerous flying weather of the central area with winds of up to 150 m.p.h.

Hurricanes are labelled alphabetically during the season of their activity. The first is "A" for Able, the second "B" for Baker and so on. The hurricane which struck the southern half of the Island of Jamaica on the night of August 17–18, 1951, was the third in the 1951 series and was named "C" for Charlie; Able and Baker occurred in June 1951 and never reached maturity.

"Charlie" was first located about 50 miles east of Martinique about midday on Wednesday, August 15, and by early morning on the following day it was obvious that, if it continued to move in the same direction, it would pass near and to the south of Jamaica on Friday, August 17. The timing at this stage was rather difficult because of frequent changes in its rate of movement but by 9 a.m. E.S.T. on August 17 it was forecast that the hurricane would commence about 9 p.m. E.S.T. on that day. During this pre-hurricane period the general public and shipping were kept informed as to developments by Press and Radio, which issued instructions as to what precautions to take in order to minimize the effects of the storm. The track of the hurricane is given in Fig. 1.

Before the arrival of the hurricane, Jamaica experienced about five hours of heavy rain which put telephones out of action, probably on account of landslides carrying away poles and breaking the lines, and it was not possible until August 24, when reports began to arrive by post, to track the actual course of the centre across the island. The eastern parishes were the first to be affected, torrential rain and winds of 80–90 m.p.h. being experienced by about 8.30 p.m. E.S.T. These conditions moved slowly westward over the southern half of Jamaica and finally cleared the extreme west by 5 a.m. E.S.T. on Saturday, August 18.

The hurricane struck Kingston, a city of about 125,000 inhabitants, at 9.45 p.m. E.S.T. on August 17 when the wind suddenly increased to an average speed of over 85 m.p.h. with gusts in excess of 110 m.p.h. This approximation is necessary as the two recording wind instruments in the district ceased to register above these limits. There have been rumours that other anemometers

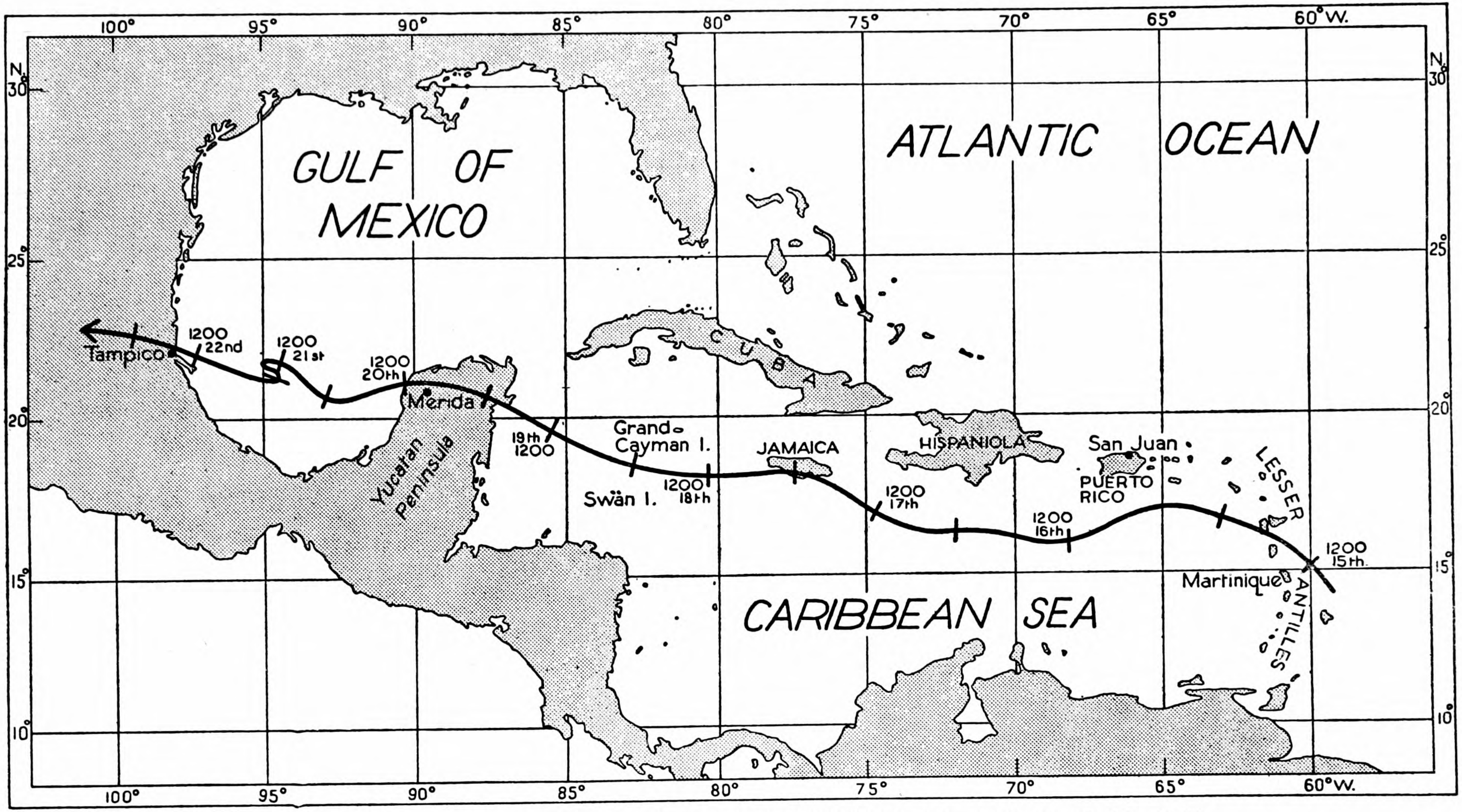

FIG I—TRACK OF THE HURRICANE ACROSS THE CARIBBEAN SEA, AUGUST 15–22, 1951 recorded gusts of 140–160 m.p.h. before being wrecked but these instruments are of the revolving-cup pattern, which over-read considerably at high speeds. It is considered that a reasonable approximation may be given as an average wind speed of 85–90 m.p.h. with gusts to 120–125 m.p.h. These hurricane-force winds continued for about six hours, during which time trees were blown down, roofs blown off and much general damage was done by flying debris, such as branches of trees, pieces of timber and sheets of corrugated iron, the latter being used extensively for garage roofs and outbuildings in the towns and as general roofing material throughout the island.

The south-east quarter of the island suffered the most—Morant Bay, Yallahs, Port Royal and parts of Kingston being the worst affected. The number of deaths in Kingston was 56 and the total for the whole island 152. There was considerable damage to shipping in Kingston Harbour and five large vessels were driven ashore.

During the passage of the hurricane, torrential rain was experienced and over a wide area in the southern parishes amounts in excess of 10 in. were recorded while extreme values of up to 17 in. fell in the Kingston area and locally along the mountain ridge. The rain-gauge at Palisadoes, the airport for Kingston, overflowed because the gauge became clogged with sand and small gravel and the actual rain collected was 430 mm. (16·93 in.); how much rain was lost is not known so we give the figure as 17+in. Fig. 2 shows the rainfall chart for Duckenfield in the extreme south-east corner of the island about 40 miles east of Palisadoes.

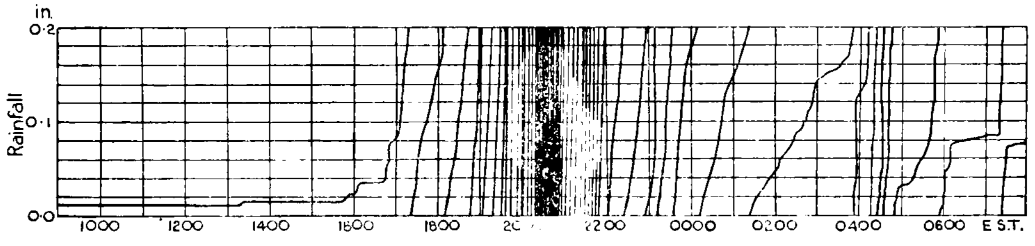

FIG. 2—RAINFALL CHART FOR DUCKENFIELD, AUGUST 17–18, 1951

For about three hours before the passage of the centre the barometer fell very rapidly, as will be seen fron the Palisadoes barogram in Fig. 3. The minimum value recorded at Palisadoes was 973 mb. (28·74 in.). It is estimated that the centre passed about eight miles south of Palisadoes Airport—that is, about ten miles south of Kingston—and that the pressure at the centre, allowing for a five-mile area of uniform pressure in the "eye", was about 964 mb. (28·47 in.). I am indebted to the Rev. Canon H. W. Cope of Savanna la Mar and to Mr. E. P. Buckley of Kingston, both keen amateur meteorologists, for providing me with half-hourly barometer readings throughout the night of the hurricane and thus assisting in tracking its course across the island. From the accompanying map, Fig. 4, it can be seen that the centre passed over the coast to the south-west of Kingston.

As is usual when a hurricane passes over land the winds decreased in violence as it travelled westwards across the southern part of the island. The wind dropped to an average of about 60–70 m.p.h. and the rain became less intense. Even so the wind was strong enough in the western areas of Jamaica to break

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ST. GEORGE'S COLLEGE, KINGSTON

Reproduced by courtesy of the Daily Gleaner, Jamaica

TYPICAL VIEW OF THE DAMAGE CAUSED TO HOUSES DURING THE HURRICANE OF AUGUST 17–18, 1951

Reproduced by courtesy of the Daily Gleaner, Jamaica

LARGE CARGO STEAMER DRIVEN ASHORE WITHIN THREE YARDS OF THE KINGSTON-PALISADOES ROAD

Reproduced by courtesy of the Daily Gleaner, Jamaica

REMAINS OF THE MAIN AIRPORT BUILDING AFTER THE HURRICANE OF AUGUST 17–18, 1951 banana plants and sugar canes and unroof houses. The northern parishes of the island escaped the worst fury of the storm. The wind there, with a highest reported value of 40–50 m.p.h., was enough to cause a fair amount of damage to crops but not to cause much structural damage. The rainfall in the north was very patchy; some places reported 5–7 in. while others escaped with a mere 2 in. which is, it may be mentioned, of the same order as the average monthly rainfall in south-east England.

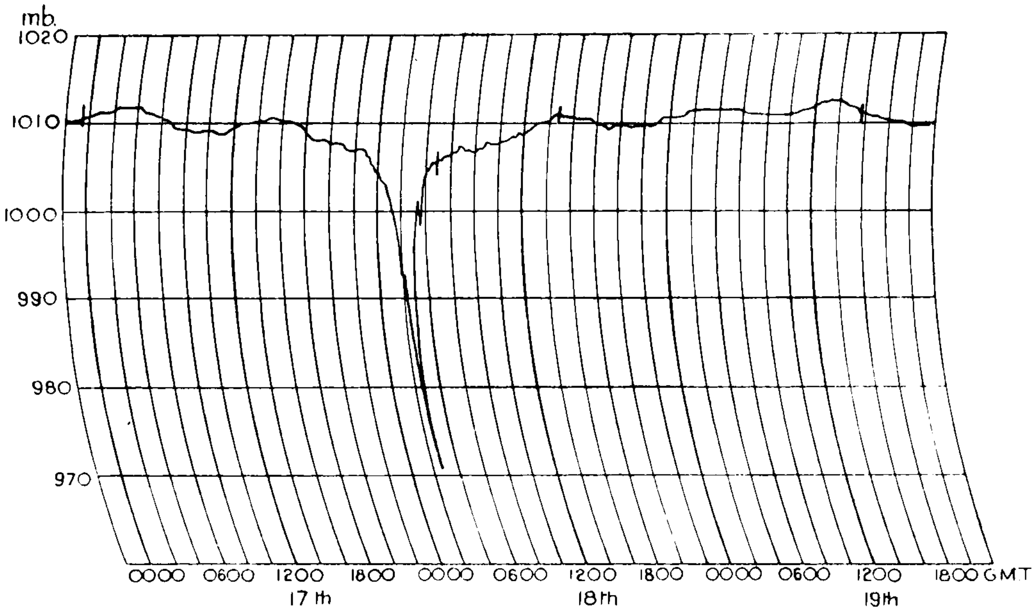

FIG. 3—BAROGRAPH FOR PALISADOES, AUGUST 17–19, 1951

As it approached Jamaica, the centre was moving towards west-north-west but it left the island at a point almost due west of the point of entry. Possibly the east-to-west range of mountains across the island had some influence on the change of track. After leaving, it resumed its normal track towards west-north-west passing between Swan Island and Grand Cayman Island about 24 hours after it had struck Kingston. In the meantime, it had regained full hurricane force and the wind was reaching 120–130 m.p.h. in gusts. By midnight of the 19th, the centre had travelled to north Yucatan and passed close to the important town of Merida during the morning of August 20. From here, it passed out into the Gulf of Mexico, where it remained almost stationary for a period of 12–15 hours. The intensity of the storm had again shown great variation, having decreased during its passage over the Yucatan Peninsula, and regained what it had lost during its slow journey over the Gulf of Mexico. By early morning on August 22 the centre was once again continuing its west-north-west movement towards Tampico, Mexico. The "eye" of the hurricane passed over this town between 1 p.m. and 1.30 p.m. on August 22 and the inhabitants there experienced the calm period, associated with the centre, between hurricane force winds of 100 m.p.h. from opposite points of the compass.

Records of hurricanes affecting Jamaica date back to 1689 and since then Jamaica has experienced 39 hurricanes, 17 of which could be classified as "violent". The following table gives the number experienced month by month during the last 262 years:—

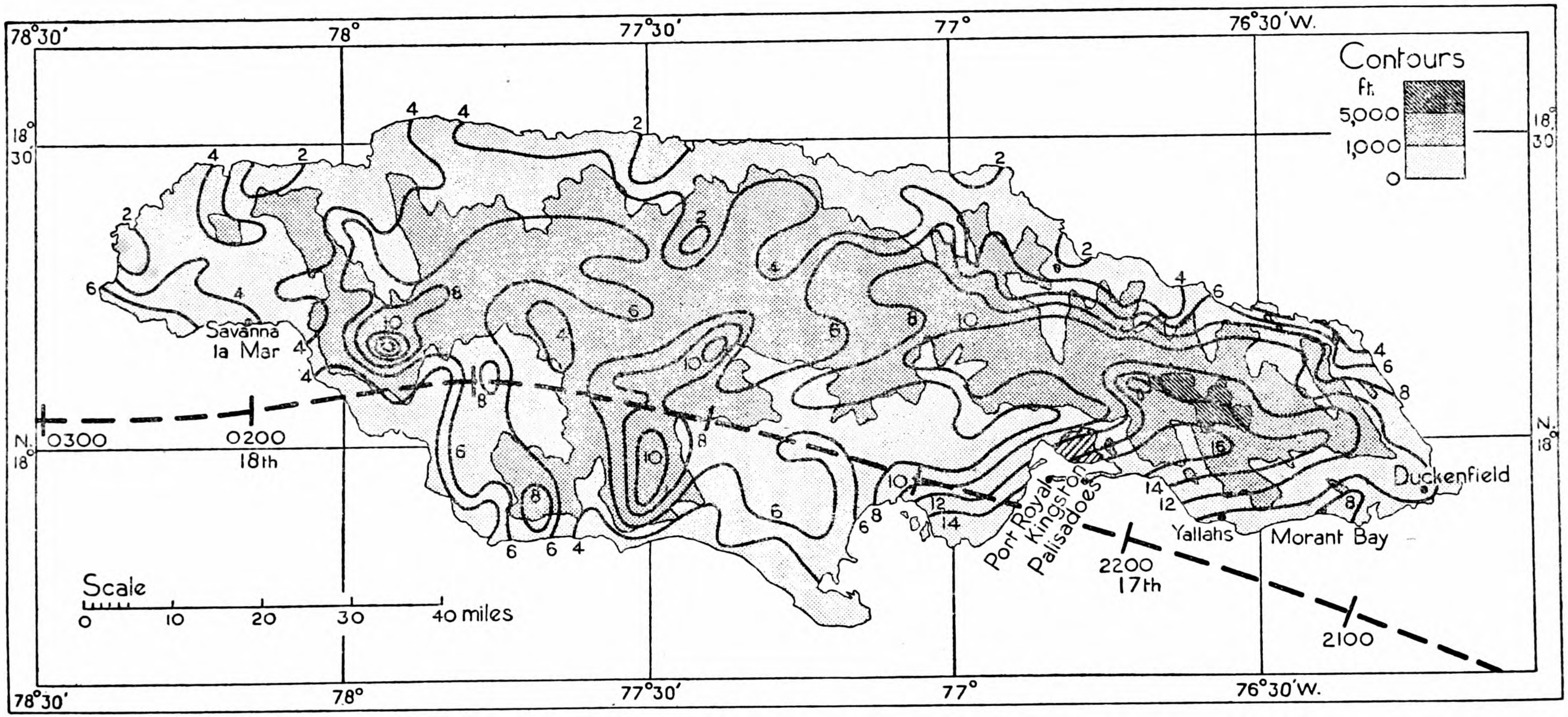

FIG. 4—RAINFALL FOR THE 24 HOURS ENDING AT 0700 E.S.T., AUGUST 18, 1951
Values of the isohyets are given in inches. The probable track of the hurricane is shown by a broken line.

	Total storms	Violent hurricanes		Total storms	Violent hurricanes
June	2	0	September ...	4	1
July	1	0	October ...	11	6
August	18	7	November ...	3	2
			Total ...	39	16

From this table it is evident that August is the month of greatest risk of hurricanes. The average frequency of violent ones is one in sixteen years but this figure must not be taken to imply any sort of periodicity as in some years there have been more than one—there were three in 1916 and two in 1813 and 1915—and on the other hand, there have been in the past 250 years, periods of over 20 years without one.

Although the October 1933 hurricane was disastrous to the western parishes, we have to go back to August 1903—48 years earlier—to find such widespread damage as that experienced during the passage of hurricane "Charlie" during the night of August 17–18, 1951.

DAILY MAXIMUM TEMPERATURE OF THE SURFACE OF THE GROUND

By R. W. GLOYNE, B.Sc.

Introduction.—Although the temperature of the surface of freely exposed ground is often required, information on this important meteorological factor is widely scattered. Two empirical formulæ were recently published dealing with the relationship between the daily maxima on the ground and in the screen which might usefully be brought to the notice of a wider public; and, in this present note, some observations on surface temperatures are discussed against the background of the two formulæ.

In the following paragraphs we shall use the terms "surface" temperature and "skin" temperature to refer to the results obtained by methods which measure respectively a mean temperature of a shallow surface layer and a true surface temperature. Vaartaja[1] has suggested that the daily maximum skin temperature might be some 9°C. higher than the corresponding surface temperature, and, as will be seen later, an additive correction of this magnitude is sufficient to reconcile surface temperatures measured by the two methods.

Empirical relationships between the maximum air temperature in the screen and maximum surface and skin temperatures.—(*a*) Penman[2], at the Rothamsted Experimental Station, Hertfordshire, obtained continuous records, covering most of the period June 1940–August 1941, of the temperature given by a mercury-in-steel thermograph, the 1-in. diameter bulb of which was half buried in fallow soil, the upper semi-circular surface being freely exposed to air and sun. This was calibrated with respect to a mercury-in-glass instrument so mounted as to give the mean temperature of the top ½-in. layer of soil. If values of this daily surface maximum are denoted by T and the corresponding screen maxima by t, Penman deduced:—

$$T \simeq t \text{ when } T < 52°\text{F.}$$
$$T \simeq 2t - 52 \text{ when } T > 52°\text{F.} \qquad \ldots\ldots\ldots(1)$$

with an accuracy of about $\pm$ 10°F. or so judging from Fig. 4 in his paper.

(*b*) Debrach[3], working near Rabat (Morocco) in 1942–43, measured the temperature of a bare soil "surface" with the aid of a fine mercury-in-glass thermometer buried 3 mm. below the surface, and found that the readings at 1300 local time of this thermometer and of that in the screen (in degrees Centigrade) were connected by the relationship

$$T = 2t - 10 \qquad \ldots\ldots\ldots(2)$$

with a tolerance of $\pm$ 5°C. This and the second of Penman's relationships are virtually identical.

(*c*) Mackenzie Taylor[4], in the Egyptian desert during 1924, used a method very similar to that employed by Penman. The relationship between his values of the monthly means of daily maximum surface temperature T and of maximum screen temperatures t (in degrees Centigrade) may be expressed as follows:—

$$T = 1{\cdot}98t - 11{\cdot}29$$

with a correlation coefficient of over 0·95.

(*d*) Vaartaja[1], in Finland, measured with the aid of fine thermocouples skin temperature (T') in a number of different types of country. If we select those few quoted results which were obtained in reasonably flat open countryside we have (in degrees Centigrade):—

t......	19·3	25·3	25·7
T'......	35·0	44·0	49·0

Adopting his suggestion (mentioned earlier) that

$$T' = T + 9 \qquad \ldots\ldots\ldots(3)$$

we have T......26·0 35·0 40·0
which compares with values 28·6°C., 40·6°C. and 41·4°C. computed by Debrach's equation (2).

(*e*) Rider and Robinson[5], in the Appendix to their paper on heat and vapour exchange over a short turf surface, quote a number of simultaneous measurements of a skin temperature and screen temperature at various heights. Since the maximum temperature is not reached at the same time at the surface as at 1·4 m., days for which appropriate observations are available are limited to four (June 20, 21 and 23 and July 1, 1949).

Using $T = 2t - 50$ we have, in the four cases, T = 90°, 97°, 88° and 102°F. which are respectively 12°, 9°, 15° and 8°F. below the observed values of T' thus leading to a relationship between T' and T approximately as given by equation (3).

(*f*) Yakuwa[6], measured temperature in plots of different soil types. From his results for a particular day we find:—

Soil type	loam	clay	"bog"	volcanic sand	sand
T(°C.)	46·7	35·9	39·0	48·6	53·5

and t = 27·5°C.

It is not clear from the paper which of the five soil types is representative but the result for "loam" is consistent with equation (2).

(*g*) Observations of T' and t in degrees Fahrenheit quoted by Pasquill[7] for three days in March agree approximately with

$$T' = 2t - 50.$$

Penman, however, found that when T < 52°F. the relationship was $T \simeq t$, and as the skin temperatures quoted by Pasquill were 62°F. or less we may allow the possibility that neither equation (1) nor equation (3) apply in this particular case.

(*h*) Johnson and Davies[8] reported the monthly means of daily maximum and minimum temperatures obtained at 1-cm. depth in various types of surface, amongst these chalk with and without a cover of short turf. Making a rough assessment of the extent to which the 1-cm. thick layer of soil (and the additional thickness of turf in one instance) decreases the diurnal range of temperature experienced at the surface, it would appear that a functional relationship of the form

$$T = at - b, \ a \doteq 2$$

represents the trend of the observations fairly well.

(*i*) In a technical memorandum[9] issued by the Meteorological Office in 1942 a few extreme surface temperatures obtained in hot countries are noted. These, which are probably surface and not skin temperatures, are found to obey the relationship (in degrees Fahrenheit)

$$T = 2t - 50$$

to an acceptable degree of accuracy.

Discussion.—There appears to be some evidence that the maximum temperatures at the surface and in the screen can be linked by a linear relationship which applies over an unexpectedly wide range of conditions. The relationship seems to be valid in dry tropical or subtropical climates throughout the year, and in temperate regions in the summer half year at least. Although both Penman and Debrach make it clear that values for any particular day may deviate appreciably (say $\pm$ 5°C.) from the average relationships expressed in equations (1) and (2), it is nevertheless striking to note that the same empirical relationship between screen and surface maxima obtains in the British Isles, where evaporation at the surface is an important sink for solar energy, as in the desert, where it can only play a minor role.

Implicit throughout is the assumption that the temperature of the air is determined by the soil temperature in the same neighbourhood. Therefore the surface temperature of small plots differing markedly in character from that of the surrounding countryside, will not necessarily be related to the air temperature by equation (1). In this, as in other similar studies, due weight must be allotted to the customary rule that the rate of development of vertical temperature, moisture and velocity profiles in the air, appropriate to the surface over which the air is flowing, is of the order of 1 ft. for every 100 ft. of unobstructed fetch from the windward boundary of the surface.

There is no need to stress the potential importance of the relationships discussed earlier if they can be established as a general rule. It is also possible that the deviations in any particular case will be related to the soil type and its condition (especially moisture content) at the time, and to short-period variations in the vertical fluxes of heat and vapour.

Summary.—An examination of some recent observations of the maximum temperature on or near the surface of the ground and of the corresponding screen air maximum temperature support the empirical relationship deduced independently by Penman in England and Debrach in Morocco.

If T = daily maximum temperature (in degrees Fahrenheit) of a layer a few millimetres thick at the surface,

t = daily maximum temperature in the screen (in degrees Fahrenheit)
T' = skin temperature of the surface (in degrees Fahrenheit),
then $T = 2t - 50$
and $T' = T + 15$

This result seems to apply generally over bare soil in dry subtropical regions throughout the year, and over bare soil and short turf in the summer half of the year in temperate regions, providing that the soil is not waterlogged and that the surface whose temperature is being observed is reasonably homogeneous for some hundreds of feet upwind.

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RADIO-WAVE PROPAGATION AT 89 Mc./sec. IN RELATION TO SYNOPTIC CONDITIONS

By C. W. SPENCER, B.Sc.

(Communication from the National Physical Laboratory)

Summary.—The correlation between wave-propagation characteristics at a frequency of 89 Mc./sec. over a 257-Km. path and the occurrence of isothermal or temperature inversion layers in the troposphere, the type of isobaric curvature, and the general weather situation is examined. It is shown that these layers may have a marked effect on the field strength at the receiving point; the curvature of the isobars has a smaller significance. Field strengths greatly exceeding the value to be expected under conditions of standard refraction may occur in any weather situation, but are more probable in some types than others.

Introduction.—Radio waves in the 1–10-m. wave-length band, i.e. in the frequency range 300–30 Mc./sec., are being used increasingly for broadcast, television and communication services. It is essential, therefore, that the propagation characteristics of radio waves in this wave-length band should be clearly understood so that the most efficient allocation of the available wave-lengths to the various services may be made. The propagation of the waves at the long wave-length end of the band is affected by the ionosphere, but when the wave-length is less than 5 or 6 m. refraction in the troposphere is the more important factor. This refraction, which varies with the weather conditions, may cause the field strength at a distance of 200–300 Km. from a transmitter to be similar to that normally expected at a distance of only 50–100 Km. under standard refraction conditions. These conditions may be defined as those under which the radius of curvature of a radio ray path, initially nearly horizontal, is four times that of the earth's surface. This corresponds to a linear gradient of refractive index with height of $-3\cdot9 \times 10^{-8}$ per metre, which is closely approached up to at least 1 Km. in a well mixed atmosphere.

Satisfactory reception of transmissions in the metre wave-length band under standard refraction conditions is not possible at points much beyond the horizon as seen from the transmitter. Meteorological situations may exist, however, which lead to either super-refraction or sub-refraction; of these the former occurs more often and has an important bearing on the planning of very high-frequency radio services.

The super-refraction may be intense enough to produce a duct in which "guided-wave" propagation[1] takes place; this type of propagation often occurs at the centimetre wave-lengths used in radar systems but is rare at metre wave-lengths. The difference is due to the magnitude of the track width of the first guided propagation mode in the two cases. This width is of the order of 25 m. and 200 m. for wave-lengths of 10 cm. and 3 m. respectively, but duct thicknesses of more than 100 m. are known to occur rarely in the region of the British Isles, the area dealt with here.

The effect of increased refraction near the ground on propagation at metre wave-lengths can usually be taken into account by slightly increasing the curvature of the ray paths; then the estimation of field strengths involves only diffraction round an earth with an effective radius suitably larger than the actual value. The effective earth-radius factor corresponding to standard refraction is $1\cdot33$; it may be as much as 3 for super-refraction conditions.

Elevated isothermal or temperature-inversion regions, however, often have a great influence on propagation at metre wave-lengths. Although still essentially super-refracting regions, they may be considered as partially reflecting layers for transmitting and receiving points well below them[2].

Mention should also be made of the scattering of radio waves caused by the variations of refractive index in turbulent eddies in the atmosphere. The extent of this phenomenon is not yet fully understood but there is reason to believe it may be the most important factor causing abnormally high field strengths at extreme ranges (several hundred kilometres), particularly at the high-frequency end of the metre wave-length band.

It has been known for some twenty years that the weather affects the propagation of metre wave-length radio waves; it is only recently, however, that sufficient systematic observations have been made in the British Isles for a general correlation between the propagation conditions and the features of the meteorological situation to be attempted. In this paper the correlation between the occurrence of isothermal and temperature-inversion regions and of field strengths exceeding those to be expected with standard refraction prevailing is investigated. The relative importance of ground-based and elevated regions is examined, together with the general influence on propagation of the isobaric curvature and the over-all weather type in the neighbourhood of the transmission path.

The period covered is only from July to December 1950, inclusive, but already some general trends are apparent; it is intended later to extend the analysis to cover a much longer period, and to examine the meteorological conditions and the propagation characteristics in finer detail.

Radio-propagation data.—It had been intended that the field-strength levels at the Radio Research Station, Slough, from the pulsed 89 Mc./sec. (3·4 m.) transmitter operated by the B.B.C. at Moorside Edge, over a non-optical distance of 257 Km. (160 miles), should be continuously recorded from 12.30 p.m. to 9.30 a.m. daily (except for Saturdays, Sundays and public holidays). An over-all examination of the recordings for the period July-December 1950, however, shows that, owing mainly to the high level of general interference, particularly during the daylight hours, a continuous record of the transmissions was not obtained. Therefore, it is not possible to derive a true statistical analysis of the field-strength variations. It is considered, however, that valuable information can be obtained by examining the meteorological conditions during the times when high field strengths were recorded.

Classification of the radio propagation data.—Because the nature of the recordings indicated that all field strengths of 3 microvolts per metre and greater are recorded, such signals have been classed as "high"; the field strength at Slough, corresponding to standard refraction[3] is of the order 1·2 μv./m.

For the analysis, each daily recording has been divided into the four observation periods, morning 0400–0930, day 1230–1700, evening 1700–2200 and night 2200–0400. If, during any part of one of these periods, the field-strength level was equal to or greater than 3 μv./m., whether continuously or in isolated rapidly fading bursts, the period has been classed as one of high field strength.

Meteorological data.—The meteorological data were obtained from the *Daily Weather Report* and *Daily Aerological Record* of the Meteorological Office. For each observation period as defined above when the transmissions took place, irrespective of whether the field strength was sufficient to be recorded or not, the following meteorological factors have been examined:—

(i) curvature of the isobars which covered the transmission path;

(ii) presence or absence of isothermal or temperature-inversion regions, with respect to pressure, shown by the radio-sonde ascents from Larkhill and Downham Market;

These regions have been classified according to whether their base was on the ground, above the ground but below 950 mb., or between 950 and 900, 900 and 800, 800 and 700 mb.; no account has been taken of any of these regions at pressure levels less than 700 mb., i.e. at heights greater than approximately 3 Km. (10,000 ft.). One of these regions is considered to have been present during an observation period if it was recorded at either Larkhill or Downham Market; no distinction is drawn between the case where a region was recorded at only one of the stations and the case where it was recorded at both of them. The location of the radio-sonde stations and of the transmission path is shown in Fig. 1.

(iii) The general weather type[4,5] as determined by the distribution of the centres of high and low pressure around the British Isles at 1200.

Normally the weather situation changes slowly from one type to another; so, to simplify the analysis, the type at 1200 has been taken to apply to the 24-hour interval starting at 0400. That is, in general, each weather type at 1200 applies to four observation periods; the change of weather type, if any, is assumed to have taken place between the 2200–0400 and the 0400–0930 periods.

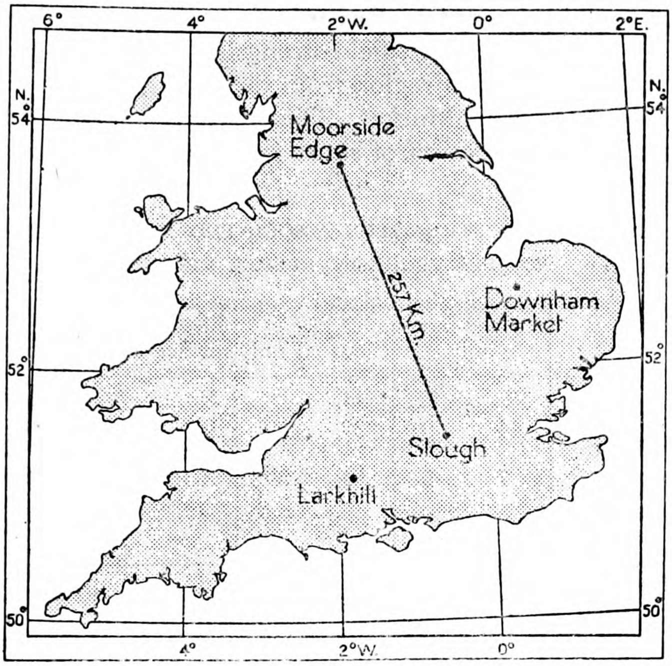

FIG. I—LOCATION OF DOWNHAM MARKET AND LARKHILL RADIO-SONDE STATIONS AND THE TRANSMISSION PATH

The weather situations have been divided amongst the eight types—anticyclonic, cyclonic, westerly, north-westerly, northerly, easterly, southerly, and col, with an additional type, indefinite, for the few synoptic situations which do not readily fall into any of the eight main types. These are often a combination of two of the main types.

Discussion of results.—*Isobaric curvature.*—It is seen from Table I that the curvature was cyclonic for about half of the observation periods and anticyclonic for about one quarter. Hence, although the chance of a high-field-strength period occurring with anticyclonic curvature seems to be twice that of it occurring with cyclonic curvature, the total number of high-field-strength periods during these seven months was about the same for each type of curvature.

TABLE I—HIGH FIELD STRENGTH ASSOCIATED WITH ISOBARIC CURVATURE

	Types of curvature								
	Anticyclonic		Cyclonic		Col		Indeterminate		Total
	No.	%	No.	%	No.	%	No.	%	No.
Number of periods ...	132	28	238	51	17	4	80	17	467
Number associated with high field strength ...	59	41	51	35	11	8	23	16	144
Percentage of given type with high field strength		45		21		65		29	...

The relatively high percentage for the occurrence of high-field-strength periods in a col situation should be noted; although it must be remembered that there were relatively few examples of this situation. It might be expected that the percentage occurrence of high-field-strength periods would lie between the cyclonic and anticyclonic values, but it is considerably higher than either. The indefinite group is made up mostly of the occasions when the isobars were practically straight.

Isothermal and temperature-inversion regions.—Table II shows that less than 1 per cent. of the high-field-strength periods occurred when there was no isothermal or inversion region from the surface to 700 mb. recorded at either Larkhill or Downham Market. This is in agreement with the accepted fact that anomalous propagation of short radio waves does not take place in a well mixed atmosphere.

TABLE II—HIGH FIELD STRENGTHS ASSOCIATED WITH ISOTHERMAL AND TEMPERATURE-INVERSION REGIONS

	Isothermal and temperature-inversion regions								
	Surface-based only		Elevated only		Elevated and surface-based		No regions		Total
	No.	%	No.	%	No.	%	No.	%	No.
Number of periods ...	44	9	232	50	123	26	68	15	467
Number associated with high field strength ...	7	5	81	56	55	38	1	0·7	144
Percentage of given type of region with high field strength ...		16		35		45		1·5	...

The fact that 56 per cent. of the high-field-strength periods can be associated with elevated regions with no simultaneous surface-based region, indicates that, at the frequency in question and over this transmission path during this time, elevated regions were of much greater importance than those based on the surface of the ground.

About 40 per cent. of the total number of elevated regions were associated with high-field-strength periods. In this connexion it is of interest to note that an analysis of the refractive-index changes through elevated layers, using Larkhill and Downham Market radio-sonde data, shows that 35–45 per cent. of these layers have a refractive-index gradient greater than that corresponding to standard refraction.

TABLE III—HIGH FIELD STRENGTH ASSOCIATED WITH BASE HEIGHTS OF ISOTHERMAL AND TEMPERATURE INVERSION REGIONS

	Base height of isothermal or temperature inversion				
	on surface	above 950 mb.	950–900 mb.	900–800 mb.	800–700 mb.
Number of periods with base of region at given height	163	50	84	219	208
Number associated with high field strength	62	27	45	93	78
Percentage at given height with high field strength...	38	54	54	42	37

The percentage number of high-field-strength periods that occurred at the same time as a temperature inversion or isothermal region with its base within a particular height interval is shown in Table III. Although the regions occur most frequently in the pressure interval 900–800 mb. (950–1,950 m., 3,100–6,400 ft.), those most likely to coincide in time with high-field-strength periods occur at a lower altitude, 950–900 mb. (490–950 m., 1,600–3,100 ft.), This may be due in part to the greater angle of incidence upon the lower layers resulting in a relatively greater reflection coefficient.[2]

General weather types.—The number of observation periods with each type of weather, and the percentage number of each type associated with high-field-strength periods are shown in Table IV.

TABLE IV—HIGH FIELD STRENGTH ASSOCIATED WITH DIFFERENT WEATHER TYPES

	AC.	C.	W.	NW.	N.	E.	S.	Col	Indef.	Total
Number of periods with given weather type	27	64	212	40	23	21	49	15	16	467
Number associated with high field strengths	21	6	57	6	0	14	24	8	8	144
Percentage of given type with high field strengths ...	78	9	27	15	0	67	49	53	50	31

AC. = anticyclonic C. = cyclonic

The great preponderance of a westerly type of weather is in agreement with the average for the British Isles over a number of years[4,5]. Anticyclonic weather is the most likely to produce high field strength, followed by easterly, col and southerly types in that order. Cyclonic and north-westerly types are relatively unlikely to produce high-field-strength periods, while none at all were recorded in the few examples of the northerly type. The indefinite group consists mainly of weather situations which were a combination of southerly with either easterly or westerly types; it falls, in this case, into the group with the larger percentages of high-field-strength periods. Westerly types lie between the two groups but it should be noted that, because of more frequent occurrence, they do in fact produce by far the greatest number of high-field-strength periods. These results are consistent with what would be expected from a simple consideration of the characteristics of the various weather types. A further interesting fact has emerged during the analysis, namely that on several occasions high field strengths coincide with the presence of the warm sector of a depression over the transmission path.

Conclusions.—High field strengths appear to be about twice as probable with anticyclonic curvature as with cyclonic curvature. The latter is, however, about twice as frequent as the former, so that the number of occasions of high field strengths over a long time are likely to be equally divided between the two types.

Isothermal and temperature-inversion regions, and in particular elevated ones, have a marked influence on the field-strength level either directly or because of some atmospheric conditions which are more likely to arise in their presence.

The weather-type analysis shows that there is no general synoptic situation which entirely precludes the possibility of high field strengths. This is in spite of the fact that, so far, no cases have been found in the northerly type, for there are so few examples of this type included in the present investigation that it would be unwise, at this stage, to make it an exception to the general conclusion.

It thus appears that there is no simple classification of the weather situation which by itself would give a reliable indication of the possibility or impossibility of the non-standard propagation of metre wave-length radio waves. On the other hand, it may be that a further examination will eventually reveal some factors common to all which are responsible for such propagation.

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The author wishes to acknowledge the advice given by Dr. J. A. Saxton on the presentation of the paper.

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TEMPERATURE AND WIND DISTRIBUTION IN THE LOWER STRATOSPHERE

By M. K. MILES, M.Sc.

Introduction.—For the purpose of this study, which is based on charts drawn at the Central Forecasting Office of the Meteorological Office, the layer between 200 and 100 mb. (say 40,000–55,000 ft.) has been taken as typical of the lower stratosphere. The thickness patterns for this layer have provided the data for studying the temperature configurations.

Radio-sonde errors at these levels are commonly large enough to make the thickness pattern uncertain on any one occasion, but by considering a sequence of charts and the wind shear in the layer (200–100 mb.) the large-scale pattern can nearly always be established with reasonable certainty.

The contour pattern is more difficult to ascertain when winds are light, so that study has been mainly concentrated on temperature distribution and certain aspects of wind behaviour.

Temperature distribution.—The broad feature in summer is a fall of temperature equatorward, but in winter there is often a more complex distribution. Where arctic air has moved far south accompanied by a cold stratosphere a belt of maximum stratosphere temperature is found in middle latitudes. Again there may be a roughly meridional distribution as during the last three weeks of February 1952, when maximum stratosphere temperature was in a belt from Newfoundland to east Greenland with temperature falling south-eastwards to a general minimum in the neighbourhood of the British Isles. These large-scale effects have been noted on several occasions to be quite persistent.

Embedded in this almost hemispherical temperature pattern there are smaller patterns associated with tropospheric systems. Warm ridges in the troposphere have cold tongues above them and cold troughs, warm tongues. These thermal tongues travel with their associated tropospheric features and decay and intensify generally in phase with them. It should be noted that the stratospheric cold tongues normally have their roots to the south so that the wind shear in the lower stratosphere ahead of a thermal ridge is usually south-easterly backing to north-easterly behind the ridge. It is occasionally possible to establish that the stratospheric wind change occurs before the tropospheric ridge axis passes. Similar evidence with cold troughs indicates a small forward displacement of the stratospheric tongue relative to the associated tropospheric thermal system. These cold troughs normally lag behind the surface pressure systems by a greater amount than this, so it appears that the thermal features of the stratosphere may occupy an intermediate position.

Warm and cold pools are fairly common in the stratosphere. Broadly speaking they occur above tropospheric cold and warm pools respectively, though many thermal troughs and ridges in the troposphere are accompanied by them. Cold pools occur on the north side of warm anticyclones and at the north-east tip of some warm sectors. In the latter situation they disappear quickly with the occlusion of the warm sector, but with warm anticyclones they can be followed for several days. They move considerably more slowly than the air near their centre at 100 mb. Warm pools often persist for several days sometimes centred directly above the cold pool or cold trough of the low, and sometimes, though less often, above the surface low-pressure centre. The majority examined have no cyclonic circulation round them at 100 mb., and occasionally there is a nearly straight flow across them. Seven cases of this kind were examined in detail, and the ratio of their speed to the mean wind near the centre at 100 mb. was found to average nearly a half, with extreme values of 0·35 and 0·70. This implies that the air in the stratosphere descends as it flows into the pool and ascends on leaving it. Rough estimates of the rate of vertical motion yield values about 5 cm./sec. The direction of movement is nearly that of the wind at 100 mb. with deviations on either side up to about 20°. A fairly common characteristic of these pools is their rapid decay when fresh cyclonic development is occurring to westwards with formation of a new warm pool over the new low. This sequence of events can be observed along the belt of maximum stratospheric temperature mentioned earlier, and suggests that the high stratospheric temperature is to some extent dynamically maintained.

The thermal features of the stratosphere mostly respond immediately to tropospheric changes. When a cold air mass warms by subsidence the associated warm pool or tongue weakens and perhaps disappears, and when a warm anticyclone collapses the associated cold pool disappears. The large meridional features mentioned earlier are probably an exception to this state of affairs. They can be thought of as exercising a control to the extent that big tropospheric changes do not occur. In February 1952 a large warm anticyclone was centred throughout on the south-east side of the stratospheric temperature maximum with a more or less stationary cold pool on its eastern side. The persistence of the thermal gradient in the stratosphere with the prevailing northerly winds at 100 mb. required a steady ascent of air on its track at an estimated rate of 10 cm./sec. That a persistent high-pressure system drifted slowly towards the southern end of the track suggests that in this case at any rate the stratosphere may have controlled the broad tropospheric events.

There is an interesting association of tropopause structure with these stratospheric patterns. The tropopause is clearly defined, generally with an inversion at the base of the stratosphere, in warm and cold pools. The inversion is normally most marked with the latter, and in this situation occur some of the lowest tropopause temperatures of middle latitudes. The arctic stratosphere is at varying heights and the tropopause is not so well defined. There is normally a region of reduced lapse rate below the tropopause or a region of temperature lapse in the stratosphere depending on the application of the criteria for choosing the tropopause. Away from the well marked stratospheric temperature patterns the tropopause is of intermediate height and often poorly defined.

Wind distribution.—Perhaps the most striking feature of the winds at 100 mb. is their steadiness and constancy over quite large areas. Broad streams of fairly constant velocity persist for days and even weeks, e.g. in December 1951 and February 1952 over the east Atlantic and British Isles. During this time the wind near the tropopause may undergo large changes of direction and speed which are compensated by equivalent changes of the wind shear in the lower stratosphere. This compensation is so complete that, for periods when the wind at 100 mb. does not exceed 30–35 kt., graphs of the wind at 200 mb. against the magnitude of the wind shear 200–100 mb. reveal approximately linear proportionality. At Larkhill for February, August and September 1951, and at ocean weather station JIG for September 1951 the observations can be readily represented by the following regression equations:—

$$V_{200-100} = 0{\cdot}9\ V_{200} - 16 \text{ kt. for } V_{100} \geqslant 20 \text{ kt.}$$
$$V_{200-100} = 0{\cdot}9\ V_{200} - 5 \text{ kt. for } V_{100} < 20 \text{ kt.}$$

where V_{200} and V_{100} are the wind strengths at 200 and 100 mb. in knots and $V_{200-100}$ is the magnitude of the wind shear vector from 200 to 100 mb. Either of these relations, depending on the wind regime at 100 mb., fits the wind observations for periods of perhaps ten consecutive days and provides a useful estimate of the wind at 100 mb. from soundings which cease at 200 mb. When the winds at 100 mb. are over 30–35 kt. or when they have a considerable component across the thermal gradient in the lower stratosphere, i.e. mainly in the winter months, such relationships will not hold. During the months mentioned above the wind shear was generally about opposite in direction to the wind at 200 mb. In over 75 per cent. of cases the angular deviation from a true reciprocal was 20° or less. These small deviations, while not affecting the validity of the two relationships above, are however significant; they represent the veering or backing of the wind in the stratosphere, and further study of the data shows that the mean direction of the wind at 200 mb. for all cases of stratospheric wind veer differs significantly from that for the cases of backing.

	Mean direction of wind at 200 mb. for all cases of Veering	Backing
Larkhill, August 1951	220°	276°
Larkhill, September 1951	221°	296°
Station JIG, September 1951... ...	234°	282°

These figures illustrate the decrease in amplitude of flow perturbations above the tropopause. It is of interest to note that, assuming the direction of the shear vector to be parallel to the 200–100-mb. thickness lines, this implies that the thermal patterns in the lower stratosphere mostly have a greater amplitude than the contour patterns near the tropopause.

Winds in the lower stratosphere are generally strongest in December and January, though even at this time winds of less than 20 kt. are not uncommon for quite long periods, e.g. the wind at 100 mb. at Larkhill did not exceed 25 kt. during December 10–22, 1951, and similarly light winds were being reported from other stations in the British Isles and Europe. Winds are generally light above anticyclones and slow-moving cold lows in the upper troposphere. Strong belts of flow appear to exist on the south-west side of such systems.

In the neighbourhood of travelling stratospheric warm pools in winter broad streams of 40–60 kt. occur often, with very little horizontal shear from the south of England to the Shetland Islands. This arises from the presence of the cold arctic stratosphere in the north causing a broadly westerly shear in the stratosphere to the north of the warm pools. This, together with the easterly shear to the south, removes the strong cyclonic shear at the tropopause, which is a characteristic feature of this situation.

The flow patterns change slowly, and it is often impossible to ascribe a general change in wind direction, say over the British Isles, to the bodily movement of a contour ridge or trough. In such cases it appears rather that a general change in the flow configuration over a large area has set in. As mentioned earlier, such changes take place at intervals of ten to twenty days. The stratospheric northerlies over the British Isles and north-west Europe in February 1952 were accompanied by light winds over the Atlantic, while for much of January and the first part of February 1951 there were light winds over the British Isles and north-west Europe with moderate westerlies over the west and central Atlantic. It would appear then that any month may show a large departure from a monthly or seasonal mean.

These slow changes and the broad air streams of constant direction make it highly probable that the flow at 100 mb. is nearly geostrophic. The rapid changes in thermal gradient which effect the compensation during large wind changes at the tropopause appear to be in response to dynamical causes. Thus, as a jet stream develops near the tropopause, stratospheric descent would appear to occur above the low-pressure side and perhaps ascent on the high-pressure side to produce the compensatory wind shear above the tropopause. Likewise steady ascent of the stratospheric northerly was necessary during February 1952 to maintain the thermal gradient from Greenland to France. The temperature decrease on the track of about 15–20°F. in 24 hr. is too large to be produced by radiation processes. This association of vertical motion with large-scale quasi-permanent wind configurations, and the steadiness of stratospheric winds above jet streams, provide two examples of one of the most interesting phenomena of the lower stratosphere.

ROYAL METEOROLOGICAL SOCIETY

World-wide oscillations in the earth's atmosphere

The Symons Memorial Lecture for 1952 was delivered to the Royal Meteorological Society, on Wednesday, March 19, by Dr. M. V. Wilkes, Director of the University Mathematical Laboratory, Cambridge, on the subject of "World-wide oscillations in the earth's atmosphere". The President, Sir Charles Normand was in the Chair.

Dr. Wilkes began by pointing out that the principal oscillations in the atmosphere are semi-diurnal, not diurnal as might be expected. The oscillations are small in temperate zones but have an amplitude of about 1 mb. at ground level at the equator. Chapman has demonstrated the uniformity of the oscillations and their independence of local characteristics over North America. Schmidt and Simpson showed that there are two components, the principal one being a travelling sine wave in advance of the sun, and the other, a much smaller standing wave centred over the poles. The first attempt to work out a tidal theory for the atmosphere was due to Laplace who assumed isothermal variations and a temperature distribution independent of height. Attempts however to detect a lunar tidal oscillation from the data then available were not successful, and it was left to Lefroy in 1874 to be the first to discover lunar tidal oscillations from 17 months' observations at St. Helena.

In 1918 Chapman tackled the problem anew, and succeeded in demonstrating the existence of a semi-diurnal lunar tide at Greenwich of amplitude 0·01 mm. of mercury and with maxima almost in phase with the moon's upper and lower transits. Chapman also checked the temperature variations associated with the lunar semi-diurnal pressure change for Batavia, and found that the results deduced from the temperature observations agreed with those calculated from the pressure variations although the pressure variation was only 0·06 mm. and the temperature variation 0·005–0·01 °C. The fact that the solar tidal oscillations are greater than the lunar suggests that the thermal effect is predominant but the solar tide is semi-diurnal whereas the thermal variation is diurnal. To overcome this difficulty Lord Kelvin suggested that the atmosphere must possess a natural period of 12 hr.—the resonance theory. This explanation, however, would also render a thermal driving force unnecessary, and no answer has yet been given as to whether the thermal or the gravitational effect is the greater. The stratospheric low-temperature barrier would give rise to oscillations in the atmosphere, and H. Lamb showed that for resonance to occur the periodicity must be within a few minutes of 12 hr. G. I. Taylor derived this periodicity from calculations based on the spread of the pressure waves from the Krakatoa explosion of 1883 and the great Siberian meteor of 1908 and found it to be only 11 hr.—too small to give rise to resonance. Pekeris, however, showed that the existence of a temperature minimum at 50 Km., acting as a second barrier, would give an oscillation, with a node, having a period of 12 hr. provided that the temperature distribution at the top were appropriately chosen. The presence of such a temperature minimum has been confirmed from rocket ascents and anomalous sound propagation. Appleton and Weekes however, who discovered lunar tidal oscillations in the E-region of the ionosphere of amplitude about 1 Km., found these oscillations to be in phase with those at the ground instead of in anti-phase as would be required by the nodal type of oscillation. However, Martyn has demonstrated that it is easy to explain this apparent discrepancy, e.g. by taking into account second-order terms neglected at lower levels, or by assuming a hot E-region with a temperature drop above, which would produce yet a third barrier and two nodes thus bringing the lunar tidal oscillations in the E-region into phase with those at the ground. Appleton and Weekes also found that the ratio of the amplitudes of the solar and lunar tidal oscillations in the ionosphere is less than at the ground, which is confirmed, according to the "dynamo" theory, by the solar and lunar quiet-day magnetic variations. Further support for the second barrier theory is provided by the fact that the phases of the magnetic variations due to the lunar and solar tides in the E-region are out of phase with the oscillations at the ground. Martyn has also detected tidal motions in the F-region of the ionosphere, but it is uncertain whether the oscillations are initiated from the E-region or introduced directly by thermal or gravitational action. There is no evidence of lunar semi-diurnal winds in the F-region and viscous damping is considerable.

[To face p. 216

Reproduced by courtesy of Capt. H. F. Jackson

EVENING SKY AT VALENTIA, SOUTH-WEST IRELAND, SEPTEMBER 14, 1936

The clouds visible are cirrus, stratocumulus vesperalis and, in the distance, banks of cumulus over the Atlantic Ocean.

Reproduced by courtesy of the Public Information Division, United States Coast Guard

UNITED STATES COAST GUARD CUTTER *YAKUTAT*

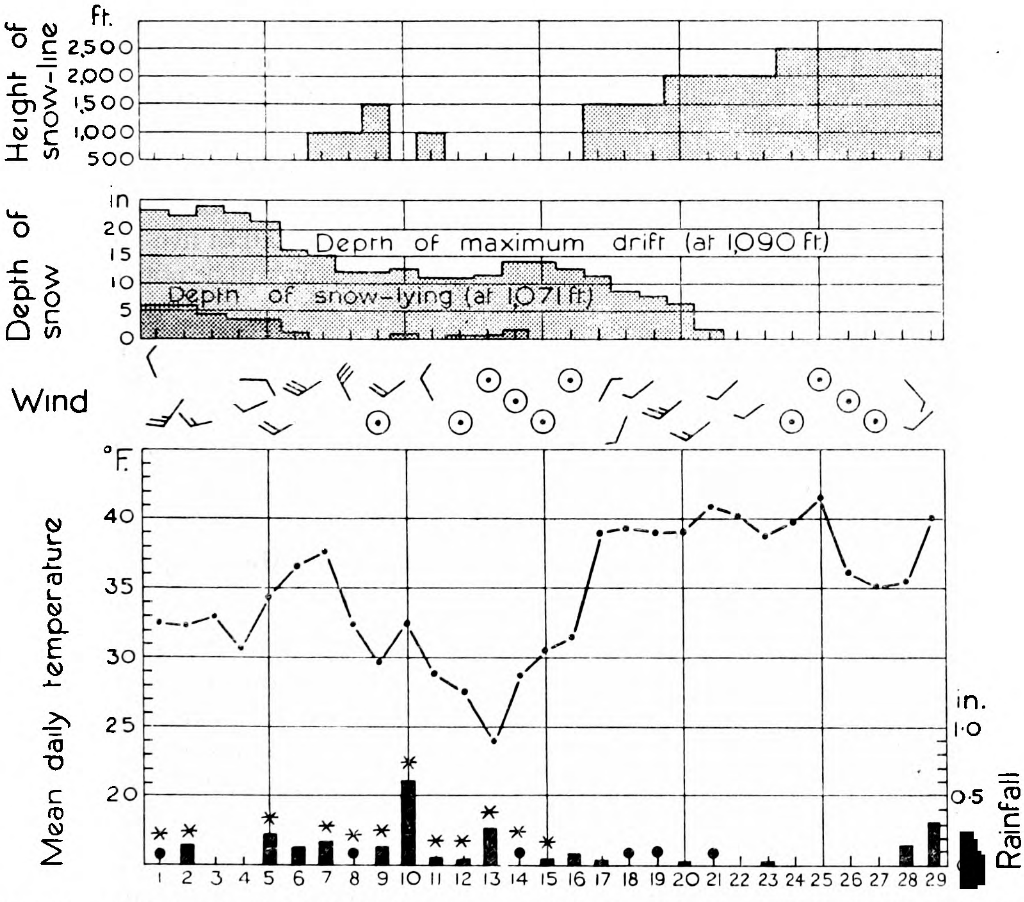
The *Yakutat*, on ocean weather station CHARLIE, being relieved by the cutter *Coos Bay*; the mail can be seen being passed from the *Coos Bay* to the *Yakutat* (see p. 218).

LETTER TO THE EDITOR

Ablation of snow deposits at Alston, Cumberland

Students of snow ablation may be interested in the following diagram showing the ablation which occurred in February 1952 at Alston. January 1952 produced a heavy accumulation of snow to which little new snow was added in February. The interest of the data for February lies in the ablation of the snow deposit laid down in January.

The three factors involved in the ablation are temperature, rainfall, and wind direction and force. Some indication of the relative value of each can be seen from the diagram. High mean temperature clearly shows a correlation with the retreat of the snow-line on the 7th and the 17th, and with the depth of the snow-drift near the observatory at Alston. From 1100 G.M.T. on the 10th heavy rain fell, but its effect on ablation was comparatively slight. This no doubt is again a reflection of mean temperature which was fairly low.



SNOW ABLATION AND WEATHER DAY BY DAY AT ALSTON, CUMBERLAND, DURING FEBRUARY 1952

The continued melting after the 7th can only be explained by the strength of the wind (SE., force 6). This was neither warm nor wet. Again the 21st showed a sudden depletion in the snow-drift at Alston after three consecutive days of moderate temperature. This seems to be the result of the strong wind (SW., force 5) of the 20th. The greater efficiency of even slight warmth caused by strong winds seems to be an important factor which needs consideration. Naturally the effect is greatest if the wind is from SW. but irrespective of direction a strong wind seems a most effective agent in the ablation process.

Since little exists in the way of data of wind force on mountain sides could not this factor easily confuse inferences made about the effects of related phenomena, such as temperature and rainfall, which are more regularly measured?

W. E. RICHARDSON

South Tyne House, The Brewery,
Alston, Cumberland, March 17, 1952

NOTES AND NEWS

Ocean weather ships of the United Stated Coast Guard

The photograph facing p. 217, for which we are indebted to the Public Information Division, United States Coast Guard, shows the United States Coast Guard cutter *Yakutat* on duty at North Atlantic ocean weather station CHARLIE (52°45′N., 35°30′W.). The ship had been at sea a month from her base at Portland, Me., and was receiving mail from the relieving cutter when the photograph was taken.

Yakutat has a displacement of 2,592 tons compared with the 1,400 tons of British ocean weather ships. She carries a Coast-Guard crew of 8 or 9 officers and 117–120 men and a United States Weather Bureau staff of five meteorologists. The balloon-filling shed and balloon-release gantries will be noticed on the boat deck.

Mr. R. K. Pilsbury writes that the ship T.S.S. *Bayano* on which he was returning from Jamaica passed near *Yakutat*, then on duty at station DOG (44°N., 41°W.) on the evening of July 25, 1951. He was able to send the message, "The Meteorological Officer, Jamaica, sends his compliments to the Weather Officer," and receive greetings in return.

Meteorological observations on a flight by a Canberra jet aircraft from England to Australia

Before the flight of a Canberra aircraft from England to Australia at the beginning of August 1951 discussions were held with the pilot, Wg Cmdr D. R. Cuming, Royal Australian Air Force, who was provided with information regarding meteorological conditions to be expected over the route, particularly equivalent headwinds and temperature at various levels, heights of tropopause and weather conditions likely to affect the flight.

Wg Cmdr Cuming offered to make meteorological observations whenever possible during the flight, and it was suggested that observations of temperature and wind at flying height, cloud type and height of cloud tops, visibility, icing and turbulence would prove very useful.

The route followed was Lyneham—El Adem (Libya)—Habbaniya (Iraq)—Mauripur (Karachi)—Negombo (Ceylon)—Changi (Singapore)—Darwin—Melbourne. The following useful observations were included in the reports given by the pilot and navigator to meteorological officers at stopping places on the route:—

(*a*) information regarding up-currents experienced at a height of 39,000 ft. east of Sardinia, which may have been associated with a jet stream with its axis considerably above 40,000 ft.

(*b*) reports of cloud tops much above the expected heights; cirrus cloud at and above 45,000 ft.; cumulonimbus cloud building up to 45,000 ft. in many places on the west side of the mountains of Sumatra with anvil cirrus above blowing westwards for about one hundred miles before dispersing

(*c*) reports of frequent moderate to heavy turbulence experienced in clear air above cirrus cloud over the sea around 20°N. on the flight from Mauripur to Negombo, the turbulence being in the nature of very frequent hard bumps for a period of 15 min.; intermittent moderate turbulence in clear air over cumulonimbus cloud between 12° and 10°N. in the nature of an occasional drop in a generally rising current or an occasional rise in a generally descending current; moderate turbulence from Ceylon to Sabang at about 45,000 ft. when flying in the same plane as 2 oktas banded cirrocumulus, for periods of 3–4 min. at 10-min. intervals, the effect on the aircraft suggesting turbulence rolls continuous with cirrocumulus rolls seen off track with their axes at right angles to the track.

A most interesting and instructive letter was received in December 1951 from Wg Cmdr Cuming who has agreed to the reproduction of the following extracts:—

"Cloud forecasts were the weakest section of the forecasts, not from the point of locality but in the estimation of the cloud tops. This was most noticeable as far as cumulus and cumulonimbus were concerned. Across India and as far as Canberra in Australia the estimates of the cumulonimbus tops were generally about 10,000–15,000 ft. too low. Where reports gave the tops at 25,000 ft. they were generally about 35,000–40,000 ft. Over those portions of the trip we were flying at 45,000 ft. and these clouds were well above us. On the direct route between Ceylon and Singapore, when we went through, it would have been impossible to have completed the trip without going through the cumulonimbus over Sumatra. There was a solid area of cumulonimbus right down the west coast of the island and there did not appear to be any breaks in the cloud below 50,000 ft. Fortunately our route was via Sabang and so we passed round the northern tip of this cloud mass.

"The forecast heights of cirrus were not bad, but again the estimated height was invariably too low. The highest cirrus we saw was between Ceylon and Singapore and this was above 45,000 ft.

"Visibility under cloudless conditions varied considerably. Oblique visibility seems to depend on the time of the day, direction of view relative to the position of the sun, haze and, from the point of view of picking up detail, the type of country flown over. Assuming that the atmosphere is clear it was found that for about an hour after sunrise and before sunset it was only possible to pick up such detail as coastlines, large rivers and mountain ranges. This was from 45,000 ft. Of course lakes were also prominent. It was quite hopeless to look for towns especially when the surrounding country was timbered. In other words, it is necessary to have a large degree of contrast in order to pick up detail. As the sun rises higher the situation improves somewhat but even under good conditions with the sun overhead it is still difficult to pick out average sized towns. Dirt roads are far easier to pick up than bitumen roads or railway lines.

"Visibility distance obviously depends on the haze and detail wanted. Coastlines and large mountains are the easiest things to see and, from 45,000 ft., we were able to see up to about 200 miles on the route from Singapore to Darwin. In fact we could see Timor at the same time as we could see the coast at Darwin, and on trips to Melbourne it is often possible to see Port Philip Bay from 170 miles. Looking up sun, if the sun is low on the horizon, it is generally hopeless and the visibility is reduced to about 40 miles. In this case the amount of haze is the predominant factor, and in the Canberra at times it reduces the visibility up sun to zero.

"On the trip from England to Australia we experienced turbulence at high altitude on every leg. However, no severe turbulence was experienced. It was invariably associated with cirrus, especially cirrus with mares' tails and cirrus that lay in lines across the sky. Flying at the same level and across these lines was reasonably bumpy. Turbulence was always noticed on the climb when passing through inversions and when passing through the tropopause. There was more turbulence, generally speaking, when going through the tropopause than through inversions. During our flying in Australia we found a considerable amount of high-altitude turbulence when flying between Brisbane and Melbourne. This is the worst route. We flew across several jet streams in this area, and on one occasion the turbulence was so severe that the navigator could not work or read some of his instruments accurately. This occurred when entering a jet stream from the polar side. The first warning that we got under these conditions was a falling off of airspeed and a few small bumps. Going in the opposite direction we noticed an increase in airspeed. Obviously the changes in airspeed must be due to fairly rapid changes in the wind speed.

"In Australia we find it useful for the tropopause to be plotted along our route because at some part of our route we invariably have to fly through it. As an example of what I mean, the tropopause at Amberley (Queensland) may be 47,000 ft. and the tropopause at Melbourne may be only 35,000 ft. Our cruising height may be 42,000 ft. and thus we get a certain amount of turbulence at the stage of the route where the tropopause falls to 42,000 ft."

R. P. BATTY

Bibliography for the second International Polar Year, 1932–33

The second International Polar Year was organized by a special commission of the International Meteorological Organization under the presidency of Dr. D. la Cour, Director of the Danish Meteorological Institute. After the end of the Year itself the labours of the Commission changed from the organization of the observing expeditions and their equipment to ensuring that the observations and registrations were made available for the benefit of science. The Commission was supported in this work by funds provided by the International Meteorological Organization, the International Association for Meteorology of the International Geodetic and Geophysical Union, and the Rockefeller Foundation.

The work of the Commission was seriously delayed by the war and by Dr. D. la Cour's death in 1942 and was not completed when the pre-war commissions were formally dissolved at the International Meteorological Organization meetings held in 1946. To complete the work the International Meteorological Organization then set up the Temporary Commission for the Liquidation of the Polar Year 1932–33. Dr. J. A. Fleming, United States, became the President of this Commission; Dr. J. M. Stagg, who had been in charge of the British Polar Year station in northern Canada, represented Great Britain; and Dr. V. Laursen of the Danish Meteorological Institute was placed in charge of the Central Bureau of the Commission situated at that Institute as Executive Secretary of the Commission.

The Temporary Commission arranged for completion of the central archives of the Polar Year at the Danish Meteorological Institute, for the completion of the publication of the weather maps of the northen hemisphere for the Polar Year* drawn by the Deutsche Seewarte, and finally for the publication of the Bibliography of the Polar Year.

The Bibliography is in three parts. Part I is a history of the organization of the second Polar Year. Part II is a bibliography arranged by countries but opening with a bibliography of the relevant publications of the International Meteorological Organization. The entry under each country begins with a statement of that country's Polar Year expeditions and continues with a list of books and articles relating to the Polar Year published in that country arranged under subjects. Part III is a subject bibliography for the whole world. The arrangement under each subject in both Parts II and III is by author's name. The title page is appropriately preceded by a page bearing only the photograph of Dr. D. la Cour.

The entries in the Bibliography were compiled, first from the collection of documents formed by Dr. D. la Cour and secondly from returns sent to Dr. Laursen by national meteorological services, institutes, observatories and individuals to whom he applied for information.

It is advisable to consult the introductions to each part before searching in the main entries, as some classes of document are given in Part II only.

The Bibliography is very clearly printed in large type. It will constitute an indispensable work of reference for all students of the wealth of observations made during the second Polar Year.

Lunar halo complex, Guernsey, April 14, 1952

Mr. S. G. Tew, a meteorological observer at the Airport, Guernsey, reports a rarely observed lunar halo complex as seen between 0250 and 0315 G.M.T. April 14, 1952. The complex varied from time to time but in all Mr. Tew observed:—

(i) the upper half of the 22° halo
(ii) the two paraselenae of the 22° halo
(iii) the paraselenic circle through the moon to beyond the paraselenae
(iv) short light pillars above and below the moon.

The paraselenae were perfectly clear and only slightly less bright than the moon itself.

The phase of the moon was three days past full.

*London, Meteorological Office. I.M.O. Northern-hemisphere Polar-Year charts. *Met. Mag., London*, **80**, 1951, p. 139.

Kodaikanal Observatory Jubilee

The first fifty years of scientific work at the Kodaikanal Observatory, south India, were celebrated at the observatory on September 18, 1951, when the Governor of Madras, in the presence of the Deputy Minister of Communications and the Director General of Observatories, formally inaugurated a new ionospheric observatory and a new 20-in. telescope for stellar spectroscopy.

BOOKS RECEIVED

Annual Reports for 1940, 1941, 1942. Christchurch Magnetic Observatory. 9½ in. × 6 in., pp. xvi + 152, New Zealand Department of Scientific and Industrial Research, Wellington, *s.a.*

Annual Reports for 1943, 1944, 1945. Christchurch Magnetic Observatory. 9½ in. × 6 in., pp. xviii + 150, New Zealand Department of Scientific and Industrial Research, Wellington, *s.a.*

The night sky 1952. 10 in. × 7 in., pp. 26, *The Times* Publishing Company Limited, London, 1951. Price: 2*s.* 6*d.*

METEOROLOGICAL OFFICE NEWS

Ocean weather ships.—*Weather Explorer* reported that on March 2, 1952, "the wind increased rapidly from force 4 to force 11 after the passage of a cold front and continued at or near force 11 for almost three days". For most of the time the vessel was forced to run before the wind, the sea being so high that it was not found practicable to heave her to. Radio-sondes had to be abandoned in these circumstances, the balloon shelter being in the after part of the ship. The meteorological office was partially flooded more than once.

When the wind did ease down sufficiently for the vessel to turn into the wind it was found that she was 168 miles from the centre of her station "grid". The station grid is an area 200 nautical miles square, in the centre of which is the station and an ocean weather ship is classified as being "on station" provided she is within the grid; so on this occasion *Weather Explorer* was literally "blown out of her grid".

WEATHER OF MAY 1952

Mean pressure during May was above normal in a large area extending from Greenland, with 1023 mb. which was 8 mb. above normal, to Scandinavia and western Europe, with values generally around 1017 mb. which were 2 mb. above normal. Mean pressure was below normal over the North Atlantic, between 35°N. and 50°N., the deficit at the Azores with 1017 mb. reaching 5 mb.

Mean temperature was generally 3–4°F. above normal in western Europe and about 2°F. below normal in eastern Europe; in the Mediterranean region mean temperature was about normal. The values of mean temperature varied from 40–50°F. in Scandinavia, 50–60°F. in Europe to 60–70°F. in the Mediterranean.

In the British Isles the weather was very warm for the time of year; at Kew Observatory it was the warmest May since records began in 1871, at Greenwich the warmest since 1848 and at Oxford since 1868. Broadly speaking the month was dry in Northern Ireland and over most of Scotland and northern England but very wet in parts of south-west England, south Wales and the south Midlands. Local thunderstorms occurred frequently during the first three weeks.

In the opening days a depression westward of Ireland moved south-east to the north-west of Spain, while associated troughs of low pressure affected southern districts of the British Isles causing rain, heavy in places in the south-west, and local thunderstorms. At Westbury in Wiltshire 2·01 in. was measured and at Bath 1·57 in. on the 1st. On the 3rd and 4th the depression moved north-east and became less deep; further rain and scattered thunderstorms occurred in southern districts and some rain fell also in the north (1·25 in. at Coventry on the 4th). On the 5th a depression over the North Sea moved north and turned west northward of Scotland, subsequently moving southward to a position south-west of Ireland. This system, with its associated troughs or secondary depressions, dominated conditions over the British Isles until the 13th, with rain or showers and local thunderstorms but long sunny periods. Rainfall was heavy locally at times, for example 2·21 in. at Borrowdale, Cumberland, on the 8th and 1·38 in. at Tenby on the 10th. On the 13th and 14th an anticyclone situated over Spain and south-west France moved north; meanwhile a trough to an Atlantic depression moved north-east across the British Isles causing appreciable rain at some places in the north of Scotland. The anticyclone continued to move north and fair, very warm weather prevailed, apart from scattered thunderstorms, until the 19th. Temperature exceeded 75°F. at many places, chiefly inland but also at some coastal stations, from the 16th to the 18th, while 80°F. was reached or somewhat exceeded locally (86°F. at Camden Square, London, on the 18th). Temperature continued very high in eastern and midland districts of England also on the 19th. On the 19th and 20th a shallow trough of low pressure moved very slowly westward over the British Isles; thunderstorms occurred locally and heavy rain caused floods in places, but the heavy rain was very local (2·56 in. at Cotleigh House near Honiton, Devon, in less than 50 min. and 2·34 in. at Kidlington, Oxfordshire, on the 19th). At Tibshelf, Derbyshire, a small tornado occurred on the 19th causing considerable local damage. Subsequently an anticyclone over Scandinavia moved south-south-west and anticyclonic conditions, with fair, though somewhat cooler weather, prevailed in most parts until the 26th. Thereafter a depression off north-west Iceland moved slowly east-south-east giving rain in Scotland on the 26th and scattered rain or showers on the 27th. In the rear of this depression, cool north-westerly winds brought a fall in temperature, with scattered, mainly slight, rain or showers, but long sunny periods in many places. During the closing days an almost stationary depression was centred westward of Ireland and an associated trough moved north over England and Wales. Rain or showers occurred in many places on the 30th and throughout the country on the 31st; rainfall was rather heavy locally on the 31st, particularly during the following night.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	°F.	°F.	°F.	%		%
England and Wales ...	86	28	+3·7	111	−1	109
Scotland	80	25	+3·1	89	−2	98
Northern Ireland ...	79	30	+2·5	66	−3	96

RAINFALL OF MAY 1952

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·07	61	*Glam.*	Cardiff, Penylan ...	3·81	156
Kent	Folkestone, Cherry Gdn.	1·21	72	*Pemb.*	Tenby, The Priory ...	4·58	211
,,	Edenbridge, Falconhurst	1·26	68	*Radnor*	Tyrmynydd	3·88	113
Sussex	Compton, Compton Ho.	3·20	144	*Mont.*	Lake Vyrnwy	3·58	111
,,	Worthing, Beach Ho. Pk.	1·79	108	*Mer.*	Blaenau Festiniog ...	3·53	62
Hants.	Ventnor Cemetery ...	2·11	121	,,	Aberdovey	3·33	133
,,	Southampton, (East Pk.)	3·03	151	*Carn.*	Llandudno	1·81	102
,,	Sherborne St. John ...	3·18	164	*Angl.*	Llanerchymedd ...	2·32	99
Herts.	Royston, Therfield Rec.	2·42	125	*I. Man*	Douglas, Borough Cem.	2·71	108
Bucks.	Slough, Upton	2·31	137	*Wigtown*	Newton Stewart ...	2·24	85
Oxford	Oxford, Radcliffe ...	2·23	119	*Dumf.*	Dumfries, Crichton R.I.	3·43	125
N'hants.	Wellingboro' Swanspool	3·45	178	,,	Eskdalemuir Obsy. ...	2·81	85
Essex	Shoeburyness	1·24	95	*Roxb.*	Kelso, Floors	1·67	87
,,	Dovercourt	1·12	81	*Peebles*	Stobo Castle	2·14	94
Suffolk	Lowestoft Sec. School ...	...	...	*Berwick*	Marchmont House ...	2·02	82
,,	Bury St. Ed., Westley H.	1·00	55	*E. Loth.*	North Berwick Res. ...	1·95	98
Norfolk	Sandringham Ho. Gdns.	2·34	128	*Midl'n.*	Edinburgh, Blackf'd. H.	1·70	83
Wilts.	Aldbourne	3·39	172	*Lanark*	Hamilton W. W., T'nhill	1·79	75
Dorset	Creech Grange... ...	2·87	141	*Ayr*	Colmonell, Knockdolian	1·85	72
,,	Beaminster, East St. ...	3·06	149	,,	Glen Afton, Ayr San. ...	2·83	94
Devon	Teignmouth, Den Gdns.	2·42	132	*Renfrew*	Greenock, Prospect Hill	1·98	61
,,	Cullompton	2·78	129	*Bute*	Rothesay, Ardencraig ...	1·97	65
,,	Ilfracombe	3·26	158	*Argyll*	Morven (Drimnin) ...	2·06	64
,,	Okehampton Uplands...	3·37	125	,,	Poltalloch	1·51	52
Cornwall	Bude, School House ...	2·45	133	,,	Inveraray Castle ...	1·75	45
,,	Penzance, Morrab Gdns.	2·06	93	,,	Islay, Eallabus	1·88	71
,,	St. Austell	3·14	130	,,	Tiree	1·39	56
,,	Scilly, Tresco Abbey ...	1·88	111	*Kinross*	Loch Leven Sluice ...	1·57	64
Glos.	Cirencester	2·68	130	*Fife*	Leuchars Airfield ...	1·90	97
Salop	Church Stretton ...	2·82	111	*Perth*	Loch Dhu	...	...
,,	Shrewsbury, Monksmore	1·63	84	,,	Crieff, Strathearn Hyd.	1·96	79
Worcs.	Malvern, Free Library...	3·49	162	,,	Pitlochry, Fincastle ...	3·29	155
Warwick	Birmingham, Edgbaston	2·58	121	*Angus*	Montrose, Sunnyside ...	2·90	142
Leics.	Thornton Reservoir ...	2·36	117	*Aberd.*	Braemar	2·99	126
Lincs.	Boston, Skirbeck ...	2·73	155	,,	Dyce, Craibstone ...	2·52	99
,,	Skegness, Marine Gdns.	1·46	86	,,	New Deer School House	1·99	91
Notts.	Mansfield, Carr Bank ...	2·38	112	*Moray*	Gordon Castle	1·63	77
Derby	Buxton, Terrace Slopes	2·62	85	*Nairn*	Nairn, Achareidh ...	1·37	77
Ches.	Bidston Observatory ...	1·84	97	*Inverness*	Loch Ness, Garthbeg ...	2·99	120
,,	Manchester, Ringway...	1·81	85	,,	Glenquoich	4·43	81
Lancs.	Stonyhurst College ...	2·83	99	,,	Fort William, Teviot ...	2·48	63
,,	Squires Gate	2·22	107	,,	Skye, Duntuilm ...	2·47	87
Yorks.	Wakefield, Clarence Pk.	1·50	76	,,	Skye, Broadford ...	3·63	86
,,	Hull, Pearson Park ...	1·18	61	*R. & C.*	Tain, Tarlogie House ...	1·28	62
,,	Felixkirk, Mt. St. John...	1·61	86	,,	Inverbroom, Glackour...	3·79	126
,,	York Museum	1·48	74	,,	Achnashellach	3·68	87
,,	Scarborough	1·28	67	*Suth.*	Lochinver, Bank Ho. ...	3·10	122
,,	Middlesbrough... ...	1·05	55	*Caith.*	Wick Airfield	1·81	87
,,	Baldersdale, Hury Res.	2·05	83	*Shetland*	Lerwick Observatory ...	3·83	183
Norl'd.	Newcastle, Leazes Pk....	1·58	80	*Ferm.*	Crom Castle	2·18	78
,,	Bellingham, High Green	2·03	85	*Armagh*	Armagh Observatory ...	1·11	47
,,	Lilburn Tower Gdns. ...	1·76	76	*Down*	Seaforde	1·90	72
Cumb.	Geltsdale	1·58	61	*Antrim*	Aldergrove Airfield ...	1·19	52
,,	Keswick, High Hill ...	3·28	103	,,	Ballymena, Harryville...	1·50	52
,,	Ravenglass, The Grove	2·62	94	*L'derry*	Garvagh, Moneydig ...	1·88	73
Mon.	Abergavenny, Larchfield	4·34	163	,,	Londonderry, Creggan	1·60	61
Glam.	Ystalyfera, Wern House	4·64	133	*Tyrone*	Omagh, Edenfel ...	1·83	71

M.O. 559 AIR MINISTRY

METEOROLOGICAL OFFICE

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WATER-FOG POINT—A FURTHER TEST

By G. A. CORBY, B.Sc., and W. E. SAUNDERS, B.Sc.

Summary.—The following note reports the results of a test of Saunders's method[1] for forecasting the water-fog point. The test was aimed primarily at ascertaining the result of applying the method simultaneously to different locations. An account is given of the experience obtained at Northolt Airport in the use of the method. Some remarks are also made regarding the differing approaches towards fog forecasting in general, as seen from the work of other writers.

Introduction.—One of the present writers, in an article[1] published in 1950, described the results of an investigation leading to a practical method of forecasting the water-fog point by the use of representative tephigram ascents. The method has been used almost exclusively by forecasters at Northolt Airport since that time with an encouraging degree of success. For example, investigations carried out, for other purposes, during the last four winters into the accuracy attained in forecasting visibility show that a considerable improvement took place during that period. It is believed that use of the method played a definite part in the improvement.

One would expect the water-fog point to be more or less constant for a given air mass. Experience strongly suggests that in radiation-fog situations this is true, and that local variations in fog development arise from differences in the degree of night cooling rather than in spatial variations of the fog-point temperature. This does not hold, of course, near coasts with on-shore winds. Hence, over areas where there has been fairly uniform heating, the fog point can be regarded within close limits as a fixed property of the air mass, with local topographical and soil variations being manifest in night-cooling differences. Local differences in the occurrence and density of radiation fog are thus believed to be almost entirely due to local variations in the cooling rate.

It was decided to test the above conception of the approximate constancy of the fog-point temperature within a given air mass, and at the same time to examine the usefulness of the fog-point method when applied simultaneously to different locations. Before reporting the results of this test, it seems desirable to comment on the adopted definition of the water-fog point (T_f).

Definition of fog point.—In assessing the value of any method for forecasting radiation fog it is essential to define with great care what is to be regarded as the fog point. To say that it is the "temperature at which fog forms" is too vague and may lead to many uncertainties which largely invalidate any test. First, it must be clearly recognized that smoke fog is not at all closely associated with relative humidity and must be dealt with by different methods from water fog. This is no mere academic distinction. Visibility in most smoke fogs is in the range 600–1,000 yd. whilst in most water fogs it is below 500 yd. In the former, aircraft using modern aids can land safely. In the latter, they often cannot. Any definition used for testing a method of forecasting radiation fog should therefore exclude smoke fog. Secondly, on radiation nights the temperature at ground level is commonly several degrees below that at screen level and shallow fog patches may form, even when at screen level the temperature is appreciably above the fog point of the air mass. It is therefore suggested that, for purposes of this sort, the fog point should be defined as "the screen-level temperature at which the general visibility falls within the fog range with relative humidity 95 per cent. or more, or at which with visibility in the fog range relative humidity rises to 95 per cent. or more". These aspects are mentioned since it is the fog point as here defined which is yielded by the method under discussion, and it is important to keep this in mind in studying the usefulness of the method.

Test of the fog-point method.—The test was applied to the period August 1–October 5, 1950. This period was specially selected in the hope that seasonal lack of domestic smoke would ensure that any fog would be mostly water fog; and in fact there was only one occasion when fog was first reported with relative humidity less than 95 per cent. The trial was restricted to inland stations in England which report hourly temperatures and for which night minima appear in the *Daily Weather Report*. On each afternoon when radiation fog was possible, the fog points were calculated from the 1500 G.M.T. Larkhill, Liverpool and Downham Market ascents using Saunders's method[1] and were plotted on a chart. An estimate was then made of the forecast fog point for each of the selected stations making due allowance for any unmistakable advective effects over the area. Where fog developed, the screen-level temperature at the time of fog formation (i.e. the actual fog point) was plotted, occasions of ground fog alone being disregarded for this purpose. When there was no fog in a potentially foggy area, the night minimum temperature was plotted.

Results of the test.—The results were analysed as follows:—

Radiation fog reported (55 occasions)	
(i) Actual T_f within ± 1°F. of forecast T_f	40
(ii) Actual $T_f >$ forecast $T_f + 1$	11
(iii) Actual $T_f <$ forecast $T_f - 1$	4
No fog within potentially foggy area (93 occasions)	
(iv) $T_{min} >$ forecast T_f	78
(v) $T_{min} \leqslant$ forecast T_f	15

We are perhaps justified in regarding the 40 occasions under (i) as successful cases, since hourly temperatures only could be used and it was not possible to arrive at the actual fog point precisely. On this assumption, and using the method of assessing the usefulness of forecasts described by Crossley[2], we find that the "useful effort" for forecasts of fog (i.e. the proportion of them which would have proved correct) was 75 per cent., whilst the "useful effort" for forecasts of no fog was 88 per cent. These percentages would of course have been much higher if a continuous period had been treated in this way, instead of a selection comprising only potentially foggy periods. They are therefore very encouraging.

Cases under (ii), (iii) and (v) appear at first to constitute failures of the method and we therefore proceed to examine them briefly.

Of the 11 fog occasions under (ii), 8 occurred in southern England on two nights when marked advective changes from the south-west took place. On both nights the radio-sonde ascents revealed a rise in dew point between 1500 and 2100 G.M.T. This rise was greater at 900 mb. than at 950 or 1000 mb., thus decreasing the hydrolapse. On 2 of the remaining 3 occasions the fog developed after rain had fallen at the stations concerned, whereas the afternoon ascent used in the analysis had not been made in rain.

On the 4 occasions under (iii), there were 2 on which the radio-sonde ascent used had been affected by rain but not the station concerned.

Among the 15 cases under (v), there were 5 in which, in a special sense, there was no representative ascent. For example, on one occasion with a westerly air stream there was no fog at stations to the lee of the Welsh hills although the forecast fog point was reached. Its value, however, had been derived from Larkhill and Liverpool ascents, neither of which was representative of air modified by passage over the hills.

In short, on most of the occasions when the method of forecasting fog would have been unsuccessful, and these are comparatively few, the failure of the method can be ascribed to the forecast fog points not applying to the air over the stations during the evening. There is nothing to indicate that the process of derivation of the fog point itself is in any way at fault; the difficulty is to ensure that the process is applied to a truly representative ascent.

We may justifiably conclude that when this method is applied to cases of water fog at a variety of stations, the accuracy is not appreciably less than that obtained in the original work[1] for stations in the London area. In the latter work, occasions when there were no representative ascents were excluded so that the basic relation could clearly be demonstated. The forecast and actual fog points were then found to be within 1°F. on 44 occasions out of 48.

General experience of the method.—The encouraging results obtained from the use of the method at Northolt during 2½ years' experience have already been mentioned, and some more specific comments on this experience, and that of other stations, may be of interest.

First, it appears now to be well substantiated that, given a representative ascent, the constructions of Types I and IIIA in Fig. 4 in the paper by Saunders[1] yield satisfactory results. Provided T_f is above the freezing point, water fog forms when T_f is reached at screen level. We have seen too that there is no obvious restriction as to locality.

Secondly, it follows from the approximate constancy of the fog point for a given air mass that the construction may also be used when the cooling is due to processes other than radiation. Thus it may be used equally for sea fog or other advection fog where, through passage over a colder underlying surface, the screen-level temperature of the air mass falls to T_f.

Three types of difficulty or sources of possible error have been encountered as follows:—

(*a*) *Advection.*—Sometimes advective change of dew point occurs in the upper part of the mixed layer, say at 2,000–3,000 ft., where the wind speed may be 20–25 m.p.h., whilst the surface wind is still light enough for fog. Thus, moister or drier air may readily be advected at this level, and T_f raised or lowered accordingly, with perhaps little or no change of surface dew point. To guard against errors from this cause, all upwind ascents must be considered. For example, in a south-westerly situation T_f for southern England may be derived from the Larkhill ascent, but Camborne also must be watched at relevant levels for moister air which may arrive in time to affect the fog point. A correction should be made if necessary.

(*b*) *"Inversion" case.*—The construction in the so-called "inversion" case (Type II in Fig. 4 in the paper by Saunders[1]) is less well established than the other categories. This is partly because it is mainly the midwinter case when there are often heavy smoke concentrations near London to complicate matters, and partly because it is often not possible to obtain the slope of the representative dew-point curve near the surface with sufficient precision—the number of dew points given on ascents is sometimes inadequate to establish the dew-point curve properly. Further investigation into this case is desirable, preferably based on non-smoky areas.

(*c*) *Effect of rain.*—The case in which rain falls during the radio-sonde ascent, but not at the station for which the fog point is required, is always troublesome and there is no obvious solution. The reverse case, where the ascent is made in dry air but there is rain at the station during the evening, is also difficult, but it has been noted that if the precipitation is of the shower type and provided there is still some surface wind after precipitation ceases, the dry-air value of T_f applies.

We may conclude that further research on the water-fog point is most needed in the "inversion" case and in the effect of rain.

Work of other writers.—It is a matter of some interest to note the choice adopted by various writers of parameters for use in forecasting fog. For example, Craddock[3] has shown that the fog point can be expressed approximately in terms of surface temperature and dew point, ignoring variations in the vertical, whilst Briggs[4] recently used temperature lapse and hydrolapse but ignored surface values. The neglect of obviously significant parameters must impose limitations on the value of any method, and it seems reasonable to suppose that the use of lapse rate of potential dew point together with surface temperature and dew point as in the present method is the better approach. This choice of parameters is indirectly supported by the work of Swinbank[5]. Swinbank does not deal explicitly with the fog point but determines the time of fog formation from two diagrams in which the other variables are mean square wind shear (effectively the square of the gradient wind speed), mean difference between 1800 dry-bulb and dew-point temperatures, and hydrolapse. In the present method wind is regarded as best allowed for in forecasting the cooling, and the parameters employed are thus only different forms of those used by Swinbank.

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4. BRIGGS, J.; Notes on the temperature at which radiation fog forms. *Met. Mag., London*, **79**, 1950, p. 343.
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SIGNIFICANCE OF MEAN CONTOUR CHARTS

By A. F. CROSSLEY, M.A.

In the issue of this Magazine for February 1952, Mr. R. W. James[1] has given a comprehensive discussion of the significance of mean flow charts. In particular he examines the relationship between the true mean wind and the wind derived from a mean isobaric chart for the same period. When the seasonal charts of pressure contours, now published in "Upper winds over the world"[2], were being prepared, it was realized that the mean wind as deduced from these charts would not be identical with the true mean. The method by which this result was reached is an extension of that used by James, and moreover has the advantage that it enables the mean ageostrophic departure arising from the "space acceleration" to be readily evaluated.

To avoid repetition we need consider only horizontal frictionless flow in the free air, for which the equations of motion may be written in Cartesian co-ordinates as:—

$$\left.\begin{aligned} \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - 2\,\Omega\, v \sin\phi &= g\frac{\partial h}{\partial x} \\ \frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + 2\,\Omega\, u \sin\phi &= g\frac{\partial h}{\partial y} \end{aligned}\right\} \qquad \ldots\ldots\ldots(1)$$

Here u and v are the horizontal wind components at time t in the direction of the rectangular axes of x and y, and h is the height of a given pressure surface above some standard level, while other symbols have their customary meaning. We shall also require the reduced equation of continuity,

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0. \qquad \ldots\ldots\ldots(2)$$

To obtain the mean motion, we must take the mean value of each term in these equations over the required period. Using a bar to denote a mean value with respect to time, and an accent to denote the departure of an individual value from the mean, we write

$$u = \bar{u} + u'\,, \quad v = \bar{v} + v'.$$

Since we are considering seasonal charts, it follows as in James's paper that we may take

$$\overline{\frac{\partial u}{\partial t}} = \overline{\frac{\partial v}{\partial t}} = 0.$$

We also have

$$\overline{u\frac{\partial u}{\partial x}} = \tfrac{1}{2}\frac{\partial}{\partial x}\overline{u^2} = \tfrac{1}{2}\frac{\partial}{\partial x}(\bar{u}^2 + \overline{u'^2})$$

since $\overline{u'} = 0$ by hypothesis. Now the vector departures of the actual wind from the mean wind have an approximately circular distribution[2]. Thus if $\mathbf{V}$ denotes the vector wind on a particular occasion, then $\mathbf{V} = \overline{\mathbf{V}} + \mathbf{V}'$ where the components of $\mathbf{V}'$ are u' and v'. The standard vector deviation of $\mathbf{V}$ is $\sqrt{(\overline{\mathbf{V}'^2})}$ and is denoted by σ. Since the distribution of $\mathbf{V}'$ is symmetrical about the point which represents the extremity of the vector $\overline{\mathbf{V}}$, we have

$$\overline{u'^2} = \overline{v'^2} = \tfrac{1}{2}\sigma^2.$$

We then have

$$\overline{u\frac{\partial u}{\partial x}} = \bar{u}\frac{\partial \bar{u}}{\partial x} + \tfrac{1}{2}\,\sigma\frac{\partial \sigma}{\partial x}.$$

Similarly

$$\overline{v\frac{\partial v}{\partial y}} = \bar{v}\frac{\partial \bar{v}}{\partial y} + \tfrac{1}{2}\,\sigma\frac{\partial \sigma}{\partial y}.$$

Also, from equation (2),

$$\begin{aligned} v\frac{\partial u}{\partial y} &= \frac{\partial}{\partial y}(uv) - u\frac{\partial v}{\partial y} \\ &= \frac{\partial}{\partial y}(uv) + u\frac{\partial u}{\partial x}, \end{aligned}$$

so that

$$\overline{v\frac{\partial u}{\partial y}} = \frac{\partial}{\partial y}(\bar{u}\bar{v}) + \bar{u}\frac{\partial \bar{u}}{\partial x} + \tfrac{1}{2}\,\sigma\frac{\partial \sigma}{\partial x},$$

since from symmetry $\overline{u'v'} = 0$. Then, with use of equation (2) again after taking mean values, we have

$$\overline{v\frac{\partial u}{\partial y}} = \bar{v}\frac{\partial \bar{u}}{\partial y} + \tfrac{1}{2}\,\sigma\frac{\partial \sigma}{\partial x}.$$

Similarly

$$\overline{u\frac{\partial v}{\partial x}} = \bar{u}\frac{\partial \bar{v}}{\partial x} + \tfrac{1}{2}\,\sigma\frac{\partial \sigma}{\partial y}.$$

We can now write down the result of taking mean values of the equations (1) with respect to time, namely

$$\left.\begin{aligned} \bar{u}\frac{\partial \bar{u}}{\partial x} + \bar{v}\frac{\partial \bar{u}}{\partial y} - 2\,\Omega\,\bar{v}\sin\phi &= g\frac{\partial \bar{h}}{\partial x} - \sigma\frac{\partial \sigma}{\partial x} \\ \bar{u}\frac{\partial \bar{v}}{\partial x} + \bar{v}\frac{\partial \bar{v}}{\partial y} + 2\,\Omega\,\bar{u}\sin\phi &= g\frac{\partial \bar{h}}{\partial y} - \sigma\frac{\partial \sigma}{\partial y} \end{aligned}\right\} \qquad \dots\dots\dots(3)$$

These are the equations of mean horizontal motion in rectangular co-ordinates. If the mean motion is such that the second-degree terms are negligible, then it is given by the equations

$$\left.\begin{aligned} -\,2\,\Omega\,\bar{v}\sin\phi &= g\frac{\partial \bar{h}}{\partial x} - \sigma\frac{\partial \sigma}{\partial x} \\ 2\,\Omega\,\bar{u}\sin\phi &= g\frac{\partial \bar{h}}{\partial y} - \sigma\frac{\partial \sigma}{\partial y} \end{aligned}\right\} \qquad \dots\dots\dots(4)$$

Now the geostrophic wind is defined as

$$u_G = \frac{g}{l}\frac{\partial h}{\partial y}, \quad v_G = -\frac{g}{l}\frac{\partial h}{\partial x},$$

where l is written for $2\Omega\sin\phi$. Therefore the mean geostrophic wind is given by

$$\overline{u_G} = \frac{g}{l}\frac{\partial \bar{h}}{\partial y}, \quad \overline{v_G} = -\frac{g}{l}\frac{\partial \bar{h}}{\partial x},$$

and is obtained by applying the geostrophic scale to the mean contour charts.

Eliminating the contour gradients from equations (4), we obtain for the components of the mean wind the expressions:—

$$\left.\begin{aligned}\bar{v} &= \bar{v}_G + \frac{\sigma}{l}\frac{\partial\sigma}{\partial x}\\ \bar{u} &= \bar{u}_G - \frac{\sigma}{l}\frac{\partial\sigma}{\partial y}\end{aligned}\right\} \quad \ldots\ldots\ldots(5)$$

The true mean wind in this case is therefore the vector sum of the mean geostrophic wind and an ageostrophic departure which is proportional to the gradient of σ^2, and is directed along the lines of equal σ with the lower values of σ to the left (to the right in the southern hemisphere). Where the contours and the isopleths of σ coincide, then the geostrophic and σ contributions to the mean wind are in the same or opposite directions according as the gradients of $\bar{h}$ and of σ are in the same or opposite directions.

From the published charts of the distribution of σ at various pressure levels it may be inferred that the greatest value of the gradient of σ^2 in any part of the world occurs between about 300 and 200 mb. in the neighbourhood of both the British Isles and the Aleutian Isles. The corresponding value of σ in each case is about 50 kt., and of the gradient about 5 kt. in 200 nautical miles. Since l is 0·4 radians/hour in latitude 50°, the greatest value of the ageostrophic departure is therefore about 3 kt. The corresponding value given by James is 1 kt., but this was inferred from observations over the British Isles for only one month (May 1948) and for the 800-mb. level only. The figure of 3 kt. now derived implies an error in the geostrophic approximation of about 10 per cent. between 300 and 200 mb. in the regions mentioned, where the mean geostrophic wind is of the order of 30 kt., which is comparatively light for these levels. At 700 mb. the mean geostrophic wind is often down to about 10 kt. over wide areas, while the ageostrophic component may amount to about 1 kt., again giving errors in the neighbourhood of 10 per cent.

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FOG AND LOW STRATUS AT PRESTWICK AIRPORT, WITH NOTES ON THE DIURNAL VARIATION OF SURFACE WIND AND TEMPERATURE

By N. E. DAVIS, M.A.

Prestwick Airport (55°31′N., 4°36′W., height 30 ft.) has the reputation of being one of the most fog-free airfields in Great Britain. This reputation is in no way diminished by the detailed consideration made in this note of the diurnal variation of fog, low stratus, wind and temperature at Prestwick.

Diurnal variation of poor visibility.—The visibilities reported at each hour of each day for the four years August 1946 to July 1950 were examined, and a record was made of the number of occasions when the visibility was less than or equal to 220, 440, 880, and 1,100 yd. Table I shows the distribution of these occasions according to months irrespective of hour, and Table II shows the distribution according to hours irrespective of month for the two seasons October to March and April to September; there were too few cases of fog to show the distribution according to months separately.

TABLE I—MONTHLY VARIATION OF FOG AT PRESTWICK AIRPORT

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Year	Mean
	number of occasions in four years													hr./yr.
⩽ 220 yd. ...	...	...	10	...	1	3	...	5	...	1	2	3	25	6
⩽ 440 yd. ...	1	1	16	...	1	3	...	8	...	3	7	6	46	11
⩽ 880 yd. ...	4	2	26	...	1	3	4	12	...	4	13	8	77	19
⩽ 1,100 yd. ...	11	2	34	...	2	7	8	14	2	5	15	15	115	29

The outstanding feature of Table I is the size of the total: 115 hr. of fog out of a possible 35,066 (0·3 per cent.) as compared with London Airport[1] and Northolt Airport[2] which had totals of 2,672 and 2,696 respectively for the same period. Fog for the most part occurs in the months November to January, June to August and also in March. The high total for March is in part due to 15 hr. of bad visibility during the blizzards of March 1947.

In the summer half year fog is confined to the hours around or just after sunrise and sunset, but in the winter half year, there is very little diurnal variation.

Fog at Prestwick Airport may be ascribed to three factors: radiation, advection and smoke. Of these, advection is by far the most important. Smoke from the main source of pollution—the Forth-Clyde Valley—has to cross a range of hills to reach Prestwick and only exceptionally would reduce visibility to fog limits. Radiation fog forming over the airfield is rare. Normally a light land breeze (generally ESE.) blows over the airfield at night in conditions of slack gradient and is sufficient to prevent the formation of radiation fog. However, in circumstances in which a light gradient wind opposes the land breeze and conditions are otherwise suitable, radiation fog may form over the airfield. About two or three fogs a year—nevertheless lasting several hours—form in this manner.

Except for these few, all fogs at Prestwick Airport are due to the advection of fog over the airfield. This is of three types: advection of radiation fog formed locally, advection of sea fog and advection of frontal or pre-frontal fog. The movement of locally formed radiation fog may result in a rapid deterioration of visibility from several thousand yards to a few hundreds in a matter of minutes. Most of the early morning fogs in summer are of this type. Sea fog arrives in a similar manner though it may be preceded by low stratus cloud. The evening fogs in summer are sea fogs.

The fogs which occur in winter are mostly of the frontal advective type. Normally they are preceded by low stratus cloud which falls to ground level. However, owing to the long night and low elevation of the sun at noon in midwinter, it is possible for radiation fog to form either directly over the airfield or near by, and subsequently drift over the airfield at any time—except for a short period around 1400 G.M.T.—provided conditions are otherwise suitable.

However, since fog at Prestwick has a frequency of only 0·3 per cent. it is not a serious obstacle to aircraft operations. A greater hazard is low stratus cloud. In the immediate vicinity of the airfield hills rise to 400 ft.; the radio-range masts are on a hill nearly 550 ft. high 2½ miles from the airport and near the approach to runway 26, while hills over 2,000 ft. occur within a radius of 12 miles. Frequent low cloud would thus present a considerable drawback to

TABLE II—DIURNAL VARIATION OF FOG AT PRESTWICK AIRPORT

Time	April-September ≤220 yd.	≤440 yd.	≤880 yd.	≤1,100 yd.	October-March ≤220 yd.	≤440 yd.	≤880 yd.	≤1,100 yd.
	Number of occasions in four years							
0000	...	...	...	...	...	...	2	4
0100	...	...	...	...	1	2	3	4
0200	...	...	1	2	1	1	2	3
0300	1	2	3	5	1	1	2	3
0400	5	5	5	6	1	1	3	4
0500	2	2	4	5	1	2	3	5
0600	1	1	1	4	2	2	2	2
0700	...	1	1	1	1	1	1	1
0800	...	1	1	2	1	2	2	2
0900	...	...	1	1	1	2	3	3
1000	...	...	...	...	1	2	2	4
1100	...	...	...	...	...	1	2	4
1200	...	...	...	...	1	2	2	3
1300	...	...	...	...	1	2	2	2
1400	...	...	...	...	...	2	2	2
1500	...	...	...	...	...	1	1	2
1600	...	...	...	...	...	1	1	4
1700	...	...	...	...	2	2	3	4
1800	...	...	...	...	...	2	2	3
1900	...	...	...	2	...	1	2	4
2000	...	...	1	2	...	1	3	5
2100	...	...	1	2	...	...	5	5
2200	...	...	1	1	...	2	4	5
2300	...	...	...	...	1	1	3	4
All hours	9	12	20	33	16	34	57	82

TABLE III—DIURNAL VARIATION OF LOW CLOUD AT PRESTWICK AIRPORT

Time	Winter ≤200 ft.	≤400 ft.	≤600 ft.	≤1,000 ft.	Summer ≤200 ft.	≤400 ft.	≤600 ft.	≤1,000 ft.	Year ≤200 ft.	≤400 ft.	≤600 ft.	≤1,000 ft.
	Number of occasions in four years											
0000	4	16	26	62	2	16	22	56	6	32	48	118
0100	1	9	20	51	6	16	25	63	7	25	45	114
0200	1	11	22	53	5	13	24	69	6	24	46	122
0300	2	8	15	51	6	21	35	89	8	29	50	140
0400	3	11	23	55	8	26	44	99	11	37	67	154
0500	4	10	25	59	9	25	51	110	13	35	76	169
0600	6	12	20	61	14	32	55	133	20	44	75	194
0700	2	12	22	70	10	27	55	134	12	39	77	204
0800	6	13	29	90	9	22	53	136	15	35	82	226
0900	10	19	28	92	7	17	41	118	17	36	69	210
1000	8	17	31	86	4	13	33	107	12	30	64	193
1100	1	17	32	87	1	11	23	94	2	28	55	181
1200	3	12	24	81	1	9	22	86	4	21	46	167
1300	3	8	28	85	3	12	23	76	6	20	51	161
1400	4	9	27	84	1	9	22	64	5	18	49	148
1500	2	7	25	85	4	10	21	73	6	17	46	158
1600	3	10	28	90	3	8	26	74	6	18	54	164
1700	4	13	28	94	1	8	22	72	5	21	50	166
1800	4	13	21	81	...	9	25	72	4	22	46	153
1900	2	11	21	69	2	8	24	68	4	19	45	137
2000	5	12	21	57	4	8	23	78	9	20	44	135
2100	5	12	16	63	3	11	19	62	8	23	35	125
2200	3	13	21	65	1	10	19	58	4	23	40	123
2300	3	11	25	57	2	8	18	61	5	19	43	118
Total	89	286	578	1,728	106	349	725	2,052	195	635	1,303	3,780
Mean	22	72	145	432	27	87	181	513	49	159	326	945

flying. There is, however, a marked diurnal variation in its frequency. This is considered in the following section.

Diurnal variation of low cloud.—The lowest cloud height reported at each hour of each day for the four years August 1946 to July 1950 was examined, and a record was made of the number of occasions when the cloud base was less than or equal to 200, 400, 600 and 1,000 ft. Tables giving the distribution of these occasions for each month separately were compiled but are not reproduced here. Table III summarizes the data for the two seasons October–March and April–September and for the year as a whole. Each figure in the table gives the number of times in four years when the lowest cloud base was less than or equal to the prescribed value for each hour of the day. The last two lines give the total number of hours of low stratus per season for the four years and the mean number per season respectively. Fig. 1 shows isopleths of percentage frequency of cloud $\leqslant$1,000 ft. The isopleths have been smoothed to allow for departures of the four years from normal. The isopleths of frequency of cloud $\leqslant$200, $\leqslant$400 and $\leqslant$600 ft. follow a similar pattern, but the frequencies are only 1 twentieth, 1 sixth and 1 third as great respectively at all times and seasons, except that the proportion of cloud $\leqslant$200 ft. rises to 1 tenth in the mornings at the time of maximum frequency and is rather less than 1 twentieth in the afternoons.

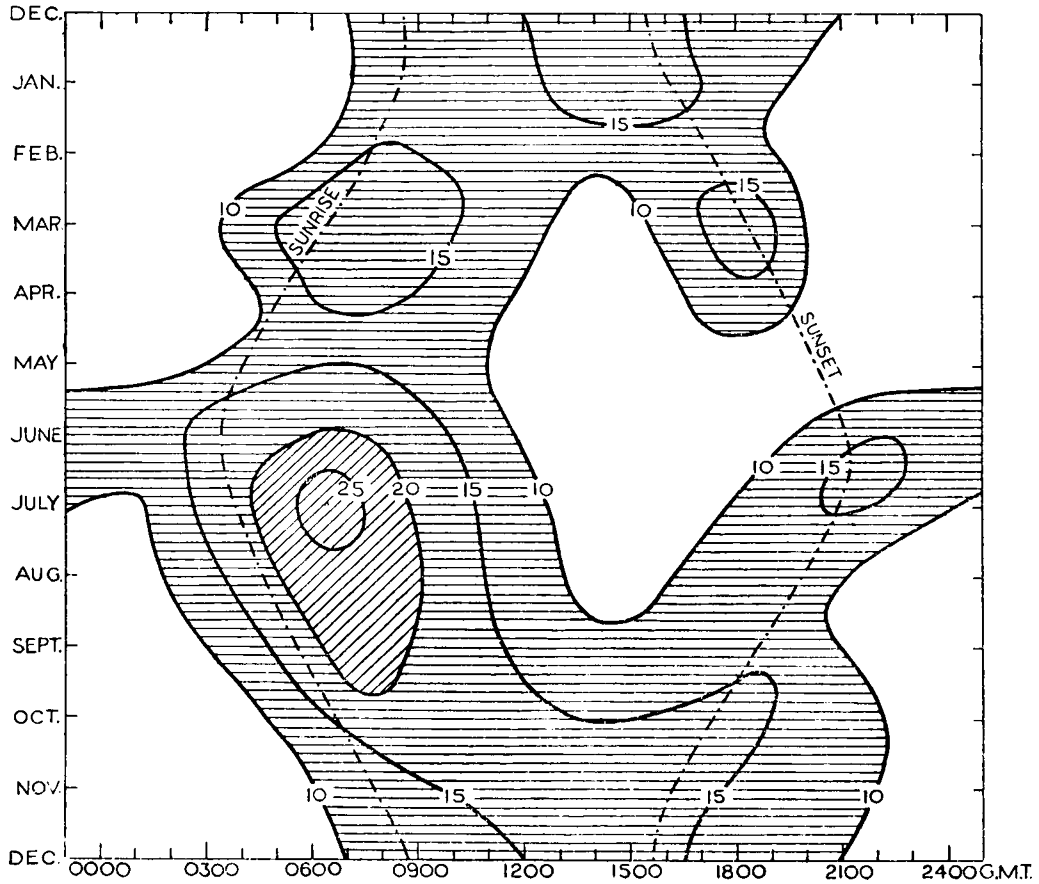

FIG. 1—PERCENTAGE FREQUENCY OF CLOUD AT OR BELOW 1,000 FT. AT PRESTWICK AIRPORT

The salient features in the variation of low cloud at Prestwick Airport to be deduced from these tables are as follows:—

(i) Considerable irregularity of diurnal variation

(ii) Relatively low frequency of low cloud in spring and relatively high frequency in summer and autumn

(iii) High frequency of low cloud about 2 hr. after sunrise throughout the year but especially in midsummer

(iv) Relatively low frequency during the middle of the afternoon in midsummer

(v) Increase of frequency about sunset

(vi) Relatively low frequency during the middle of the night.

These variations are to be explained by consideration of the stability of the lowest layers and their moisture content. These in turn depend on the amount of incoming radiation, the sea temperature, the local wind direction and the general synoptic situation.

The fact that the general synoptic situation is to a great extent responsible for the presence or absence of low cloud is the reason for the irregularities in the tables. The greater the number of frontal passages in a month the greater—in a broad sense—the number of occasions of low cloud. Table IV gives the mean-sea-level pressure at Prestwick for each month for the period, the normal (1901–30) pressure, the departure from normal and the number of occasions of cloud below 1,000 ft.

Subnormal pressure is associated with greater depressional activity, more frequent frontal passages, and consequently a greater frequency of low cloud. This is confirmed by Table IV, for, apart from March, the frequency of low cloud is greater for those months with negative departures of pressure. The isopleths given in Fig. 1 have been smoothed on the lines indicated by Table IV.

If a rough correction is made by adding 16 occasions for each millibar above normal and subtracting 16 for each millibar below normal, Table IV shows that,

TABLE IV—MEAN-SEA-LEVEL PRESSURE AT PRESTWICK AND ITS RELATION TO CLOUD AMOUNT

Period: August 1946–July 1950

	Mean-sea-level pressure			Occasions of cloud ⩽ 1,000 ft.	
	Average (1946–50)	Normal (1901–30)	Difference from normal	Actual (1946–50)	Corrected
		millibars			
January	1010	1011	−1	346	330
February	1013	1011	+2	183	215
March	1015	1010	+5	322	402
April	1009	1012	−3	330	282
May...	1016	1014	+2	192	224
June...	1014	1015	−1	407	391
July...	1014	1014	0	402	402
August	1014	1012	+2	337	369
September	1013	1015	−2	384	352
October	1017	1011	+6	277	373
November	1009	1010	−1	324	308
December	1011	1008	+3	276	324
Year...	1013	1012	+1	3,780	3,972

apart from March, cloud below 1,000 ft. is relatively less frequent from February to May and more frequent from June to October. This is contrary to the usual experience of coastal stations in that low stratus cloud is more frequently experienced in the spring when the sea temperature is relatively low, and less frequently in the autumn. At Prestwick, however, the synoptic situation normally more than outweighs the sea-temperature effect. In spring, south-westerly weather types are at a minimum, while the air masses of westerly and north-westerly types are more unstable than usual, so that Prestwick, which is protected by hills from low stratus from other directions experiences a minimum of low cloud. In summer and autumn south-westerly types are the most frequent in Scotland, so that Prestwick tends to have a maximum of low cloud. Further, the frequency of light gradient winds is at a maximum in summer, and sea breezes which tend to bring in low stratus (especially in the evening) are most frequent.

The exceptional March figure can now be explained by the fact that, though pressure was much higher than usual, south-westerly types were rather frequent especially in March 1950, so that Prestwick might be described as receiving a double amount of low cloud. An increase of the south-westerly type would increase the frequency of low cloud in any case, but occurring at a time when the sea temperature is relatively low, an exceptionally high total of low cloud is produced.

The diurnal variation of low cloud would be expected to show a maximum about sunrise when the stability of the lowest layers is at a maximum, and a minimum in the middle of the afternoon. The diurnal variation of low cloud at Prestwick is in the main, however, to be accounted for by variations in the local wind direction which cause variations in the moisture content of the lowest layers.

In conditions of slack gradient at night an ESE. land breeze blows across the airfield descending from hills to the east and south-east. Consequently the moisture content of the lower layers is generally below saturation and the formation of low stratus is unlikely. This land breeze dies out shortly after sunrise and is replaced by air from the sea, with a consequent maximum in the frequency of low stratus about 2 or 3 hr. after sunrise. In the depth of winter insolation is insufficient to produce convection to disperse the stratus, though the base may lift to above 400 ft., and it persists all day until the land breeze sets in again some hours after sunset. In summer, however, convection is sufficient to lift the base of the stratus in the afternoon and the frequency of very low cloud is at a minimum. Towards sunset, convection dies down while the sea breeze still persists, so that low stratus again forms. At midsummer, the night is short and the land breeze may not blow so that low stratus may persist all night. In the other summer months the setting in of the land breeze about 2 hr. after sunset produces a reduction in the frequency of low stratus.

Diurnal variation of surface wind.—The diurnal variation of surface wind has been generally indicated in the previous paragraphs; Table V illustrates the variation. This table gives the number of occasions per thousand of the various wind speeds and directions at 0300 and 1500 G.M.T. in winter and summer.

Whenever the gradient is slack, an ESE. wind blows over the airfield from about 2 hr. after sunset to just after sunrise, and a W. or WSW. wind from

TABLE V—DIURNAL AND SEASONAL VARIATION OF SURFACE WIND AT PRESTWICK AIRPORT

Period: 1946–50

Mean Speed	NNE.	NE.	ENE.	E.	ESE.	SE.	SSE.	S.	SSW.	SW.	WSW.	W.	WNW.	NW.	NNW.	N.	All directions
kt.	*Number of occasions per thousand*																
December–February																	
	0300 G.M.T.																
0																	62
1– 3	5	5	12	16	16	13	7	3	3	...	2	2	...	2	5	3	94
4– 6	6	12	7	16	20	21	12	8	5	8	...	4	...	7	7	1	134
7–10	6	18	22	14	26	29	9	21	14	8	17	12	14	10	12	7	239
11–16	...	7	14	17	15	20	10	32	31	33	25	26	12	12	4	...	258
17–21	2	2	5	1	13	6	6	15	9	13	19	18	9	7	4	...	129
22–27	...	...	2	...	2	2	...	6	5	6	25	9	13	2	1	...	73
28–33	...	...	...	...	2	...	...	...	...	2	...	2	...	...	...	...	6
34–40	...	...	...	...	...	...	...	...	...	...	2	2	...	...	...	...	4
1– 6	11	17	19	32	36	34	19	11	8	8	2	6	...	9	12	4	228
7–16	6	25	36	31	41	49	19	53	45	41	42	38	26	22	16	7	497
>16	2	2	7	1	17	8	6	21	14	21	46	31	22	9	5	...	212
	1500 G.M.T.																
0																	27
1– 3	4	...	3	11	14	8	4	2	2	3	4	8	1	2	...	...	66
4– 6	4	3	9	8	13	16	12	4	...	...	9	6	3	2	4	4	97
7–10	8	26	15	18	29	27	22	18	11	17	8	10	17	13	7	6	252
11–16	3	15	17	17	24	21	10	33	21	40	37	14	20	22	14	2	310
17–21	...	6	3	7	10	6	3	14	19	22	33	26	15	3	3	...	170
22–27	...	...	...	1	6	1	4	8	7	8	13	9	2	4	...	...	63
28–33	...	...	...	...	2	...	...	...	...	2	3	6	...	3	3	...	19
34–40	...	...	...	...	...	...	...	...	...	2	...	...	...	...	...	...	2
1– 6	8	3	12	19	27	24	16	6	2	3	13	14	4	4	4	4	163
7–16	11	41	32	35	53	48	32	51	32	57	45	24	37	35	21	8	562
>16	...	6	3	8	18	7	7	22	26	34	49	41	17	10	6	...	254
June–August																	
	0300 G.M.T.																
0																	157
1– 3	8	9	12	25	28	16	6	2	...	...	5	6	2	8	5	...	132
4– 6	11	16	18	15	34	25	9	2	4	7	5	4	2	...	6	5	163
7–10	17	30	22	13	19	12	35	29	11	30	19	21	24	19	5	1	307
11–16	4	11	8	2	6	5	16	24	17	26	43	15	14	10	7	...	208
17–21	...	4	...	1	1	...	...	3	1	2	9	6	...	4	...	...	31
22–27	...	...	...	...	...	...	...	...	...	...	...	...	2	...	...	...	2
1– 6	19	25	30	40	62	41	15	4	4	7	10	10	4	8	11	5	295
7–16	21	41	30	15	25	17	51	53	28	56	62	36	38	29	12	1	515
>16	...	4	...	1	1	...	...	3	1	2	9	6	2	4	...	...	33
	1500 G.M.T.																
0																	4
1– 3	...	...	...	...	...	...	...	...	...	...	2	...	...	2	...	...	4
4– 6	...	2	...	4	...	...	...	...	...	3	14	32	13	5	1	1	75
7–10	10	14	4	7	14	13	18	7	8	52	97	116	51	18	2	4	435
11–16	2	5	12	4	8	8	16	25	19	62	91	59	37	20	...	...	368
17–21	...	...	4	1	2	5	2	20	4	10	7	9	17	7	...	...	88
22–27	...	3	4	...	...	...	1	9	4	1	...	...	2	...	...	...	24
28–33	...	...	...	...	...	...	...	...	...	...	2	...	...	...	...	...	2
1– 6	...	2	...	4	...	...	...	...	...	3	16	32	13	7	1	1	79
7–16	12	19	16	11	22	21	34	32	27	114	188	175	88	38	2	4	803
>16	...	3	8	1	2	5	3	29	8	11	9	9	19	7	...	...	114

about 2 hr. after sunrise to about sunset. The remarkable feature especially in summer is the concentration of light winds from an easterly point at 0300 and from a westerly point at 1500.

In winter, daylight is short, and the sun is at a low elevation and sets about 1600 G.M.T. so that there is frequently insufficient heating to prevent the land breeze in conditions of slack gradient from blowing at any time. In summer, on the other hand, the reverse is true, so that light W. winds may persist well into the night.

Diurnal variation of temperature.—Fig. 2 shows curves of the diurnal variation of screen temperature for the 4 months, January, April, July and October, and the table gives the standard deviation of the temperature at certain hours.

The essential features of this figure are:—

(i) Small fall of temperature at night in January and October

(ii) Relatively rapid rise of temperature in April mornings and late maximum

(iii) Slow rise of temperature on July mornings.

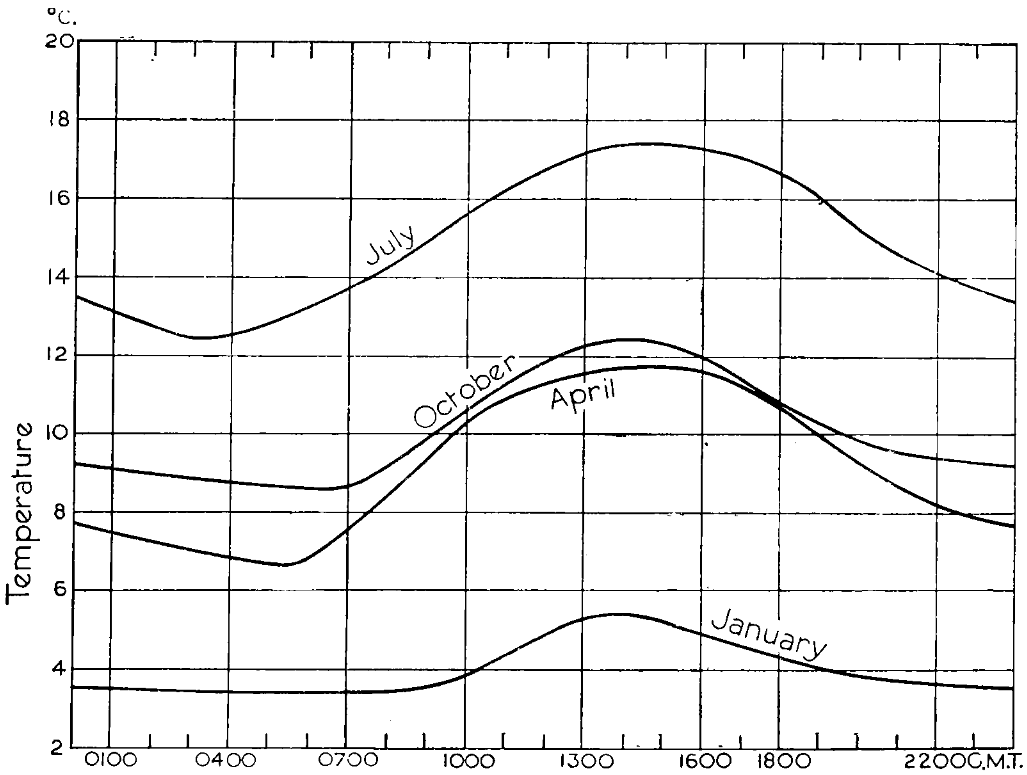

FIG. 2—DIURNAL VARIATION OF TEMPERATURE AT PRESTWICK

The temperature curves had already been worked up for the 5-year period 1942–46, and though the curves might suffer slight translation up or down if based on another period, their form would be retained.

	Standard deviation at							
	0100	0400	0700	1000	1300	1600	1800	2200
	degrees Centigrade							
January... ...	4·2	4·2	4·0	3·8	3·1	3·3	3·6	4·1
April	2·6	2·8	2·4	2·2	2·6	2·6	2·4	2·2
July	1·8	2·0	1·6	1·8	2·2	2·6	2·4	1·7
October... ...	3·1	3·2	3·3	2·6	2·2	2·2	2·4	2·8

January and October are cloudy months for the most part so that outward radiation is much reduced. Further when clear skies and light winds occur together at night, the land breeze blows with great regularity, and so, as stagnation is prevented, temperature tends to be kept up.

April is a month with minimum low-cloud amounts, consequently temperature shows a quicker rise than in other months, but the sea breeze tends to set in regularly so that a flat and delayed maximum occurs.

July is generally a cloudy month especially shortly after sunrise when low stratus cloud is most frequent; as a consequence temperature rises very slowly after sunrise. Though the low cloud tends to break and lift during the morning, the sea breeze causes a rather flat maximum.

The airfield and the aircraft operator.—From the aircraft operator's point of view the worst time for operations is the period 1–3 hr. after sunrise, in summer especially, when very low cloud and occasionally fog are most liable to occur. As fog is exceptional, services in and out of Prestwick will not be subject to much delay or diversion on account of low cloud or poor visibility provided the aircraft are fully equipped with instrumental landing aids for a safe descent to low levels.

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2. SAUNDERS, W. E., and SUMMERSBY, W. O.; Fog at Northolt Airport. *Met. Mag., London*, **80**, 1951, p. 255.

SEVERE TURBULENCE OVER THE INNER HEBRIDES

By H. S. TURNER, B.A.

The writer, in an article[1] published in April 1951, drew attention to a number of cases of standing waves to the lee of high ground encountered by pilots of British European Airways Corporation and the associated meteorological conditions were discussed. A recent occurrence of extremely severe turbulence followed by powerful vertical currents, in circumstances pointing to the existence of a standing wave, is described in this note.

The aircraft, a B.E.A. Dakota, was flying from Glasgow to Benbecula on the morning of December 21, 1951, and the severe turbulence was encountered approximately over the island of Rhum. Some of the passengers were thrown out of their seats with such force that injuries were sustained and extensive damage was done to the cabin interior. Previously, at 8,500 ft. the captain had noted alternate up- and down-currents of 500–1,000 ft./min., the periodic time of the oscillations being approximately 4 min. He then descended to about 5,500 ft. and at 1010 G.M.T. entered an 8 oktas stratocumulus layer near Rhum. At 1013 the violent turbulence occurred, lasting for less than a minute and was followed immediately afterwards by a vigorous up-current of at least 2,000 ft./min. for 1–2 min.

The area in question was subject to a strong south-westerly current in advance of an approaching warm front. The tephigrams for the 0800 G.M.T. ascents at Stornoway and Aldergrove, illustrated in Fig. 1, indicated stability of the air mass apart from a shallow layer near the surface. The upper air temperature observations, in fact, indicated that vertical currents were unlikely to arise from air-mass instability. Conditions were thus favourable for a standing wave, namely a fast-flowing and markedly stable air stream with a shallow unstable layer underneath.

The source of origin of the waves cannot be determined with certainty, but it seems most likely that the steady up-and-down motion was due to standing waves set up by the mountains of Northern Ireland, or possibly the small islands off the coast of Scotland or the mainland itself. The motion, however, was not observed until the aircraft had passed Ardnamurchan Point. Allowing for the speed of the aircraft and the angle between its track and the air stream, this would involve a wave-length of about 6 miles which is consistent with what is normally found in these cases. As regards the severe turbulence, this might well have occurred at one of the troughs of a separate train of waves set up by the island of Rhum itself and possibly reinforcing the other wave-train. This could also then account for the powerful vertical current which followed. The fact that the severe turbulence was distinct from the strong up-current makes it unlikely that orographic convection was responsible.

Alternative explanations to the one given involve a degree of instability not shown in the ascents. Obvious instability (see Fig. 1), ceased at 925 mb. but

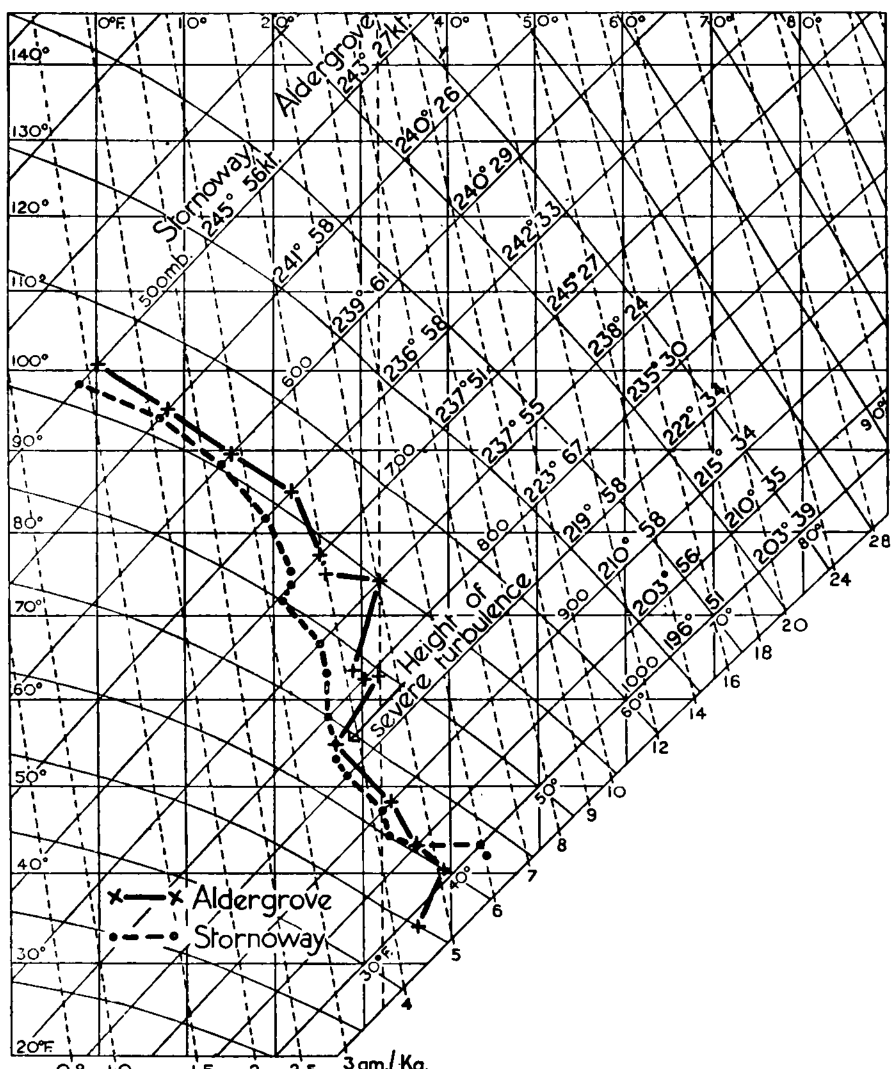

FIG. I—TEPHIGRAM FOR STORNOWAY AND ALDERGROVE ASCENTS, 0800 G.M.T., DECEMBER 21, 1951

[*To face p.* 240

DUSTSTORM NEAR MAFRAQ, JORDAN

Photographs taken from 10,000 ft. at 1400 G.M.T. on April 17, 1951 (see p. 248).

FIG. I—APPROACHING THE FOG BELT

FIG. 2—THE SOUTHERN EDGE OF THE FOG BELT

BELT OF SEA FOG OVER THE NORTH SEA

(See p. 249)

FIG. 3.—VERTICAL VIEW OF THE FOG BELT

FIG. 4.—OVER THE MIDDLE OF THE FOG BELT

BELT OF SEA FOG OVER THE NORTH SEA

(See p. 249)

To face p. 241]

FIG. 5—NORTHERN EDGE OF THE FOG BELT

FIG. 6—LEAVING THE FOG BELT

BELT OF SEA FOG OVER THE NORTH SEA

(see p. 249)

modifications in the air stream might have created a saturated adiabatic lapse rate up to the height at which severe turbulence was experienced. It is difficult, however, to believe that rising currents of any convective origin, ascending at 2,000 ft./min. and lasting more than a minute, could have been met at this height, which was the base of a much more stable layer.

Our knowledge of the precise mechanism of standing waves remains somewhat sketchy, and, as it would appear that they can on some occasions be of significance, aviation would benefit if pilots of powered aircraft reported cases as they occur for study by the meteorologist.

REFERENCE

1. TURNER, H. S.; Standing waves and powered flight. *Met. Mag., London*, **80**, 1951, p. 106.

CUMULONIMBUS CLOUDS OVER SUMATRA

By R. FROST, B.A.

Until recently very little information has been available about cloud development above 25,000 ft. in the region of the intertropical front, and although there were theoretical grounds for thinking that cumulonimbus clouds might extend up to 55,000 ft., the level at which the tropopause is reached over the equator, the only observations (which are little known) in support of this appear to be those of van Bemmelen[1], who made photographic measurements of cumulonimbus clouds over Batavia from two points, and found that the tops of these clouds were in most cases above 33,000 ft. and occasionally reached 50,000–53,000 ft.

In view of the introduction by British Overseas Airways of Comet aircraft operating at 40,000 ft. on the London–Singapore route, the following confirmatory observations of cumulonimbus development over Malaya and Sumatra may be of interest to forecasters for this route.

During the period April 18 to June 18, 1950, calculations of the heights of certain cumulonimbus clouds over Malaya and Sumatra were made by an R.A.F. Transport Command pilot from measurements of the angle of elevation of the clouds with a bubble sextant, and simultaneous observations of the range of the clouds on the aircraft radar.

In general a number of measurements were made over about 10 miles of run towards the cloud and the mean of such observations taken. The scatter of the results indicated that the mean would be in error by less than 1,100 ft. The mean heights of the tops are given in Table I. It can be seen from this table that many cumulonimbus clouds had tops well above 40,000 ft., the highest occurring at 54,600 ft.

TABLE I—MEASURED CLOUD-TOP HEIGHTS OVER SUMATRA AND MALAYA, 1950

Date	Time	Mean height	No. of obs.	Date	Time	Mean height	No. of obs.
		ft.				ft.	
May 4	1238	43,310	1	June 1	1402	38,310	5
	1655	44,500	1		1525	47,960	7
May 19	1523	34,000	2		1615	47,520	7
May 24	1530	22,540	1		1715	48,760	7
May 26	1641	29,200	1		1750	41,770	5
May 30	1445	36,970	1	June 2	1435	40,236	6
	1510	40,600	3		1508	41,660	5
May 31	1515	38,570	6		1640	54,600	4
	1800	37,370	6	June 10	1330	44,100	5

In August 1951 during the flight of an R.A.F. Canberra bomber to Australia the pilot reported that in the tropics, especially around Sumatra, the tops of the cumulonimbus clouds were well above 45,000 ft. Over the west coast of Sumatra and on the direct route between Ceylon and Singapore he found a solid area of cumulonimbus cloud (which he was fortunately able to bypass to the north) which did not appear to have any breaks below 50,000 ft.

I am indebted to Sqdn-Ldr Thirlwell, the pilot of the Transport Command aircraft, and to Wg-Cmdr Cumming, the pilot of the Canberra, for these observations. A note on the meteorological observations made by Wg-Cmdr Cumming during this flight is published in the July 1952 *Meteorological Magazine* on p. 218.

REFERENCE

1. BEMMELEN, W. VAN; Die Erforschung des tropischen Luftozeans in Niederländisch-Ost-Indien, *Luftfahrt u. Wiss., Berlin,* 1913, Heft 5, p. 48.

SOME EFFECTS OF THE COHERENCE OF METEOROLOGICAL TIME-SERIES

By R. P. WALDO LEWIS, M.A., M.Sc., and D. H. McINTOSH, M.A., B.Sc.

It is now generally realized that statistical formulæ based on the assumption of random sampling from a set of uncorrelated values cannot automatically be applied to geophysical and meteorological time-series (such as a sequence of daily pressure or temperature readings) which often have a considerable amount of coherence (alternative names are conservation, persistence, auto-correlation, or autoregression). In particular, if the standard deviation of the individual terms of a coherent series is σ, then the standard deviation σ_n of the set of means of n consecutive terms is not $\sigma/\sqrt{n}$, as given by the theory of random sampling, but some other number. Brooks and Carruthers[1] quote an example from daily pressure readings at Kew in the winter of 1938–39: standard deviation of the individual readings was 11·1 mb., whereas that of the means of two consecutive readings was not $11\cdot1/\sqrt{2}$ ($= 7\cdot8$ mb.) but 10·4 mb.

Chapman and Bartels[2] consider n consecutive terms of a series as being equivalent to n' random terms, each repeated n/n' times, and find a relation between n/n', σ and σ_n'

$$n/n' \equiv \varepsilon(n) = n\sigma_n^2/\sigma^2 = \text{“equivalent number of repetitions”}.$$

It is often convenient to have a formula for σ_n in terms of the correlation coefficients r_1, r_2, r_3,.........between successive terms, terms two apart, terms three apart,.........and so on. If the original series is u_1, u_2,.........u_N (N very large) where the u's may without loss of generality be taken to be departures from a mean,

$$r_1 = \frac{u_1u_2 + u_2u_3 + \dots\dots\dots + u_{N-1}u_N}{(N-1)\sigma^2}$$

$$r_2 = \frac{u_1u_3 + u_2u_4 + \dots\dots\dots + u_{N-2}u_N}{(N-2)\sigma^2}$$

....

The expression for r_p contains a factor $N - p$ in the denominator, but for small p we may replace this by N, since N is supposed large; r_p will in practice diminish with increasing p, usually becoming inappreciable after r_4 or r_5.

Consider a mean of n consecutive terms given by

$$m_{nx} \equiv \frac{u_x + u_{x+1} + \dots\dots\dots + u_{x+n-1}}{n}$$

On squaring, this gives

$$\begin{aligned} n^2 m_{nx}^2 = & (u_x^2 + u_{x+1}^2 + \dots\dots\dots + u_{x+n-1}^2) \\ & + 2(u_x u_{x+1} + u_{x+1} u_{x+2} + \dots\dots\dots + u_{x+n-2} u_{x+n-1}) \\ & + 2(u_x u_{x+2} + u_{x+1} u_{x+3} + \dots\dots\dots + u_{x+n-3} u_{x+n-1}) \\ & + \dots\dots\dots \end{aligned}$$

On the right-hand side there are n terms in the first bracket, $n - 1$ in the second, $n - 2$ in the third, etc. Summing both sides for $x = 1, 2, \dots\dots\dots (N - n)$ and dividing by N, if N is very much larger than n, we have

$$n^2 \sigma_n^2 = n\sigma^2 + 2(n-1) r_1 \sigma^2 + 2(n-2) r_2 \sigma^2 + \dots\dots\dots + 2 r_{n-1} \sigma^2$$

or $$\sigma_n^2 = \frac{\sigma^2}{n} \left[1 + \frac{2}{n} \left\{ (n-1) r_1 + (n-2) r_2 + \dots\dots\dots + r_{n-1} \right\} \right] \quad \dots\dots\dots (1)$$

In a recent paper Brooks[3] gives a modification of equation (1) on the assumption that $r_n = r_1^n$. As this is not always true, however, it is advisable to leave equation (1) as it stands. For example, if we construct a coherent series by taking 3-term running means of a random series,

$$r_1 = 0{\cdot}67$$

$$r_2 = 0{\cdot}33 \neq r_1^2 = 0{\cdot}45.$$

For $n \geqslant 3$ $\quad r_n = 0 \neq r_1^n \; (r_1^3 = 0{\cdot}30, r_1^4 = 0{\cdot}20, \dots\dots\dots).$

The "equivalent number of repetitions" is given by the coefficient of σ^2/n i.e.

$$\varepsilon(n) = 1 + \frac{2}{n} \left\{ (n-1) r_1 + (n-2) r_2 + \dots\dots\dots + r_{n-1} \right\} \quad \dots\dots\dots (2)$$

The expression (2) may be used to estimate the number of effectively independent terms to which a number n of coherent terms is equivalent. In this case, n is frequently the total number of terms available, and we have to estimate the r's from this limited sample instead of from the theoretical total of N terms. Knowledge of the number of independent terms is necessary for assessing the significance of various statistics, such as the correlation coefficient between two coherent series.

As an example we consider the departures of the Edinburgh daily mean temperature for 1950 from the corresponding 50-year average. For these $r_1 = 0{\cdot}76$, $r_2 = 0{\cdot}54$, $r_3 = 0{\cdot}37$, $r_4 = 0{\cdot}27$, $r_5 = 0{\cdot}21$ and $\sigma = 4{\cdot}8$°F. (these values of $r_2 \dots\dots\dots r_5$ compare with $r_1^2, \dots\dots\dots r_1^5$, namely 0·58, 0·44, 0·34, 0·25, implied in Brooks's formula). If we consider 30-day means, expression (2) gives (ignoring terms in r_6 and beyond)

$$\varepsilon(30) = 5{\cdot}0.$$

It is noteworthy that the daily mean temperatures for one month yield only about six (30/5) independent values. (Compare the "persistence length" of three days for daily temperature readings made at a fixed hour—an obviously less coherent series—mentioned by Carruthers[4] in a recent paper.) We therefore have, from equation (1),

$$\sigma_{30} = 4{\cdot}8\sqrt{(5{\cdot}0/30)} = 2{\cdot}0\text{°F}.$$

Actual calculation from the 336 30-day running means over the whole year gives $\sigma_{30} = 1 \cdot 8°F.$ while the standard deviation of the 12 monthly means (i.e. of separate blocks of about 30 values) is 2·4°F.—in fair agreement considering the smallness of the sample. These values of σ_{30} compare with a value of $4 \cdot 8/\sqrt{30}$ or 0·9°F., calculated on the basis of independence between successive daily values.

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1. BROOKS, C. E. P., and CARRUTHERS, N.; Statistical methods in climatology. London, 1944, p. 15.
2. CHAPMAN, S., and BARTELS, J.; Geomagnetism. Vol. II. Oxford, 1940, p. 584.
3. BROOKS, C. E. P.; The variability of means of a series of observations. *Met. Mag., London,* **77,** 1948, p. 283.
4. CARRUTHERS, N.; The accuracy of a mean of *n* temperature observations as an estimate of the mean temperature for a particular month. *Met. Mag., London,* **78,** 1949, p. 65.

METEOROLOGICAL RESEARCH COMMITTEE

The Meteorological Research Committee held its 63rd meeting on March 26. The Committee considered reports from Sub-Committees. The Chairman, Prof. G. M. B. Dobson, announced that he would cease to be Chairman of the Committee after the meeting, and the Director of the Meteorological Office stated that Sir David Brunt had accepted an invitation to succeed Prof. Dobson as Chairman of the Committee.

The twentieth meeting of the Synoptic and Dynamical Sub-Committee of the Meteorological Research Committee was held on May 14, 1952.

The Committee reviewed long-range forecasting methods and also considered a paper by Mr. Sawyer and Mr. Bushby[1] on a baroclinic model suitable for numerical integration.

A paper by Mr. G. W. Hurst[2] dealing with the profile of a jet stream observed on January 18 was received with interest as it suggested a possible technique for measuring jet streams over desert areas where no radar network existed.

ABSTRACTS

1. SAWYER, J. S. and BUSHBY, F. H.; A baroclinic model atmosphere suitable for numerical integration. *Met. Res. Pap., London,* No. 715, S.C. II/104, 1952.

Authors adopt as a model a baroclinic fluid in which the thermal wind is constant in any vertical column and its speed is proportional to the vertical pressure difference through the layer. With certain assumptions a system of 3 simultaneous differential equations is derived to compute the rates of change of height of a contour surface, thickness 1,000 mb. to that surface, and average vertical velocity throughout the column. A method of solution is given but to forecast values 24 hours ahead would be very laborious without electronic computing machinery.

2. HURST, G. W.; The profile of a jet stream observed 18th January, 1952. *Met. Res. Pap., London,* No. 722, S.C. II/107, 1952.

On June 18, 1952, an aircraft flew at 30,000 ft. from Yarmouth to Pembroke and back on a more southerly track, crossing a well marked northerly jet stream. Vertical photos were taken every 12 seconds; the winds calculated from these fixes are presented in diagrams. They show a rapid increase from 80 kt. in longitude 0° to nearly 180 kt. between 2¼° and 3°W., and a slow decrease to 160 kt. in 5°W.

BOOK RECEIVED

Geophysical Notes, **4,** 1951, Nos. 1–8, 10 in. × 7 in., Geophysical Institute, Tokyo University, Tokyo, 1951.

ERRATUM

June 1952, PAGE 184, line 46; *for* "maximum" *read* "latter".

ROYAL METEOROLOGICAL SOCIETY

The Annual General Meeting was held on April 23, 1952, with the President, Sir Charles Normand, in the Chair.

The Buchan Prize for 1947–51 was awarded to Dr. G. D. Robinson, the Hugh Robert Mill medal for 1952 to Dr. J. Glasspoole, and Darton Prizes to Dr. H. L. Penman, Mr. J. M. Craddock, Mr. A. J. Whiten, and to Messrs. E. G. Bowen and K. A. Davidson jointly.

Presidential Address—Atmospheric ozone and the upper air conditions

Sir Charles Normand opened his address by pointing out that although all the ozone brought to normal surface pressure and temperature would form a layer about 3 mm. thick compared with a corresponding thickness of 8 Km. for the atmosphere as a whole, yet it effectively cut short the ultra-violet end of the solar spectrum, a fact of great biological importance. More important to the meteorologist is the relation between ozone and weather, from which it seems that ozone may be acting as an indicator of air movements in the stratosphere.

Dobson long ago established an inverse correlation between the amount of ozone and the surface pressure. The relation between the amount of ozone and the meteorological situation was now being investigated by the Ozone Commission (of which Sir Charles is Secretary) of the International Association of Meteorology. Dobson spectro-photometers have been brought into use at a number of stations in western Europe for examination of the variations of ozone with place. With this apparatus readings of the amount of ozone can be made by using the radiation coming through clouds if direct observation of the sun is impossible. However, the ozone observational network outside the British Isles was incomplete in 1951, and so the address dealt mainly with the observations made at Oxford. Sir Charles showed the relations between ozone amount and the structure of the troposphere over long periods with parallel curves and correlation coefficients, and used 300-mb. contour charts to illustrate typical individual cases of high and low ozone amounts. The observations confirm Dobson's conclusion of ozone tending to be low above anticyclones and high above depressions, but the main result has been the striking anti-parallelism between ozone content and the thickness of the 500–300-mb. layer and the heights of the 300-mb. surface and of the tropopause. In terms of the long-wave pattern of the zonal flow in the upper troposphere, ozone is high in the troughs and low in the ridges.

The changes appear to be explicable in terms of vertical currents in the stratosphere above tropospheric disturbances since ozone content increases with height to a maximum between 20 and 30 Km. and then decreases. This raises the question of the determination of the vertical distribution of ozone and Sir Charles discussed methods of finding it. Rocket- and balloon-carried spectrographs can be used to record the changes in the solar spectrum with height but are very expensive in use. A much simpler method is the one due to Dobson and Götz of observing from the ground the changes in intensity of two lines in the ultra-violet spectrum of the zenith radiation as the altitude of the sun or moon increases or decreases near rising and setting.

The address will be published in the *Quarterly Journal of the Royal Meteorological Society.*

At a meeting of the society on May 21, 1952, the President, Sir Charles Normand, in the Chair, the following papers were read:—

*Goody, R. M.—A statistical model for water-vapour absorption**

This paper in physical research is, Dr. Goody claimed, an effort to solve one small part of the problem of radiation in the atmosphere. The radiation spectrum of water vapour in the infra-red consists of a large number of lines, the observed wave-lengths of which agree very well with those calculated from the molecular structure by means of the quantum theory. Schnaidt's method of calculating the absorption or transmission of these lines could not be used since it assumed regular spacing of the absorption lines, and for water vapour the spacing was seemingly very haphazard.

Dr. Goody started with an arbitrary line shape (intensity of absorption plotted against wave-length) and an expression for the total transmission in a wave-band, making the simplifying assumption that the absorption lines have a random distribution. By trying an exponential form for the probable intensity of a line and, following Prof. Cowling, using the Lorentz shape for each line he could then calculate the total transmission in a wave-band, and could compare his results with the data calculated by Prof. Cowling in a few special bands (in one case with four different pressures). Except for the wave-band 300–350 $cm.^{-1}$ agreement was very good, all the points (Cowling's data) appearing to lie on the curves given by Dr. Goody's equations.

Mr. Curtis followed Dr. Goody's account with a description (to be published shortly) of how he had applied the equations to a path along which the pressure varies. With typical water-vapour distributions the agreement with observed data was good, but application to the absorption and transmission by ozone was not so good, and he thought more success would be obtained by graphical methods.

Dr. Scorer was surprised that Dr. Goody should be disappointed with the fit of one of the curves; it fitted better than many curves he had seen in meteorology. Prof. Sheppard asked if there was any sound information on the line shape. Dr. Goody replied that it was the accurate balance between two measurements that was required which meant greater accuracy was required in his formula; with regard to line shape, information in all other regions was consistent in all grades of spectroscopy, i.e. the Lorentz shape held up to heights of 30 Km. where the Doppler effect becomes important.

Thompsom, B. W.—An essay on the general circulation of the atmosphere over south-east Asia and the west Pacific†

In the absence of Mr. Thompson, who was in Hongkong, this paper was read by Mr. G. S. P. Heywood, Director of the Royal Observatory, Hongkong. This paper is a preliminary survey based on observations during the period September 1947–September 1949 when information was (and still remains) very sparse, particularly in the upper air and over China. With the help of reports from transport aircraft it has proved possible to draw up model charts for each season of the year showing typical conditions (neither mean nor actual) at the surface, 2,000 ft. and 10,000 ft. At the two upper levels conditions are represented by flow charts, the 10,000-ft. chart being the more likely to be accurate since

Quart. J. R. met. Soc., London,* **78, 1952, p. 165.
†Quart. J. R. met. Soc., London, **77**, 1951, p. 569.

transport flights usually took place at that height. The most important features of these charts are the comparatively shallow cold northerlies over China in winter associated with the Siberian anticyclone (winter monsoon), the North Pacific trades, the upper westerlies from northern India, the movement northwards of the westerlies from the Indian Ocean during spring and early summer (summer monsoon), the convergence zones between similar and dissimilar air masses which appeared and disappeared, and the formation of typhoons. Mr. Thompson also thought that the classical intertropical front of India in July was in reality the polar front of Asia.

Mr. Durst said that Dr. Hare had produced similar model circulation maps during the war, but they had not been published because the results did not differ from those published previously by Chinese workers. He did not remember seeing the "classical" position before; Hare's position was very similar to Thompson's. There then followed some discussion on the nature of the intertropical front or convergence zone and the origin of the air on either side of it. Mr. Sawyer said that the intertropical front followed the thermal equator. Dr. Forsdyke said a very large part of the supply of air in the Indian monsoon does come from the South Indian Ocean and extended to a height of at least 10,000 ft.; further east there was a weaker gradient across the equator, and he would not be surprised at the occurrence of limited convergence zones as described in Thompson's paper.

Mr. Veryard thought the jumpiness of the intertropical front (which he had observed in the Sudan) could be explained by the shallowness of the underlying warm moist air. Sir Charles Normand drew attention to the major properties of air in north-west India—the difference in humidities—and to the formation of cyclones in the Bay of Bengal preceded by westerly winds to the south of the main easterly current and squally weather.

Mr. Heywood, in conclusion, doubted whether Mr. Thompson had read the Chinese reports, but he had the advantage of more upper air information. Regarding the nature of the westerlies from India, since they had a very long sea track by the time they reached Hongkong, it did not seem to matter where the air had originated.

LETTER TO THE EDITOR

Speed of development and localization of thunder clouds

An interesting example of the rapidity with which thundery activity can develop and of its localized character in the initial stages occurred at Elmdon Airport, Birmingham, on Sunday, May 18, 1952. The synoptic situation and upper air temperature favoured the development of thunderstorms soon after the critical temperature (75°F.) at the surface was reached. The freezing level was 10,500 ft.

During the morning the sky was clear apart from some fragments of cirrus cloud and a small cumulus cloud "permanently" over the cooling towers at the Power Station, Hams Hall, but at 1230 G.M.T. very small flat cumuli formed at 3,500–4,000 ft. when the critical temperature was reached. About five minutes later two of these clouds over the western side of the airfield quickly developed vertically to an estimated height of 12,000–15,000 ft. These "twin" clouds were comparatively close to each other and covered much less than 1 okta of the sky, but from 1246 G.M.T. onwards short lightning flashes were distinctly observed (thunder clearly heard) between the protuberances at or near the top of each cloud and between the clouds. The development of these clouds was not quite simultaneous, and it seemed that the presence of the second cloud provided the trigger action.

At 1255 there was another development about 2–3 miles to the west, but this was on a larger scale and covered about 1–2 oktas of the sky. Heavy rain (very large drops) and some hail were first observed at 1315 G.M.T. There followed further outbreaks and the general thundery conditions lasted about two hours.

A. W. BERRY

Elmdon, May 20, 1952

NOTES AND NEWS

Auroral arch of January 29, 1952

At 1930 G.M.T. on January 29, 1952, a well defined auroral arch, with a dark segment below, was visible from the meteorological office at Shawbury. At 2000 the arch extended from 310° to 050° true, and was of a moderately bright, homogeneous white colour. The arch had a sharply defined lower edge, and extended from 7° to 10° above the horizon in the centre, with a glow of lesser intensity extending to roughly 15° above the horizon. The arch remained quiescent but decreased slightly in intensity until 2040 when it began to pulsate and occasionally very faint white rays could be seen extending upwards.

At 2045 another arch developed above the original one, extending from 265° to 020° true, the elevation of the ends being 20° and of the centre 25° above the horizon.

By 2055 the arches had degenerated into a diffuse glow extending from roughly west-north-west to north-north-east and elevation 25° above the horizon. This glow gradually decreased in intensity until 2130 when it disappeared altogether, and continuous observation of the phenomenon ceased.

Visibility during the period of observation was between 10 and 15 miles, with 1 okta altocumulus at 10,000 ft. and 3–4 oktas cirrus and cirrocumulus to the south. Measurements of elevation and bearing were made with a theodolite on the meteorological office roof, using Polaris as azimuth.

C. A. ROBINSON
D. J. GEORGE

Duststorm near Mafraq

The two photographs facing p. 240 were taken at 1400 G.M.T. on April 17, 1951, from an aircraft of R.A.F. Station, Shawbury, flying at 10,000 ft. between Malta and Habbaniya. The position, 32°24′N., 36°49′E., is near Mafraq, Jordan, and the top of the rising dust layer shown was estimated to be at 11,000 ft.

Meteorological observations from the desert regions of Jordan and western Iraq are too scanty for this duststorm to be associated with any particular feature of the synoptic situation. Between April 15 and 20, 1951, however, the Levant and western Iraq came under the influence of a series of fronts, the first of which reached Sinai early on April 15, and subsequently became very slow-moving on reaching western Iraq; showers and scattered thunderstorms were reported in the area, and much rising dust in Iraq.

The phenomenon of dust rising to 10,000 ft. or more over central and southern Iraq due to frontal systems approaching from the west is not infrequent during the months of October and November and again from March to May or June. Well marked sandstorms further to the west are relatively rare owing to the harder nature of the surface; at Rutba for instance Coles* has shown that the frequency of duststorms is low compared with other stations in Iraq.

Sea fog

The photographs in the centre of this Magazine illustrate a belt of sea fog over the North Sea on April 30, 1942. They were all taken from a height of 6,000 ft. from a Rhombus meteorological reconnaissance aircraft within a few miles of 54°45'N., 2°30'E. at about 1300 G.M.T. The belt was 10–50 miles wide, lying in a direction east-south-east to west-north-west with top about 500 ft. above sea level. Except for the vertical views the photographs show the appearance of the fog on the starboard side of the aircraft as it flew across the belt on a course of 030° true.

There had been an easterly wind current across the North Sea for nearly a week with almost cloudless weather from the 25th onwards. As the wind backed to east-north-easterly cloud developed, the first sign of low cloud being this belt of sea fog; cirrostratus was visible at this time to the east. A minor front passed through eastern districts of England during the evening of May 1 and the cloudless spell was over.

Heavy rainfall in Devon on May 19, 1952

Major J. M. Salusbury-Trelawny has forwarded some interesting details of the heavy rain experienced at Cotleigh House, four miles east-north-east of Honiton, on May 19, 1952.

At 1550 G.M.T., an unobtrusive brown-coloured cloud appeared over the hill, a few points south of due west. In less than five minutes rain started falling, and immediately developed into a torrential downpour with hailstones over half an inch in diameter. Rain ceased entirely by 1640.

The track of the storm, which was accompanied by a great deal of thunder and lightning, was nowhere more than 1½ miles wide, and it passed to the south-east, petering out about two miles away. A great deal of soil was washed off neighbouring fields and 4-ft. high walls were demolished.

This fall of 2·56 in. in under 50 min. ranks as "very rare" in the classification used in *British Rainfall*, where such a fall is regarded as likely to occur once in about 300 years at an individual station. There are, however, other comparable falls on record for south-west England.

July 28, 1948: 3·08 in. in 50 min. at Halford (Dyche), 12 miles north of Taunton.

June 21, 1933: 2·75 in. in 45 min. at Temple Combe, 10 miles east-north-east of Yeovil.

June 23, 1946: 2·35 in. in 45 min. at Cullompton, 12 miles west of Honiton.

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*COLES, F. E.; Dust-storms in Iraq. *Prof. Notes met. Off., London*, **6**, No. 84, 1938.

During the day pressure was almost uniform at about 1018 mb. over the whole of the British Isles with anticyclones to the north-east and south-west. What surface wind there was seemed to drift from the west or north in the western parts and from the east in the eastern parts of England. There had been a warm anticyclone over the country during the preceding week but this had collapsed slowly leaving warm stagnant air behind. This was moderately dry above 3,000 ft., but in the south of England was very moist at low levels, dew points of 57–60°F. being common (at Boscombe Down a dew point of 66°F. was recorded at 1200 G.M.T. implying a moisture content of 13–14 gm./Kg.). The air mass was unstable, provided the surface temperature reached 74°F., and, since the weather was initially fine, this temperature was reached in many places away from the coast and local thunderstorms occurred. There was a cold front drifting westwards over the North Sea, but this did not affect England until the following day when a tornado was experienced at Tibshelf in Derbyshire.

North Greenland Expedition

The Norwegian M.V. *Tottan* sailed from Deptford on July 8, 1952, carrying the British North Greenland Expedition, and the following message was sent to Commander C. J. W. Simpson, R.N., Leader of the Expedition:

> "The Meteorological Office wish you bon voyage and every success in North Greenland."

The Meteorological Office has lent Mr. R. A. Hamilton to act as Deputy Leader and Chief Scientist of the Expedition. The equipment taken on the *Tottan* included 87 packages of meteorological stores supplied by the Instruments Division of the Meteorological Office.

The Expedition is to operate from a main base in Queen Louise Land about 50 miles inland from the east coast and from a smaller station at 9,000 ft. near the centre of the ice-cap in latitude 77°N. (approximately). An extensive programme of geophysical and glaciological research is to be undertaken. The meteorological work will be largely, though not exclusively, associated with the requirements of the glaciological investigations.

Professor of Meteorology, University of London

Sir David Brunt, M.A., Sc.D., Secretary of the Royal Society, is retiring from the chair of Meteorology in the University of London (Imperial College of Science and Technology).

Asst. Prof. P. A. Sheppard, B.Sc., F.Inst.P., Reader in Meteorology in the University, has been appointed to succeed Sir David as Professor with effect from October 1, 1952.

Sir David Brunt is a member of the Meteorological Committee and Chairman of the Meteorological Research Committee. Asst. Prof. Sheppard is Chairman of the Instruments Sub-Committee of the Meteorological Research Committee.

REVIEWS

The terrestrial atmosphere. By N. C. Gerson*. *Sci. Progress, London,* **40,** 1952, pp. 245–254.

Mr. Gerson's article is a highly condensed survey of selected characteristics of the earth's atmosphere, mainly at levels beyond those reached by modern

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*of the Geophysics Research Division, A. F. Cambridge Research Center, Cambridge, Mass.

sounding balloons. A brief general sketch of a subdivision of the atmosphere into six shells according to properties is followed by sections dealing with the constituents, temperature, electron densities, aurora, airglow and air motion in the ionosphere. These topics are, of course, not mutually independent. Knowledge of the constituents, and their condition, of the attenuated regions of the atmosphere results from study of the emission spectra of the aurora and of the airglow at night and twilight. Deductions as to the temperature above about 100 Km. depend largely on the evidence provided by ground-based radio and spectrographic measurements, though discrepancies exist between the inferences drawn from the two classes of evidence. The radio data and the observed occurrence of aurora at heights of about 1,000 Km. lead to estimates of temperatures of 2,000–3,000°A. at 300–400 Km.

It is convenient to have in a general scientific review this compact presentation of current knowledge and opinion concerning the higher layers of the atmosphere where complexity, if different in character and origin, appears to be not less in degree than in the lower, presumably more earth-influenced, layers in which most meteorologists are normally more immediately interested. Notable progress in the exploration of the upper atmosphere by a variety of indirect methods has been made in the past two or three decades. It is to be expected that developments on these lines in conjunction with the new facility for obtaining measurements with instruments conveyed to great heights will greatly increase our knowledge and, not improbably, reveal fresh problems.

H. W. L. ABSALOM

The climate of Blue Hill according to air masses and winds. By Photios P. Karapiperis, *Harvard met. Stud.*, No. 9, 10 in. × 7 in., pp. 105, Harvard University Press, Cambridge Mass., 1951. Price: $1.25.

This investigation is in two parts. Part I is a study of seasonal surface winds (direction and speed) which accompany different air masses at Blue Hill Meteorological Observatory (42°13′N., 71°07′W.) in New England. The observations of wind were obtained from a 3-cup anemometer at the hour ending 0100, 52 ft. above the ground at Blue Hill from December 1947 to November 1950. The winds were divided (*a*) with respect to eight directions subdivided into maritime (between ENE. and S.), continental (between WSW. and N.) and transitional (NNE. and NE., SSW. and SW.) according as the underlying surface over which the air flowed was respectively wholly oceanic, land, or partly land and partly ocean, and (*b*) into speeds 1–15 m.p.h., 16–30 m.p.h., over 30 m.p.h., and according as the flow of the air from a particular direction was or was not maintained for a distance exceeding 200 miles. The six air masses, cA arctic continental air, cPk polar continental air colder than surface over which it is moving, cP polar continental air, cPw polar continental air warmer than surface, mP polar maritime air and mT tropical maritime air, used were those published once a day in the Washington *Daily Weather Map* of 0130. The two air masses cP and cPw were grouped together.

From the results of Part I Karapiperis deduces "that persistent winds and, to a fair degree, strong winds from a certain direction are fairly closely related to the occurrence of air masses whose source regions are in their directions". The closeness of the connexion between air mass and wind direction can be gauged from a study of Table 4 which shows that at 0130 in autumn the probability of continental winds of 16–30 m.p.h. being associated with air masses (cP and cPw), cPk, and mP is respectively 21, 74 and 5 per cent. This appreciable departure from one-to-one correspondence between air mass and wind direction and speed must, to some extent, invalidate Karapiperis's conclusion that "it is possible to study air-mass climatology without depending on the availability or homogeneity of air-mass data". Accordingly, Part II, which is a study, by seasons at 0700 and 1300, of the influence on the climate at Blue Hill during the ten years 1941–50 of the same categories of wind direction (maritime, continental and transitional) and speeds dealt with in Part I, but omitting travel greater than 200 miles from the same direction, cannot, as Karapiperis considers, "provide a valid substitute for a strictly air-mass climatic study".

The climatic elements examined in Part II are those of wind, temperature, relative humidity, cloudiness and fog (mainly low stratus since the Observatory is at a height of 635 ft.), precipitation and visibility. Seasonal values are given in tables, illustrated by diagrams, as percentage frequencies of the total number of observations at each of the hours 0700 and 1300. Only broad class intervals of each element are used: 18°F. for temperature, 25 per cent. for relative humidity.

The results of Part II lead Karapiperis to the conclusion that "Once the wind is forecasted the rest of the weather picture is shown here" [in Part II]. This conclusion needs examination. Let it be supposed that it is autumn and that continental winds (i.e. winds from between WSW. and N.) 16–30 m.p.h. are expected and that it is desired to forecast (*a*) temperature (*b*) relative humidity at 0700 and (*c*) the amount of precipitation (rain and snow) of the hour before 0700. Tables 10, 14 and 25 show respectively that the approximate probability of occurrence (*a*) of temperature lying between 15° and 32°F., 33° and 50°F., 51° and 68°F., and 69° and 86°F. to be respectively 24, 52, 20 and 4 per cent.; (*b*) of relative humidity having values between 100 and 76 per cent., 75 and 51 per cent. and between 50 and 26 per cent, to be respectively 46, 53 and 1 per cent.; and (*c*) of precipitation amounting to between trace and 0·04 in., between 0·05 and 0·09 in., and equal to and greater than 0·10 in. to be respectively 70, 23 and 7 per cent. Such information can hardly be said to be of assistance to the forecaster on this occasion or to a climatologist for planning purposes.

J. E. BELASCO

Southern Rhodesia Rainfall Handbook, and Supplement No. 1. Prepared by the Department of Meteorological Services. 13 in. × 8 in., pp. 30 and 55, *Illus.*, Government Printing and Stationery Department, Salisbury, Southern Rhodesia. 1951. Prices: 7*s.* 6*d.* and 2*s.* 6*d.*

The success of many of the development schemes in the rapidly expanding economy of Southern Rhodesia depends on the provision of adequate water supplies. Therefore a knowledge of the rainfall and its variations is essential.

This Handbook discusses the rainfall records of some 300 stations selected for their position, reliability and length of record—the 30-year period 1916–45 has been chosen where possible. Further handbooks will be published, dealing with special aspects of the rainfall and supplements will be issued giving details of monthly and annual rainfall and number of rain days—Supplement No. 1 for the eastern area has been issued with this handbook.

The average annual rainfall chart, discussed in Chapter II, reflects the orographic features of Southern Rhodesia and the climatic features of South Africa where there is a general diminution of rainfall from the east coast to the west and from north to south. The well marked seasonal distribution of rainfall is described; much of the rain in the early part of the season from September to November comes from thunderstorms and showers.

Chapter III discusses the variability of monthly and annual rainfall with a series of diagrams for 25 stations showing means, medians and quartiles of the rainfall distribution. An interesting analysis has been made of 10-day periods of rain for four stations, and it is shown that the rainfall for a particular 10-day period is likely to be below the long-term average of the 10-day period, especially in October. The length of the records is too short for the consideration of secular trends, but there is some evidence of a diminution of rainfall in parts of the eastern areas. No periodicity in the rainfall has been established.

Chapter IV describes an experiment on the variation of rainfall over small distances. Over the Colony as a whole the conclusion was reached that about 75 per cent. of the variation of the rainfall is common to all stations.

Chapter V deals with the incidence of rainfall. Sequences of dry and wet days were analysed, and it is shown that once a wet or dry spell has lasted 3 days the chance is about 3 to 1 that it will persist. The intensity of rainfall at Salisbury was investigated (over a period of 18 years) with the interesting result that it could be described as being divided about equally into one third of light, one third moderate, and one third heavy rainfall (light being taken as less than 0·25 in./hr. and heavy as more than 1 in./hr.). Bulawayo rainfall shows similar features.

The statistical basis of the arguments in the previous chapters is given in Chapter VI. In the section on "Heavy daily falls", it is suggested that the formula (due to Brooks and Carruthers) for the maximum daily fall, R, expected once in Y years, might be tested: it is $R = K(1 + \log Y)$ where K = mean annual maximum rainfall in a day. It is also suggested that in Chapter III percentiles would be worth giving and in Chapter IV that the variation of rainfall with position might be investigated by the use of regression coefficients, with latitude, longitude and altitude as independent variates.

J. PEPPER

METEOROLOGICAL OFFICE NEWS

Birthday Honours.—We congratulate Mr. A. G. King on the award to him of the B.E.M. Mr. King was associated with the production of the *Daily Weather Report* for over 50 years and had been in charge of the Meteorological Office Unit of H.M. Stationery Office since its formation in 1920. This unit was transferred to the Central Forecasting Office, Dunstable, in 1940. Mr. King retired in September, 1951.

Staff losses.—The office has lost the services of four of its Principal Scientific Officers, namely, Messrs. O. M. Ashford, J. L. Galloway, A. H. Gordon and G. J. W. Oddie. The first three have been seconded to the Secretariat of the World Meteorological Organization at Geneva, and the last named to the International Civil Aviation Organization at Montreal. We wish them all success in their new spheres.

Another Principal Scientific Officer whose services are lost to the office temporarily is Mr. R. A. Hamilton. He has joined the British North Greenland Expedition as Chief Scientist.

Ocean weather ships.—The cricket team of o.w.s. *Weather Observer* visited Hillhead High School, Glasgow—which "adopted" the ship some time ago—with the object of playing against the school, but bad weather prevented the match. The ship presented to the school a trophy shield embossed with the ocean-weather-ship crest for the inter-house relay race.

Sports and Athletics.—A good year of sport culminated in many successes at the Air Ministry and Ministry of Civil Aviation annual sports meeting at The White City on July 2. The Bishop Shield was won by the Office (for the fourth successive year) with a total score of 126 points. The achievements of the staff in winning every swimming event, gaining points in football and in ladies' netball contributed much to this success. The runners-up were the Ministry of Civil Aviation, who scored 66 points. The Jones Memorial Cup, awarded for the highest number of points at the annual sports meeting, was won by the Office for the third consecutive year, the outstanding win being the men's relay race in record time for these meetings. The Social and Sports Committee will circulate a list of individual successes to all branches and local offices.

The Social and Sports Club of the Office at Harrow held its third annual athletic meeting at Alperton in the evening of June 25. The high light of the evening was the tug-of-war which was won by a scratch team made up of officials on the spot, a result which caused some consternation in tug-of-war circles and considerable excitement amongst the spectators. Mrs. R. G. Veryard kindly presented the medals and certificates.

Flight Officer (Mrs.) J. K. Frith (R.A.F.V.R.–Met.) has been selected to shoot for Great Britain at the International Archery Championship meeting being held at Brussels from July 19 to July 26.

WEATHER OF JUNE 1952

Mean pressure was high over Europe and most of the Atlantic east of 40°W., generally 2 mb. above normal. Mean pressure was low from Scandinavia to Greenland and over North America, the greatest deficit of pressure, 7 mb., occurring between Norway and Iceland. The highest mean pressure, 1024 mb., was recorded in the Azores; mean pressure decreased steadily north-eastwards from the Azores to 1006 mb. in the Norwegian Sea.

Mean temperature over Europe and the Mediterranean was generally 2–6°F. above normal. The mean temperature varied from 50–55°F. in Scandinavia to 60–70°F. in west Europe and 70–80°F. in the Mediterranean region. In the south-east of the United States the mean temperature was between 80° and 85°F., about 9°F. above normal.

In the British Isles, broadly speaking, the weather was wet in the west and north and dry in the south and east. Temperature was changeable during the first three weeks, but the last week was warm, particularly the last three days.

On the 1st and 2nd a depression moved north-east over the British Isles causing rain and local thunderstorms, with a gale on our south-west coasts. Thereafter an anticyclone moved quickly north-east from Spain to central Europe, while a depression south of Iceland moved slowly east and associated troughs of low pressure crossed the British Isles. Scattered showers were recorded in Scotland and Ireland on the 3rd and rain or showers, heavy in places, on the 4th and 5th; thunderstorms were experienced locally in England on the 5th and 6th. Temperature rose in south and east England on the 5th, reaching 78°F. at Camden Square, London. The duration of bright sunshine exceeded the average in all districts during the first week. On the 8th a shallow depression off north-west Ireland moved east-south-east causing widespread rain in southern districts. Subsequently a belt of high pressure extended from the Azores across the southern districts of the British Isles to Germany and a short spell of fair, warm weather prevailed over much of the country, though cloudy conditions with some rain occurred in the north of Scotland. Temperature reached 80°F. at Camden Square on the 12th. On the 12th and 13th a small depression over the Bay of Biscay moved to southern England and then turned north-east. Thunderstorms occurred widely in southern England and the Midlands on the 13th, the storms being severe locally, notably in the Bristol, Torquay and Bognor areas; at Long Ashton near Bristol, 2·21 in. was registered. A cool rather unsettled period ensued, which lasted until the 21st. On the 14th and 15th pressure was low over Scandinavia and high to the north-west of the British Isles; cool northerly winds prevailed with scattered rain or showers. On the 17th and 18th a depression off the west of Scotland moved east and became less intense, while an associated trough moved across England; rain occurred widely and there was local thunder. On the 19th and 20th a small depression west of Iceland moved south-east and on the 21st another depression westward of Scotland moved east-south-east to the North Sea. Further rain occurred, heavy in places (3·24 in. at Blaenau Festiniog and 3·16 in. at Llechwedd Quarry, both in Montgomeryshire, on the 21st), but falls were slight in the south. In the north of Scotland the period 7th–16th was unusually dull; at Duntuilm, Isle of Skye, the total sunshine for the ten days was only 6·2 hr., the lowest there for any ten days in June since records were first begun in 1934. Frost occurred locally on the night of the 15th–16th; at Ross-on-Wye the temperature on the grass fell to 30°F., a most unusual occurrence there for mid June. Subsequently the Azores anticyclone spread north-east and a belt of high pressure lay over southern districts maintaining fair, warm weather for the remainder of the month. Atlantic depressions moving north-east caused rain at times, however, in northern districts, chiefly on the 24th and 28th. Except in the north and north-west of Scotland the last week was warm, the last four days being very warm. For example, temperature rose to 85°F. at Bournemouth on the 27th, 86°F. at Greenwich Observatory on the 28th, 89°F. at Camden Square and Greenwich and 88°F. at Southend on the 29th, and 89°F. at Camden Square and Greenwich and 88°F. at Southend, East Malling and Scarborough on the 30th.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	89	31	+1·1	86	0	98
Scotland	78	24	−0·6	130	+4	80
Northern Ireland ...	76	33	0·0	98	+3	84

RAINFALL OF JUNE 1952

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·59	79	*Glam.*	Cardiff, Penylan ...	2·29	91
Kent	Folkestone, Cherry Gdn.	0·81	41	*Pemb.*	Tenby	3·42	143
,,	Edenbridge, Falconhurst	1·26	57	*Mer.*	Aberdovey	3·62	133
Sussex	Compton, Compton Ho.	1·78	71	*Radnor*	Tyrmynydd	3·92	120
,,	Worthing, Beach Ho. Pk.	1·22	70	*Mont.*	Lake Vyrnwy	2·79	87
Hants.	Ventnor Cemetery ...	1·29	68	*Mer.*	Blaenau Festiniog ...	9·38	144
,,	Southampton (East Pk.)	1·20	60	*Carn.*	Llandudno	1·43	75
,,	Sherborne St. John ...	1·70	80	*Angl.*	Llanerchymedd ...	2·53	107
Herts.	Royston, Therfield Rec.	1·15	51	*I. Man*	Douglas, Borough Cem.	2·55	105
Bucks.	Slough, Upton... ...	1·14	55	*Wigtown*	Newton Stewart ...	3·14	119
Oxford	Oxford, Radcliffe ...	1·33	59	*Dumf.*	Dumfries, Crichton R.I.	2·80	111
N'hants.	Wellingboro' Swanspool	1·14	54	,,	Eskdalemuir Obsy. ...	4·35	138
Essex	Shoeburyness	1·40	80	*Roxb.*	Kelso, Floors	1·91	91
,,	Dovercourt	1·39	79	*Peebles*	Stobo Castle	2·65	91
Suffolk	Lowestoft Sec. School...	1·54	85	*Berwick*	Marchmont House ...	2·65	115
,,	Bury St. Ed., Westley H.	1·58	75	*E. Loth.*	North Berwick Res. ...	2·16	130
Norfolk	Sandringham Ho. Gdns.	0·98	45	*Midl'n.*	Edinburgh, Blackf'd. H.	2·43	121
Wilts.	Aldbourne	1·81	78	*Lanark*	Hamilton W. W., T'nhill	2·46	112
Dorset	Creech Grange... ...	1·36	59	*Ayr*	Colmonell, Knockdolian	2·44	96
,,	Beaminster, East St. ...	1·67	74	,,	Glen Afton, Ayr San. ...	3·24	108
Devon	Teignmouth, Den Gdns.	1·75	91	*Renfrew.*	Greenock, Prospect Hill	4·21	135
,,	Cullompton	1·36	64	*Bute*	Rothesay, Ardencraig...	4·32	141
,,	Ilfracombe	2·38	110	*Argyll*	Morven (Drimnin) ...	4·39	145
,,	Okehampton Uplands...	2·33	84	,,	Poltalloch	3·71	122
Cornwall	Bude, School House ...	1·92	96	,,	Inveraray Castle ...	5·47	138
,,	Penzance, Morrab Gdns.	1·33	60	,,	Islay, Eallabus... ...	4·42	169
,,	St. Austell	1·34	52	,,	Tiree	3·48	136
,,	Scilly, Tresco Abbey ...	1·11	64	*Kinross*	Loch Leven Sluice ...	2·76	126
Glos.	Cirencester	1·92	80	*Fife*	Leuchars Airfield ...	2·24	134
Salop	Church Stretton ...	...	...	*Perth*	Loch Dhu	4·93	118
,,	Shrewsbury, Monksmore	2·11	101	,,	Crieff, Strathearn Hyd.	2·61	99
Worcs.	Malvern, Free Library...	2·23	96	,,	Pitlochry, Fincastle ...	2·20	105
Warwick	Birmingham, Edgbaston	1·55	67	*Angus*	Montrose, Sunnyside ...	2·08	125
Leics.	Thornton Reservoir ...	1·87	87	*Aberd.*	Braemar	1·86	95
Lincs.	Boston, Skirbeck ...	1·83	101	,,	Dyce, Craibstone ...	3·04	163
,,	Skegness, Marine Gdns.	0·78	43	,,	New Deer School House	2·79	140
Notts.	Mansfield, Carr Bank...	1·73	77	*Moray*	Gordon Castle	2·31	113
Derby	Buxton, Terrace Slopes	3·58	111	*Nairn*	Nairn, Achareidh ...	1·64	93
Ches.	Bidston Observatory ...	1·80	82	*Inverness*	Loch Ness, Garthbeg ...	2·85	125
,,	Manchester, Ringway...	2·29	95	,,	Glenquoich	7·02	143
Lancs.	Stonyhurst College ...	3·94	128	,,	Fort William, Teviot ...	5·20	146
,,	Squires Gate	2·67	128	,,	Skye, Duntuilm ...	4·23	163
Yorks.	Wakefield, Clarence Pk.	1·22	57	,,	Skye, Broadford ...	6·71	171
,,	Hull, Pearson Park ...	2·02	98	*R. & C.*	Tain, Tarlogie House ...	1·16	63
,,	Felixkirk, Mt. St. John...	2·09	95	,,	Inverbroom, Glackour...	4·50	160
,,	York Museum	1·71	83	,,	Achnashellach	5·28	140
,,	Scarborough	1·28	70	*Suth.*	Lochinver, Bank Ho. ...	3·72	174
,,	Middlesbrough... ...	1·04	55	*Caith.*	Wick Airfield	2·92	162
,,	Baldersdale, Hury Res.	1·49	68	*Shetland*	Lerwick Observatory ...	3·66	204
Norl'd.	Newcastle, Leazes Pk....	1·71	81	*Ferm.*	Crom Castle	2·93	108
,,	Bellingham, High Green	2·12	92	*Armagh*	Armagh Observatory ...	2·27	90
,,	Lilburn Tower Gdns. ...	1·62	78	*Down*	Seaforde	2·22	80
Cumb.	Geltsdale	3·23	120	*Antrim*	Aldergrove Airfield ...	2·55	106
,,	Keswick, High Hill ...	2·99	103	,,	Ballymena, Harryville...	2·97	102
,,	Ravenglass, The Grove	3·13	120	*L'derry*	Garvagh, Moneydig ...	2·20	87
Mon.	Abergavenny, Larchfield	2·12	87	,,	Londonderry, Creggan	2·94	104
Glam.	Ystalyfera, Wern House	4·64	123	*Tyrone*	Omagh, Edenfel ...	3·21	114

M.O. 559 AIR MINISTRY

METEOROLOGICAL OFFICE

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METEOROLOGICAL OBSERVATIONS IN CENTRAL ICELAND

By F. G. HANNELL, B.Sc. and R. H. A. STEWART, B.Sc. (Tech.)

In August and September 1951 the British Schools Exploring Society's Thirteenth Expedition operated four meteorological stations in central Iceland. These were located around the margins of the Hofsjökull ice-cap at points A, B, C and D as shown in Fig. 1. The intention was to set up, for the first time, a synoptic reporting station in central Iceland and to investigate the effects of Hofsjökull on local weather conditions, with particular reference to surface winds. Certain aspects of the work are dealt with separately below.

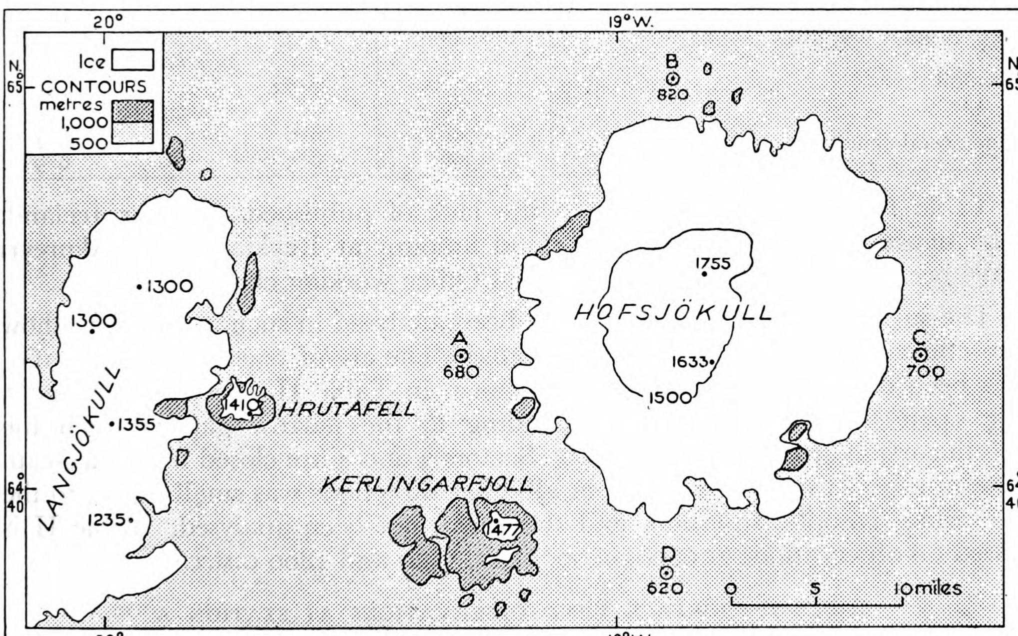

FIG. 1—POSITIONS OF THE METEOROLOGICAL STATIONS ROUND THE MARGINS OF HOFSJÖKULL

All heights are given in metres

Observations at the main meteorological station.—The main station, station A, was located at the Expedition's Base Camp. Observations commenced on August 5 and were made at all daylight synoptic hours until September 11. These observations were passed to Reykjavik by W/T for transmission to Dunstable, using the identification "ice-cap" in place of a station number. So far as is known, this was the first occasion on which observations from central Iceland have been immediately available to forecasters.

The station, at an altitude of 2,250 ft. (680 m.) above sea level, was situated on an undulating plain of fluvio-glacial debris and volcanic rock, almost bare of vegetation and about four miles west of the ice edge. Thermometers, screen and rain-gauge were of standard pattern and wind speeds were measured from ground level by means of a hand anemometer. Wind directions were obtained from an improvised wind-sock about 20 ft. above the ground.

Certain observations made at this station are compared in Table I with those reported from Reykjavik (64°08′N., 21°57′W.) and Akureyri (65°41′N., 18°05′W.) during the same period. Both these stations are less than 100 ft. above sea level.

TABLE I—COMPARISON OF OBSERVATIONS AT STATION A WITH THOSE REPORTED FROM OTHER ICELANDIC STATIONS

	Time of observation	Station A	Reykjavik	Akureyri
	G.M.T.		*degrees Fahrenheit*	
Mean temperature ...	0600	38·5	48·2	44·1
	0900	41·7	50·3	45·8
	1200	44·5	53·5	49·1
	1500	47·0	55·6	50·3
	1800	46·3	55·1	50·2
Mean night minimum temperature	1800–0600	35·8	...	...
Lowest night minimum temperature	1800–0600	25·4	...	...
			inches	
Rainfall	...	1·72	...	...
			oktas	
Mean total cloud	0600	6·6	5·7	6·7
	1500	6·3	5·8	6·9

Table I is incomplete owing to the lack of published data for Iceland. The figures for temperature and cloud amount at Reykjavik and Akureyri have been obtained from Meteorological Office working charts.

The surface wind observations have been analysed in such a way as to show the effect of the surrounding high ground. The arc of true bearing 340–160° has been divided into five sectors as shown in Table II. Sectors 1, 2 and 5 are open sectors, the last corresponding to the narrow gap between the Kerlingarfjoll group and Hofsjökull. Sectors 3 and 4 are closed by the ice-cap. The number of cases of wind from all other directions was small owing to the prevailing synoptic situation, and they have not been analysed. Table II is based on observations at 0600, 0900, 1200, 1500 and 1800 G.M.T.

TABLE II—SURFACE WIND OBSERVATIONS AT STATION A

Sector	Bearing	No. of Cases	Frequency	Mean Speed
	° true		%	kt.
1	340– 10	40	21·3	11·9
2	20– 50	57	30·4	15·0
3	60– 90	14	7·6	9·6
4	100–130	22	11·8	10·7
5	140–160	22	11·8	9·8
All other directions		26	13·9	8·5
Calm		6	3·2	...

Sector 5 has been restricted to 20° in order to show the effect of the narrow gap mentioned above. A possible explanation of the relatively high frequency in sector 4, a closed sector, is given later in this paper.

In view of the position of this area, on the air route across Iceland from Reykjavik to Akureyri (see Fig. 2), the following notes on visibility, cloud and precipitation are included.

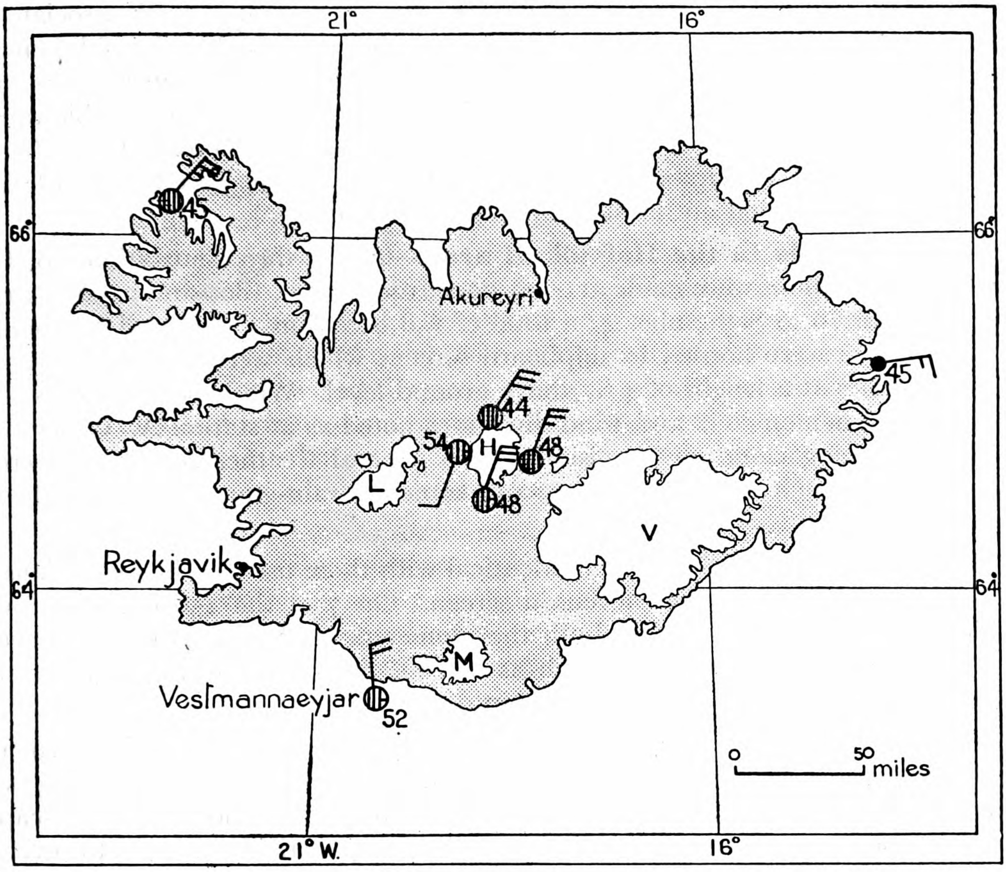

FIG. 2—SURFACE WIND AND SEA-LEVEL TEMPERATURE, 1200 G.M.T., SEPTEMBER 4, 1951

This map also shows the positions of the four main ice-caps of southern Iceland

L ... Langjökull V ... Vatnajökull
H ... Hofsjökull M ... Myrdalsjökull

Visibility.—This was normally excellent, varying between 20 and 60 miles. Deteriorations were due to:—

(i) Station in cloud. Fog occurred on five occasions, all of them at 0600 G.M.T.

(ii) Dust. Large areas of the land surface in this region are of volcanic dust and sand which is easily raised by the wind. Observed deteriorations in visibility due to this cause were very local, but given a prolonged dry spell and strong winds it seems probable that a general dust haze could be produced.

Cloud.—The height and amount of low cloud in the area depended mainly on orographic influences and therefore on wind direction. If low cloud was present at all it was rare for all the surrounding high ground to be clear of cloud. In particular, with the N.–NE. winds which prevailed during the period, cloud caps were very common on Hrutafell and the east side of Langjökull and less common on the Kerlingarfjoll group and the west side of Hofsjökull. On many occasions it could be seen that the cloud broke to small amounts on the south-west horizon, and it was obvious that the southern coastal area was deriving considerable shelter from the ice-caps and other areas of high ground.

Precipitation.—There were four periods of prolonged rainfall, each associated with the passage of a depression to the south of Iceland, the heaviest fall being 0·34 in. on August 20. The remaining precipitation came from showers or troughs of low pressure in the prevailing N.–NE. air stream. Measurable rain fell on 29 days out of the 38 for which records are available. Snow fell on 2 days only at station A, the first as early as August 20, but there were frequent falls throughout the period on the surrounding high ground.

Surface winds in the Hofsjökull area.—At the three outstations, B, C and D, observations were made at 0600, 0900, 1200, 1500, 1800 and 2100 G.M.T. from August 10 to September 4; a total of 156 occasions. Dry- and wet-bulb thermometers were housed in shipboard screens which were suspended from bamboo poles at a height of 4 ft. above ground level. Wind speeds were read from hand anemometers and wind directions noted as at station A. Observations concerning cloud cover, visibility and general weather conditions were also made at each of these stations, and standard rain-gauges were installed at C and D.

At station A a shipboard screen, identical with those used at the outstations, was exposed alongside the Stevenson screen. On 7 of the 156 occasions on which they were read the dry-bulb thermometers in these two screens gave readings which differed by as much as 0·6°F., but on the great majority of occasions such readings agreed to within 0·2°F.

Whenever an unstable air mass moved over the Hofsjökull region, the warmer layers at ground level were cooled during their ascent of the ice-cap slopes. Such cooling invariably gave rise to thick mists and rain or snow on the ice-cap itself whilst the surrounding plains remained comparatively clear. However, on those occasions when the region came under the influence of an air mass which was stably stratified, it would seem that whilst stability was preserved and probably intensified over the ice-cap it was often destroyed over the surrounding plains of volcanic rock and fluvio-glacial debris.

This frequent development or preservation of air-mass stability over Hofsjökull was of considerable importance in connexion with the surface wind circulation, as is evident from the figures given in Table III.

TABLE III—FREQUENCY OF NORTHERLY, EASTERLY AND WESTERLY WINDS

Wind direction	Bearing	Station A (west)	Station B (north)	Station C (east)	Station D (south)
	° true		*number of occasions*		
Northerly ...	340– 20	49	21	65	51
Easterly ...	70–110	13	33	2	38
Westerly ...	250–290	3	4	25	10

These show that the effectiveness of the barrier provided by the stable air mass over Hofsjökull was such that the station which experienced winds from a certain quarter on the fewest occasions was the one situated on the side of the ice-cap facing that quarter. In this connexion it is also significant that northerly winds were weakest at station B. Here their mean speed was only 7 kt. as compared with 13, 14 and 11 kt. at stations A, C and D respectively. In the same way easterly winds were weakest at station C where their mean speed was only 7 kt. as compared with 9, 13 and 12 kt. at stations A, B and D respectively.

The figures given in Table III show that a station on the leeward side of the ice-cap experienced winds from a particular quarter very much more frequently than did the station on the windward side. The higher figure for the leeward station in each case would seem to suggest that on certain occasions air was drawn off the ice-cap on this side.

It has previously been reported that small ridges of high pressure occasionally appear to windward of the higher massifs in Iceland as a result of a banking up of air, and that troughs of low pressure or even shallow cyclonic centres appear on the leeward sides[1]. It is now suggested that during the long summer days any such tendency for the development of a low-pressure centre on the leeward side of Hofsjökull is reinforced by the heating of those extensive areas of bare sand and rock which surround this ice-cap. As a result of this a stable stratified air mass frequently becomes unstable over these plains, and this is usually evidenced by the development of small cumulus clouds at very low levels (see Figs. 3 and 4 in the centre of this magazine).

Over a low-lying area near a mountain katabatic winds would normally be expected only between sunset and sunrise under conditions favourable to radiation. However, it is seen from Table IV that in the neighbourhood of Hofsjökull such winds off the ice-cap were experienced as frequently during the warmer afternoon hours as they were at the other times. Moreover, at each of the four stations the winds which blew off the ice-cap during these warmer hours were stronger than their evening and morning counterparts.

TABLE IV—WINDS OFF THE ICE-CAP

Station	At 1200, 1500 and 1800 G.M.T. No. of occasions	At 1200, 1500 and 1800 G.M.T. Mean velocity	At 2100, 0600 and 0900 G.M.T. No. of occasions	At 2100, 0600 and 0900 G.M.T. Mean velocity
		kt.		kt.
A	8	9·5	8	9·2
B	10	7·7	7	5·6
C	15	6·8	12	6·6
D	26	11·5	29	10·6

These figures suggest that on many occasions when winds off the ice-cap were experienced, these were the result of a drawing off of air to replace that which was rising over the stony plains. Support for this suggestion is provided by the figures given in Table V, for these show that on many occasions when a wind blew off the ice-cap during the afternoon this could not be regarded as a continuation of the wind on the opposite side.

On several occasions when conditions were most favourable to convection over the plains, winds which blew off the ice-cap at 1200 or 1500 G.M.T. had a cooling effect, which suggests that in spite of any adiabatic warming consequent upon their descent they were still cooler than the heated air which they replaced. On the other hand, winds which blew off the ice-cap at other times of day never showed this cooling effect. On the contrary they quite frequently demonstrated the föhn effect.

TABLE V

Station	No. of occasions when winds off the ice-cap were experienced at 1200, 1500 and 1800 G.M.T.	Bearing of such winds	No. of occasions when winds on the opposite side of the ice-cap were included within the same arc
		°true	
A	8	60–120	2
B	10	140–200	6
C	15	250–310	3
D	26	330– 30	14

It is seen from Fig. 2 that the four main ice-caps of southern Iceland lie in the shape of a horseshoe which is open to the west. During the long summer days the stony surface in this horseshoe area is strongly heated, and it seems probable that as a result of this a low-pressure area frequently develops here, from which troughs extend up between the ice-caps like outstretched fingers from the palm of a hand. In addition to what has been reported above in connexion with winds off the ice-cap and the development of low-level cumulus cloud, the following facts further support this suggestion that areas of comparatively low pressure showed a tendency to develop to the west, south and east of stations A, D and C respectively.

(i) Station C experienced northerly winds more frequently than did any of the other stations (see Table III).

(ii) Northerly winds were strongest at station C, where their mean velocity was 14 kt. as compared with 13, 7 and 11 kt. at stations A, B and D respectively.

(iii) Stations A, B and D each experienced southerly winds on 16 occasions, whereas the corresponding figure for station C was only 5.

(iv) Whilst station A experienced easterly and south-easterly winds on 24 occasions, the corresponding figure for station C was only 5.

(v) Station C experienced westerly and north-westerly winds on 33 occasions, whereas the corresponding figure for station A was only 6.

(vi) Station D experienced easterly winds more frequently than did any of the other stations (see Table III).

Fig. 5, reproduced from the *Daily Weather Report*, shows conditions at 1200 G.M.T. on September 4, 1951. Winds and sea-level temperature at the Expedition's four meteorological stations at this time, together with readings reported from three of the coastal stations, are represented in Fig. 2. The marked differences between readings at Vestmannaeyjar, just off the south coast, and station A on the one hand, and between station A and stations B, C and D on the other, would seem to indicate that under the influence of a small depression, which had developed in the horseshoe area as postulated above, the occluded front had swung northwards, so that station A was located on its southern side. In fact, its passage across this station between 1000 and 1100 G.M.T. was clearly indicated by marked changes both in wind direction and temperature. The main depression shown in Fig. 5 moved north-eastwards fairly rapidly along a track which lay just off the east coast, but the occlusion, which showed signs of being anchored in the neighbourhood of station A, did not pass across the Hofsjökull area as a whole until the following morning, when south-westerly winds and rain were experienced at all four stations.

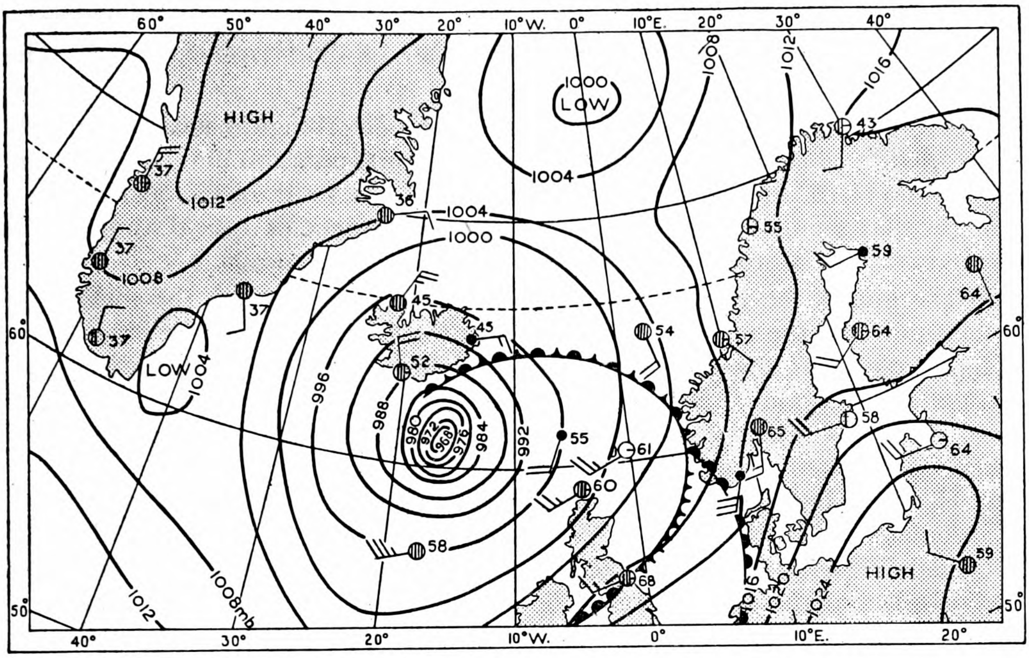

FIG. 5—SYNOPTIC CHART, 1200 G.M.T., SEPTEMBER 4, 1951
This chart has been copied from the *Daily Weather Report*

It is considered that observations in this area over a much longer period might well show that the development of low pressure by convection over these stony plains in summer is of considerable importance in the formation of small secondaries on the north side of those major depressions which move from west to east off the south coast of Iceland.

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RARE PARHELION SEEN AT OXFORD, AND A NOTE ON THE FREQUENCY OF SOLAR AND LUNAR HALOS AND ASSOCIATED OPTICAL PHENOMENA, 1882–1951

By J. G. BALK

On January 20, 1952, a parhelion to the solar halo of 8° radius was seen at the Radcliffe meteorological station, Oxford, similar to that observed from Northolt by Mr. J. G. Shipcott on August 5, 1951, and reported in the *Meteorological Magazine* for November 1951.

When the meteorological observations were taken at 0900 G.M.T. the sky was cloudless except for a small belt of cirrus cloud, about 30° in length and 3–5° in width, moving in a north-west–south-east direction. At 0920 this belt of cloud was passing across the sun, and in a small break a parhelion, brightly coloured with red towards the sun, appeared to the right of the sun at a distance of 8°. A small portion of the parhelic circle was also present, about 2° in length, which extended from the parhelion outwards, giving the appearance of a white "spur" to the parhelion. Similar "spurs" have frequently been observed in the past in connexion with parhelia to the 22° solar halo. The phenomenon lasted for about five minutes, disappearing as the break in the belt of cloud moved away to the south-east.

The surface meteorological conditions at the time were as follows:—

Wind NNW. force 2, air temperature 31°F., visibility 1,100–2,200 yd. The altitude of the sun was 9°.

A search through the records of the Radcliffe meteorological station (formerly the Radcliffe Observatory) shows that this is the first occasion that the parhelion to the halo of 16° diameter has been observed. As a result of this search it was thought that a note on the frequency of the occurrence of optical atmospheric phenomena at Oxford would be of interest.

Before giving the results it is necessary to comment upon the method of observation and the number of observers at the Observatory. The observation of halos, etc., was always a part of the ordinary meteorological routine at the Radcliffe Observatory. Before 1908 the staff consisted of the first, second and third assistants and the computer. The third assistant was responsible for taking the meteorological observations and reducing them. In June 1907 Mr. H. G. S. Barrett was appointed third assistant, having previously served in the meteorological section at the Royal Observatory, Greenwich, where he had made a special study of optical phenomena. He carried on with this work at Oxford, and the observation of optical phenomena became a speciality in which the remainder of the staff collaborated with enthusiasm and vigilance. In 1920 Mr. J. G. Balk was appointed third assistant. In 1935 when the Radcliffe Observatory was transferred to Pretoria the meteorological section was taken over by the University of Oxford, assumed the title "Radcliffe Meteorological Station", and was placed under the supervision of the School of Geography. Since this date the observations have been made by Mr. Balk. Before 1935 the Radcliffe Observatory was favourably situated for the observation of halos, standing in spacious grounds with an almost uninterrupted view of the sky in all directions, and with the various staff rooms all facing due south. Being also an astronomical observatory the night sky was under observation for a considerable period during the hours of darkness. Most of the observations were made by direct vision, but a dark reflector, consisting of a piece of plate glass blackened at the back, which eliminated all glare was used to enable a more careful study to be made of parhelia, arcs of contact, etc. The halos observed were seldom complete, but rarely less than 60° in length. No observation was counted as a true halo unless the distinctive colours were seen. In doubtful cases the radius was measured and it was established that the arc did not move with the clouds. In all cases the solar and lunar halos are those of 22° diameter unless otherwise stated.

Table I gives the mean number of days per month with solar and lunar halos for the periods before and after the observation became more specialized, and also for the complete period, 1882–1951.

TABLE I—HALOS OBSERVED AT RADCLIFFE METEOROLOGICAL STATION

Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
						Solar halos							
1882–1907	1·3	2·5	3·9	5·4	5·4	4·5	3·2	3·4	3·4	2·8	2·1	1·4	39·3
1908–51	9·6	8·6	11·1	12·1	12·0	11·0	10·9	11·1	10·5	10·1	9·2	8·9	125·1
1882–1951	6·5	6·3	8·5	9·6	9·6	8·6	8·0	8·2	7·9	7·4	6·6	6·1	93·3
						Lunar halos							
1882–1907	2·2	1·3	1·7	1·3	1·3	0·3	0·0	0·7	1·3	1·4	2·2	1·8	15·5
1908–51	4·2	3·9	3·6	3·2	1·6	0·9	0·6	1·2	2·3	3·2	4·0	5·3	34·0
1882–1951	3·4	2·9	2·9	2·5	1·5	0·7	0·4	1·0	1·9	2·6	3·3	4·0	27·1

During the period 1908–51 the highest number of days with solar halos in a year was 177 in 1927 and the least, 67 in 1912. The highest monthly total was 21, in April 1923, and the lowest 1, in June 1908, February 1917, February 1932, February 1934, and January 1941. The longest periods of consecutive days with solar halos were 12 days, February 12–23, 1914, and 10 days, June 29–July 8, 1922, and March 24–April 2, 1932. The longest period with no solar halo was one of 31 days from August 28th to September 27, 1912.

The greatest number of lunar halos visible in a year was 55 in 1923 and the smallest 16 in 1918. The highest monthly totals were 11 in January 1928 and December 1947.

All the observers agree that in view of the fact that on several occasions the halo was only visible momentarily, many occurrences must have passed without being noted.

The total numbers of halos and associated phenomena observed at the Radcliffe meteorological station during various periods are given in Table II.

TABLE II—NUMBER OF OCCASIONS WITH HALOS AND ASSOCIATED PHENOMENA

	1882–1907 (26 yr.)	1908–51 (44 yr.)	1882–1951 (70 yr.)
		number of days	
SOLAR:			
22° halo	1,020	5,503	6,523
Upper arc of contact to 22° halo	1	305	306
Lower arc of contact to 22° halo	0	14	14
Parhelion to 22° halo	50	784	834
46° halo	2	81	83
Circumzenithal arc	0	34	34
90° halo	1	0	1
Parhelic circle	1	7	8
Anthelion	1	0	1
Sun pillar	1	152	153
LUNAR:			
22° halo	402	1,498	1,900
Upper arc of contact to 22° halo	0	16	16
Lower arc of contact to 22° halo	0	1	1
Lunar corona	92	739	831
Paraselenae to 22° halo ...	7	47	54
46° halo	0	21	21
Moon pillar	0	30	30
Zodiacal light	46	493	539
Zodiacal band	0	73	73
Counter glow (Gegenschein) ...	2	42	44
Aurora	22	27	49

During the period 1882–1951 there were several days with displays of solar halos and associated phenomena, the most outstanding being that of December 22, 1900, between 0900 and 1100 G.M.T. when the 22°, 46° and 90° halos, parhelia and upper arc of contact to the 22° halo, parhelic circle and anthelion were observed, together with a column of white light extending upwards from the horizon through the anthelion (altitude at 1000, 10°) to a height of 12°.

Since 1935, with the introduction of more powerful street lighting and to a lesser extent to the glare from the headlights of motor vehicles, the displays of zodiacal light, aurora, etc., have been more difficult to see from the confines of the city. The same trouble necessitated the removal of the Observatory to Pretoria. During the past 19 years the zodiacal light has been observed on only 43 nights, 30 of these were during the period of the last war when the black-out was in operation.

Figures of halo frequency comparable with those at Oxford since 1908 are available from the Montsouris Observatory, Paris, and are published in the *Annales des services technique d'hygiene de la ville de Paris, Tome III, Météorologie.* On p. 24 of this publication the number of days of solar or lunar halos are given and on p. 25 the frequency of various types of halo, etc.

Table III gives the results for the two Observatories for the 10 years 1908–1914 and 1919–1921.

TABLE III

	Number of days with solar or lunar halos											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Oxford	93	86	124	113	112	99	83	74	88	89	99	122
Montsouris	72	94	158	164	146	144	113	112	107	128	83	93

	Annual totals of days with solar or lunar halos										
	1908	1909	1910	1911	1912	1913	1914	1919	1920	1921	Total
Oxford	84	95	120	106	83	105	164	120	145	160	1,182
Montsouris	134	146	158	132	126	135	138	138	159	148	1,414

According to the frequency table for Montsouris given on p. 25 of the above publication the following are the totals for the 20 years 1898–1914 and 1919–21, which may be compared with the Oxford figures in Table II:—

22° solar halo...	2,577	46° solar halo...	167
Upper arc of contact to 22° solar halo	187	Parhelic circle	33
Parhelion to 22° solar halo	575	Sun pillar	50

SPEED OF WARM FRONTS

By A. G. MATTHEWMAN, B.A.

Summary.—An account is given of some statistical tests of certain empirical, kinematical, and dynamical formulae for the speed of warm fronts.

Formulae in use.—In practical forecasting the speed of a front may be estimated in various ways, one of which is the application of objective rules to the current data and the analysed chart. On the basis of recent charts prepared at the Central Forecasting Office some of these rules have been tested.

The most common practice in estimating the speed of a warm front is to take the speed u_F as some proper fraction of the geostrophic wind component measured at the front and at right angles to the front u_J. The fraction is variously taken as 60–80 per cent. by Petterssen[1], 50–70 per cent. by Byers[2], and as $\frac{2}{3}$ or as $\frac{3}{4}$ by various other practising forecasters; no doubt there are also other preferences, a state of affairs which is not surprising since no formula is accurate and the best regression equation must depend on many factors such as geographical locality and season of the year.

Another relationship which may be useful is the approximate equality between the speed of the warm front and the component of actual measured wind speed normal to the front above the friction layer (say at about 900 mb.) and on the cold side of the front. The equality would be exact, for kinematical reasons, if the frontal surface were a substantial surface of discontinuity with the cold air moving horizontally[1].

Further, it is possible to derive dynamical expressions for the frontal speed, which depend on the equations of motion. Of these one form was given in an unpublished research paper by Matthewman[3], and another by Miles[4], but for use in practical work on synoptic charts perhaps the most satisfactory is that given by Økland[5] which is practically identical with the following:

$$u = u_J - \frac{1}{l}\frac{dv}{dt} + f,$$

where u and v are respectively the wind components normal to and parallel with the front, f is a frictional term, l is the Coriolis parameter, and d/dt indicates differentiation following the motion of the fluid.

Then

$$u = u_J - \frac{1}{l}\left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}\right) + f.$$

Accepting the kinematical approximation mentioned above that the speed of the front is given by the component u in the cold air, with w, the vertical velocity, and f, the frictional effect which is assumed negligible, we have

$$u_F = u_J - \frac{1}{l}\frac{\delta v}{\delta t} + v\frac{\partial v}{\partial y} \qquad \text{............(1)}$$

where $$\frac{\delta v}{\delta t} = \frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x},$$

and is the rate of change of v with time at a point moving with the front. Although the component u normal to the front is often significantly different from u_J, the component v parallel with the front is more reasonably taken as given approximately by the geostrophic component v_J. In any case, in common with Økland, we make the approximation $v = v_J$. The terms can then be estimated from the contours at 900 mb., which, in practical work, cannot be easily distinguished from the mean-sea-level isobars.

The present paper gives some new statistical tests of the formulae.

Data.—For the period 1949–51 all warm fronts near the British Isles were re-examined. As is well known many fronts which are justifiably so marked on working charts do not fit at all well with the classical model, and also in many cases there is no upper air observation at a time and place which permits the frontal structure to be known with any confidence. In order to obtain a reasonably homogeneous set of data only those warm fronts were included in which there was an observation of wind, temperature and humidity within the cold air ahead of the front showing a "frontal zone" of reduced lapse rate with the lower boundary of the zone between 910 and 840 mb. and with wet-bulb potential temperature increasing above the boundary. It was also required that the position of the front at the surface should be well defined and the run of the isobars tolerably certain. All the statistics, except some relating to the connexion between u_F and u_J, were obtained from this set of 37 special cases.

The speed of the front u_F was taken as the average displacement per hour in the direction at right angles to the front for the 6-hr. period centred at the time of the chart (which was approximately synchronous with the upper air observations used). The wind component at right angles to the front was taken from the radar wind observation referring to 900 mb. and below the frontal zone. Geostrophic components were estimated in the conventional way but special care was taken with the isobars. The value u_J refers to the component at the frontal position on the surface chart, the value u_J' refers to the component in the same direction but measured 75 miles ahead of the front. The quantity $\delta v/\delta t$ of equation (1) was not considered in the statistics as there were too few occasions where it was of significant magnitude.

The quantity $v\,\partial v/\partial y$ was estimated from its geostrophic approximation by a simple finite-difference approximation to the pressure gradient. A square scale similar to that suggested by Økland (although earlier and independently devised) was used.

When density and latitude variations are neglected (fully justifiable in this problem) it is clear that

$$v_J \frac{\partial v_J}{\partial y} = \tfrac{1}{2}\frac{\partial}{\partial y}(v_J{}^2)$$
$$\propto \frac{\partial}{\partial y}\left(\frac{\partial p}{\partial x}\right)^2.$$

If A, B, C, D is a square scale orientated with AB along the x-axis, and if p_a, p_b, p_c, p_d are the pressures at the points A, B, C, D, then with linear approximation

$$v_J \frac{\partial v_J}{\partial y} \propto \{(p_b - p_a)^2 - (p_c - p_d)^2\}.$$

The scale was taken with side 150 miles and was used by placing the side AB along or tangential to the front. With units of miles per hour and millibars we find sufficiently closely that, at latitude 50° approximately,

$$\frac{v_J}{l}\frac{\partial v_J}{\partial y} = \tfrac{3}{8}\{(p_b - p_a)^2 - (p_c - p_d)^2\}.$$

Statistical tests.—Various correlation coefficients, regression equations and variances were determined and are listed with brief comments in the next section. No attempt has been made to introduce sophisticated statistical tests and procedures, but it is worth while to comment on a special point which must frequently arise in synoptic meteorology. We are dealing with a turbulent fluid with fluctuations on a wide range of space and time scales, and the terms we use, such as wind velocity, geostrophic wind, pressure gradient, position of a front, etc., are taken with a common-sense interpretation according to the particular problem on hand. When numerical estimates are made, especially when they are to be handled statistically, it is, however, necessary to be a little more definite. In relating the quantities for our present problem we want "synoptic estimates" which we may take as implying values averaged or smoothed over distances of the order of 100 miles and periods of an hour or two. Nothing more precise can have much practical application in synoptic meteorology for the observations are themselves at wider intervals. For the best network in the world, upper air observations have a space grid of some 200 miles and a time interval of 6 hr. or more.

A geostrophic wind is obtained from a pressure gradient on a chart based on observations which are smoothed by eye in the drawing of isopleths. The standard deviation in estimating a synoptic pressure gradient from a good network of observations is about 4 m.p.h. A measured upper wind is averaged over two or three minutes. It is liable to short-period fluctuations of standard deviation also about 4 m.p.h.

The position of a front on a chart is always uncertain, but to a varying degree depending on the data and the nature of the front. The well marked fronts with which we are concerned may be placed with a standard deviation of perhaps 20–30 miles (greater precision is often meaningless) and a "speed" estimated from a 6-hr. displacement cannot have a standard error less than some 5 m.p.h.

Thus the quantities with which we are concerned, having mean values of the order of 25 m.p.h. and standard deviations σ of about 10 m.p.h., may be regarded as estimated from quantities which include a "random" element ε of say 4 m.p.h. The maximum correlation which could be obtained between perfectly correlated quantities liable to such random errors is of course less than unity. If, for example, it were strictly true, according to physical theory,

that $$u_F = ku_J$$
or $$u_F = u$$
the maximum correlation coefficient obtainable, apart from sampling errors, would be

$$r = \frac{(\sigma^2 - \varepsilon^2)}{\sigma^2} .$$

The best formula for estimating u_F from an observation of u (both in miles per hour) would, instead of the equality, be

$$u_F = 0{\cdot}84\, u + 4 .$$

It will be found that correlations in this neighbourhood are actually obtained so that improvement by a general statistical formula will be difficult.

Results.*—*Linear relation between the speed of the warm front u_F and the component of geostrophic wind perpendicular to the warm front, measured at the front u_J or measured 75 miles ahead of the front in the cold air u_J'.*—Table I sets out the main statistics for this comparison. In the first column all cases in the vicinity of the British Isles are allowed excluding regions within 100 miles of the ends of the warm fronts and excluding the immediate vicinity of high ground. The working charts were not however revised. The correlation coefficient 0·72 is quite high. When, however, only the special set of cases (defined on p. 267) are accepted and the charts are carefully revised the correlation coefficient goes up to the high value of 0·82.

TABLE I—RELATION BETWEEN u_F AND u_J OR u_J'

	Warm fronts on routine unrevised charts 1949–51	Set of special warm fronts (defined on p. 267)	Set of special warm fronts taking u_J' instead of u_J
Number of cases	101	37	37
Correlation coefficient ...	0·72	0·82	0·85
Regression equation ...	$u_F = 0{\cdot}55\, u_J + 5{\cdot}5$	$u_F = 0{\cdot}60\, u_J + 2{\cdot}4$	$u_F = 0{\cdot}70\, u_J' + 3{\cdot}0$
Root-mean-square residual	7·1	5·9	5·4
Mean value of u_F	22·9	18·9	18·9
Mean value of u_J ...	31·7	27·6	22·7(u_J')
Standard deviation of u_F ...	10·2	10·3	10·3
Standard deviation of u_J ...	13·5	14·1	12·5(σ_J')

* All speeds are in miles per hour.

The formula

$$u_F = \tfrac{2}{3}u_J$$

is clearly very good as an average, and in the special cases is hardly distinguishable statistically from the regression

$$u_F = 0{\cdot}6u_J + 2{\cdot}4\,.$$

The third column in the table refers to the use of u_J', the normal geostrophic wind component 75 miles ahead of the front. This arose in the use of the more complex formula. Not only is the correlation improved (and probably significantly so) from 0·82 to 0·85 but the mean value is nearer to u_F. The regression equation

$$u_F = 0{\cdot}7u_J' + 3$$

must be very difficult to improve upon with the type of data.

Relation between the speed of the warm front u_F and the component u of the actual wind at 900 mb. perpendicular to the surface front.—The correlation is near the theoretical limit for the type of data, and the two quantities u_F and u have very nearly the same mean values and the same variances. The data are therefore consistent with the hypothesis that, with suitably smoothed values, $u_F = u$ is a physical relationship valid for well marked warm fronts.

TABLE II—RELATION BETWEEN u_F AND u

Number of cases	37	Mean value of u_F	18·9
Correlation coefficient	0·85	Mean value of u_J	18·5
Regression equation	$u_F = 0{\cdot}80\,u + 4{\cdot}1$	Standard deviation of u_F	10·3
Root-mean-square residual ...	5·5	Standard deviation of u	10·9

The rule $u_F = u$ gives root-mean-square residual 5·9

Although the regression equation is statistically the better formula for estimating u_F from a wind measurement the advantage over the theoretical formula is slight.

Relation between the speed of the front u_F and the dynamical estimate $u_J' - (v_J/l)\,(\partial v_J/\partial y) \equiv u_J' - \Delta$.— The approximate theoretical equation

$$u_F = u_J' - \frac{v_J}{l}\frac{\partial v_J}{\partial y}$$

gives root-mean-square residual 5·8.

TABLE III—RELATION BETWEEN u_F AND $u_J' - \Delta$

Correlation coefficient	0·84	Mean value of $u_J' - \Delta$	19·3
Regression equation ...	$u_F = 0{\cdot}85\,(u_J' - \Delta) + 2{\cdot}5$	Mean value of u_J'	22·7
		Mean value of Δ	3·4
Root-mean-square residual ...	5·6	Standard deviation of u_F	10·3
Mean value of u_F	18·9	Standard deviation of $u_J' - \Delta$ ...	10·3

It is clear from comparison with the third column of Table I that this complex formula is no improvement on the simpler regression on u_J', although it seems to be a little better than using u_J at the front.

It is however significant that the additional term Δ brings the average values and variances almost exactly into line. It fails to improve on the correlation, probably because the value is near the maximum attainable, but the data are consistent with the assumption that the theoretical approximation

$$u_F = u_J' - \frac{v_J}{l}\frac{\partial v_J}{\partial y} = u_J' - \Delta$$

is close to the physical truth.

In the circumstances it was improbable that any further advantage could be gained by a double linear regression of u_F on u_J' and Δ, and this proved to be so. By least squares the best equation was found to be

$$u_F = 0{\cdot}77u_J' - 0{\cdot}33\Delta + 2{\cdot}6\,,$$

but the root-mean-square residual is thereby only reduced from 5·6 to 5·4.

Conclusions.—The data are consistent with the physical assumption that the speed of a well defined warm front is equal to the component of the actual wind speed in the cold air below the frontal zone and above the friction layer, say at 900 mb. If such an observation is available it can be used as an estimate of frontal speed with an algebraic mean error less than 1 kt. and root-mean-square error less than 6 kt. A statistical regression equation is only a slight improvement.

The use of the geostrophic component is good. The best regression equation for the special warm fronts is

$$u_F = 0{\cdot}6\, u_J + 2{\cdot}4\,,$$

which has a root-mean-square residual of 5·9, but

$$u_F = \tfrac{2}{3}\, u_J$$

with a root-mean-square residual of 6·0 is almost as good.

If u_J' is measured 75 miles ahead of the front (and so probably more representative of cold air above the friction layer) the correlation reaches the very high value of 0·85 for this type of data, and the best formula is

$$u_F = 0{\cdot}7\, u_J' + 3{\cdot}0$$

with a root-mean-square residual of 5·4.

The introduction of the dynamical term does not, with these data, give any statistical advantage, but the results are consistent with the assumption that a very good physical approximation is given by the equation

$$u_F = u_J' - \frac{v_J}{l}\frac{\partial v_J}{\partial y}\,.$$

The straight use of this formula gives algebraic mean error less than 1 kt. and root-mean-square error less than 6 kt.

The question which arises of course is, to what use the results may be put and the answer must be related with the practical politics of forecasting. It must not of course be supposed that the forecaster is dependent on such formulae and such formulae alone, or that there are likely to be circumstances where the small statistical advantages of one formula over another will be of any significance either for the particular occasion or in the long run. Almost certainly the best procedure on any given occasion will be to use the relationship most suited to the available data. If an observed wind is available in the right place it should be taken. For all rough purposes the two-thirds rule is probably as good as any, but it may often be worth while to check with the dynamical estimate, especially when the quantity Δ is obviously significant, which can be judged by inspection.

It is hoped to collect a greater number of examples in which this term has large magnitude and investigate more fully the optimum size of the square-scale, and the best position to make the measurements. In one case, January 26–30, 1940, a warm front moved with a mean speed 12·5 m.p.h. less than that given by the two-thirds rule but only 5·1 m.p.h. less than that given by the dynamical approximation as estimated above. Further improvement may yet be obtainable.

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FOG AT NORTH FRONT, GIBRALTAR

By A. WARD

Introduction.—The hourly observations made at the airfield at North Front since June 1943, on which the present investigation is based, provide the only reliable data giving the frequency of fog at Gibraltar; the earlier observations were made from badly exposed sites on the Rock, and prior to 1938 they were only made at infrequent intervals[1]. The topography of the Rock and the surrounding country is shown in Figs. 1 and 2.

In order to illustrate the variability of the fog observations, a comparison is made between the frequencies of fog at North Front, Windmill Hill, and in the Straits, but the main purpose of the paper is to set out the facts about fog formation at North Front and to discuss the associated forecasting problems.

Types of fog in the vicinity of Gibraltar.—Experience based on 14 years of continuous observation by Meteorological Office staff at Gibraltar shows that the most important type of fog there is sea fog, formed in the Straits and over the sea east of Gibraltar, and advected over North Front by light on-shore winds. Sea fog may occur with both easterly and westerly winds[1], but extensive fog is almost always associated with easterly winds, to which North Front is completely exposed.

Occasionally during the wet season, the visibility may be reduced to fog limits by heavy rain (either associated with upper-level thunderstorms arriving from north Africa or with vigorous cold fronts moving south-eastwards across Spain and Portugal) or by the low cloud and rain associated with slow-moving or quasi-stationary fronts in the Straits of Gibraltar.

During recent years there have been two occasions when visibility at North Front was reduced to less than 1,100 yd. by dust and sand carried from French Morocco by a strong south-south-westerly wind. A full description of the duststorm which occurred on December 5, 1950 was given in the July 1951 *Meteorological Magazine*[2].

Radiation fog does not occur at North Front, but small patches are occasionally observed at the mouth of the Guadarranque river at the northern end of Gibraltar Bay.

Seasonal variation of fog.—*Monthly distribution.*—Table I shows the average monthly number of days of fog, i.e. days when the visibility fell below 1,100 yd. at any time, at North Front, Windmill Hill and in the Straits. Fog is most frequent during the summer months, and occurs more often in the Straits than at North Front or Windmill Hill.

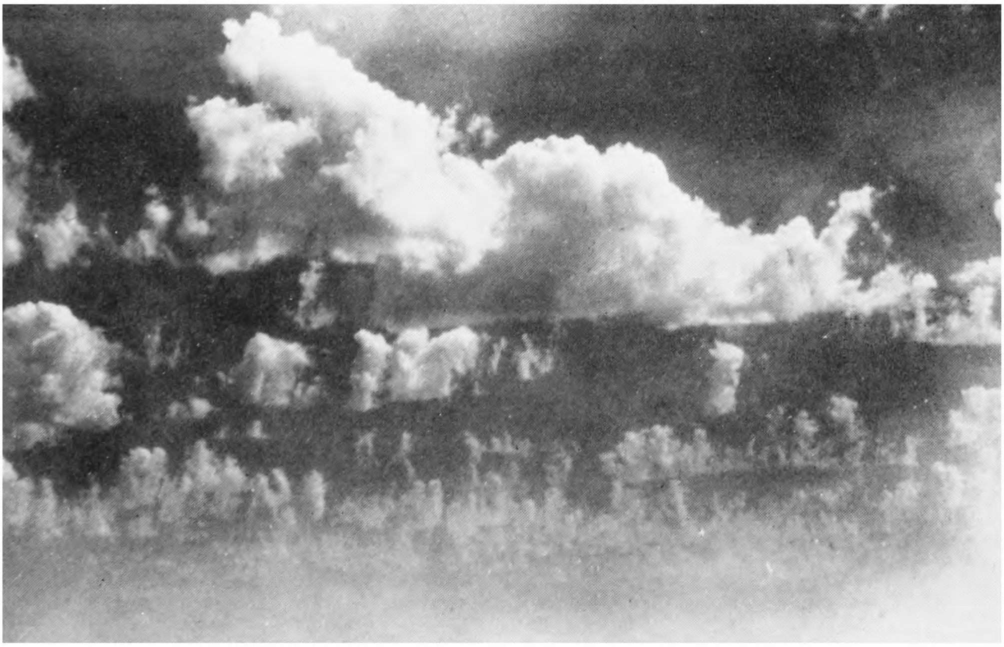
[*To face p. 272*

Reproduced by courtesy of J. K. McNair

CAPT. N. F. ISRAEL, D.S.C., WITH THE SHIELD PRESENTED BY O.W.S. *Weather Observer* TO HILLHEAD HIGH SCHOOL, GLASGOW, FOR THE INTER-HOUSE RELAY RACE

Left to right:—Mr. I. P. McIntosh (Meteorological Officer-in-Charge), Mr. Stewart, W. S. Marson (School Captain), Capt. Israel, Mr. L. Lambert (Radio Overseer), Mr. Paterson (Headmaster), J. F. MacLeod (School Captain).

(see p. 254)



ALTOCUMULUS FLOCCUS AT STRADISHALL, JULY 1, 1952, ABOUT 1430, BASE ABOUT 10,000 FT.

(see p. 284)

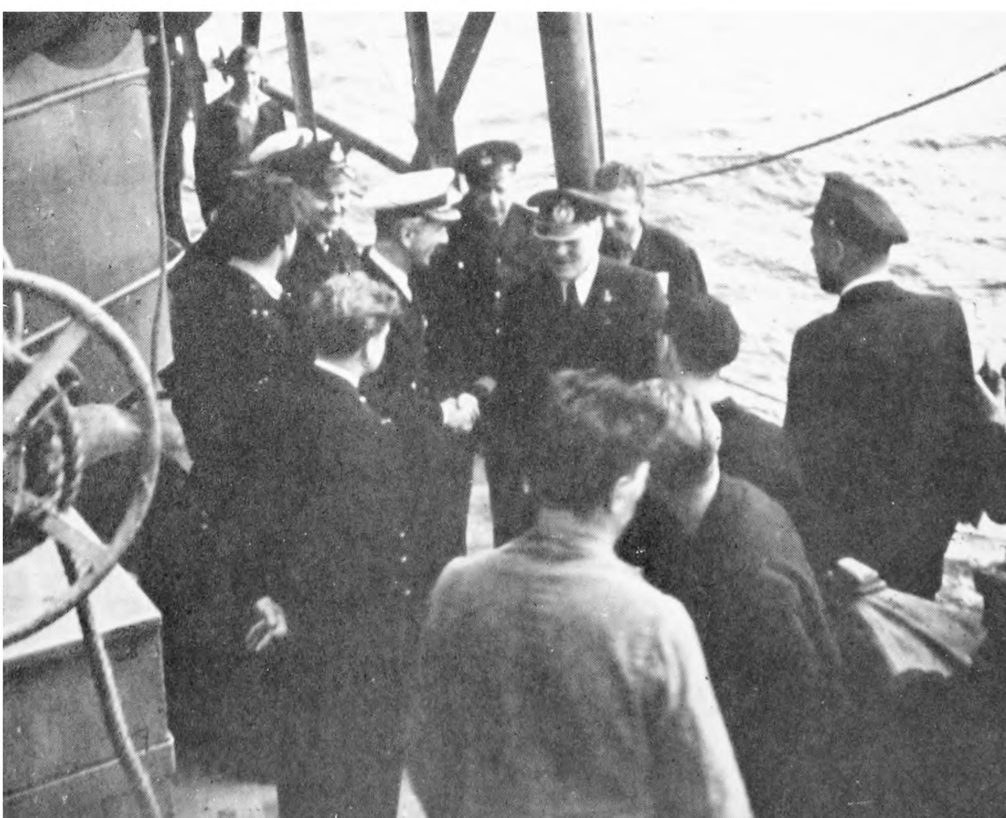
FIG. 3—DEVELOPMENT OF LOW-LEVEL CUMULUS CLOUDS AT 0920 G.M.T.
View taken from the summit plain of Hofsjökull looking towards the stony plain near station A
(see p. 261)

FIG. 4—DEVELOPMENT OF LOW-LEVEL CUMULUS CLOUDS AT 0940 G.M.T.
View taken from the summit plain of Hofsjökull looking towards the stony plain near station A
(see p. 261)

To face p. 285

Reproduced by courtesy of J. K. McNair

Capt. J. P. Groen of the o.s.v. *Cumulus* being welcomed aboard the o.w.s. *Weather Observer* by Capt. N. F. Israel



Reproduced by courtesy of J. K. McNair

Netherlands and British staff aboard o.w.s. *Weather Observer*

VISIT OF CAPTAIN AND OFFICERS OF O.S.V. *Cumulus* TO O.W.S. *Weather Observer* ON STATION JULIETT MAY 10, 1952

(see p. 284)

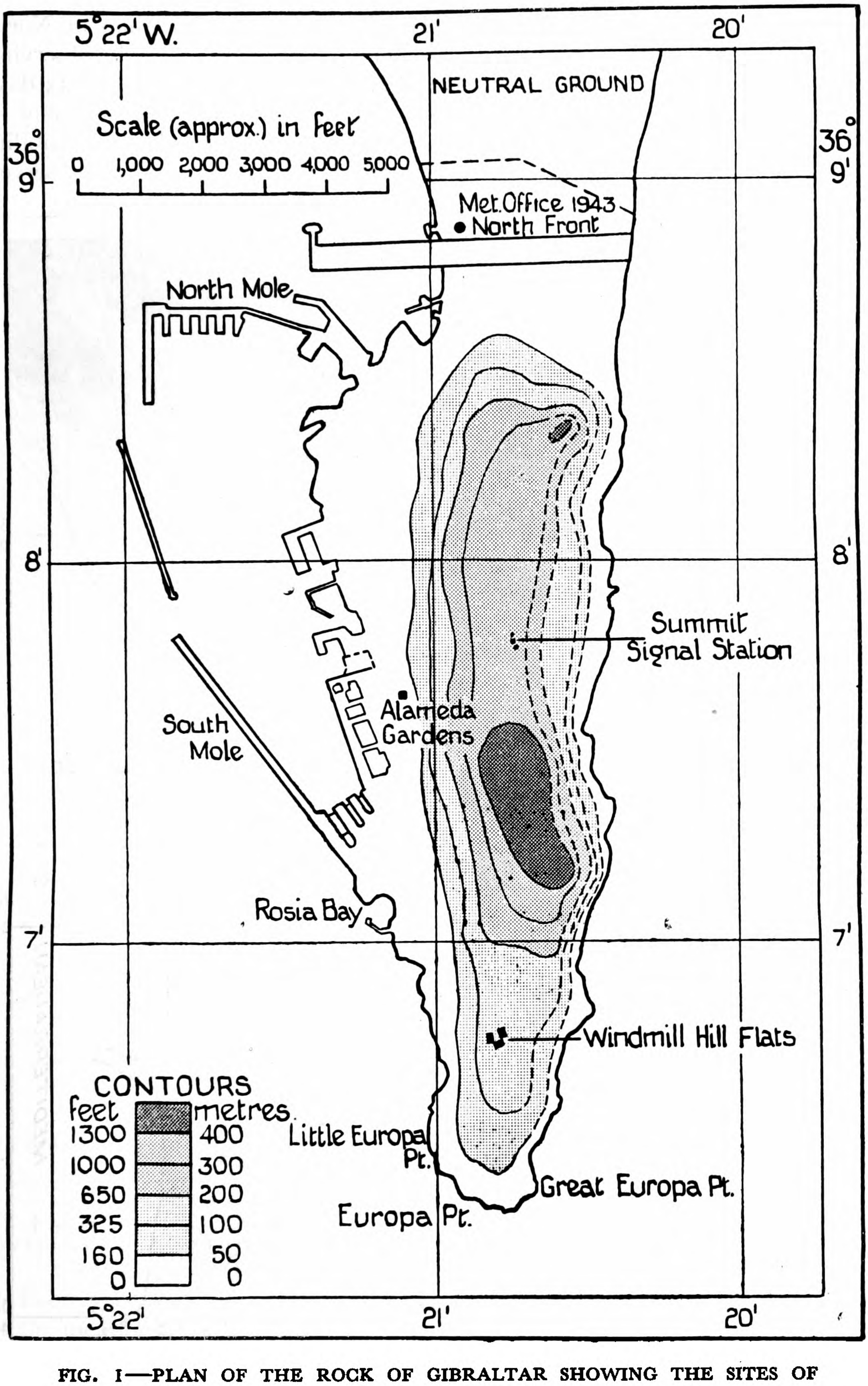


FIG. 1—PLAN OF THE ROCK OF GIBRALTAR SHOWING THE SITES OF THE METEOROLOGICAL STATIONS

Approximate contours are drawn for 10, 100, 200, 300 and 400 m.

The frequency of fog at Windmill Hill is appreciably less than at North Front, largely because of the difference in height above sea level of the observing stations. During the period June 1943 to December 1947 there were 43 days on which fog occurred at both stations. On 32 days, fog occurred only at North Front; Windmill Hill was above the fog and reported good visibility on 24 of these days, while on the remaining 8 days low stratus was observed

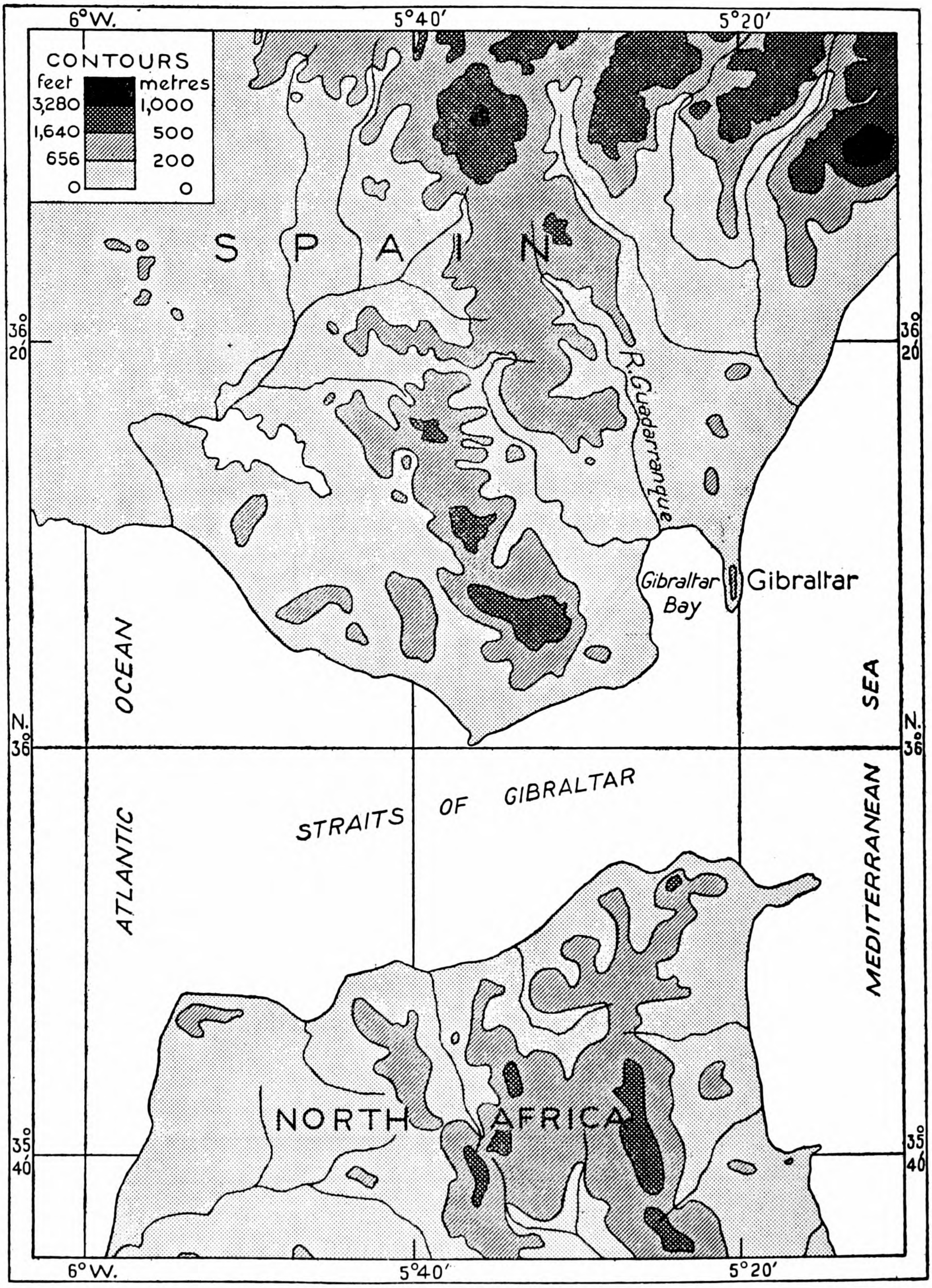


FIG. 2—THE STRAITS OF GIBRALTAR

TABLE I—MONTHLY FREQUENCY OF FOG AT GIBRALTAR

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
						number of days							
North Front *	0·1	0·6	0·4	0·7	0·7	2	4	4	3	0·9	0·9	0·4	18
Windmill Hill†	0·1	0·5	0·5	0·4	0·7	1	3	1	2	1	0·4	0·1	11
Straits‡	0·7	1	0	0·5	2	5	11	8	4	3·5	2·5	0	38

* Based on hourly observations during the period June 1943 to August 1951 inclusive.
† 10-year mean, period 1938 to 1947 inclusive.
‡ Based on observations, from the last quarter of 1935 until 1939, from the Meteorological Office at Windmill Hill[3]. The exact criterion used to define "fog over the Straits" is not known, so that the frequencies may not be strictly comparable with those for North Front and Windmill Hill.

with base at between 50 and 300 ft. above station level, a lifting of the fog which was probably due to the additional turbulence over the southern end of the Rock. On 12 days fog occurred only at Windmill Hill; extensive low stratus with base below 600 ft. was observed at North Front on 9 of these days, while on the remaining 3 days the fog appears to have been very local.

Relation to sea temperature.—The major cause of reduction of visibility to fog limits at North Front is sea fog. Pure sea fog is formed in warm damp air which passes over a cold sea surface; the air is cooled below its dew point, and condensation results[4]. It is to be expected, therefore, that the frequency of fog at North Front will be a maximum when the difference between the mean air temperature and the mean sea temperature is greatest, and the difference between the mean dew point and the mean sea temperature least. Table II shows that from June to September inclusive, when fog is most frequent, the mean air temperature is 5–8°F. above the mean sea temperature, and the mean dew point only 1–3°F. below the mean sea temperature.

TABLE II

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						degrees Fahrenheit						
Mean air temperature*	56	58	60	63	65	72	76	78	74	69	63	57
Mean dew point†	49	51	53	55	57	64	67	67	67	63	58	51
Mean sea temperature‡	59	58	57	60	62	65	68	70	69	66	63	59
Mean air temperature minus mean sea temperature	−3	0	+3	+3	+3	+7	+8	+8	+5	+3	0	−2
Mean sea temperature minus mean dew point	10	7	4	5	5	1	1	3	2	3	5	8
						number of days						
No. of days of fog	0·1	0·6	0·4	0·7	0·7	2	4	4	3	0·9	0·9	0·4

* Mean air temperature = ½(mean max. + mean min.), May 1946 to March 1951.
† Mean dew point = ½(mean 0300 dew point + mean 1500 dew point), January 1945 to March 1951.
‡ Values for northern Straits[1].

Table III shows that the difference between the mean sea-fog point (defined as the mean dew point 3–6 hr. before the onset of fog at North Front) and the mean sea temperature is positive during the months June to September inclusive, when fog is most frequent, and negative during the remaining months. Although there are too few observations to permit of any firm conclusions, nevertheless there does seem to be some relationship between the change of sign of this difference and the seasonal and local variations of sea temperature.

TABLE III

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						degrees Fahrenheit						
Mean sea-fog point	...	57	56	59	60	66	70	71	70	64	61	...
Mean sea-fog point minus mean sea temperature	...	−1	−1	−1	−2	+1	+2	+1	+1	−2	−2	...
						number of observations						
No. of observations	...	3	3	6	6	12	23	23	20	6	6	...

From June to September, the normal distribution of sea temperature over the area east and west of Gibraltar is a decrease from east to west[5] so that air moving westwards undergoes a steady cooling, a well marked temperature inversion is established, and the lower layers of air acquire a large moisture content. If the dew point of the easterly air stream is initially high, the progressive cooling effect of the sea surface will result in the development of fog in the vicinity of Gibraltar. Conditions are particularly favourable for fog development after a wind change from west to east, when a spell of westerly winds has brought cool Atlantic water into the Straits[1].

From October to May, however, the normal distribution of sea temperature is fairly uniform over the area east and west of Gibraltar[5], and is not so favourable for fog development in the vicinity of Gibraltar. During these months the mean sea temperature exceeds the mean sea-fog point, indicating that a necessary condition for fog development is a sea-surface temperature below average. This condition is most probable after a prolonged spell of westerly winds has brought water of Atlantic origin much colder than normal into the Straits. The distribution of sea temperature from west to east will then follow the summer pattern, and a wind change from west to east will favour the development of fog.

Diurnal variation of fog.—Tables IV and V show that, although fog may occur at any time of day, it is most frequent during the period midnight to 0800 G.M.T. The fog is often very patchy, and even at night frequently clears within two hours of the time of onset. During the day, the surface heating and increased turbulence over the Rock and the isthmus normally result in a rapid lifting and dispersal of the fog, and a complete clearance by midday. On a large number of occasions the fog also disperses for a considerable distance out to sea, but sometimes fog patches may persist for long periods only a short distance off the eastern end of the airfield.

TABLE IV—TIME OF ONSET AND DURATION OF FOG

Time of onset of fog	Duration of fog <1 hr.	1–2 hr.	2–4 hr.	4–6 hr.	6–8 hr.	8–12 hr.	Total
G.M.T.			*percentage frequency*				
0000–0300	4·9	7·7	7·0	2·8	1·4	0·7	24·5
0300–0600	8·4	6·3	7·7	3·5	0·7	0·7	27·3
0600–0900	3·5	5·6	3·5	1·4	...	...	14·0
0900–1200	2·1	4·2	2·8	...	...	...	9·1
1200–1500	1·4	0·7	0·7	...	...	...	2·8
1500–1800	1·4	0·7	...	...	...	...	2·1
1800–2100	...	2·1	0·7	1·4	1·4	0·7	6·3
2100–2400	3·5	3·5	2·8	0·7	1·4	2·1	14·0
Total	25·2	30·8	25·2	9·8	4·9	4·2	

The onset of fog is at times sudden, and it may sweep round both ends of the Rock to envelop North Front, Windmill Hill and most of the Bay within a few minutes.

TABLE V—HOURLY DISTRIBUTION OF FOG

Hour (G.M.T.) centred at											
0030	0130	0230	0330	0430	0530	0630	0730	0830	0930	1030	1130
percentage frequency of total number of occasions											
6·6	7·3	7·8	8·0	8·6	8·3	8·4	6·6	4·7	4·7	4·9	3·1

Hour (G.M.T.) centred at											
1230	1330	1430	1530	1630	1730	1830	1930	2030	2130	2230	2330
percentage frequency of total number of occasions											
1·6	1·0	1·0	0·5	0·5	0·7	0·7	1·0	2·1	3·3	4·2	4·4

Fog in relation to wind.—Observations of fog during the period investigated show that 42 per cent. occurred with easterly winds of less than 5 kt., 40 per cent. with easterly winds of 5 to 10 kt., 10 per cent. with easterly winds of 10 to 15 kt., and 8 per cent. with westerly winds of less than 5 kt.

The sea fogs affecting North Front may be classified as follows:—

Fog occurring after a wind change from west to east (48 per cent. of total occasions).—Fog of this nature may develop at any time of day after a wind change from west to east, provided that the dew point exceeds the sea temperature. The time lapse between the change of wind and the onset of the fog is usually less than 18 hr. The fog may be extensive when the wind change to east occurs after a long spell of westerlies. With continuing light easterly winds, the fog may recur on the second and third nights after the wind change, but after the easterly winds have been established for some time the drift of warmer Mediterranean water produces a rise in sea temperature and the fog formation ceases. The following example is a case of this type.

September 7, 1950. Fog from 2040 to 2230 G.M.T.

A deep depression moved north-eastwards over the British Isles on September 5, 6, and 7, 1950, while the associated cold front moved south-eastwards at decreasing speed into the Bay of Biscay. A ridge of high pressure from the Azores anticyclone developed north-eastwards over Spain ahead of the weakening cold front on the 6th and 7th, resulting in a change of wind at Gibraltar from west to east at 1200 G.M.T. on the 7th. The fog developed at 2040 on the 7th, cleared at 2230, re-formed at 0640 on the 8th, and finally cleared at 0950 G.M.T. The dew points were 64–65°F. during the spell of westerly winds, rising to 69–72°F. with the onset of the easterly winds. The mean sea temperature in September is 69°F.

Fog occurring during a spell of easterly winds (30 per cent. of total occasions).—Fog may develop during a spell of easterly winds, even though it may not have occurred after the initial wind change to east. It is invariably associated with the influx of moister air from the east, and a steadily rising dew point at Gibraltar, as in the following example.

August 14, 1950. Fog from 0100 to 0140 G.M.T.

A pronounced ridge of high pressure from the Azores anticyclone to north Spain and the western Mediterranean resulted in a spell of easterly winds at Gibraltar. The wind change to east occurred on the 10th, and light easterly winds continued until the 16th. The dew points were 65–70°F. on the 10th and 11th, rising to 72–74°F. by the 13th. The fog developed at 0100 on the 14th, and cleared at 0140 G.M.T., and shortly afterwards the dew point dropped to 68–70°F. The mean sea temperature in August is 70°F.

Fog occurring at the end of a spell of easterly winds (20 per cent. of total occasions).—The general change of wind from east to west, after a spell of easterly winds, is often preceded by a short period of light and variable winds, and during this period the reduced turbulence and consequent accumulation of moisture in the lower layers favours the formation of fog. With initially high dew points the fog may be very extensive, and at times the Straits are completely filled. On these occasions, fog banks may drift into the northern half of the Bay, and approach North Front from the west. All fogs which occurred with westerly winds were of this nature. This type of fog usually develops late in the night, as in the following example.

July 6, 1948. Fog from 0400 to 0600 G.M.T.

A well developed ridge of high pressure over north Spain and the western Mediterranean, from an anticyclone centred in mid Atlantic, resulted in a spell of moderate to fresh easterly winds at Gibraltar. The southward movement of a cold front over the Bay of Biscay and north Spain on the 4th and 5th produced a fall in pressure over the western Mediterranean, and the easterly wind at Gibraltar slowly moderated, becoming light and variable during the evening of the 5th. Fog developed at 0400 on the 6th, and cleared at 0600 G.M.T. The dew points throughout were 65–66°F. The mean sea temperature in July is 68°F.

Precipitation fog at North Front (2 per cent. of total occasions) occurs only in the heavy rain associated with upper-level thunderstorms moving northwards from north Africa, or with vigorous cold fronts moving south-eastwards across Spain and Portugal.

The low stratus and rain associated with quasi-stationary fronts in the Straits of Gibraltar occasionally produce fog in the vicinity of Gibraltar[1], but not, during the period investigated, at North Front. However, since these fronts result in very poor conditions at North Front, during which there is a considerable risk of fog, the synoptic situation is considered worthy of note. The following three examples are of interest.

September 9, 1949

The upper air charts for 0300 G.M.T. on the 9th showed a cold pool centred to the west of Gibraltar. Thundery medium-level cloud developed over north Africa during the morning of the 9th and spread towards Gibraltar. During the early afternoon, a thunderstorm moved towards Gibraltar from the south-west. Very heavy thundery rain commenced at 1255 and continued until 1415 G.M.T., the total rainfall during this period[6] being 97·2 mm. The visibility in rain was at times reduced to 200 yd.

March 7, 1951

A deep depression moved north-north-eastwards over south-west England and west Wales on the 7th, while the associated cold front moved quickly south-eastwards over Spain and Portugal, and cleared Gibraltar by 2200 G.M.T. The pre-frontal rain commenced at Gibraltar at 1200 G.M.T., and the surface wind gradually freshened to south-westerly 22–25 kt. The visibility was reduced to 400–800 yd. in moderate to heavy rain between 1600 and 1700 and between 1930 and 2030 G.M.T.

March 14, 1951

A deep depression moved north-north-eastwards over the Bay of Biscay and the British Isles on the 13th and 14th, while the associated cold front moved south-east, and cleared Gibraltar by 2000 G.M.T. on the 13th. The cold front became retrograde on the 14th, as a wave depression moved quickly east-north-eastwards from the Azores. As the front moved slowly northwards towards Gibraltar, the surface wind backed to easterly, and increased to 8–12 kt. Frontal drizzle commenced about 1000 G.M.T., and continued until the passage of the front at 0600 G.M.T. on the 15th, when the surface wind veered to south-westerly. For long periods, the visibility was reduced to 1,200 yd. in drizzle, with a cloud base of 300–400 ft.

Forecasting fog.—Fog at North Front is almost always associated with easterly winds. At all times of the year, and in particular during the summer months when the surface wind is easterly or when a change from west to east seems likely, a close watch must be kept on the observations of dew point in relation to sea temperature in the area to the east of Gibraltar. In this connexion, however, it must be emphasized that the dew points reported by coastal stations east of Gibraltar, because of the many local peculiarities and the effect of off-shore winds, are frequently not representative of the air mass over the sea. Forecasting difficulties are further increased by the lack of regular observations of sea temperature from the area east of Gibraltar, and by the considerable variations which follow a general change of wind direction. Fog is more probable when a wind change from west to east follows a prolonged spell of westerly winds. The sea temperature may then be expected to be well below average. The effect of a change of wind on the sea temperature is of paramount importance in forecasting fog, and the reader is referred to a more detailed discussion of this subject elsewhere[3].

If observations of sea temperature and dew point to the east of Gibraltar are lacking, the average and extreme values of sea-fog point during the period investigated, given in Table VI, may be of value in assessing the possibility of fog formation.

TABLE VI—SEA-FOG POINTS

	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
					degrees Fahrenheit					
Mean sea-fog point	57	56	59	60	66	70	71	70	64	61
Lowest sea-fog point	56	55	55	57	58	61	65	63	63	58

Owing to the lack of homogeneity in the easterly air stream the fog frequently forms in isolated patches, and on over 50 per cent. of occasions of fog the period during which North Front is affected is less than two hours. If the horizontal extent of the fog is known from aircraft observations, it is possible, by estimating the rate of drift of the fog bank, to forecast the time of onset or clearance with a high degree of accuracy.

Fog at North Front is subject to a very marked diurnal variation, with a maximum frequency about dawn and a minimum frequency during the afternoon. In midsummer, the surface heating over the Rock and the isthmus results in a complete clearance during the forenoon. At other times of the year, particularly if there is a layer of cloud above the fog, the clearance may be delayed until the early afternoon, and on very isolated occasions fog may persist all day.

Apart from the general changes of surface wind from west to east or from east to west due to a changing pressure distribution, the forecaster must also be alert for any local or temporary variations in wind, since these may significantly affect the onset or clearance of fog, e.g. a temporary backing of an easterly surface wind to NE. or NNE. may result in a bank of fog being carried to the south of the Rock without affecting North Front. With very light easterly winds the katabatic effect assumes considerable importance, and often causes a complete reversal of wind from a light easterly to a light westerly during the night, the wind reverting to a light easterly after dawn. Under these conditions, fog which may be over North Front at dusk is gradually cleared by the katabatic flow during the night, only to return again with the onset of the easterly wind after dawn.

REFERENCES

1. London, Meteorological Office. Weather in home waters and the north-eastern Atlantic. Vol. II, Pt. I, Appendix, Gibraltar. London, 1944.
2. WARD, A.; Duststorm at North Front, Gibraltar. *Met. Mag., London,* **80,** 1951, p. 196.
3. GORDON, A. H.; Topographical factors affecting the forecasting of weather at Gibraltar. Meteorological Office, London, 1940.
4. London, Admiralty, Hydrographic Department. Admiralty weather manual. London, 1941, p. 222.
5. London, Meteorological Office. Monthly meteorological charts of the Atlantic Ocean. London, 1948.
6. PEPPER, J.; Very rare rainfall at Gibraltar on September 9, 1949. Typescript, Meteorological Office, London, 1949.

At the meeting of the Society held on June 18, 1952, Dr. R. C. Sutcliffe Vice-President in the Chair, the following papers were read:—

*Taylor, R. J.—Dissipation of kinetic energy in the lowest layers of the atmosphere.**

Mr. Taylor's paper was read by Dr. Pasquill. Taylor calculated the vertical flux of kinetic energy and the rate of dissipation of kinetic energy in the lowest layers from observations of mean wind and the eddy components, assuming that the mean vertical mass flux is zero and that the wind profile is logarithmic. The observations were made at heights of 2 m. or 29 m. near Melbourne on occasions of small lapse rate and moderate wind. It was found that the dissipation of kinetic energy within a layer near the ground could account for about a quarter of the rise of temperature observed in the layer; this is an observation of much importance as the dissipation of kinetic energy is normally neglected in a study of the vertical heat transfer in the lowest layers. Dr. R. C. Sutcliffe, Prof. P. A. Sheppard, Dr. G. D. Robinson and Dr. Pasquill took part in the discussion in which the chief point raised was the validity of the supposition that the mean vertical flux of mass is zero. This assumption is particularly important because in the formula for flux of kinetic energy the vertical mass flux is multiplied by half the square of the mean wind. Dr. Robinson said his measurements showed that at any one point this quantity was not zero when measured over periods of minutes; some values of energy flux measured at Kew, after subtracting the part proportional to the vertical mass flux, agreed with Taylor's values.

Murray, R. and Johnson, D. H.—Structure of the upper westerlies; a study of the wind field of the eastern Atlantic and western Europe in September 1950.†

Mr. Murray's and Mr. Johnson's paper, read by Mr. Murray, described cross-sections of the atmosphere made twice a day during September 1950 from the surface to 150 mb. along the lines Greenland–Malta and Azores–Sweden, crossing near Larkhill. September 1950 was unusually stormy and the depressions followed one another across the British Isles. It was found that one or more wind maxima occurred on every occasion on these sections and with the centre of maximum wind near the tropopause. The general structure of these jet streams was similar to that described by previous writers but with variations in detail. The wind shear on the warm side of the maxima was only about two-thirds of the shear on the cold side where the shear averages 20 kt./100 miles and may exceed 100 kt./100 miles. Mr. Murray showed sample cross-sections and also charts showing the situation of the jet streams relative to the surface isobars and fronts. Their situation relative to fronts was usually as previously described, but such complexities as divided jet streams and double jet streams were found. On September 26 jet streams in the nearly opposite directions of north to south and south-west to north-east were observed over western Europe.

During the discussion, in which the paper was welcomed as a fundamental contribution to synoptic climatology, Mr. Gold said he was interested to see jet streams could blow from north or south as well as from a westerly point; Prof. Sheppard inquired if changes in the thermal field produced characteristic

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* *Quart. J. R. met. Soc., London,* **78**, 1952, p. 179.
† *Quart. J. R. met. Soc., London,* **78**, 1952, p. 186.

changes in wind structure; Mr. Galloway thought there should be a velocity discontinuity across the tropopause; and Mr. Bannon inquired if there were differences in structure of jet streams in winter and summer, and between those over the British Isles and the southern United States. Mr. Murray thought that the only difference between summer and winter was that intense jet streams were more frequent in winter, and as regards the southern United States jet streams that they appeared to have the stronger shear on the warm side. Dr. Sutcliffe discussed the possibility of a jet stream completely encircling the globe as the polar front had once been thought to do. The low-latitude jet stream over the subtropics was always present where observations were available, but it was uncertain if it was broken over the oceans.

OFFICIAL PUBLICATION

The following publication has recently been issued:—

Observer's handbook

The "Observer's handbook" is the authoritative manual of surface meteorological observing. It covers all standard observations at all types of meteorological stations, whether synoptic stations where the major interest is in forecasting, ordinary climatological stations maintained for more varied and general interests in weather records, or those climatological stations having behind them other special interests as in the case of crop weather and health resort stations. Various types of highly specialized observations, including upper air observations, do not come within the scope of the Handbook.

The new Handbook differs from its predecessors (the successive editions of the "Meteorological observer's handbook") in two important respects. It has been written with the needs of modern meteorology in mind, and due prominence is therefore given, in the relevant sections, to the international codes which have been in use since January 1, 1949. Secondly, the body of the book is concerned with observing proper, and it is therefore assumed that the station has been properly sited and equipped on the scale appropriate to its class and is in full working order. The first chapter contains a summary of the observing procedure at each type of station with some general notes on observing, and the following chapters are devoted in turn to the details of observing the separate elements.

The selection of the site and other matters which must receive attention when the station is first set up are, however, discussed in an appendix. Other appendices cover such matters as, for example, the recording of observations and the preparation of barometer correction cards, which are relevant to the techniques of observing but do not strictly belong to them.

Where instruments are concerned sufficient information is given for the purposes of day-to-day use and maintenance, but for more complete details of design and construction the reader is referred to the separate "Handbook of meteorological instruments", which is to be published later.

ERRATUM

JULY 1952, PAGE 213; Owing to an error in conversion of velocity units the estimates of vertical motion in the stratosphere are in error by a factor of ten. Therefore

line 21, *for* "5 cm./sec." *read* "0·5 cm./sec."
line 40, *for* "10 cm./sec." *read* "1 cm./sec."

LETTER TO THE EDITOR

South Polar atmospheric circulation

A recent article on the "South Polar atmospheric circulation and the nourishment of the antarctic ice-cap" by H. H. Lamb has just been called to our attention. Impressions received from analysing a two-year series of southern hemisphere weather charts for the period July 1948–June 1950 are somewhat at variance with Lamb's ideas of antarctic cyclones and anticyclones.

First, it appears futile to refer to sea-level pressure systems over Antarctica. Doubtless a shallow anticyclone exists over the ice-cap, with an indeterminate circulation aloft. But to extend a surface analysis so as to cover the continent requires much imagination, the results of which may not reliably fulfil our expectations. Our Weather Bureau—Massachusetts Institute of Technology Southern Hemisphere Project—has had considerable data from whaling vessels for several summer seasons, but our analysts do not consider that such data are sufficient to allow a detailed analysis over the continent. It is our considered opinion, however, that there is not much likelihood that well developed cyclonic vortices exist there as surface systems. If there are weak cyclonic systems emerging from Antarctica, as stated by Lamb, such systems should certainly increase in intensity, inasmuch as they would be passing out over a warm surface.

The fact that the *Balaena* was as much as 200 miles from the coast is significant. In summer-time there seems to be evidence in favour of the existence of a storm track that approximates the ice-edge. Observations made from ships that far from the coast may not, therefore, faithfully represent conditions on the continent. Observations from the combined expedition at Maudheim and the French expedition at Adélie Land have not, in our opinion, ever shown any evidence of cyclones having passed over Antarctica. They rather give the impression of high pressure over the continent, with cold air seeping out constantly behind the eastward-moving cyclones along the coast. Winter-time pressures of as high as 1023 mb. have been observed at Adélie Land in our recent series, although the mean is considerably lower. At Maudheim there have been observed pressures of 1019 mb., while the stations on Palmer Peninsula have had pressures as high as 1030 mb. with definite evidence of occasional winter-time outbreaks of polar anticyclones that have reached as far north as South Africa.

It is also our opinion that the Ross and Weddell Seas, because of the surface temperature contrast they offer to the cold continent, are likely to have lower pressure than the other ice-covered areas at the same latitude. The low pressures are not *a priori* evidence that cyclonic situations occur from time to time over the South Polar regions, as stated by Mr. Lamb. The occurrence of cloud sheets and clouds with vertical growth can be explained by the relatively warm and moist air from the north passing over a high and cold continent. The stability conditions of such air will determine the type of cloud forms to be observed. Such overrunning may contribute considerable amounts of precipitation to the ice-cap. As regards cloud banks emerging from the interior, there is every reason to believe that cold air does move out from the continent and should be associated with clouds and precipitation just off shore due to its passing over a warm undersurface.

Mr. Lamb's effort to explain, in part, the South Polar circulation is commendable, but perhaps based upon insufficient data. Our own feeling is that much more in the way of continuing observations are required before the meteorologist can hope to portray successfully such a circulation on a surface weather chart.

MORTON J. RUBIN

185 Ash Street, Waltham 54, Mass., June 10, 1952,

[Mr. Rubin's comment seems to imply a hasty reading of the evidence presented in my article on the South Polar atmospheric circulation. The article admittedly suffered from excessive abbreviation, especially in that there was no space to elaborate the justification for the analysis of each day's chart in the illustrative synoptic sequence. Every possible check and countercheck was used. Indeed the sequence was chosen not solely for the interesting developments portrayed, but still more because the checks and counterchecks were particularly convincing over this period.

Sea-level isobars may be drawn over Antarctica with about the same reservations as over Greenland. Depressions, including even some well developed cyclonic vortices, are now known to pass across all parts of Greenland on occasion. He would be a bold man who would assert that the same cannot happen in Antarctica. To say that pressures as low as 932 mb. at Little America (77°S.) in the Ross Sea (observed by Court in 1941) do not imply cyclonic situations over the South Polar regions requires a pressure gradient of at least 60–70 mb. in the 800 miles between there and the South Pole, even if Mr. Rubin will allow the strong cyclonic circulation to extend as far as the pole itself.

Cyclonic circulations centred over the continental ice are certainly necessary to explain the westerly winds sometimes reported at coastal observation points, still more so the north-westerly winds noted on the ice-cap near the magnetic pole in the Adélie Land sector by Shackleton's expedition. No doubt these cyclonic circulations are often rather weak, but they tend to be rejuvenated if and when they emerge once more over the ocean. Nor can the evidence presented of occasional warm anticyclones with deep-reaching circulation, probably up to the observed high tropopause, be brushed aside without discussion. The main point, which concerns future expeditions to the interior of Antarctica even more than it concerns meteorologists, is that it now seems prudent to admit much more variability in the atmospheric circulation patterns and weather types occurring over Antarctica than was formerly realized or than seems to be so far accepted by Mr. Rubin.

It seems necessary to make clear that it is not a fact that the *Balaena* was as much as 200 miles from the antarctic coast during the period analysed. This figure was quoted in connexion with an occurrence nearly two weeks later, when she was on her way home. In March the ship was generally within 100 miles of the coast and occasionally within sight of it. Our aircraft flew over the coastal mountains, and the smaller sea-going craft gave reports close to the coast and along the edge of the at-that-time narrow ice belt within 150–200 miles of the *Balaena*. Normal frontal medium-cloud systems, occasionally with embedded cumulonimbus, as on March 17, 1947, were rather frequently seen over the continent itself (i.e. direct observation), and, in this case, emerging from the interior in a wind stream with general southerly components.

Mr. G. de Q. Robin, of the recently returned Norwegian-British-Swedish expedition based at Maudheim in the Norwegian sector, has commented that he believes their observations will be found to bear out all the conclusions I stated except perhaps the suggestion of any net up-slope drift of the accumulated snow in Antarctica. It is greatly to be hoped that this expedition's material will be used together with the data now available from Prince Edward Island and Heard Island and from the Falkland Islands Dependencies in Antarctica for other specialized synoptic studies to broaden our knowledge of the day-to-day weather processes over Antarctica.—H. H. LAMB.]

NOTES AND NEWS

Altocumulus floccus at Stradishall, West Suffolk

The lower photograph facing p. 272 was taken at Stradishall, West Suffolk, on July 1, 1952, looking south-south-east at about 1430. It shows altocumulus floccus, base about 10,000 ft., which gave a moderate shower beginning at 1426 and lasting two minutes only. A number of similar showers from only 2–4 oktas of cloud were reported over East Anglia during the day and rain from a seemingly clear sky was reported in the London area. Altocumulus castellatus was observed at Harrow.

The clouds were associated with upper air instability. A shallow depression moved northwards from the Bay of Biscay on July 1 and thunderstorms occurred over south-west England. July 1 was the last and hottest day (92°F. was recorded at Camden Square and London Airport) of a warm spell that had occurred in the southern part of England during the last week in June.

Ocean weather stations

The International Civil Aviation Organization introduced on November 1, 1951, a new phonetic alphabet. This has meant the renaming of the ocean weather stations from JIG and ITEM to JULIETT and INDIA. The positions are unchanged and the renaming took effect from May 1, 1952.

At this time O.W.S. *Weather Observer* was on station JULIETT. On May 10, *Weather Observer* was relieved by the Netherlands O.S.V. *Cumulus*. During the take-over of station duties on this day, Capt. J. P. Groen of the *Cumulus*, accompanied by his Chief Meteorological Officer, Oceanographical Officer and Radio Supervisor, visited *Weather Observer*, staying for an hour and a half. Three of *Weather Observer's* Officers returned the visit. Photographs illustrating the visit are reproduced facing p. 273.

During their visit mutual difficulties were discussed.

WMO Bulletin

We welcome the publication of the first number of the *WMO Bulletin* published by the World Meteorological Organization. The purpose of the *Bulletin* is to provide periodically a summary of the activities of the World Meteorological Organization and of developments in international meteorology of interest to members of the Organization and others concerned with the application of meteorology to human activities. To begin with the *Bulletin* will be published quarterly in separate French and English editions.

The contents of the first number include:—

A general account of the functions of the World Meteorological Organization with list of member states and of the officers.

A description of the new Headquarters building and a map of Geneva showing its location.

Notes on collaboration with other international organizations, on the activities of Regional Commissions and on the Technical Assistance Programme for under-developed countries.

A list of publications by the World Meteorological Organization.

Calendar of coming events.

Details of the sale and free distribution arrangements will be settled by the Executive Committee at its meeting in September 1952.

OBITUARIES

Dr. A. Crichton Mitchell.—The following facts relating to the late Dr. Crichton Mitchell's services to the Royal Meteorological Society should be added to my note published in the June 1952 number.

Dr. Crichton Mitchell was a life Fellow of the Scottish Meteorological Society, elected into Fellowship in 1891, and became a life Fellow of the Royal Meteorological Society when the two Societies were amalgamated in 1921. He was at one time a Secretary and later a Vice-President of the Royal Meteorological Society. He represented the Society on the Committee of the Meteorological Office, Edinburgh, from 1928 to 1937.

R. A. WATSON

Frederick William George Ruddle.—It was with great regret that we heard of the sudden death of Mr. F. W. G. Ruddle, Experimental Officer, on June 8. Mr. Ruddle joined the Office as an Observer early in 1935, transferring to the Carpenter scientific grades when the grade of Observer was abolished in 1940. In the 17 years he was with the Office Mr. Ruddle set a fine example of devoted and conscientious service and was held in high esteem both by his colleagues and his R.A.F. associates.

BOOKS RECEIVED

Zur Meteorologie und Meteorobiologie des Alpenföhns. By W. Mörikofer. *Verh. schweiz. naturf. Ges., Davos*, pp. 11–32. Illus. 1950.

Erweiterung des Frigorimetermessbereiches zur Miterfassung der Aufwarmungsgrosse. By H. Wierzejewski. *Verh. schweiz. naturf. Ges., Davos*, pp. 153–4, 1950.

METEOROLOGICAL OFFICE NEWS

Ocean weather ships.—Ocean weather ships have been co-operating with Dr. G. V. T. Matthews of the Department of Zoology, University of Cambridge, in his experiments on the homing of gulls.

Twenty ringed manx Shearwaters were despatched from the island of Skokholm, off the coast of Pembrokeshire, to Glasgow railway station where they were collected by Captain A. W. Ford for conveyance to the o.w.s. *Weather Recorder* to take to sea on June 18 for release at least 100 miles from land. Instructions were that the birds should not be fed at all and that a sunny day should be chosen for their release in case they should use the sun as an aid to navigation.

The birds were released between 1033 and 1125 on Friday, June 20, in position 56° 40′N., 10° 42′W. (345 miles north-north-west of Skokholm). The sun was visible throughout, though the sky was covered with 7 oktas thin stratocumulus at 3,500 ft. and with 7 oktas cumulus at 1,800 ft. The wind was 17 kt. from 290°.

Most of the birds circled, or partly circled, the ship before heading off, and, of the 20 birds, 6 went off in the north-east quadrant, 8 in the south-east quadrant, 3 in the south-west quadrant, and 2 in the north-west quadrant. One bird settled on the sea not far from the ship.

A letter received subsequently from Dr. Matthews reported that, when he stopped checking, 18 of the 20 birds had returned to Skokholm; the first arrival came in on the night of Saturday, June 21, 5 more arrived on the Sunday, and 2 on the Monday, the others coming in at intervals.

Dr. Matthews expressed great satisfaction with the result which gave him most valuable data. He hopes to be able to arrange for another release next year.

Examination successes.—We congratulate the following on their achievements in passing their examinations while working in the office:—

J. E. Burns—Part I, B.Sc. London, special physics.

J. L. Burn—Intermediate B.Sc. London, physics, pure mathematics and geography.

D. F. Winter—Higher National Certificate in electrical engineering.

Horticultural Show.—The staff of the Office were represented in all three sections—flowers, fruit, and vegetables—of the annual show of the Air Ministry and Ministry of Civil Aviation Horticultural Society held on July 8. The exhibitors were Misses H. G. Chivers and D. J. Wordsworth, and Messrs. B. G. Brame, N. E. Davis and H. A. Scotney, and all gained prizes.

WEATHER OF JULY 1952

Mean pressure was generally above normal over the North Atlantic and western Europe, and below normal in north Scandinavia and the Mediterranean region. The highest mean pressure, 1027 mb., which was 7 mb. above normal, occurred in the area north-east of the Azores as far as latitude 45°N. In west Europe mean pressure was uniform, between 1017 and 1020 mb., generally 3 mb. above normal, but in the Mediterranean, mean pressure was 1 or 2 mb. below normal in places. The lowest mean pressure, 1009 mb., occurred between Scandinavia and Greenland; this was 2 mb. below normal.

Mean temperature was above normal in most of Europe; in most places it was between 65° and 75°F., generally 5°F. above normal, but nearly 10°F. above normal locally in south-east France. In Scandinavia, however, where mean temperature was in the region of 60°F., it was about 2°F. below normal.

In the British Isles the weather was drier than usual except at a few scattered places chiefly in the north-west. It was warm on the whole except in the north of Scotland. Sunshine was mostly somewhat below the average but in south and east Scotland and extreme north-east England there was a considerable excess. An absolute drought prevailed at many places in the south of England towards the end of the month.

On the 1st a depression over the Bay of Biscay moved north-north-east across England, while another off west Scotland moved north-east; heavy thunderstorms occurred widely in western, central and northern England, and local thunderstorms in south-west Scotland and Northern Ireland (1·73 in. of rain fell at Bredbury, Cheshire, in 25 min., 1·72 in. at Ilkeston, Derbyshire, in 30 min., and 1·23 in. at Nottingham in 15 min.). It was very warm on the 1st, particularly in the south-east where temperature approached 90°F. at a number of places and reached 92°F. at Camden Square, London Airport and Southampton. A cold front moved across south-eastern districts on the 2nd with little rainfall, but a rain area developed behind the front and it was persistently wet on the 3rd, though amounts were small except in the extreme south-east. Temperature fell rapidly, the maximum at London Airport on the 3rd being 60°F. as compared with 92°F. on the 1st. On the 4th an anticyclone moved north-east across the British Isles being centred over southern Scandinavia by the 6th, and temperature rose again reaching 80°F. in some places on the 5th and 88°F. at Mildenhall on the 6th. The 4th was an unusually sunny day in northern districts; 16·2 hr. was registered at Leuchars. Between the 6th and the 8th a complex depression off our south-west coasts moved north over Ireland and western Scotland. In the early hours of the 6th there was a widespread outbreak of thunderstorms in the south-western half of England and much of Wales; the storms were severe in places and 1·32 in. of rain fell in 72 min. at Minehead. Later that day thunderstorms occurred fairly widely but rainfall was variable. Subsequently pressure was high to the south and low to the north of the British Isles and a westerly type of weather developed which lasted until the 19th. In the southern half of the country there was little or no rainfall during this spell except at some places, chiefly in the south-east, on the 11th. The period 12th–18th was mainly cool. By the 20th a ridge of high pressure extended north-east over the British Isles from the Azores anticyclone and a spell of warm, close, dry weather ensued, though slight rain fell at times, mainly in the west and north of Scotland. From the 26th to the 28th a depression over Iceland moved to a position off Denmark; temperature fell considerably and scattered rain occurred, mostly in the north and east. Drought conditions ended at some places in the south on the 29th when minor troughs of low pressure moving in from the Atlantic brought westerly winds and local rain accompanied by some rise in temperature. At a number of places in the south of England, however, the drought persisted until the end of the month.

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 ...	92	32	+1·6	47	−5	97
Scotland	82	33	+0·6	79	0	114
Northern Ireland ...	75	40	+1·4	55	−3	78

RAINFALL OF JULY 1952

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	0·70	29	*Glam.*	Cardiff, Penylan ...	2·87	93
Kent	Folkestone, Cherry Gdn.	1·12	53	*Pemb.*	Tenby, The Priory ...	1·52	52
,,	Edenbridge, Falconhurst	0·82	36	*Radnor*	Tyrmynydd	1·93	47
Sussex	Compton, Compton Ho.	0·64	23	*Mont.*	Lake Vyrnwy	2·78	78
,,	Worthing, Beach Ho. Pk.	0·79	39	*Mer.*	Blaenau Festiniog ...	3·35	39
Hants.	Ventnor Cemetery ...	0·41	20	,,	Aberdovey	1·88	54
,,	Southampton, (East Pk.)	0·31	14	*Carn.*	Llandudno	1·62	72
,,	Sherborne St. John ...	0·68	30	*Angl.*	Llanerchymedd ...	1·29	45
Herts.	Royston, Therfield Rec.	0·66	26	*I. Man*	Douglas, Borough Cem.	1·41	46
Bucks.	Slough, Upton... ...	0·44	23	*Wigtown*	Newton Stewart ...	2·21	70
Oxford	Oxford, Radcliffe ...	0·29	12	*Dumf.*	Dumfries, Crichton R.I.	2·65	81
N'hants.	Wellingboro' Swanspool	0·45	20	,,	Eskdalemuir Obsy. ...	3·63	89
Essex	Shoeburyness	0·57	31	*Roxb.*	Kelso, Floors	1·53	58
,,	Dovercourt	0·83	41	*Peebles*	Stobo Castle	2·36	81
Suffolk	Lowestoft Sec. School...	1·61	71	*Berwick*	Marchmont House ...	1·42	47
,,	Bury St. Ed., Westley H.	0·95	38	*E. Loth.*	North Berwick Res. ...	1·96	76
Norfolk	Sandringham Ho. Gdns.	0·92	36	*Midl'n.*	Edinburgh, Blackf'd. H.	2·23	79
Wilts.	Aldbourne	0·34	14	*Lanark*	Hamilton W. W., T'nhill	2·46	86
Dorset	Creech Grange... ...	0·96	39	*Ayr*	Colmonell, Knockdolian	2·76	88
,,	Beaminster, East St. ...	0·98	38	,,	Glen Afton, Ayr San. ...	4·84	115
Devon	Teignmouth, Den Gdns.	0·88	38	*Renfrew*	Greenock, Prospect Hill	2·87	78
,,	Cullompton	1·05	39	*Bute*	Rothesay, Ardencraig...	3·76	95
,,	Ilfracombe	1·56	61	*Argyll*	Morven (Drimnin) ...	...	...
,,	Okehampton Uplands...	1·46	45	,,	Poltalloch	4·67	113
Cornwall	Bude, School House ...	0·89	36	,,	Inveraray Castle ...	4·25	85
,,	Penzance, Morrab Gdns.	1·35	50	,,	Islay, Eallabus... ...	3·35	98
,,	St. Austell	1·36	41	,,	Tiree	2·81	78
,,	Scilly, Tresco Abbey ...	2·07	93	*Kinross*	Loch Leven Sluice ...	2·12	74
Glos.	Cirencester	0·19	7	*Fife*	Leuchars Airfield ...	1·62	62
Salop	Church Stretton ...	1·06	40	*Perth*	Loch Dhu	2·95	61
,,	Shrewsbury, Monksmore	0·67	32	,,	Crieff, Strathearn Hyd.	2·24	75
Worcs.	Malvern, Free Library...	1·08	47	,,	Pitlochry, Fincastle ...	1·97	73
Warwick	Birmingham, Edgbaston	1·73	75	*Angus*	Montrose, Sunnyside ...	2·22	84
Leics.	Thornton Reservoir ...	0·55	22	*Aberd.*	Braemar	0·96	37
Lincs.	Boston, Skirbeck ...	0·36	16	,,	Dyce, Craibstone ...	2·20	73
,,	Skegness, Marine Gdns.	0·41	19	,,	New Deer School House	1·91	62
Notts.	Mansfield, Carr Bank...	0·64	24	*Moray*	Gordon Castle	2·37	74
Derby	Buxton, Terrace Slopes	2·97	76	*Nairn*	Nairn, Achareidh ...	1·74	68
Ches.	Bidston Observatory ...	1·13	44	*Inverness*	Loch Ness, Garthbeg ...	2·38	75
,,	Manchester, Ringway...	3·30	119	,,	Glenquoich	6·32	98
Lancs.	Stonyhurst College ...	3·46	89	,,	Fort William, Teviot ...	3·52	72
,,	Squires Gate	1·17	42	,,	Skye, Duntuilm ...	3·00	80
Yorks.	Wakefield, Clarence Pk.	1·15	45	,,	Skye, Broadford ...	2·86	52
,,	Hull, Pearson Park ...	2·53	108	*R. & C.*	Tain, Tarlogie House ...	1·89	69
,,	Felixkirk, Mt. St. John...	1·71	63	,,	Inverbroom, Glackour...	3·68	99
,,	York Museum	1·67	66	,,	Achnashellach	5·71	117
,,	Scarborough	2·24	92	*Suth.*	Lochinver, Bank Ho. ...	3·70	122
,,	Middlesbrough... ...	1·29	50	*Caith.*	Wick Airfield	1·60	61
,,	Baldersdale, Hury Res.	1·33	46	*Shetland*	Lerwick Observatory ...	1·82	79
Norl'd.	Newcastle, Leazes Pk....	0·92	36	*Ferm.*	Crom Castle	1·92	55
,,	Bellingham, High Green	1·57	48	*Armagh*	Armagh Observatory ...	1·70	59
,,	Lilburn Tower Gdns. ...	1·24	50	*Down*	Seaforde	1·51	47
Cumb.	Geltsdale	3·38	98	*Antrim*	Aldergrove Airfield ...	1·73	62
,,	Keswick, High Hill ...	3·99	104	,,	Ballymena, Harryville...	2·04	59
,,	Ravenglass, The Grove	2·63	70	*L'derry*	Garvagh, Moneydig ...	1·87	58
Mon.	Abergavenny, Larchfield	1·36	55	,,	Londonderry, Creggan	2·24	61
Glam.	Ystalyfera, Wern House	2·50	54	*Tyrone*	Omagh, Edenfel ...	1·40	41

M.O. 559 AIR MINISTRY

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RELATION OF ATMOSPHERIC HUMIDITY AT LOW LEVELS OVER THE SEA TO WIND FORCE AND THE DIFFERENCE IN TEMPERATURE BETWEEN AIR AND SEA

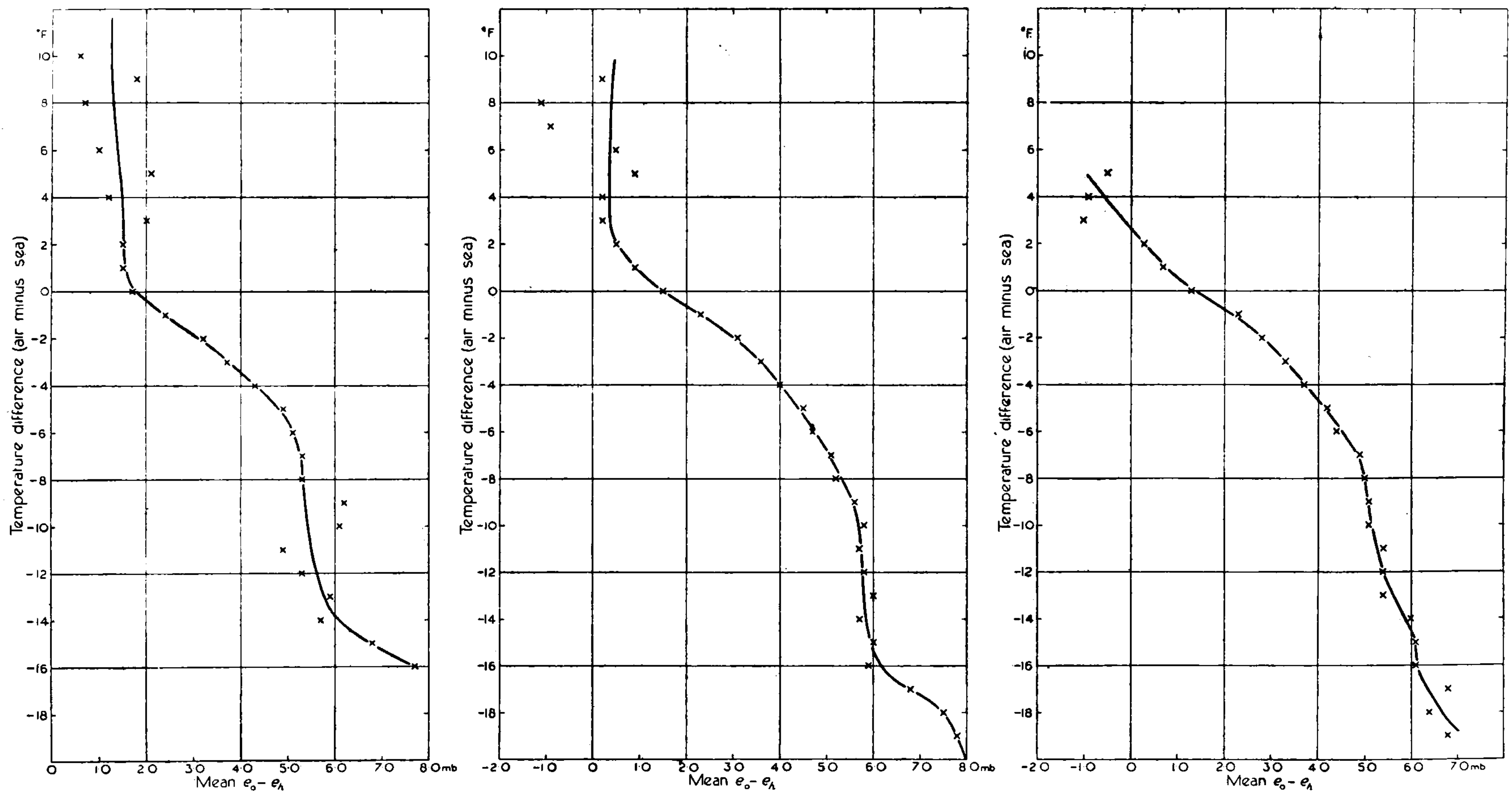
By A. H. GORDON, M.S.

The water vapour that evaporates from the surface of the sea passes first into a laminar layer about 1 mm. thick. Molecular diffusion alone transports water vapour in this layer for no turbulence exists at this level. Above this skin layer, a turbulent boundary layer extends upwards about 100 m., characterized by a logarithmic variation of wind with height and transport by eddy diffusion. Brunt[1] deduces an approximate relation for the height z to which sea-surface conditions will have diffused in time t given by

$$z^2 = 4kt$$

where k is the coefficient of eddy diffusion of the property diffused. Taylor deduced a value of 10^3 for heat diffusion under stable conditions and Brunt quotes 10^5 for "more normal conditions". With stable conditions Taylor found k increased from 1×10^3 with wind force 2 to 3×10^3 with wind force 3. The vertical transfer of heat and water vapour by eddy diffusion is therefore seen to be a function of both lapse rate and wind force.

Vapour pressure.—Tunnell[2] has derived an empirical linear relation between $e_0 - e_h$ and $T_s - T_h$ where e_0 is the saturation vapour pressure at the sea-surface temperature T_s, and e_h is the vapour pressure at the level of the ship's bridge at temperature T_h. It is obvious that these two quantities are related because they are not independent variables; e_0 is dependent on T_s and e_h is limited by its saturation value at T_h. In order to test the validity of Tunnell's linear relationship curves have been drawn (in Fig. 1) of the mean value of $e_0 - e_h$ for each individual whole degree (Fahrenheit) temperature difference (air minus sea) for the three wind-force groups 0–3, 4–6 and >6. All British ocean-weather-ship observations up to the end of 1950 have been used in this analysis. The curves for wind forces 0–3 and 4–6 are fairly similar. A relation approximating to linear occurs from 0° to −6°F. temperature difference (air minus sea) for wind-force group 0–3, and from 3° to −10°F. temperature difference for wind-force group 4–6. Beyond these limits the quantity $e_0 - e_h$ tends to change less markedly, and remains relatively constant as the sea gets increasingly cold with respect to the air. The physical basis for this empirical result can be explained on the grounds that the vertical transfer of water vapour is less under very stable conditions than under unstable conditions, since the coefficient of eddy diffusion decreases with increasing stability. Fig. 1 shows that the curve appears to approximate a linear relation



Wind-force group 0–3

Wind-force group 4–6

Wind-force group >6

FIG. 1—RELATIONSHIP BETWEEN MEAN $e_o - e_h$ AND THE TEMPERATURE DIFFERENCE (AIR MINUS SEA) FOR 3 WIND-FORCE GROUPS

more nearly for wind-force group>6 throughout the temperature-difference range, although there are no values of temperature difference greater than +6°F. to test the relation beyond that limit. This result may be explained on the grounds that strong winds so increase mechanical turbulence near the sea surface, particularly because of the roughness of the sea surface, that under stable conditions water vapour is transported vertically to a greater extent than when the wind is less strong.

Fig. 2 shows the pattern of $e_0 - e_h$ as a function of temperature difference and wind force. Mean values of $e_0 - e_h$ based on less than 10 observations have been neglected in drawing the pattern. The pattern shows that the mean value of $e_0 - e_h$ increases with increasing warmth of the sea with respect to the air and with decreasing wind force.

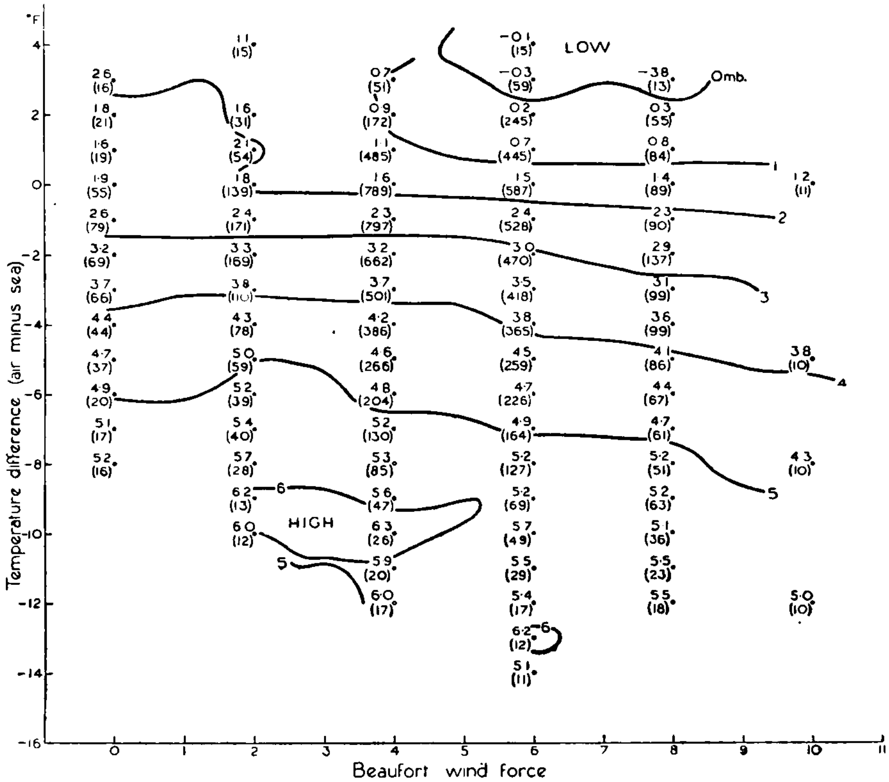


FIG. 2—MEAN VALUES OF $e_0 - e_h$ EXPRESSED AS A FUNCTION OF TEMPERATURE AND WIND FORCE

The numbers in brackets indicate the numbers of observations.

From these results it is clear that care must be exercised in using an empirical linear relation for obtaining e_h irrespective of the temperature difference or the wind force.

Tables, too bulky for publication in the *Meteorological Magazine*, have been prepared in the Meteorological Office, which give the mean vapour pressure for every combination of air and sea temperature observed at the British ocean weather stations.

Relative humidity.—An analysis was made of all British ocean-weather-ship observations up to the middle of January 1951 to determine the distribution of relative humidity as a function of the wind force and temperature difference (air minus sea). The observations were tabulated in groups comprising all combinations of wind force and one degree (Fahrenheit) temperature differences (air minus sea); 50 percentile and 10 percentile values of relative humidity were then computed for each combination and plotted. The isopleths drawn through these values illustrate a pattern of the distribution of relative humidity as a function of the two variables concerned. Patterns showing the percentage frequency of observations within specified 5-per-cent. ranges of relative humidity for each wind force and each (air minus sea) temperature difference were also drawn, together with a curve showing the frequency distribution of all observations within each 5-per-cent. range.

Previously an analysis had been made of the distribution of relative humidity as a function of wind force and wind direction only[3].

Analysis of observations.—The distribution pattern of the 50-percentile value of relative humidity aboard ship is shown in Fig. 3 as a function of wind force and air-minus-sea temperature difference. Values based on less than 10 observations have been disregarded in drawing the pattern. The pattern shows a belt of high relative humidity when the air is the same temperature as or slightly warmer than the sea. It shows a region of low relative humidity with light winds when the air is much colder than the sea, and another less well defined region with light winds when the air is considerably warmer than the sea. The relative humidity tends to increase with increasing wind strength, particularly when the temperature difference is large, either positive or negative.

Fig. 4 shows the 10-percentile frequency pattern of relative humidity also as a function of wind force and temperature difference. Maximum values

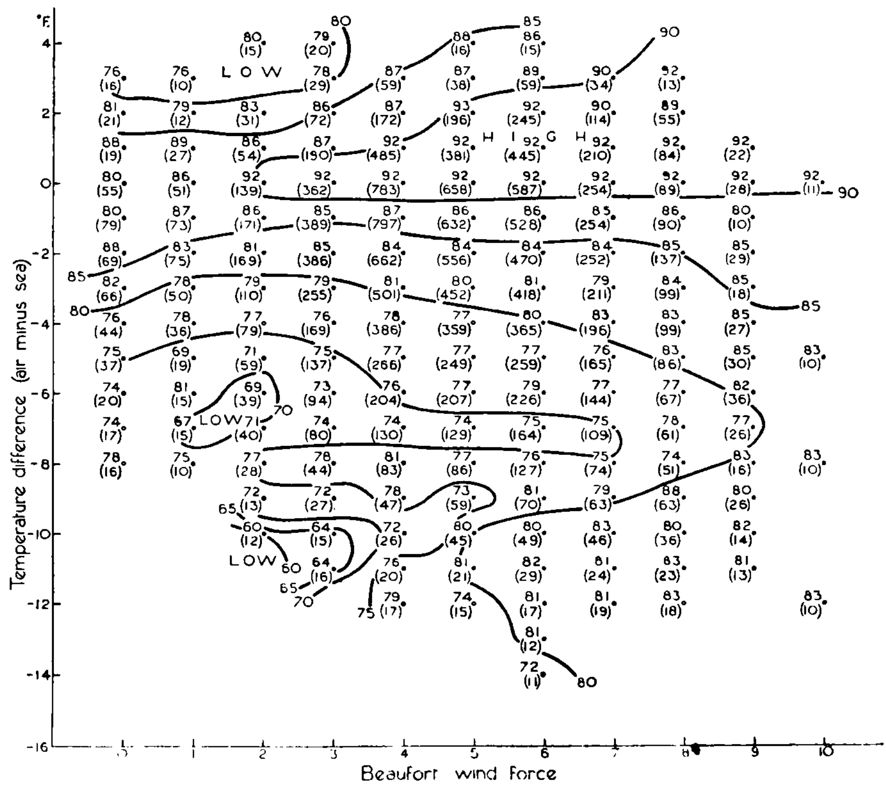


FIG. 3—DISTRIBUTION PATTERN OF 50-PERCENTILE VALUES OF RELATIVE HUMIDITY

The numbers in brackets indicate the numbers of observations.

are centred with wind force greater than 5 when the sea is colder than the air. Minimum values are found with light winds when the sea is 7°F. warmer than the air.

Fig. 5 shows the percentage frequency of observations within 5-per-cent. ranges of relative humidity as a function of the temperature difference. Outstanding features of this pattern are the high frequencies within the 83–93-per-cent. range when the sea is 16°F. warmer than the air, within the 88–98-per-cent. range when the sea is 11–14°F. warmer than the air and also within this range when the sea is from 2° warmer to 4°F. colder than the air. When the sea is 4–10°F. warmer than the air the frequencies are spread out more evenly throughout all ranges and maximum frequencies tend to occur within the 78–83-per-cent. range. The pattern thus brings out the fact that the air is most humid when the sea is more than 12°F. warmer than the air and also when it is colder than the air, and driest when the sea is 4–10°F. warmer than the air.

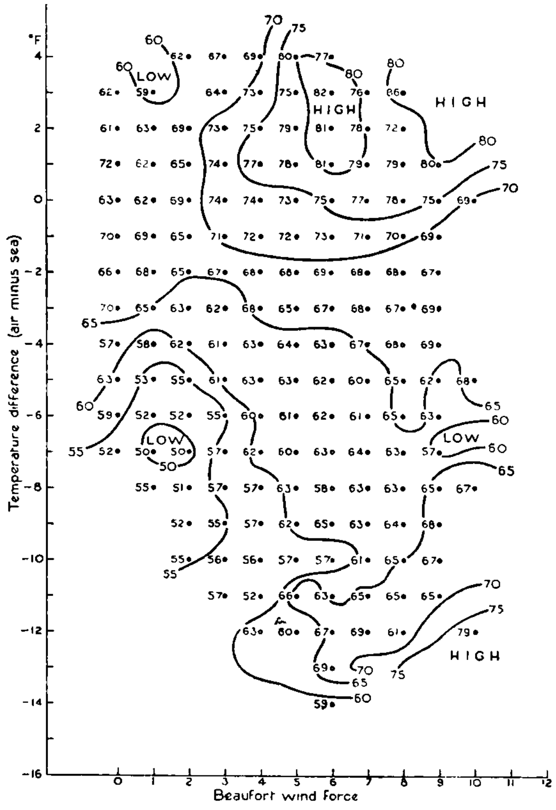


FIG. 4—DISTRIBUTION PATTERN OF 10-PERCENTILE VALUES OF RELATIVE HUMIDITY

The high humidities which are found when the sea is much warmer than the air occur because the saturation vapour pressure of the air is low relative to the sea and is quickly approached as water vapour is transported upward from the sea. The saturation vapour pressure is not approached so rapidly when the temperature difference is less great. When the sea is colder or only a little warmer than the air, the air and sea approach equilibrium conditions and relative humidities are high.

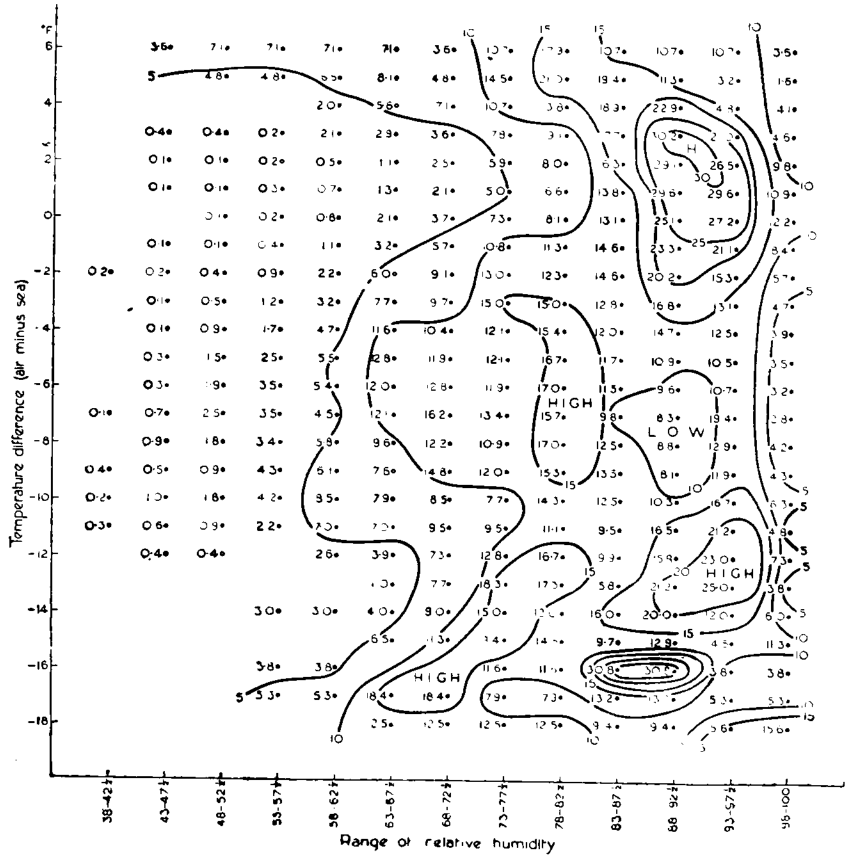


FIG. 5—FREQUENCY PATTERN OF RELATIVE HUMIDITY AS A FUNCTION OF TEMPERATURE DIFFERENCE

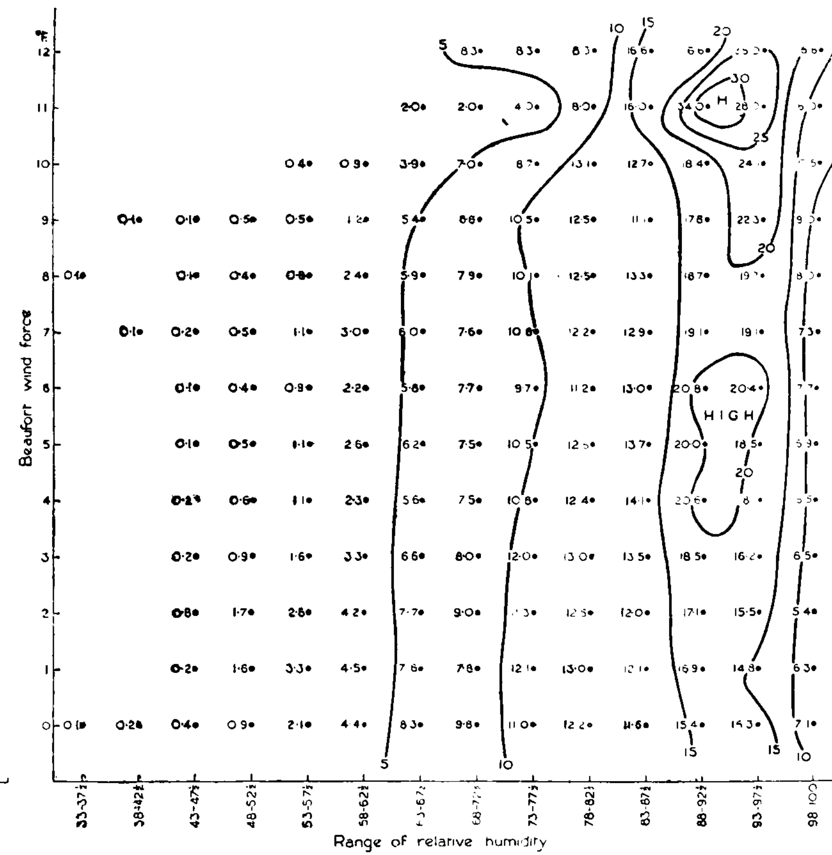


FIG. 6—FREQUENCY PATTERN OF RELATIVE HUMIDITY AS A FUNCTION OF WIND FORCE

Fig. 6 shows the frequency pattern within 5-per-cent. ranges of relative humidity as a function of wind force. Maximum frequencies are found within the 88–98-per-cent. range for all wind forces, but the frequency within this range is greater for strong winds than for light winds. As a whole, frequencies of the lower ranges are greater for light winds and frequencies of the higher ranges are greater for strong winds.

Fig. 7 shows the frequency distribution of the total number of observations within these ranges of relative humidity irrespective of other controlling variables.

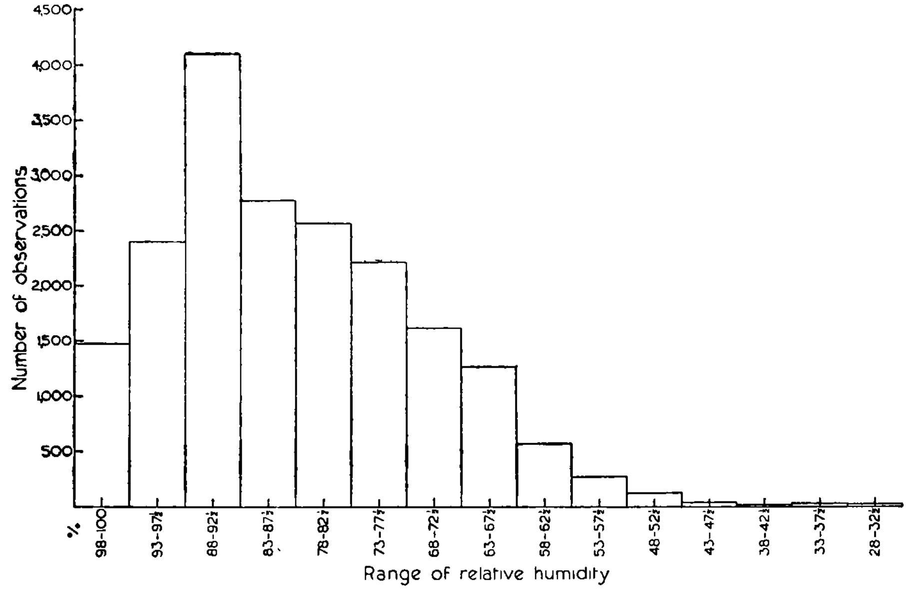


FIG. 7—FREQUENCY DISTRIBUTION OF THE TOTAL NUMBER OF OBSERVATIONS WITHIN 5-PER-CENT. RANGES OF RELATIVE HUMIDITY

Conclusions.—It is evident from the results of the analysis that the relative humidity is controlled by both the temperature difference (air minus sea) and the wind force. Relative humidities tend to be higher with strong winds than with light winds. They tend to be high when the sea is colder than the air and also when the sea is 10°F. or more warmer than the air; they tend to be low when the sea is warmer than the air by less than 10°F.

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2. TUNNELL, G. A.; Vapour pressure over the sea. *Met. Mag., London*, **81**, 1952, p. 77.
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METHOD FOR CALCULATING FROM THE TEPHIGRAM THE THICKNESS OF THE LAYER OF AIR BETWEEN ANY TWO STANDARD PRESSURE LEVELS

By S. A. CASSWELL

The methods usually employed for calculating layer thicknesses compare the plotted temperature curve with either an isotherm or a line of constant potential temperature on a tephigram. In most cases the actual curve is very different from the particular line with which it is being compared, so that it is difficult to estimate accurately the equality of the areas cut off on either side if the layer is more than 100-mb. thick.

By using any straight line the method given here allows a much greater accuracy to be obtained quickly. A correction for water vapour content is quite simple and reasonably accurate. When the height of every 100-mb. level is required this method may have little advantage, but for calculating one or two levels, or for checking figures received in teleprinter or W/T messages, it has proved useful and speedy, and forecast curves on the tephigram can quickly be checked against forecast thicknesses.

Mean temperature calculation.—Any uniform lapse rate is represented on the tephigram by a curve which is very nearly a straight line. Taking it as a straight line gives errors which are negligible, e.g. for the layer 1000–500 mb. the error in mean temperature is between zero and plus 0·15°F.

This figure has been obtained by drawing on a tephigram various lines of constant lapse rate. When the lapse rate is nil, and also when it has the value of the dry adiabatic, the lines are straight. At intermediate values there appears to be a slight deviation, but this is only just discernible on the tephigram, and the error incurred appears to be positive and not greater than 0·15°F.

In any layer of uniform lapse rate a pressure p can be found at which the temperature is equal to that of an isothermal layer of the same thickness, and this pressure varies little with variations of lapse rate and does not vary with temperature. It may be calculated as follows:—

Let I be an isothermal atmosphere of temperature T, and II be an atmosphere of uniform lapse rate β°C./m. with temperature T_0 at pressure p_0.

Consider the thickness z of the layers between pressures p_0 and p_1 in these atmospheres. Let z be measured in metres, temperature in degrees Absolute, and pressure in millibars. Then, from Brunt's "Physical and dynamical meteorology", Chapter II, equations (17) and (19), we have:

in I $$z = 67{\cdot}4\, T(\log p_0 - \log p_1)$$

in II $$\frac{T_0 - \beta z}{T_0} = \left(\frac{p_1}{p_0}\right)^{29.3\beta} \qquad \dots\dots\dots(1)$$

or $$z = \frac{T_0\left\{1 - \left(\frac{p_1}{p_0}\right)^{29.3\beta}\right\}}{\beta}.$$

These thicknesses are equal when

$$T = \frac{T_0\left\{1 - \left(\frac{p_1}{p_0}\right)^{29.3\beta}\right\}}{67{\cdot}4\beta\,(\log p_0 - \log p_1)}. \qquad \dots\dots\dots(2)$$

The height (in metres) at which atmosphere II has this temperature T is $(T_0 - T)/\beta$. The pressure p at this point is given by putting $z = (T_0 - T)/\beta$ and $p_1 = p$ in equation (1) and eliminating T by means of equation (2):

$$\left(\frac{p}{p_0}\right)^{29.3\beta} = \frac{1 - \left(\frac{p_1}{p_0}\right)^{29.3\beta}}{67{\cdot}4\beta\,(\log p_0 - \log p_1)}.$$

Application.—The straight line cutting off equal areas is assumed to have a lapse rate β. When the value of β varies between 0·01 and zero (the dry adiabatic and the isothermal) p varies little. Errors in the mean temperature for variations in the mean lapse rate are likely to be between $-0 \cdot 1^{\circ}$ and $+0 \cdot 1^{\circ}$F., when β is taken as $0 \cdot 005$ as it is in the formula:

$$\left(\frac{p}{p_0}\right)^{0\cdot 1465} = \frac{1 - \left(\frac{p_1}{p_0}\right)^{0\cdot 1465}}{0 \cdot 337 \,(\log p_0 - \log p_1)} ,$$

where p_0 and p_1 are the pressures at the bottom and top of the layer respectively. The value of p for various layers is as follows:

layer 1000–700 mb..........841 mb.

layer 700–500 mb..........595 mb.

layer 1000–500 mb..........714 mb.

The conversion scale in Fig. 1 is calculated from the formula*:

$$\text{Height in feet} = 221 \cdot 1\, T(\log p_0 - \log p_1)$$

where T is the mean virtual temperature in degrees Absolute.

Correction for moisture content.—Let x be the humidity mixing ratio, then x gm. of water vapour are mixed with 1,000 gm. of air. The density of water vapour is 5/8 that of air at the same temperature and pressure.

The masses are in the ratio $x/1{,}000$; thus their pressures are in the ratio $8x/5{,}000$. Since the density of water vapour is 3/8 less than that of air, then the mixture of $8x/5{,}000$ of water vapour to one unit of air reduces the density by $3x/5{,}000$.

For dry air to have the same density as the mixture we are considering, its temperature (T in degrees Absolute) would have to be increased by this fraction. Thus the virtual temperature

$$T' = T\left(1 + \frac{3x}{5000}\right)$$

or
$$T' - T = \frac{3x\,T}{5000} .$$

If $T = 278^{\circ}$A. (5°C.) then $T' - T = x/6$ when temperatures are in degrees Absolute or Centigrade. If $T = 290^{\circ}$A. (63°F.) then $T' - T = x/3 \cdot 2$ when temperatures are in degrees Fahrenheit. Taking for convenience, $T' - T = x/3$ for Fahrenheit temperatures the maximum error is $+0 \cdot 3^{\circ}$F. with temperatures between 40° and 80°F. when the air is saturated, and proportionately less for lower relative humidities.

Thus errors should seldom be as great as $0 \cdot 5^{\circ}$F., which is equivalent to 20 ft. in the layer 1000–500 mb., and no greater than the probable error of observation.

Conclusion.—The practical steps are as follows:—

(i) By means of a straight line on a transparent ruler, estimate any straight line on the tephigram such that the temperature curve between the pressure levels concerned cuts off equal areas on each side of it. The straight line may

* See BRUNT, D.; Physical and dynamical meteorology. 2nd edn, Cambridge, 1939, Chapter II, equation (16).

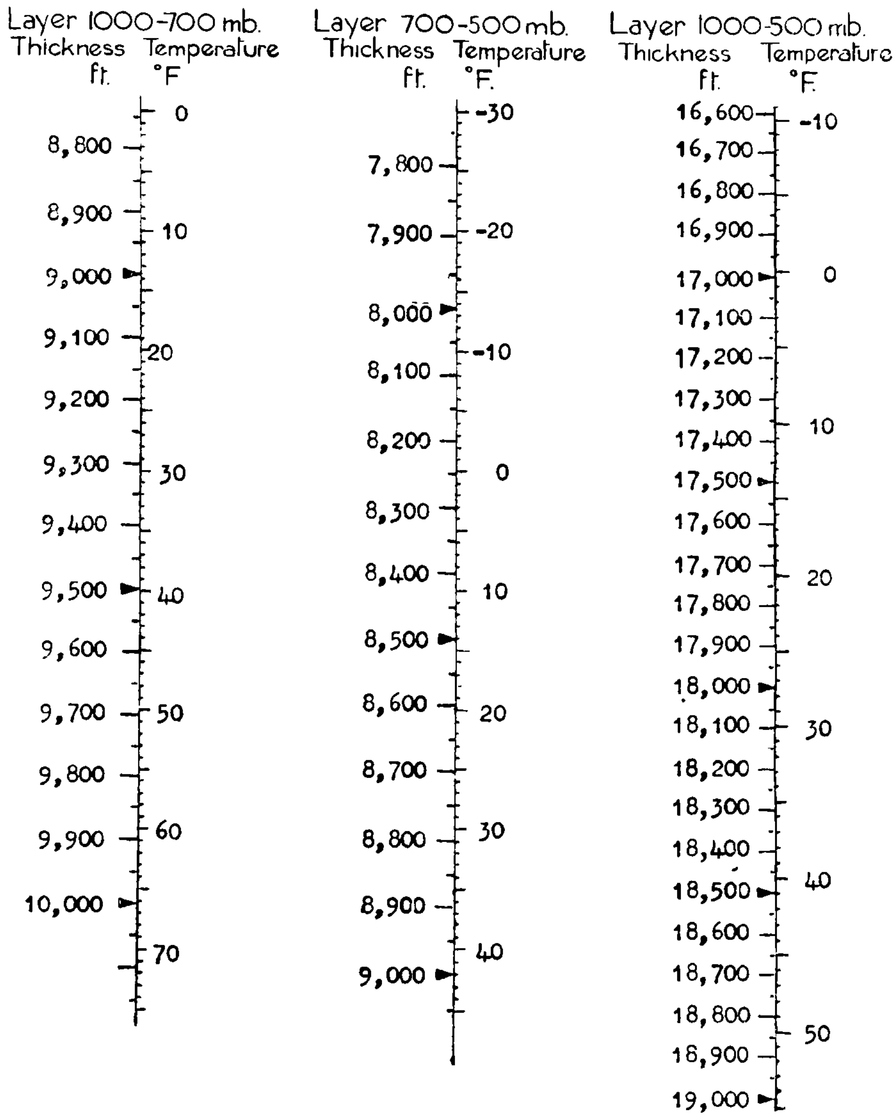

FIG. 1—CONVERSION TABLE

be in any direction, and should be taken so that the areas to be compared are as small as possible.

(ii) Note the temperature at a fixed pressure, p, on this line (for the layer 1000–500 mb., $p = 714$ mb.; for 1000–700 mb., $p = 841$ mb.; for 700–500 mb., $p = 595$ mb.).

(iii) Estimate roughly the mean moisture content of the layer in grammes per kilogramme taking the dew-point temperature instead of the dry-bulb temperature curve. Divide this figure by 3 if the temperatures are measured in degrees Fahrenheit or by 6 if in degrees Centigrade, and add the result to the temperature obtained in step (ii) to obtain the mean virtual temperature of the air column.

(iv) Read off the thickness height corresponding to this temperature on a conversion scale such as is shown in Fig. 1.

ERRATUM

August 1952, PAGE 250, lines 12–15; *delete* "There was a cold front . . . . . Derbyshire."

VERTICAL VARIATION IN TEMPERATURE AND HUMIDITY WITH ON-SHORE AND OFF-SHORE WINDS NEAR THE COAST OF SOUTH-EAST ENGLAND

By R. H. PEDLOW, B.Sc.

Summary.—Hourly values of temperature and vapour density at 1·1, 15·2, 47·2 and 106·7 m. were recorded three miles inland from the coast near Rye, Sussex, over the period July 1945 to June 1948[1]. These hourly values have been used in an examination of the effects of sea passage on the temperature and humidity structure of the atmosphere. The investigation was limited to the summer months, June, July and August, because of the infrequency of on-shore winds at other seasons.

General case of on-shore and off-shore winds.—In the first place, from tabulations of hourly anemograph readings for 10 m., all occasions of on-shore and off-shore winds were selected. Off-shore winds were defined as those between 240° and 50°, and on-shore winds as those between 135° and 210°. Hours when the wind blew from the other sectors—approximately 50 per cent.—were ignored. The first hour of calm after the cessation of an off-shore wind was regarded as being a continuation of that régime, but no similar extension of on-shore winds was made. On-shore winds were not accepted as such until the fetch of wind within the appropriate sector had reached 10 miles, which ensured a sea track of at least 5–7 miles before the air to be sampled crossed the coast; after crossing the coast, the air then had a land track of 3–5 miles, depending on its direction, before reaching the station. The number of occasions of off-shore wind at each hour varied between 110 and 134, but the on-shore winds were few, being never more than 26 at any hour and ranging between 5 and 10 for 12 hours of the day. (It is unfortunate that the commonest direction of a sea breeze at the station is in the sector 210–240° where the length of land track varies rapidly with azimuth.) Caution must therefore be used in the interpretation of the data, and the midday period must be regarded as much more significant than the night hours. As an indication of the reliability of the mean values, probable errors have been calculated for some of the 15·2 – 1·1-m. differences and are given in Table I.

TABLE I—MEAN VALUES OF DIFFERENCES OVER THE INTERVAL 15·2 – 1·1-m. INCLUDING PROBABLE ERRORS

	Temperature difference		Vapour density difference	
	On-shore wind	Off-shore wind	On-shore wind	Off-shore wind
G.M.T.	*degrees Fahrenheit*		*milligrammes per cubic metre*	
0100	+0·4±0·14	+0·9±0·07	−450±110	− 70±27
1200	−1·9±0·14	−1·2±0·08	−900± 56	−500±25

Mean hourly values of temperature, vapour density and vertical differences in these elements were found and tabulated in Tables II and III, which also give the average differences for the three height ranges for on-shore and off-shore winds for the periods 0700–1800, 1900–0600 and 0100–2400 G.M.T.

As one would expect, with few exceptions the on-shore winds show, by comparison with off-shore winds, a higher vapour density at all levels at all hours and a steeper humidity lapse rate at all levels with the difference most marked in the lowest layer. But the on-shore winds also show a generally higher temperature at all levels especially during the midday period, a higher diurnal range of temperature, a higher maximum temperature and a steeper

TABLE II—MEAN HOURLY VALUES OF TEMPERATURE AND TEMPERATURE DIFFERENCES FOR OCCASIONS OF ON-SHORE AND OFF-SHORE WINDS DURING SUMMER MONTHS

	ON-SHORE WINDS					OFF-SHORE WINDS				
	Temperature at 1·1 m.	Temperature difference* over height intervals (m.) 15·2 −1·1	47·2 −15·2	106·7 −47·2	No. of hours	Temperature at 1·1 m.	Temperature difference* over height intervals (m.) 15·2 −1·1	47·2 −15·2	106·7 −47·2	No. of hours
G.M.T.		*degrees Fahrenheit*					*degrees Fahrenheit*			
0100	55·8	+0·4	+0·1	+0·8	5	53·2	+0·9	+0·4	+0·4	124
0200	54·6	+0·4	+0·1	0·0	9	52·7	+0·9	+0·4	+0·6	125
0300	54·6	+0·5	+0·3	+0·3	11	52·2	+0·9	+0·6	+0·3	124
0400	54·6	+0·3	0·0	0·0	10	51·9	+1·0	+0·4	+0·5	124
0500	55·8	+0·1	−0·2	+0·1	7	52·7	+0·5	+0·4	+0·5	129
0600	56·9	−0·2	−0·3	−0·1	8	54·6	−0·1	−0·3	+0·3	132
0700	56·8	−0·6	−0·4	−0·2	8	56·6	−0·2	−0·8	−0·1	134
0800	59·4	−0·8	−0·7	−0·2	11	59·6	−1·4	−1·1	−0·4	130
0900	64·6	−1·3	−0·8	0·0	11	61·0	−1·1	−1·2	−0·5	128
1000	65·7	−2·0	−1·0	−0·2	13	61·7	−1·3	−1·2	−0·5	122
1100	69·1	−1·9	−1·2	−0·4	17	62·3	−1·4	−1·2	−0·6	117
1200	70·5	−1·9	−1·1	−0·6	25	63·0	−1·2	−1·2	−0·7	113
1300	70·3	−1·8	−1·4	−0·4	24	63·4	−1·3	−1·3	−0·5	110
1400	69·7	−1·6	−1·2	−0·4	26	63·9	−1·2	−1·2	−0·6	111
1500	69·3	−1·7	−0·9	−0·4	25	63·1	−0·8	−1·0	−0·5	114
1600	68·8	−1·6	−0·6	−0·5	22	62·8	−0·6	−1·0	−0·6	113
1700	66·3	−1·2	−0·8	−0·4	20	62·2	−0·4	−0·9	−0·5	111
1800	63·1	−0·8	−0·7	−0·4	20	60·7	−0·1	−0·7	−0·5	111
1900	59·5	−0·2	−0·4	0·0	15	58·4	+0·4	−0·4	−0·3	115
2000	57·8	+0·3	0·0	+0·5	10	56·3	+0·8	−0·1	−0·1	115
2100	57·6	+1·2	+0·3	+0·8	10	55·1	+1·0	+0·1	+0·2	113
2200	58·9	+0·5	+0·3	+1·6	6	54·5	+1·1	+0·3	+0·3	117
2300	58·6	+0·3	0·0	+1·1	7	53·9	+1·2	+0·3	+0·3	118
2400	56·9	+0·4	+0·2	+0·9	6	52·6	+1·7	+0·2	+0·5	120
12-hr. averages 0700–1800	66·1	−1·4	−0·9	−0·3	...	61·7	−0·9	−1·1	−0·5	...
1900–0600	56·8	+0·3	0·0	+0·5	...	54·0	+0·9	+0·2	+0·3	...
24-hr. average 0100–2400	61·5	−0·6	−0·4	+0·1	...	57·9	0·0	−0·4	−0·1	...

* Increase of temperature with height is reckoned as positive.

lapse rate in the lowest layer, none of which can be ascribed to the effect of the sea.

There are two possible explanations, not mutually exclusive and probably both contributing to the effects: (i) a number of sea breezes are included in the on-shore winds during daylight hours, so that selection of occasions of on-shore winds is, in part, a selection of fine days with a high maximum temperature; (ii) those on-shore winds which are not local sea breezes but are part of a general southerly air stream, must reflect the influence not only of the sea-crossing but also of the more remote history of the air mass. Generally speaking, southerly air has a greater overall stability than northerly, and larger diurnal range and higher day-maximum temperature are consequences of that comparative stability which is perhaps discernible in the layers above 15 m., though the difference between the on-shore and off-shore winds in these layers is too near the probable error of the temperature differences concerned to be confidently quoted as evidence. The greater stability above 15 m. of the on-shore as compared with the off-shore wind—whether a consequence of air-mass characteristics or of shallow sea breezes—by retarding the convective dispersal of water vapour, must contribute to the maximum of vapour density with on-shore winds being later and higher in value than the maximum with off-shore winds, and must assist in bringing about the steep low-level humidity lapse rate which at first sight is attributable solely to the sea-crossing.

TABLE III—MEAN HOURLY VALUES OF HUMIDITY AND HUMIDITY DIFFERENCES FOR OCCASIONS OF ON-SHORE AND OFF-SHORE WINDS DURING THE SUMMER MONTHS

	ON-SHORE WINDS				OFF-SHORE WINDS			
	Vapour density at 1·1 m.	Vapour-density difference* over height intervals (m.) 15·2 −1·1	47·2 −15·1	106·7 −47·2	Vapour density at 1·1 m.	Vapour-density difference* over height intervals (m.) 15·2 −1·1	47·2 −15·1	106·7 −47·2
G.M.T.	*milligrammes per cubic metre*				*milligrammes per cubic metre*			
0100	9,380	−450	−400	−290	9,340	− 70	−250	−160
0200	9,530	−250	−310	−330	9,170	− 60	−230	−100
0300	9,570	−240	−380	−120	9,110	− 50	−170	−100
0400	9,550	−330	−370	−190	9,110	− 10	−150	− 90
0500	9,860	−420	−480	−100	9,310	− 90	−160	− 80
0600	10,720	−440	−250	−140	9,780	−360	−220	− 90
0700	10,590	−550	−130	−180	10,300	−520	−340	−180
0800	10,390	−580	−230	− 80	10,330	−630	−260	−120
0900	11,670	−760	−240	−130	10,050	−580	−270	− 40
1000	11,020	−670	−300	−140	9,840	−550	−280	− 40
1100	11,450	−820	−430	− 80	9,790	−490	−350	− 90
1200	11,740	−900	−590	−110	9,790	−500	−310	−120
1300	11,020	−750	−400	− 90	9,700	−490	−280	−100
1400	10,990	−790	−420	−140	9,890	−510	−290	−100
1500	10,660	−800	−260	−250	9,700	−430	−290	− 70
1600	10,920	−940	−320	−210	9,610	−430	−250	− 70
1700	10,560	−620	−250	− 90	9,570	−420	−280	− 60
1800	10,100	−510	−260	− 90	9,510	−380	−250	− 80
1900	10,090	−450	−260	+100	9,470	−340	−270	− 90
2000	10,090	−300	−250	+110	9,370	−230	−270	−130
2100	10,210	−220	−470	−190	9,400	−150	−290	−150
2200	10,570	−230	−300	−190	9,390	−120	−310	−200
2300	10,440	−300	−190	−170	9,310	− 70	−310	−200
2400	9,770	−530	−290	−160	9,160	− 30	−260	−140
12-hr. average								
0700–1800	10,930	−720	−320	−130	9,840	−490	−290	− 90
1900–0600	9,980	−350	−330	−140	9,330	−130	−240	−130
24-hr. average								
0100–2400	10,450	−540	−320	−140	9,580	−310	−260	−110

* Increase of vapour density with height is reckoned as positive.

Selected occasions.—Since selection of on-shore winds is thus partially a selection of a particular air mass, the results so far discussed are applicable only to the eastern part of the south coast of England, and for that reason a different approach was made. Occasions had been noticed when sudden changes occurred in the relative-humidity traces simultaneously with changes in wind direction across the line of the coast. After elimination of occasions which were or might have been associated with precipitation or change in the general air mass, there remained 13 examples, all of which occurred during the period 0900–1800 G.M.T. In the following discussion of these 13 cases, "on shore" and "off shore" are not limited by their definition on p. 299.

Values of mean temperature and humidity were found for the 10-min. nearly steady periods immediately before and after the change (which occupied an interval of from 10 to 50 min.). Average values of temperature and humidity and of differences in these elements for the 13 occasions are given in Table IV.

TABLE IV—MEAN VALUES OF TEMPERATURE AND HUMIDITY DERIVED FROM 13 OCCASIONS OF SUDDEN WIND CHANGE IN SUMMER

	Temperature at 1·1 m.	Temperature difference over height intervals (m.) 15·2−1·1	47·2−15·2	106·7−47·2	Vapour density at 1·1 m.	Vapour-density difference over height intervals (m.) 15·2−1·1	47·2−15·2	106·7−47·2
		degrees Fahrenheit				*milligrammes per cubic metre*		
On-shore wind	65·7	−1·5	−1·0	+0·2	10,850	−660	−310	0
Off-shore wind	68·7	−1·3	−1·2	−0·3	10,070	−830	−290	−30
Difference*	−3·0±0·5	−0·2±0·2	+0·2±0·1	+0·5±0·1	780±100	+170±100	−20±80	+30±50

* on-shore minus off-shore values.

To estimate the possible influence of diurnal change on the difference in profile which we ascribe to change from land track to sea track, the mean changes in temperature and humidity over the 13 periods between the initial and final steady states were found from curves of diurnal change for clear days in summer[1]. The effect of diurnal variation in vertical temperature difference was less than 0·05°F. over all the height intervals, and in humidity difference +20 mg./m.^{3} over the 15·2 − 1·1-m. interval, and −10 mg./m.^{3} over the 47·2 − 15·2-m. and 106·7 − 47·2-m. intervals, i.e. sufficiently smaller than the change in the values of these differences from off-shore to on-shore, except in the latter two instances where the degree of uncertainty already precludes discussion.

The number of occasions is small and the scatter considerable, but as far as temperature is concerned, the changes in lapse rate between on-shore and off-shore winds were fairly uniform in sense and agree well with the model of the air over the sea, initially unwarmed compared with that over the land replacing the latter and undergoing heating in the lowest layer; whilst the undercutting of the warm air by the cold produces, soon after its inception and at a few miles from the sea, a mixing zone and inversion a little below 100 m.

On-shore winds show the expected increased vapour density at all heights; on only one day was the sea air the drier, and this was the warmest of the selected days when transpiration apparently exceeded evaporation from the sea. The contrast between on-shore and off-shore winds in respect of vertical differences of humidity is small, the scatter is large, and the sense of the average difference is reproduced in only half of the individual cases. In short, no significant pattern emerges.

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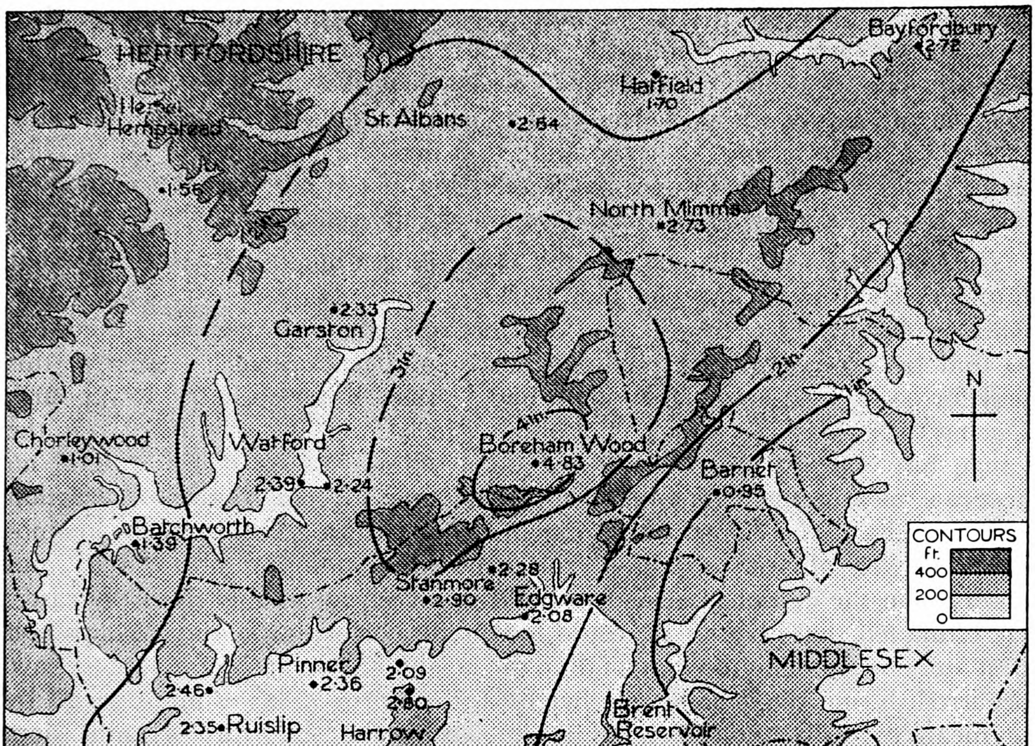
STORM OF AUGUST 6, 1952, CENTRED OVER BOREHAM WOOD

A very intense rainstorm accompanied by thunder and lightning occurred over an area in Hertfordshire and Middlesex on the evening of August 6, 1952. Accounts which appeared in the press, describing the damage due to flooding and lightning, indicated that the rainfall was of very unusual intensity. Moreover, the occurrence aroused particular interest among drainage engineers, since much of the precipitation, which seems to have been entirely in the form of rain, fell on built-up areas and gave rise to an exceptionally severe test of storm-water drainage systems.

In many places there were thunderstorms or thundery showers in the afternoon, but over the area under consideration the bulk of the day's rainfall, measured for the 24 hr. beginning at 0900 G.M.T. on the 6th, fell during a short time between 1800 and 2000 G.M.T. on that day. The 24-hr. totals are plotted on the accompanying map, with tentative isohyets drawn at 1-in. intervals. More than 2 in. fell in an irregular area extending from Ruislip to Ware and possibly beyond, and from Willesden to St. Albans. The area which received 3 in. or more cannot be accurately defined since, with one exception, there were no records of falls exceeding 2.90 in. The exception was the fall of 4·83 in. recorded by the gauge at Boreham Wood, which, according to reports of flooding



AREAS OF HEAVIEST RAINFALL DURING STORM OF AUGUST 6, 1952

and eye-witness accounts of the rain as it fell, must have been very near the centre of the storm. This fall exceeded any previously recorded in one rainfall day in Hertfordshire or in any of the bordering counties.

The thunderstorms developed in the central area of a small depression which moved northwards from France. During the afternoon temperature rose to 75–78° over much of southern England with a dew point about 60°F. The air at the surface and at 950 mb. could rise to the tropopause at about 37,000 ft., but the lapse rate above 850 mb. (5,000 ft.) only averaged very slightly above the saturated adiabatic. To the north of the area most affected there was less sunshine and a slightly lower temperature, and this difference became accentuated after the first storms broke out just north of the hottest region. By 1800 there was a well marked line of convergence between a light southerly wind over south-east England and a cooler ENE. wind over East Anglia and the Midlands. In the next hour or two cool NE. – N. surface winds spread over the storm area, opposing the weak south-westerly upper current in which the clouds drifted. There must have been a rapid building up of fresh cumulonimbus cells on the south-west boundary of the storm. The approach of a poorly defined cold front from south-west probably increased the convergence, producing the pincer movement characteristic of the heaviest rainstorms.

A number of autographic records are available for analysing the timing of the storm, and in addition some observers with standard gauges made special readings covering the period of most intense rain. From the evidence thus brought together it appears that in several places the falls merit the duration-intensity classification of "very rare", which describes a fall such as is likely to occur at any one station not more than once in 160 yr.[1] At other places the falls were "remarkable", corresponding to a frequency of not more than once in 40 yr. The following notes give a selection of the most intense individual falls for which the records can be accepted as fully reliable:—

Boreham Wood.—Mr. Court, rainfall observer at Furzehill Road, wrote that thundery showers occurred in the afternoon from about 1430 to 1700 G.M.T. Rain ceased for about 45 min. and then began again with increasing intensity, so that by 1800 it was "exceedingly heavy and continuous", lasting in this way for 90 min. or more. By 2000 it had "abated to an ordinary downpour". During the storm it was noted that about 4 in. of rain had accumulated in the gauge but efforts were concentrated on avoiding loss by overflow, and no accurate measurement was made until the time for the routine observation next morning. Mr. Court also commented that "during the storm the anemometer slowed almost to a stop, the wind vane pointing north, but from observation the cumulus seemed to build up overhead mainly from the east". He estimated that about 1 in. could have fallen before 1800 and perhaps half that amount after 2000 so that a fall in the neighbourhood of 3·25 in. must have occurred during the 2 hr. at the height of the storm. This estimate seems by no means excessive and such a fall lies well within the "very rare" classification. It could not be expected to occur, at any one station, more than once in two or three centuries. The photograph facing this page shows the main street, Shenley Road, where flood-water reached a depth of about 2 ft. In Furzehill Road the water was 15 ft. wide and nearly 1 ft. deep, flowing down the slope "fast enough to make it difficult to walk through".

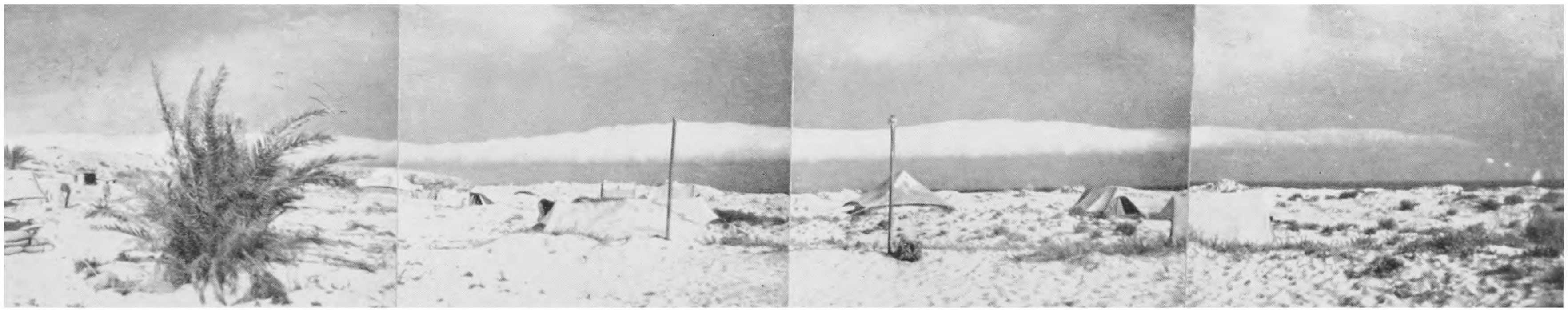
Harrow.—Mr. Hyla Greves, Welldon Crescent, recorded a "very rare" fall of 2·80 in. in 2 hr. between 1840 and 2040 G.M.T. This observation was supported by another reading of 2·87 in. in the same time only a short distance away.

Wembley.—The gauge at the Town Hall recorded 2·67 in. for the rainfall day. There was no preliminary shower in the afternoon at Wembley, and the chart from the autographic gauge shows a "very rare" fall of 2·00 in. in 30 min. from 1910 to 1940 G.M.T.

Stanmore and Edgware.—A fall of 2·70 in. at Harrow Council Offices, Stanmore, has been widely reported as having occurred in 45 min. duration, this having been obtained from a first reading of the chart. This would have qualified for the classification "very rare". Examination of the autographic chart showed,

Reproduced by courtesy of H. T. Court

FLOODING AT SHIRLEY ROAD, BOREHAM WOOD, HERTS., AUGUST 6, 1952
The water is above the bottom of the bus radiator; it was still raining when the photograph was taken (see p. 302).



Reproduced by courtesy of E. A. Lunson

LINE SQUALL AT SANYET EL QUTEIFIYA ON THE COAST OF THE WESTERN DESERT, EGYPT, APRIL 1942.

On this particular morning the weather was overcast and squally. The photograph was taken about 0800 and shows the long cloud over the beach and running out to sea. About 20–25 min. later the squall hit the encampment, and although no damage was done it was very gusty and squally for about 15 min. with local rising sand and sudden wind shift. A similar squall, which occurred about 2100 led to local sandstorms.

Photos by R.A.F.

1428 G.M.T.

1435 G.M.T.

ROLL CLOUD WITH PASSAGE OF LINE SQUALL OVER SOUTH FARNBOROUGH, NOVEMBER 6, 1947

(see p. 316)

EDDIE STRUCTURE OBSERVED TOWARDS THE NORTHERN EDGE OF A CUMULONIMBUS CELL, LOOKING NORTH-WEST FROM TENGAH AIRFIELD
(see p. 314)

Reproduced by courtesy of J. Waling

ROLL CLOUD PHOTOGRAPHED FROM T.E.V. *Beaverlake* AT 2155, JULY 14, 1951 AT 52°01′N., 53°40′W.
(see p. 317)

however, that the pen had not recorded correctly throughout the storm, and the timing of the fall has had to be re-estimated from other evidence. Instrumental records from Stanmore (Meteorological Office Training School) and Edgware were used, together with eye-witness accounts of the storm. The revised estimates are:—

> 24-hr. fall 2·90 in., of which 2·60 in. fell during the evening storm, probably in 1½–2 hr. beginning at 1830 G.M.T.; about 90 per cent. of this, say 2·35 in., probably fell in 1 hr. 15 min. beginning at 1845 G.M.T.

This is a "remarkable" fall which just fails to reach the "very rare" classification. The records from the Meteorological Office Training School and from Edgware both showed "remarkable" falls, the former 2·00 in. in 1 hr. 15 min. starting at 1845 G.M.T. (24-hr. total 2·28 in.) and the latter 2·08 in. in the same time starting at 1830 G.M.T., with 1·75 in. of this amount in the first 40 min.

Garston, near Watford (Department of Scientific and Industrial Research Building Research Station).—From a fall of 2·34 in. in 5 hr. beginning at 1630 G.M.T., 1·61 in. fell in 45 min. between 1740 and 1825 G.M.T. The most intense part of the fall ranks as "remarkable".

Other "remarkable" falls were reported from Brent Reservoir, Ruislip, and Eastcote Lane, Harrow. Among the larger falls in 24 hr. were 2·73 in. at North Mimms, which is known not to have included a "remarkable" fall, and 2·72 in. at Bayfordbury.

This account has been assembled with the aid of records contributed by official Meteorological Office stations, other official and public bodies, and many voluntary private observers, some of whom, on realizing that the storm would be of unusual interest, were able to take special and careful note of events as they occurred.

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FREQUENCY OF SPELLS OF LIGHT WIND

By A. F. JENKINSON, B.A.

The average number of spells of light wind (Beaufort force less than 4 at all reported observations) in a period of N days that last for x or more days can be expressed in the form $Nf^{x+1} \log_e(1/f)$, where f is the average frequency of light winds.

The average monthly frequencies of spells of light wind at Brindisi were obtained from data for the period 1935–37 and 1939 (observations at 0700 and 1800), and the average monthly frequencies during the winter and summer months at Malta (Luqa) were obtained from hourly records for the period July 1947–February 1952. The lengths of spells were measured in units of hours. Spells of length $\geqslant$ 24 hr., $\geqslant$ 48 hr., etc., were then recorded as $\geqslant$ 1 day, $\geqslant$ 2 days, etc. The average percentage frequencies of light wind, from the same observations, were:—

	%
Brindisi, average during the year	72
Luqa, average during winter (December–February) ...	52
Luqa, average during summer (July–August)	83

The frequencies are plotted on a logarithmic scale against the length of spell in Fig. 1, and it will be seen that the points obtained lie on straight lines with slopes of 0·14 ($= \log_{10} 1/0{\cdot}72$) for Brindisi, 0·28 ($= \log_{10} 1/0{\cdot}52$) for Luqa in winter and 0·08 ($= \log_{10} 1/0{\cdot}83$) for Luqa in summer.

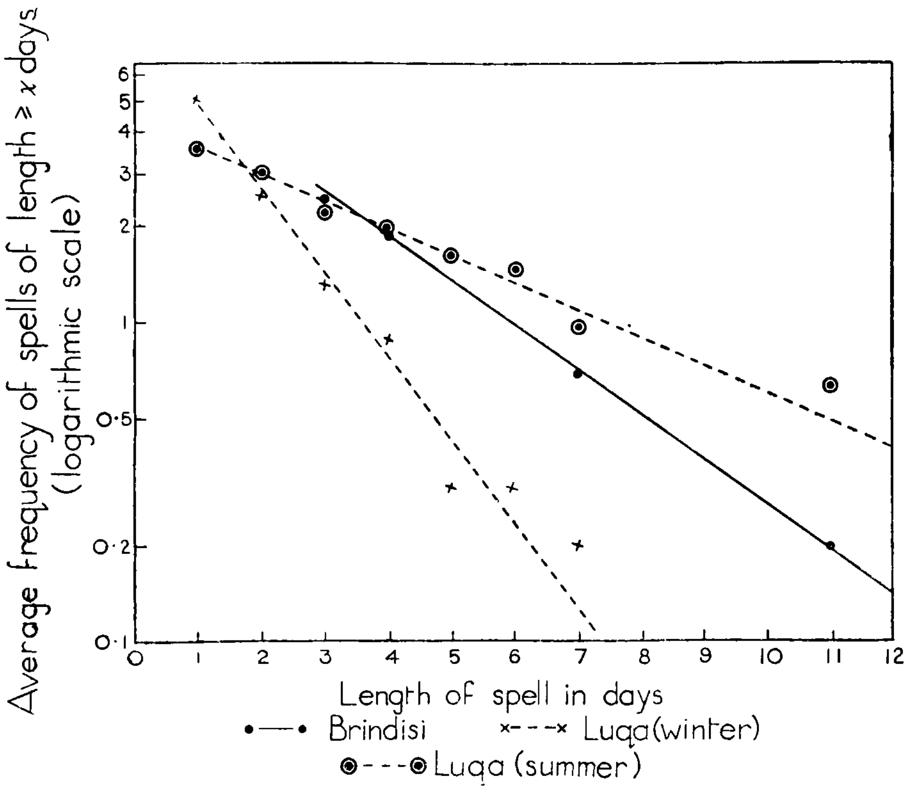

FIG. 1—RELATION BETWEEN THE NUMBER OF SPELLS PER MONTH WITH LENGTH GREATER THAN OR EQUAL TO x DAYS, AND x

This leads one to propose the statistical model

$$f' = kf^x,$$

where f' is the frequency in a period of N days of spells of light wind lasting for x or more days and f is the average frequency of light winds (k is a constant).

Then the number of days taken up by spells of x to $x + dx$ days is

$$-x \frac{d}{dx} (kf^x)\, dx$$

Therefore

$$Nf = \int_0^\infty -x\, d(kf^x)$$

$$= \int_0^\infty kf^x dx$$

$$= \frac{k}{\log_e \frac{1}{f}}$$

Therefore $$k = Nf \log_e \frac{1}{f}$$

i.e. $$f' = Nf^{x+1} \log_e \frac{1}{f}$$

Taking $N = 30$ days for a monthly interval, Table I gives the number of spells of 3, 4–6, 7–10, 11–20, and > 20 days for $f = 0{\cdot}40, 0{\cdot}45, 0{\cdot}50 \ldots\ldots\ldots 0{\cdot}90$, together with the number of spells of duration three days or more and the length of spell which is most likely to occur once. Table II gives a comparison of observed and theoretical frequencies for Brindisi and Luqa.

TABLE I—THEORETICAL FREQUENCY OF SPELLS OF LIGHT WINDS IN PERIODS OF 30 DAYS

f	Spells of duration, days 3	4–6	7–10	11–20	>20	⩾3	Most probable longest spell
	Number of spells in 30 days						*days*
0·40	0·42	0·26	0·02	0	0	0·70	2·6
0·45	0·54	0·40	0·04	0	0	0·98	3·0
0·50	0·65	0·57	0·08	0·01	0	1·31	3·4
0·55	0·73	0·75	0·14	0·01	0	1·63	3·8
0·60	0·79	0·93	0·22	0·03	0	1·97	4·3
0·65	0·79	1·07	0·33	0·07	0	2·26	4·9
0·70	0·77	1·18	0·47	0·12	0	2·54	5·6
0·75	0·68	1·18	0·59	0·26	0·01	2·72	6·4
0·80	0·55	1·01	0·66	0·41	0·02	2·65	7·2
0·85	0·38	0·83	0·63	0·55	0·05	2·44	8·1
0·90	0·21	0·50	0·45	0·58	0·15	1·89	9·0

TABLE II—FREQUENCY OF SPELLS OF LIGHT WINDS AT BRINDISI AND LUQA

BRINDISI $f = 0{\cdot}72$ Length of spell	Observed frequency	Theoretical frequency	LUQA (winter) $f = 0{\cdot}52$ Length of spell	Observed frequency	Theoretical frequency	LUQA (summer) $f = 0{\cdot}83$ Length of spell	Observed frequency	Theoretical frequency
days			*days*			*days*		
⩾ 3	2·6	2·5	⩾ 1	5·0	5·3	⩾ 1	3·6	3·6
⩾ 4	1·8	1·9	⩾ 2	2·6	2·7	⩾ 3	2·3	2·5
⩾ 7	0·7	0·7	⩾ 3	1·3	1·4	⩾ 7	0·9	1·1
⩾11	0·2	0·2	⩾ 4	0·9	0·8	⩾11	0·8	0·5
⩾21	0	0	⩾ 5	0·3	0·4	⩾21	0·1	0·04
			⩾ 6	0·3	0·2			
			⩾ 7	0·2	0·1			

A STANDING WAVE AT DUNSTABLE

By G. H. LEE and O. W. NEUMARK

Introduction.—The top of the hill above the London Gliding Club site at Dunstable is about 250 ft. above the ground to the north-west, and the average slope is about 1 : 2½. The slope faces about 15° north of west. Launches by winch to over 800 ft. can now be obtained by gliders in easterly winds, whereas previously power cables prevented launches of more than 300 ft. above the site. Only once, until recently, was lift found to the lee of the slope in a south-easterly wind, and then, in 1937, with a wind direction of 160° on the surface veering to 225° at 2,500 ft. Neumark observed a visible standing wave three times in 1947 in easterly winds, before the higher launches could be made; and then, as on the occasion described below, there was a temperature inversion at less than 3,000 ft. Twice there was a bank of fog on top of the ridge which dissolved and reformed again in a line parallel to the ridge, and once there was a haze layer at about 1,500 ft. whose undulations became visible and there was a darkening of the haze over Totternhoe. It is now well known that standing waves occur at Dunstable far more frequently than was once supposed; most often they are marked by clear breaks in an overcast sky.

Flight of September 22, 1951.—The early part of the day was sunny but towards the end of the afternoon a layer of what appeared to be thin medium cloud gradually thickened. No appreciable thermal activity was noticed at all by Lee during the day in several flights with pupils in a T.21B 2-seater glider. The launch was towards the hill and directly in the lee of it, and nothing especially remarkable was noticed until about 1700 G.M.T. when it was observed that a pupil practising turns near the Tring Road lost less height than was expected.

Later, at about 1730, the phenomenon was investigated by another pupil by flying a few beats up and down the Tring Road. In this case reduced sink, corresponding to an upward air velocity of 2 ft./sec., was found (taking the sinking speed of the T.21B as 3 ft./sec.).

The surface wind at 1800 was about 110°, 10–12 kt., and had increased, and at 1805 Lee and Neumark were launched in J. E. Furlong's *Dragonfly*. The light was already waning. The cable was released at 900 ft., and it seemed that there was an appreciable strengthening of wind between 700 and 1,000 ft. above the site. At 1,500–2,000 ft. the wind appeared to have veered to about 140–150°, 15–20 kt., but even so all the radio-sonde winds at Downham Market and Larkhill at 1500–2100 G.M.T. showed a much more southerly wind, and it seems cannot be taken as representative of the winds near Dunstable, for the Chilterns appear to deflect the wind from its general direction on many occasions.

After flying directly down wind, lift was found after crossing the Tring Road, and several beats at heights between 1,500 and 2,200 ft. were made up and down to find the extent of the area of lift, which is shown in Fig. 1. The magnitude of the lift was steadily increasing during the flight, and the vertical air velocity reached about $5\frac{1}{2}$ ft./sec. at a height of 2,200 ft. above the launching point, i.e. at about nine times the height of the hill.

A sharply defined haze layer could be seen and was estimated to lie at about 2,500 ft. above the launching point, but no undulation in the haze top could be detected from 2,200 ft. In spite of the continuous lift it was necessary to break off the ascent because of approaching darkness. Descent was made mainly in tight circles in the down-current over the slope, and the landing was assisted by car headlights at 1840.

A Tutor sailplane, flown by A. Doughty, landed one minute later after reaching 1,500 ft. from a later launch.

The following is extracted from an account of the phenomenon by A. Doughty:—

"I had never heard of a wave before but had often heard the Club's ground engineer, Mr. Walker, talk about being able to fly right out to Totternhoe at sundown without much loss of height when the katabatic wind begins to blow. On this particular day shortly after 1700 G.M.T. the wind-sock was hanging limply round the mast; about 20 min. later it started to fill out again

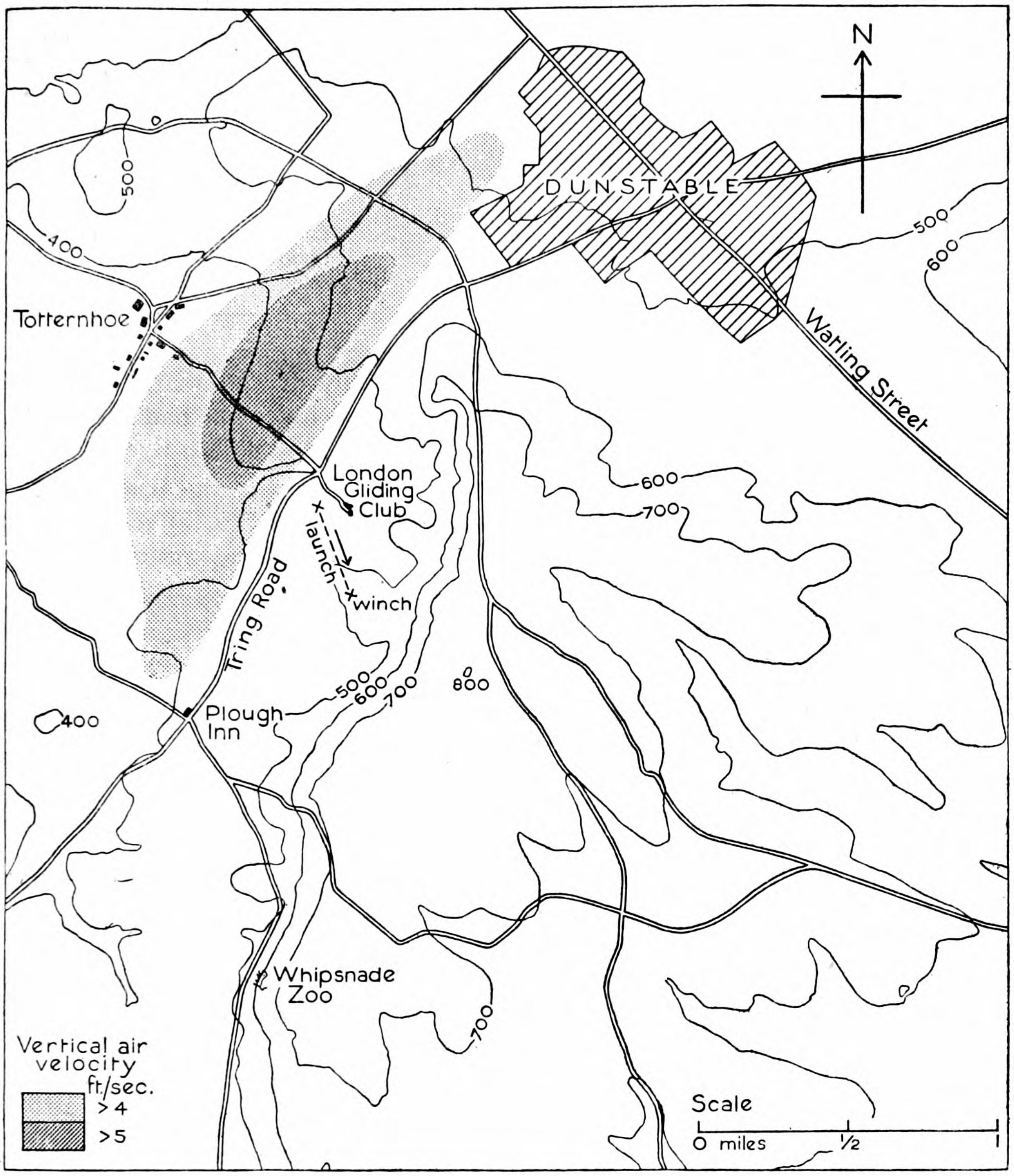

FIG. 1—MAP SHOWING AREA OF BEST LIFT ON SEPTEMBER 22, 1951
Contour heights are given in feet

as the wind freshened . . . I landed after 28 min. in the air and found that the wind had freshened to about 20 m.p.h. and two small lenticular clouds had formed above Totternhoe. By 1930 the wind had dropped and the clouds had cleared away."

[The synoptic charts for Saturday, September 22, 1951, show a depression centred west of Ireland and an anticyclone over Germany with south-east England in a south-easterly air stream.

The observations at Larkhill and Downham Market of the inversion giving the haze layer observed by the authors at about 2,900 ft. above M.S.L. (the height of the gliding club site is 450 ft. above M.S.L.) over the Dunstable area at 1800 G.M.T. are set out in the following table:—

	Time	Pressure	Height above M.S.L.	Temperature
	G.M.T.	mb.	ft.	°F.
Larkhill ...	1500	862	4,450	58
		922	2,600	52
Downham Market	1500	900	3,300	56
		940	2,140	52
Larkhill ...	2100	865	4,250	56
		903	3,050	52
Downham Market	2100	878	3,900	57
		933	2,250	55

The air above the inversion was very dry.

In the afternoon the lapse rate was approximately dry adiabatic from the ground to the base of the inversion, but by 2100 an inversion had formed in the layer below as follows:—

		Pressure	Height	Temperature
	G.M.T.	mb.	ft.	°F.
Larkhill ...	2100	956	1,510	56
		968	1,150	54
Downham Market	2100	970	870	58
		1006·8 (surface)	120	53

Ed. *M.M.*]

OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

Climatological atlas of the British Isles.

This is the first reasonably complete climatological atlas of the British Isles to be published. The Atlas contains the results of the collection of the records of weather data made by thousands of climatological observers. These include not only those connected with the Meteorological Office and some Local Authorities and other interested bodies but also very many voluntary observers to whose enthusiasm British climatology is greatly indebted.

The Atlas is divided into ten sections, each dealing with one of the climatological elements: pressure, wind, temperature, rainfall, snow, thunder, humidity, fog and visibility, sunshine, and cloud. Every section is complete in itself. All except that on cloud have plates of maps and diagrams of average and extreme conditions. The distribution of an element is superimposed on a map as bold lines and in most instances is emphasized by colour-shading, e.g. red for temperature, green for humidity. Maps of average conditions are mostly for the 30-year period, 1901–30, selected by the International Meteorological Organization. Each section also has an introduction describing the methods of making the observations and correcting the data, interesting items concerning extreme values or comparison with long-period averages and, where necessary, tables and diagrams to supplement the plates. Information about the plates and a bibliography are included in the sections. There is a preface by the Director of the Meteorological Office, Sir Nelson Johnson, and a general introduction containing a gazetteer and a map of the stations mentioned in the Atlas. A coloured map, showing the orographical features of the British Isles, to aid the reader to understand the distribution of the elements, forms the frontispiece.

No. 106.—Occurrence of high rates of ice accretion on aircraft. By A. C. Best, M.Sc. Measurements of liquid-water content in strongly convective cloud at great heights in America are compared with theoretical values and good agreement is found. The same method of computing the amount of liquid water in clouds with much higher temperatures at the base is thus justified. After taking account of the variation with drop diameter of the temperature of spontaneous freezing of small drops, the probability of an aircraft encountering various concentrations of supercooled liquid water in strongly convective cloud in low latitudes is assessed.

METEOROLOGICAL RESEARCH COMMITTEE

The 21st meeting of the Synoptic and Dynamical Sub-Committee of the Meteorological Research Committee was held at Dunstable on July 3, 1952.

The Chairman, Sir Charles Normand, announced with regret the resignation of Professor G. C. McVittie as a member of the Sub-Committee consequent upon his taking up an appointment in the United States.

The Committee considered papers by Mr. R. Murray and Miss S. Daniels[1] on the transverse flow at the entrance and exit to jet streams, by Miss E. E. Austin[2] on upper winds over Aden, and by Mr. J. K. Bannon[3] on the classification of temperatures in the upper troposphere and lower stratosphere according to tropopause pressure.

Other matters discussed included (i) a preliminary analysis of the errors in forecasting fog and (ii) sea-surface temperature in the eastern North Atlantic.

ABSTRACTS

1. MURRAY, R. and DANIELS, S.; Transverse flow at entrance and exit to jet streams. *Met. Res. Pap., London,* No. 690, S.C. II/99, 1952.

The wind components across the jet axis were found from 200 mb. below to 100 mb. above maximum wind levels in 1948–50. A component of 8 kt. from right to left (looking down stream) was found at the entrance, 6 kt. from left to right in centre, and 12 kt. from left to right at exit. Mean pressure levels were 279 mb. at entrance and 306 mb. at exit. The probable circulations are shown schematically.

2. AUSTIN, E.; Upper winds of Aden. *Met. Res. Pap., London,* No. 729 (revised) S.C. II/100, 1952.

Radar winds at Aden, August 1948–December 1950, are summarized for levels of 900 to 100 or 60 mb. and discussed. Points noted include sharp transition from westerlies to easterlies at 200 mb. in May and back to westerlies in October, and persistent easterlies in July (55 kt. at 100 mb.). An addendum by C. S. Durst gives winds between Cairo and Entebbe in July 1951.

3. BANNON, J. K.; Classification of temperatures in the upper troposphere and lower stratosphere according to tropopause pressure. *Met. Res. Pap., London,* No. 731, S.C. II/111, 1952.

Both upper air temperature and tropopause pressure (P_c) are functions of advection and vertical motion. For 20-mb. steps of P_c, mean pressure-temperature curves 500–100 mb. are drawn for Larkhill (England) in January, April, July and October, 1948–50. Lapse rates are discussed and causes of variation examined, and several significant correlations found. A high mean lapse rate in lower stratosphere in autumn is related to the autumn minimum of ozone. Suggestions are made for future investigation.

BOOKS RECEIVED

Aktinometrische Untersuchungen während des Internationalen Polarjahres 1932/1933 auf dem Jungfraujoch (3471 m). By W. Mörikofer and W. Schüepp. *Arch. Met. Wien,* B, **2,** 1951, pp. 397–426.

Untersuchung über die Wirkungsweise des Solarigraphen Moll-Gorczynski. By P. Bener. *Arch. Met. Wien,* B, **2,** 1950, pp. 188–249.

ROYAL METEOROLOGICAL SOCIETY

Visit to London Airport

This year the annual summer meeting of the Royal Meteorological Society was held at London Airport on July 16.

From the roof of the air traffic control building it was possible to obtain a view of the whole airport, whilst listening to the Aerodrome Controller talking by radio-telephone to pilots of aircraft on landing or preparing to take-off. Meantime, on the floor below the Approach Controller was, again by radio-telephony, dealing with aircraft approaching the airport. On the ground floor of the same building was the flight information room wherein were diagrams covering the whole of western Europe and the Mediterranean, showing information on aviation matters other than weather, i.e. serviceability of airports, danger zones and the state of navigation aids.

The Society inspected a Hermes air liner, with its 40 supercomfortable seats, and were impressed with the complicated array of dials and equipment in the cockpit on the one hand and the tiny all-electric kitchen on the other. A tour of the airport perimeter was also enjoyed, passing the "airstop" for helicopters, and the maintenance units of many of the 23 operating companies using the airport. A Comet aircraft could be seen undergoing maintenance inspection, and Mr. Housego, the Chief Public Relations Officer, gave details of performance and comparative times of flight on the South African route where, at present, there are three Comet flights per week.

Of greatest interest, however, was the visit to the meteorological office where a roster of 5 forecasters and 12 assistants is maintained continuously. The senior forecaster is normally engaged on forecasting for the Atlantic routes, three others deal respectively with Mediterranean, European and local routes, and the fifth draws the upper air charts and prepares the upper air analyses. For other than short flights, forecasts are issued in the form of a vertical cross-section accompanied by the composite surface chart for the flight, and in the case of North Atlantic flights composite upper air charts, on the basis of which the tracks across the ocean are planned. The hourly position and weather reports made by aircraft crossing the North Atlantic are plotted in the meteorological office. Continuous watch is kept on the development of the synoptic situation and amendments of forecasts are signalled to the aircraft as necessary. Similar information issued by foreign meteorological services and received from in-coming pilots was exhibited, and showed the reports of the weather entered by the crew as experienced during the flight.

Synoptic surface and upper air charts are drawn to cover the whole area of operations, based on information received by 8 teleprinters and 2 W/T receivers. The charts are hourly, three-hourly and six-hourly, dependent upon the purpose for which each is required.

A special organization is required for Comet flights as their flight plan demands an initial climb to height, then relatively level flight until near destination, followed by rapid descent to the terminal. Because of the high consumption of fuel at low levels particular stress is laid on accurate landing forecasts, as any diversion due to weather (or any other cause) should be decided before the aircraft descends. For the flight itself forecast winds are required at levels up to 40,000 ft.

The observational equipment is of normal standard except for the addition of a photo-electric visibility meter which was described to the visitors by Dr. K. H. Stewart. A distant-reading cup generator anemometer and a direction indicator are connected to dials in the observers' room and in air traffic control.

After tea, Mr. W. M. Witchell, a Vice-President of the Society, thanked the Airport Commandant, Air Marshal Sir John D'Albiac, for permission to visit the airport, and drew comparisons between the present-day London Airport and Croydon on the occasion of the Society's visit there in 1934. Sir John, in reply, stressed the importance of meteorology in the economics of flight planning and, above all, in the safety of aircraft.

INDUSTRIAL PHYSICS CONFERENCE AND EXHIBITION

The Institute of Physics held its fourth Industrial Physics Conference in the Royal Technical College, Glasgow, from June 25 to 28. On the first morning after the formal opening by The Rt. Hon. Lord Bilsland (President of the Scottish Council) there were lectures and discussion on "Physics in the service of metallurgy", opened by Sir Andrew McCance, F.R.S. (Deputy Chairman, Colvilles Ltd.), and "Meteorology in industry", opened by Sir Robert Watson-Watt, F.R.S. Someone remarked that the only connexion seemed to be the difficulty in pronouncing either of the words. It was interesting to learn how completely physical techniques, the spectrograph, ultra-sonic waves and isotope tracer elements, had ousted the slow and cumbersome chemical analysis methods in metallurgical processes.

Opening the discussion on meteorology in industry, Sir Robert Watson-Watt pointed out that although there was no means of assessing the value of long-period forecasts four or five weeks ahead, it must be a very appreciable percentage of the national income. Thirty years ago L. F. Richardson had reached the discouraging conclusion that an excessive number of computers could only forecast tomorrow's weather from today's observations in many weeks' work. Electronic computing machines of today encouraged one to believe that attempts of this sort were now worth while. Sir Robert went on to say that he believed it essential that some meteorologists should be directly employed by industry. These meteorologists should be of as high a standing as the best in the State Service.

Sir Nelson Johnson, Director of the Meteorological Office, said he felt that he should give a warning that long-period forecasts were not, in his opinion, "just round the corner". Electronic brains could only evaluate clearly formulated problems, and we were far from being able to feed into a machine material in a form which would enable the machine to supply forecasts. Before this could be done it was first necessary to establish mathematical equations which took account of all the factors involved. These equations would then have to be simplified to make their solution possible—the difficulty here being to know which terms to retain and which to omit. And thirdly there was the problem of the boundary conditions to be assumed.

Mr. R. A. Watson, Superintendent of the Edinburgh Meteorological Office, agreed with Sir Robert that it was only when the industrialist and the meteorologist had frank discussions on their problems that the meteorologist could play his proper part. He thought the state meteorologist had access to far more information, published and unpublished, than the private consultant could command. Multiplication of private enterprise would raise questions of the protection of the public. We already had weather prophets claiming divine inspiration.

Other discussions of interest, but not touching meteorological subjects, took place throughout the meeting, and visits were arranged to laboratories and works in the neighbourhood. The social side of the meeting was well catered for with functions of various kinds, including steamer and coach tours. On the whole the weather was kind.

An exhibition of instruments, apparatus and books had been arranged in the Technical College. A large number of firms and research organizations were represented, and it was impossible to do more than nibble at the fare provided. An interesting exhibit was a working model of a heat pump which used a large tub of soil as a source of low-grade heat to produce hot water "by the consumption of only a fraction of the electrical energy that would have been used by an immersion heater". The quotation is from the description issued by the Electrical Research Association. Meteorologists are required to collaborate more and more with engineers in dissipating colossal stores of low-grade heat in cooling towers. Even a small fraction of this waste would be of account in world economics. The National Physical Laboratory had diagrams and photographs of smoke plumes from chimneys and funnels. The casual visitor was left with the impression that the only property of the atmosphere of importance in dissipating smoke was the ratio of the wind speed to the vertical velocity of the smoke as it leaves the top of the chimney. Probably a talk to the demonstrator would have removed this false impression but this was not possible.

R. A. WATSON

LETTERS TO EDITOR

Eddy structure at the base of a cumulonimbus cloud

An opportunity was offered at Tengah, Singapore, during the morning of March 12, 1952, for photographing a particularly good example of eddy structure at the base of a cumulonimbus cloud. This structure, although not common, has been observed by the writer on other occasions, but seldom with such definition.

At 0915 zone time (G.M.T. + 7) a cumulonimbus cloud was observed at a distance of about four miles on a bearing of 290° from the station. The well defined eddy structure of the base could be seen towards the northern edge of the cloud, and it persisted for a quarter of an hour or so with little or no apparent change.

The surface wind at the time was 330°, 5 kt., having backed just previously from NE. Altocumulus castellatus was present to the north and north-east of the station, together with some high-level cumulus based between 5,000 and 6,000 ft.

Rain could be seen (extreme left of upper photograph facing p. 305) falling from the cumulonimbus which was moving fairly quickly towards Tengah. A shower commenced at the the station at 0929 when the surface wind backed to 260°, 5 kt. The rain became moderate at 0945 and ceased at 1010 when the shower cloud had moved eastwards across the station.

The mammatus formation also seen in the photograph was neither extensive nor well defined.

P. G. RACKLIFF

R.A.F. Station, Tengah, Singapore, April 21, 1952.

Unusual condensation trails

At about 1710 G.M.T. on June 4, 1952, near Stanwell, Middlesex, with the sun behind me, I noticed at an angle of elevation of about 30° a condensation trail which had just been formed from the north and running in a roughly north-south direction. The aeroplane although audible was not seen; from its steady note I judge that it was not in a violent climb or dive. At its junction with a tenuous cloud the trail became "negative" and continued as such (i.e. as a dark grey lane) along the course through the cloud until it petered out. There was no apparent change of direction between the two parts of the trail, the whole track being straight or possibly gently curved. Although I made no direct estimates at the time I think that each part subtended an angle of about 5°.

Over the subsequent 5–10 min. the course of events was as follows. The normal portion of the trail took on the common pendulous, beady appearance and then was spread out, apparently westwards, developing as a cloud. On the other hand the "negative" trail did not widen noticeably, retaining roughly its original width with, however, a few small dark (i.e. "negative") beads developing. After about 5 min. the normal trail at its junction with the negative was about 4 times the width of the latter. The tenuous cloud itself slowly dispersed, the negative trail of necessity disappearing with it. In the end the white, short dense cloud formed from the "positive" trail alone remained of the features described.

I would be interested to know what conditions along the track could account for the effects observed. At any rate it seems that there must have existed a marked variation of humidity, but it is not easy to account for the striking contrast in behaviour of the two parts of the trail as time progressed.

H. G. HOPKINS

Radio Research Station, Slough, Bucks., June 16, 1952

[The nearest meteorological station, London Airport, reported 1 okta cumulus at 3,500 ft. and 4 oktas cirrus at the time of Dr. Hopkins's observation. The Larkhill ascent at 1500 showed a wind of from 220°, 10 kt. in the lowest layers veering and increasing with height to 244°, 46 kt. at 250 mb. (35,000 ft.) in the upper part of the troposphere.

The ascent showed an inversion of 2° F. between 864 mb. (4,700 ft.) and 838 mb. (5,500 ft.). Otherwise there was a fall of temperature to the tropopause (−78°F., 222 mb., 37,100 ft.). Temperature rose to −59°F. in the stratosphere. The humidity was low at all points to the highest observation of that element at 350 mb. (27,000 ft., dry bulb −33°F., dew point −43°F.), with differences between dry bulb and dew point of the order of 10° except from the low inversion to 14,000 ft. where the differences exceeded 30°.

The Mintra-level curve crossed the temperature curve at 350 mb., but as noted above the air was not saturated at that level. The cirrus clouds were presumably higher.

A similar phenomenon*, except that the cloud formation took place some ten minutes after the aircraft had passed, was observed over the sea near Lübeck, Germany, at midday on August 8, 1938. The aircraft responsible was proved to be flying along a very sharp inversion (temperature 38°F.) at 3 Km. with very dry air above. The cloud through which the aircraft cut a lane was a thin sheet spreading out along the inversion from cumulus over the land.

It is very unlikely that the aircraft responsible for the effects observed by Dr. Hopkins was flying along the inversion at 5,000 ft. because the air was dry above and below, no cloud was noted at that level, and he would probably have seen the aircraft at so low a level.—Ed., *M.M.*]

Ablation of snow deposits at Alston, Cumberland

I was very interested in Mr. Richardson's illustrated note on the above in the July issue of the *Meteorological Magazine.* There is no doubt that wind velocity must play a large part in the ablation of snow cover, but the measurement or estimation of its velocity over snow beds in corries must be rather difficult.

In steep-sided corries, such as those among the buttresses of Ben Nevis, the direction of the ambient wind must greatly modify the effect, however great the speed. The increase in speed of winds blowing into the corries, due to funnelling, must greatly increase the ablation. On the other hand, snow beds in corries to the lee of the wind, apart from lee-side eddies, would probably be little ablated by wind alone. If accompanied by rainfall, however, the ablation might be accelerated even in lee-side corries.

D. L. CHAMPION

47 Norrys Road, Cockfosters, Herts., July 28, 1952

NOTES AND NEWS

Line squall at South Farnborough, Hampshire

The photographs in the centre of this Magazine were taken during the passage of a line squall over South Farnborough. The squall, which gave very little rain (only a trace being measured during 12 hr.), was associated with a cold front from a depression which formed south of Newfoundland on November 6, 1947.

This depression moved eastwards but did not begin to occlude until it reached the mid Atlantic on the 10th, when its easterly movement increased rapidly. The centre of the depression crossed north Scotland about 0300 G.M.T. on the 12th, and the cold front passed over South Farnborough at 1428 when these photographs were taken.

Roll cloud

The photograph of the roll cloud facing the lower part of p. 305 was taken from 52°01′ N., 53°40′W. at 2155 on July 14, 1951, by Mr. J. Waling 3rd Officer (and one of the observers) of T.E.V. *Beaverlake* on a voyage from London to Three Rivers on the St. Lawrence. The elongated round formation of cloud, extending from horizon to horizon, was observed in an otherwise cloudless sky. As the cloud, moving in an east-south-easterly direction at about 600 ft., passed over the ship the wind veered from WSW. force 4 to W. force 6 and the pressure rose sharply from 1011·4 to 1012·8 mb. Immediately after the

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*KUHLBRODT, E.; Flugzeug bewirkte auf seiner Bahn gleichzeitig Wolkenauflösung und Wolkenbildung. *Z. angew. Met., Leipzig*, **55**, 1938, p. 346.

transit the wind backed to WSW. force 4 as previously, and shortly afterwards the formation decayed into a line of cumulus cloud. Maximum visibility was experienced during the whole period and the air temperature was constant at 53°F. The photograph was taken just after the cloud had passed over the ship and just before it began to decay.

OBITUARY

Dr. Robert Edward Watson.—Dr. R. E. Watson, formerly a Principal Scientific Officer in the Meteorological Office, died suddenly on May 28, 1952, little more than a year after his retirement at the end of his 62nd year. The news came as a shock to the many who knew him. Deep sympathy is felt for Mrs. Watson and family.

Dr. Watson was born in Yorkshire. He became a student at University College, Nottingham, graduated in London University in 1911 and then lectured in mathematics and physics at Halifax Technical College. He served with the Royal Garrison Artillery during the First World War, 1914–18, and was twice wounded in France in 1917.

As an invalided officer Dr. Watson joined the Meteorological Office in March 1918, but after about a year at Kew Observatory and Falmouth Observatory relinquished the appointment for private reasons. On re-appointment as Senior Professional Assistant in July 1920 he returned to Kew Observatory. During almost nine years, under Dr. C. Chree and later Dr. F. J. W. Whipple as Superintendent, Dr. Watson's fondness and aptitude for instrumental work found scope in most of the Observatory's activities. His first *Geophysical Memoir* discussed the results of comparisons of the pyrheliometers used in measuring solar radiation at Kew. In another field, Dr. Watson was responsible for preparing, installing and generally supervising the magnetographs used in 1923 at the Sandwell Park Colliery, near Birmingham to obtain continuous records of magnetic declination and horizontal force 1,800 ft. underground, and of declination above ground. These mine records were the first of their kind obtained in this country. They and records from the permanent observatories were used in an investigation, arising from the requirements in mine surveying, to determine how far regular and irregular magnetic changes registered at one observatory were representative of changes at the same time in other parts of the country. The subject was discussed by Chree and Watson in a Royal Society paper and a *Geophysical Memoir.* Dr. Watson took a prominent part in the installation of the Galitzin seismographs when they were transferred to Kew from Eskdalemuir Observatory towards the end of 1925.

Perhaps Dr. Watson's chief personal interest was in atmospheric electrical measurements. He made extensive experiments with mercury micro-voltameters in the hope that they could be used to measure the air-earth current. A characteristically thorough investigation of the technique of determining the electrical conductivity of the air and of the electrical potential gradient by means of the Wilson universal electrometer was published as a *Geophysical Memoir*, and led a few years later to the construction of an underground laboratory to enable measurements to be made over a flat surface free from near obstructions. This has now been standard procedure at Kew for more than twenty years. Relationships between atmospheric pollution and electrical potential gradient at Kew were discussed by Chree and Watson in a paper to the Royal Society. Dr. Watson was awarded the Ph.D. of London University in 1927.

In mid 1929 Dr. Watson, in the grade of Assistant Superintendent, moved to Eskdalemuir to take charge of the Observatory which had been established among the Dumfriesshire moors twenty years earlier with magnetic work as a primary commitment. During his tenure of this post, a Schuster-Smith coil magnetometer was acquired for the measurement of horizontal force.

The increasing provision which was being made for meteorological services to civil and military aviation led to Dr. Watson's transfer to that very different sphere of work at the beginning of 1934. After a few months of acclimatization at Lympne to the fresh type of duties, he went on to the Royal Air Force Headquarters (later No. 1 Group) at Abingdon. From this point his career lay with the Royal Air Force, advising senior officers and supervising the work of subsidiary meteorological offices at airfields. To him, as to many of his colleagues, the Second World War, 1939–45, brought changes in location and long interruption of home life. Early in the war it fell to him to investigate and report on the war-time requirements for the meteorological instruction of members of aircrew. Following periods with the School of Air Navigation and at a Group Headquarters in Inverness he occupied the post of senior or chief meteorological officer at Headquarters Fighter Command 1941–44, at Headquarters No. 3 Group, and finally, from 1948, at Headquarters Bomber Command. He became Wing Commander R.A.F.V.R. (Meteorological Branch) in 1944. "Doc." Watson was widely known in the Royal Air Force and was well liked. It is known that his services were highly appreciated.

The care for securing precision in measurement and observation displayed by Dr. Watson while at Kew, Falmouth and Eskdalemuir Observatories was in harmony with neatness of personal appearance and habits. He was very sociable, keenly interested in sporting affairs and devoted to golf. It is sad that he has gone so soon.

WEATHER OF AUGUST 1952

During the first half of the month pressure was high between the Azores and Greenland and Iceland; in the second half of the month, high pressure developed from the eastern United States to south-west Europe. Mean pressure generally over Europe, the North Atlantic and North America differed very little from normal; over most of Europe it was about 2 mb. below normal; mean pressure in Finland fell to 1006 mb. which was 5 mb. below normal.

Mean temperature was generally 2–5°F. above normal in Europe and North America, but in Scandinavia, mean temperatures of 45–50°F. were 2–5°F. below normal; in southern Algeria a mean temperature of 99°F. was recorded.

In the British Isles the weather during the first 19 days was unsettled, with severe rainstorms at times, particularly in the south. The storm in the south-west on the 15th will long be remembered for the great destruction and heavy loss of life sustained at Lynmouth. Over much of the country fair weather prevailed from the 20th onwards but in the north of Scotland considerable rain fell at times after the 23rd.

In the opening days of the month a complex depression covered the British Isles; rainfall was fairly heavy in places, and there were widespread thunderstorms on the 2nd. From the 6th to the 8th shallow depressions to the south-west of the British Isles and over northern France moved slowly north giving thunderstorms and heavy rain, notably on the 6th in the London area and the Home Counties where some flooding occurred and 4·83 in. of rain was registered at Boreham Wood, Hertfordshire. On the 9th a deep depression off the south of Ireland moved north-north-east over the country causing strong winds in England and Wales and widespread rain, heavy locally, particularly in Northern Ireland, south-west Scotland and the Isle of Man. Subsequently a belt of rather low pressure extended from south-west of Ireland to Norway, while pressure was relatively high on the continent; rain fell in most districts except the south-east on the 11th, but mainly fair, warmer weather prevailed over much of England and Wales from the 12th to the 14th. On the 15th a small depression moved slowly from a position near Brest east-north-east across southern England and was associated with severe thunderstorms and exceptionally heavy rainfall in the south of England; locally in north Devon and north Somerset more than 7 in. of rain fell in the 24 hr. ending at 0900 on the 16th, while a fall of 9·00 in. was registered at Longstone Barrow, Exmoor. Floods occurred over a wide area, notably at Lynmouth where the water rushing down from the moors washed away the bridges and almost destroyed the town; many people lost their lives. On the 18th a deep depression off southern Ireland moved south-east to west France and later turned north-east to west Germany; more heavy rain fell in parts of southern England (2·47 in. at Hastings, the heaviest fall there in 24 hr. since 1875). The 18th was a very cold day for the time of year; at Marlborough the maximum temperature, 54·7°F., was the lowest recorded there in August since records were first taken in 1864. On the 19th a ridge of high pressure off our north-west coasts moved slowly south-east and the weather improved; apart from some rain in the north of Scotland mainly fair weather prevailed until the 26th. On that day troughs associated with a deep depression over Iceland moved south-east and rain fell over Scotland, north Ireland and the extreme north of England. Thereafter pressure was high in a ridge from an anticyclone north of the Azores to central Europe and low to the north of the British Isles. Strong winds and local gales occurred in Scotland on the 27th and 28th and rain occurred, chiefly in the north-west and north. In the early hours of the 30th a shallow depression over Brittany spreading north-east was associated with rain in the Channel Islands and locally on the south coast of England. On the 30th and 31st a depression south of Iceland moved slowly north-east and associated troughs crossed the British Isles giving heavy rain in the north of Scotland on the 30th and mainly slight rain in the west and north of the British Isles on the 31st. A gale occurred in north Scotland on the 31st. The last week was warm except in the north of Scotland.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	81	35	+1·0	126	−1	101
Scotland	75	27	+0·4	115	−1	93
Northern Ireland ...	72	37	+0·5	124	−2	89

RAINFALL OF AUGUST 1952

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·54	115	*Glam.*	Cardiff, Penylan ...	6·02	142
Kent	Folkestone, Cherry Gdn.	4·09	171	*Pemb.*	Tenby	4·95	130
,,	Edenbridge, Falconhurst	3·55	135	*Mer.*	Aberdovey	4·01	90
Sussex	Compton, Compton Ho.	2·90	94	*Radnor*	Tyrmynydd	5·70	106
,,	Worthing, Beach Ho. Pk.	2·04	90	*Mont.*	Lake Vyrnwy	5·47	103
Hants.	Ventnor Cemetery ...	2·01	99	*Mer.*	Blaenau Festiniog ...	7·75	69
,,	Southampton (East Pk.)	4·06	155	*Carn.*	Llandudno	2·75	98
,,	Sherborne St. John ...	2·49	103	*Angl.*	Llanerchymedd ...	4·04	112
Herts.	Royston, Therfield Rec.	5·02	195	*I. Man*	Douglas, Borough Cem.	5·16	135
Bucks.	Slough, Upton... ...	2·57	118	*Wigtown*	Newton Stewart ...	3·34	80
Oxford	Oxford, Radcliffe ...	4·27	187	*Dumf.*	Dumfries, Crichton R.I.	3·93	97
N'hants.	Wellingboro' Swanspool	3·27	137	,,	Eskdalemuir Obsy. ...	4·49	87
Essex	Shoeburyness	3·07	173	*Roxb.*	Kelso, Floors	4·75	161
,,	Dovercourt	2·12	118	*Peebles*	Stobo Castle	4·24	119
Suffolk	Lowestoft Sec. School...	4·31	196	*Berwick*	Marchmont House ...	3·54	107
,,	Bury St. Ed., Westley H.	3·33	128	*E. Loth.*	North Berwick Res. ...	2·18	69
Norfolk	Sandringham Ho. Gdns.	2·24	83	*Midl'n.*	Edinburgh, Blackf'd. H.	4·53	141
Wilts.	Aldbourne	5·53	209	*Lanark*	Hamilton W. W., T'nhill	3·56	104
Dorset	Creech Grange... ...	2·74	96	*Ayr*	Colmonell, Knockdolian	5·68	142
,,	Beaminster, East St. ...	5·04	161	,,	Glen Afton, Ayr San. ...	3·89	72
Devon	Teignmouth, Den Gdns.	3·88	172	*Renfrew.*	Greenock, Prospect Hill	5·93	115
,,	Cullompton	5·59	183	*Bute*	Rothesay, Ardencraig...	6·56	135
,,	Ilfracombe	7·51	209	*Argyll*	Morven (Drimnin) ...	6·42	122
,,	Okehampton Uplands...	10·54	249	,,	Poltalloch	5·79	118
Cornwall	Bude, School House ...	7·44	264	,,	Inveraray Castle ...	7·28	111
,,	Penzance, Morrab Gdns.	3·57	113	,,	Islay, Eallabus... ...	5·29	121
,,	St. Austell	4·61	127	,,	Tiree	3·53	84
,,	Scilly, Tresco Abbey ...	3·56	129	*Kinross*	Loch Leven Sluice ...	3·99	104
Glos.	Cirencester	3·60	120	*Fife*	Leuchars Airfield ...	3·49	113
Salop	Church Stretton ...	2·79	84	*Perth*	Loch Dhu	5·19	77
,,	Shrewsbury, Monksmore	2·03	73	,,	Crieff, Strathearn Hyd.	4·71	112
Worcs.	Malvern, Free Library...	4·73	164	,,	Pitlochry, Fincastle ...	3·34	94
Warwick	Birmingham, Edgbaston	3·66	135	*Angus*	Montrose, Sunnyside ...	2·25	81
Leics.	Thornton Reservoir ...	3·72	133	*Aberd.*	Braemar	3·17	93
Lincs.	Boston, Skirbeck ...	2·61	109	,,	Dyce, Craibstone ...	4·69	155
,,	Skegness, Marine Gdns.	1·67	68	,,	New Deer School House	4·16	141
Notts.	Mansfield, Carr Bank...	2·22	80	*Moray*	Gordon Castle	4·15	131
Derby	Buxton, Terrace Slopes	2·64	60	*Nairn*	Nairn, Achareidh ...	3·55	146
Ches.	Bidston Observatory ...	2·21	72	*Inverness*	Loch Ness, Garthbeg ...	5·46	168
,,	Manchester, Ringway...	1·28	39	,,	Glenquoich	8·57	104
Lancs.	Stonyhurst College ...	7·62	151	,,	Fort William, Teviot ...	5·92	95
,,	Squires Gate	3·23	94	,,	Skye, Broadford ...	6·06	94
Yorks.	Wakefield, Clarence Pk.	1·24	48	,,	Skye, Duntuilm ...	5·03	113
,,	Hull, Pearson Park ...	1·23	42	*R. & C.*	Tain, Tarlogie House ...	4·27	158
,,	Felixkirk, Mt. St. John...	2·25	79	,,	Inverbroom, Glackour...	4·07	97
,,	York Museum	1·67	66	,,	Achnashellach	6·43	102
,,	Scarborough	1·81	65	*Suth.*	Lochinver, Bank Ho. ...	4·78	143
,,	Middlesbrough... ...	1·79	65	*Caith.*	Wick Airfield	3·48	127
,,	Baldersdale, Hury Res.	3·73	113	*Shetland*	Lerwick Observatory ...	5·36	178
Norl'd.	Newcastle, Leazes Pk....	2·46	87	*Ferm.*	Crom Castle	4·09	99
,,	Bellingham, High Green	4·45	126	*Armagh*	Armagh Observatory ...	3·86	107
,,	Lilburn Tower Gdns. ...	4·52	160	*Down*	Seaforde	4·93	131
Cumb.	Geltsdale	3·83	93	*Antrim*	Aldergrove Airfield ...	4·23	117
,,	Keswick, High Hill ...	8·55	164	,,	Ballymena, Harryville...	7·04	165
,,	Ravenglass, The Grove	4·59	101	*L'derry*	Garvagh, Moneydig ...	5·35	136
Mon.	Abergavenny, Larchfield	6·35	213	,,	Londonderry, Creggan	6·14	132
Glam.	Ystalyfera, Wern House	6·91	112	*Tyrone*	Omagh, Edenfel ...	4·42	104

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RELATION OF THE HEIGHT OF THE MAXIMUM WIND TO THE LEVEL OF THE TROPOPAUSE ON OCCASIONS OF STRONG WIND

By E. E. AUSTIN, M.A. and J. K. BANNON, B.A.

Introduction.—Professor G. M. B. Dobson, in a classical paper[1], examined the variation of wind with height and showed that over Europe the maximum wind speed usually occurs just below the level of the tropopause. The data for Dobson's analysis were observations of wind made by following the path of sounding balloons, and such observations were necessarily obtained on occasions of little cloud and light or moderate wind; the maximum wind exceeded 60 kt. on only nine occasions. A similar but less extensive analysis is described in the present note using the wind and temperature observations made at Larkhill and Lerwick but restricting occasions to those when the maximum wind was 70 kt. or more.

Statistics of level of maximum wind and tropopause.—During the period 1948–50 four upper air observations were normally made each day at Larkhill and Lerwick. From these observations those with a maximum wind speed $\geqslant$ 70 kt. were extracted. Frequency tables for each station were then prepared, for ranges of 10 mb., for

(*a*) pressure at the level of maximum wind
(*b*) pressure at the tropopause
(*c*) pressure at the level of maximum wind minus the pressure at the tropopause.

These frequencies are shown in the histograms in Fig. 1. The mean values of (*a*), (*b*) and (*c*) for the whole period and the standard deviations are given in the first part of Table I. Also in this table are the correlation coefficients between (*a*) and (*b*) for the two stations. In the latter part of Table I the same statistics are given for the six months May to October only.

Fig. 2 shows mean monthly values of tropopause pressure and pressure at the level of maximum wind for each month of the period 1948–50 for both Larkhill and Lerwick. The number of observations available in each month is also given.

Discussion.—The results presented in Table I and Figs. 1 and 2 do not agree with Dobson's findings for what he calls high and moderate winds, which showed that the level of maximum wind usually occurred just below the tropopause. This discrepancy is not surprising as in Dobson's data the great majority of maximum winds were less than 60 kt. Winds of 70 kt. or more

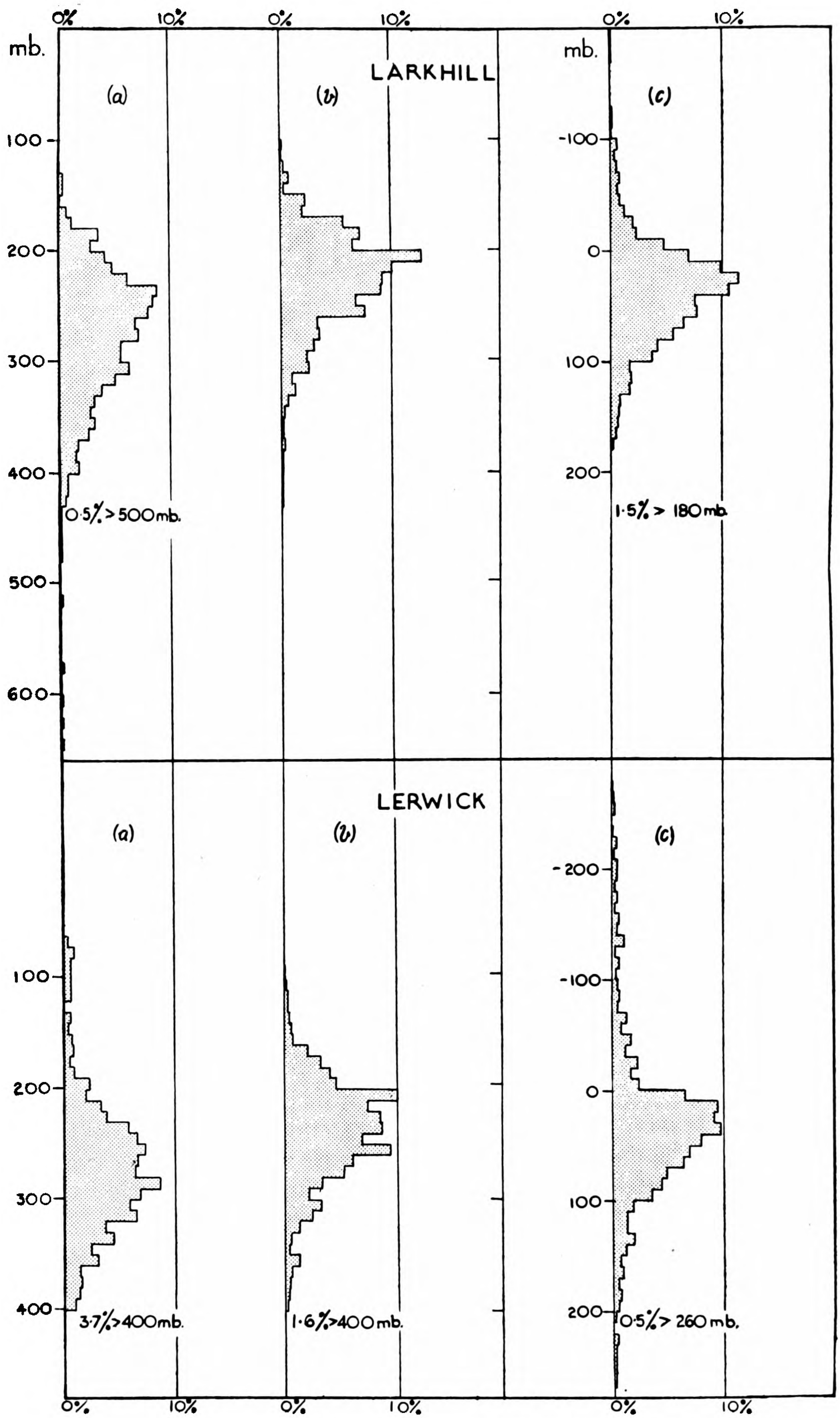

FIG. 1—FREQUENCIES OF (*a*) PRESSURE AT LEVEL OF MAXIMUM WIND, (*b*) TROPOPAUSE PRESSURE, AND (*c*) DIFFERENCE IN THESE PRESSURES
Maximum wind > 70 kt.

TABLE I—STATISTICS OF THE PRESSURE AT THE LEVEL OF MAXIMUM WIND AND AT THE TROPOPAUSE FOR OCCASIONS OF WIND ⩾ 70 KT.

Period: 1948–50

	All months				May–October only			
	Level of maximum wind (*a*)	Tropopause (*b*)	Difference (*c*)	Correlation between (*a*) and (*b*)	Level of maximum wind (*a*)	Tropopause (*b*)	Difference (*c*)	Correlation between (*a*) and (*b*)
	mb.	mb.	mb.		mb.	mb.	mb.	
LARKHILL								
Mean pressure	268	226	42	0·43	258	219	39	0·33
Standard deviation	58	45	56	—	52	39	54	—
LERWICK								
Mean pressure	278	244	34	0·18	281	239	42	0·28
Standard deviation	71	52	81	—	57	49	64	—

over Great Britain in the upper troposphere and lower stratosphere, however, are in most cases associated with a jet stream, and the tropopause surface in such circumstances has considerable slope and is often discontinuous (see, for example, Murray and Johnson[2]). A sounding through, or on the anticyclonic side of, the axis of a jet stream will find the level of maximum wind below the tropopause; a sounding on the cyclonic side of the jet stream close to the axis will also find the level of maximum wind below the tropopause, but if further from the axis and in the zone of discontinuous or sloping tropopause or through the true polar tropopause, then the tropopause may be at or below the level of maximum wind. Since the maximum wind falls off rapidly with horizontal distance on the low-pressure side of a jet stream, occasions of maximum winds ⩾ 70 kt. are more likely to be those near or on the anticyclonic side of a jet-stream axis. This, presumably, explains the mean pressure at the level of maximum wind being higher, in most cases, than the mean tropopause pressure, as seen in Fig. 2.

Further confirmation of these ideas is seen in the comparison of the monthly mean tropopause pressures for the occasions of strong winds (⩾70 kt.) with the means for all occasions; for the three years considered, the monthly mean tropopause pressure for strong winds was 12 mb. lower at Lerwick and 7 mb. lower at Larkhill, on the average, than the corresponding monthly mean tropopause pressure for all occasions. Of the 36 months considered there were only eight months for each station respectively, in which the mean tropopause pressure for all occasions was less than the corresponding mean pressure on occasions of strong wind. These figures support the hypothesis that the majority of soundings of strong wind, if associated with a jet stream, were through the higher, warm-air tropopause.

The differences between the statistics for Lerwick and Larkhill are interesting. At Lerwick, though the mean pressure at the level of maximum wind is greater than that of the tropopause, there is a much greater variation of the level of maximum wind than at Larkhill (see Table I and Fig. 1). This is very largely because the level of maximum wind at Lerwick in winter and early spring is often well into the stratosphere. These occasions are mainly associated with fresh arctic air just to the north of the British Isles, and though the tropopause at Lerwick is then below the average height and presumably a true arctic-type tropopause, yet the wind continues to increase above it, indicating a cold stratosphere over the Norwegian Sea. Riehl[3] has drawn attention to the very

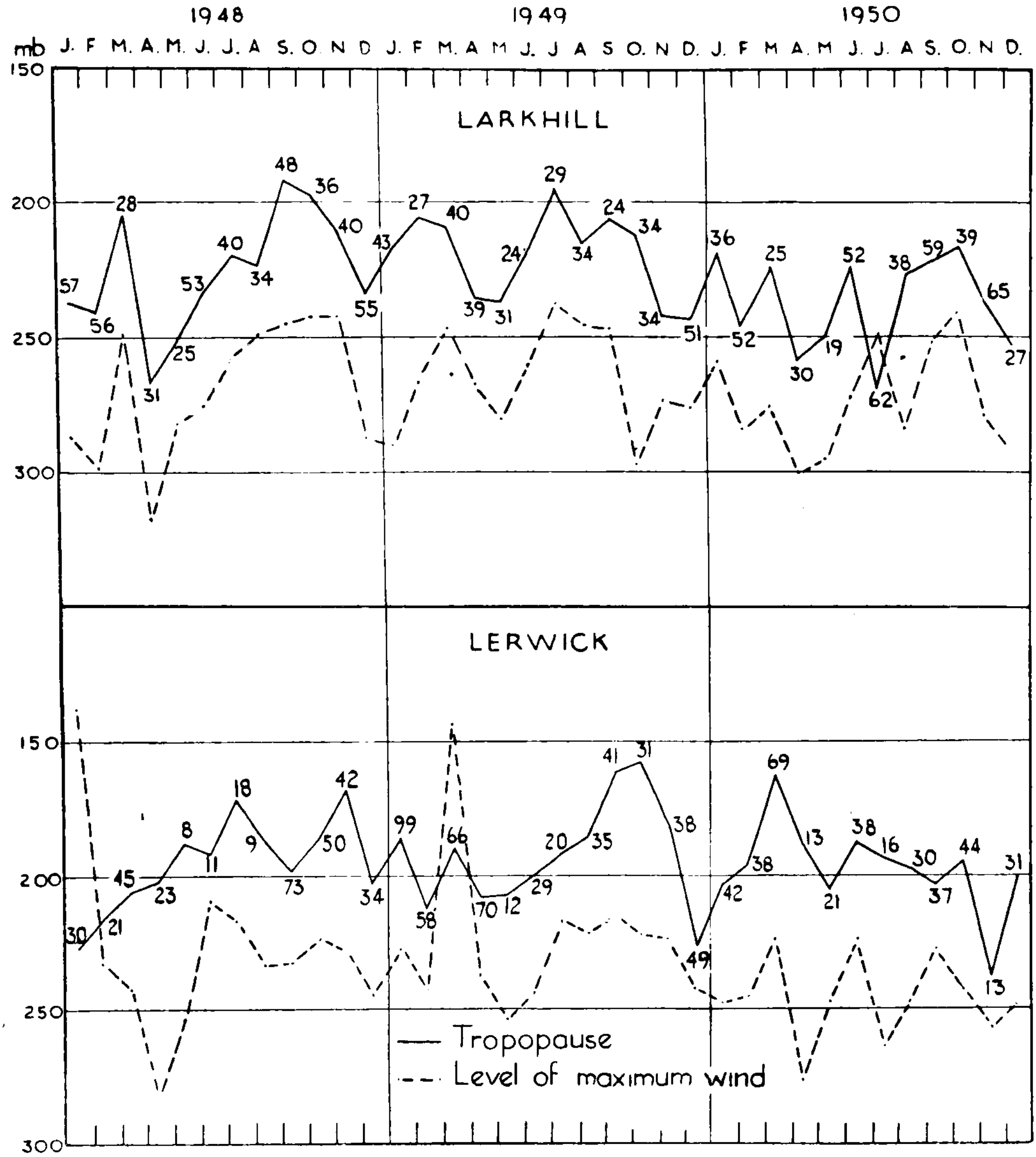

FIG. 2—COMPARISON OF PRESSURE AT TROPOPAUSE WITH LEVEL OF MAXIMUM WIND ON OCCASIONS WITH MAXIMUM WIND ⩾ 70 KT.

The figures give the numbers of observations for each month.

cold stratosphere which is sometimes found in winter over the semi-permanent depression at the 300-mb. level over and to the north of Canada, contrasting it with the more usual situation when the polar stratosphere is comparatively warm, the wind decreasing with height above the tropopause. These occasions of wind increasing with height in the stratosphere occur frequently at Lerwick in winter and early spring; it is seen from Fig. 2, for example, that in January 1948 and March 1949 the mean level of the maximum wind was well above the mean tropopause level. In summer, however, the relation between the level of maximum wind and the tropopause at Lerwick is more like that at Larkhill. The latter part of Table I, for the months May to October, demonstrates this.

Conclusions.—General conclusions to be drawn from the above analysis seem to be that with high winds, the maximum wind over the British Isles occurs most frequently at a pressure between 20 and 40 mb. higher than that of the tropopause. Though the monthly means usually vary in sympathy (Fig. 2) correlation between the levels of the tropopause and the height of maximum wind is small. In winter, at Lerwick, there are often occasions when the maximum wind occurs well above the tropopause, but such occasions are much less frequent at Larkhill.

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INTERPRETATION OF RAINFALL VARIABILITY

By J. C. FOLEY, B.Sc.

It has long been recognized that in addition to information regarding the average rainfall of a region it is important to know something of its behaviour in regard to variation from "normal" from one year to another. Various indices of variability have been proposed to denote this characteristic, but many writers have felt that they have not succeeded in their purpose. It may be that it is rather much to expect a single-value factor to express a quantity so variable and complex in itself.

Apart from the value of deriving a simple measure of rainfall variability which will meet practical requirements it is of interest to be able to form a picture of what variability really signifies, and how, over a long period of years, the rainfall amounts at any particular place are distributed in relation to a modal or "normal" value. The purpose of this paper is to discuss variability of rainfall from this point of view.

Various methods of expressing variability or reliability of rainfall are summarized by Loewe[1]. These include:—

Rainfall range—difference between the highest and lowest annual amounts recorded in the series of years.

Relative rainfall range—measure of variation used by Gherzi, the ratio of the rainfall range to the average rainfall.

Hellmann's ratio of variation, or variability quotient—ratio of the amounts recorded in the wettest and driest years in the series.

Average variability—(*a*) absolute average variability, or the sum of deviations from the average divided by the number of years; (*b*) average relative variability, the absolute average variability divided by the average rainfall.

Relative variability—term applied by Conrad to the absolute average variability expressed as a percentage of the arithmetic mean.

Loewe discusses at length other expressions for variability, Maurer's variability indices. These forms of index are designed to meet objections to some of the simpler forms of ratio referred to above, and it is claimed that they are more satisfactory for comparing variabilities in regions of very different average rainfall. For example, the magnitude of an index which is derived by dividing the highest by the lowest recorded annual totals depends to some degree on the magnitude of the extremes of rainfall. Similarly if we take the difference between the highest and lowest totals and divide this difference by the average rainfall, the result is influenced by the magnitude of the average rainfall. The index will tend to be high in a case where the average rainfall is low and in an extreme case tends to be infinitely high. Thus the magnitude of average relative variability index $\sum|x - \bar{x}|/n\bar{x}$ will tend to become high in a low rainfall region since the smaller $\bar{x}$ becomes, the larger is the value of the expression. It is true that $\sum|x - \bar{x}|$ is also low in low rainfall regions but the ratio $\sum|x - \bar{x}|/\bar{x}$ is not as a rule constant. We may reduce the ratios $\sum|x - \bar{x}|/n\bar{x}$, for all stations compared, to a standard basis of 100 for $\bar{x}$, but still the objection is not altogether overcome. It is stated by Conrad[2] that statistics of 360 stations scattered over the earth yielded a correlation between V_r, the value of the expression for relative variability, and $\bar{x}$, the normal rainfall. This is not a linear correlation but a hyperbolic curve which for low values of $\bar{x}$ gives values of V_r rising sharply towards infinity (Fig. 1).

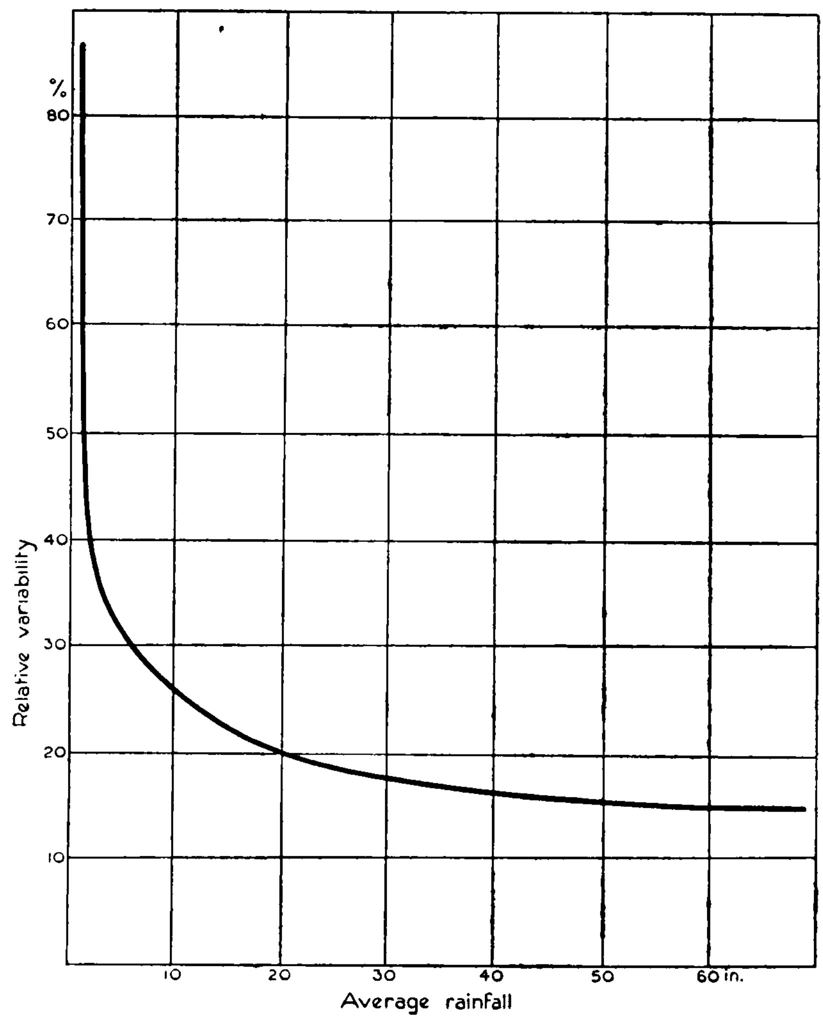

FIG. 1—COMPARISON OF RELATIVE VARIABILITY WITH AVERAGE RAINFALL (after Conrad[2])

Questions are thus raised as to how reliable are various expressions for variability, or rather, how serious is the error arising out of the mathematics of the derivation of an index. In particular, is the error of sufficient importance to warrant the employment of a highly complex and laborious process as an alternative?

There are one or two observations to be made regarding the basis of such expressions.

It must be remembered that all such expressions depend on the assumption that the relatively few samples analysed are representative of the very large number required to give an adequate basis for such an analysis. The number of samples at our disposal is small and by accepting these as the best available we admit the possibility of error.

A rainfall variability map has a limited application. Its significance is only apparent when read in conjunction with an average rainfall map. We should not seek for something more in it than what it purports to show. The criticism is sometimes made that a place in a semi-arid area may have the same variability index as a station in a wet region, but, whereas in the latter case the index would be of no particular significance in view of the abundance of rain, in the former case it may be of the highest significance. This criticism is valid if it is directed against the feature already referred to, namely the unsatisfactory nature of an index which reflects the mathematics of its derivation. It is reasonable to seek an index which is independent of such influences, but we should not infer that an index can express the magnitude of rainfall as well as its behaviour as regards deviation from an average.

This idea is carried further by some who claim that highly abnormal rainfall occurrences are of economic importance and should not be eliminated from the data used in the calculation of a variability index. Others argue that the index should indicate prevailing tendencies or the more normal experience. It is difficult to see how the importance of abnormal features can be disclosed by such an index. Such abnormalities may be disturbing factors which modify the index in such a manner that it no longer shows the normal characteristics of the place. The sections of this paper which follow are based on the assumption that the omission of extreme values is justified in order that the normal experience of a station may be more truly represented. A weakness of the relative variability index is that it includes unduly disturbing elements which it would be preferable to indicate in some other manner. For example, Burketown in Queensland has a much higher variability than surrounding stations according to some variability maps, but unless we examine the individual annual recordings of this station we cannot tell whether this feature is due to a peculiarity in the general experience of the locality or to the influence of a few abnormally high or low recordings. This is illustrated by a cumulative frequency graph in Fig. 2. If the abnormalities are systematically omitted we obtain an unequivocal expression for the normal experience. It will be noted that a moderately high percentage of high annual rainfalls at this station (contributed largely by tropical cyclones) accounts for the high variability index. There is a marked difference between this curve and that for Townsville (Fig. 2). Both stations have an index of approximately 500 according to Maurer's formula (Fig. 5). Burketown's experience might be described by regarding the upper 90 per cent. of the curve as representing the ordinary

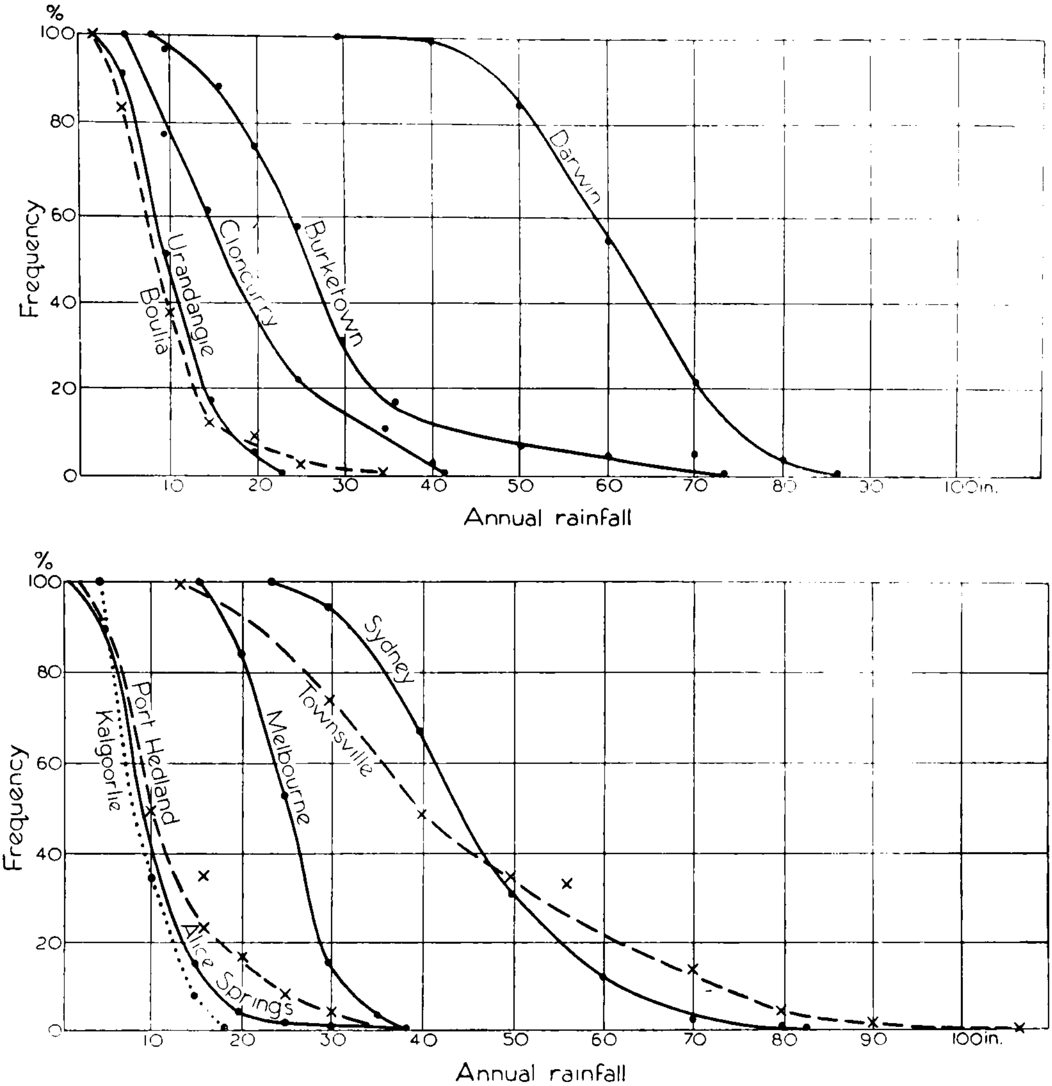

FIG. 2—CUMULATIVE FREQUENCY CURVE OF ANNUAL RAINFALL
In regions with summer rainfall the year is reckoned from July to June; elsewhere it is a calendar year

rainfall behaviour and the lower 10 per cent. as abnormal occurrences. No single index can be expected to reveal both features.

The relative variability index, apart from this fault if it may be conceded that it is a fault, seems reasonably accurate for practical purposes. The expression for relative variability is $100 \sum|x - \bar{x}|/n\bar{x}$.

According to Conrad, variabilities with an annual rainfall greater than 20–28 in., derived from this expression, can be compared with one another without serious error. An inspection of the graph on which this statement is based (Fig. 1) suggests that values of the index with an annual rainfall down to 10 in. may also be compared, with but a moderate degree of error. Values of variability in regions of low rainfall tend to be unduly high, but this is of little economic significance. In view of all the circumstances the employment of a laborious process of deriving an exact expression of variability, e.g. Maurer's indices, in preference to a simpler method for deriving an approximate value, does not seem to be justified.

An alternative expression for variability is the semi-interquartile range expressed as a percentage of the median. This method is said to give a convenient approximate measure of variation with the advantages that the quartiles and median are easily picked out.

It is said to be fairly "satisfactory when the frequency distribution is fairly symmetrical and uniform in its graduation from greatest to least; but if the distribution is conspicuously skew, or if there are erratic differences in frequency between successive values of the variable, it is better to choose a measure which gives the magnitude and position of each recorded observation its due weight in the deviation sum."[3]

Rainfall statistics usually give a skew distribution, but the amount of skewness is not large as a rule, and a smoothed distribution curve probably gives a closer approximation to the true rainfall experience than a summation of individual deviations from an arithmetic mean, or median, over the period for which records are available.

One of the most convenient forms of curve to work with is the cumulative frequency curve, sometimes called a graduation curve. The type of curve adopted for the purpose of this paper is one which expresses the percentage frequency of years in which the annual rainfall exceeds certain amounts (Fig. 2).

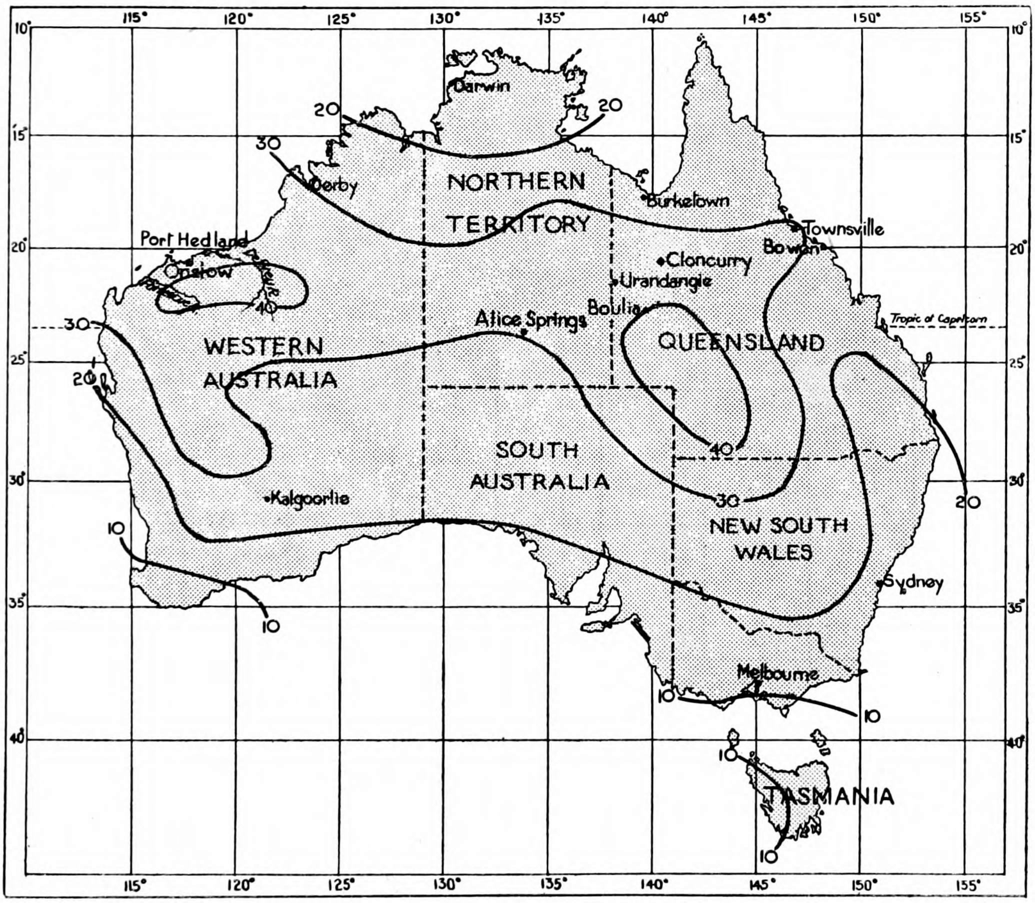

FIG 3.—RAINFALL VARIABILITY IN AUSTRALIA

$$\text{Variability} = \frac{\text{semi-interquartile range} \times 100}{\text{median}}$$

For example, the extreme lowest rainfall will be exceeded on 100 per cent. of occasions and the highest recorded rainfall on zero per cent. The median rainfall will be exceeded in 50 per cent. of the years, the lower quartile in 25 per cent. and so on. In the usual form of frequency curve the lower quartile would apply to low values which would be exceeded on 75 per cent. of the years. In this form of curve the magnitudes are inverted. From the steepest part of the curve we may read off the mode or the percentage of years in which the most frequently occurring amount is registered.

This curve serves to illustrate in a striking manner the meaning of variability. In a wet region the curve usually falls away gradually and extends over a wide range of rainfall values. In a dry region the curve will tend to fall steeply over a small range and to be confined to the field of small values. These features may appear surprising at first sight as it is commonly accepted that the

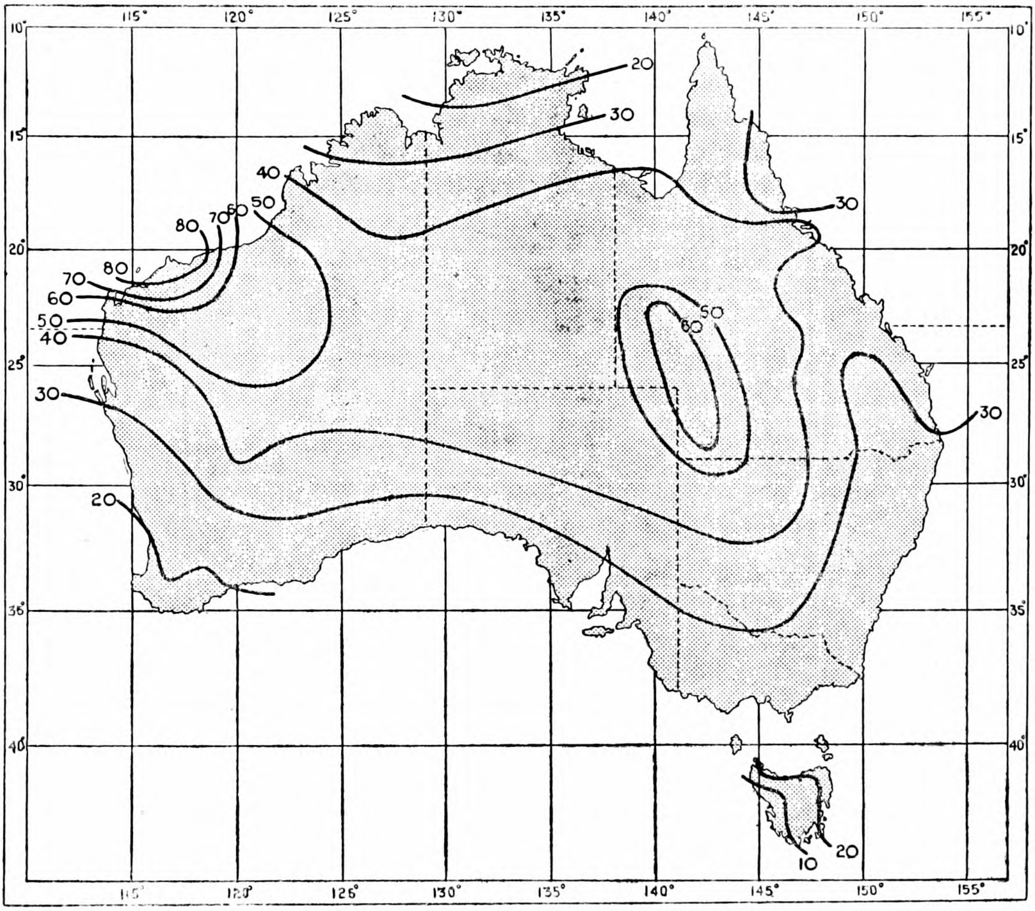

FIG. 4—RAINFALL VARIABILITY IN AUSTRALIA

$$\text{Variability} = \frac{95 \text{ per cent. range} \times 100}{4 \times \text{median}}.$$

lower the rainfall, the higher the variability. However, in the expression from which the variability is derived, the range, which varies approximately with the median, is divided by the median, i.e. the index is the ratio of large quantities in a wet region and of small quantities in a dry region. Such a curve clearly shows the quartile deviation or the deviations from any point chosen as a point of reference. The mean deviation from the average, or from the median, may also be looked upon as an integration of the deviations of all points on the curve from either the arithmetic mean or the median rainfall.

A variability map has been drawn based on the semi-interquartile range at 77 stations over Australia (Fig. 3). This shows the same general features as other well known maps based on the mean deviation from the arithmetic mean. Areas of maximum variability of over 40 per cent. occur over the Fortescue and De Grey regions of Western Australia and over south-western Queensland, while a variability of over 30 per cent. is found over inland areas between latitudes 20°S. and 25°S., touching the east coast at Townsville, the west coast between the tropic and Derby and projecting southward to 30°S. over Western Australia and north-western New South Wales. The lowest variabilities are found in western Tasmania, south Gippsland and on the south coast of Western Australia.

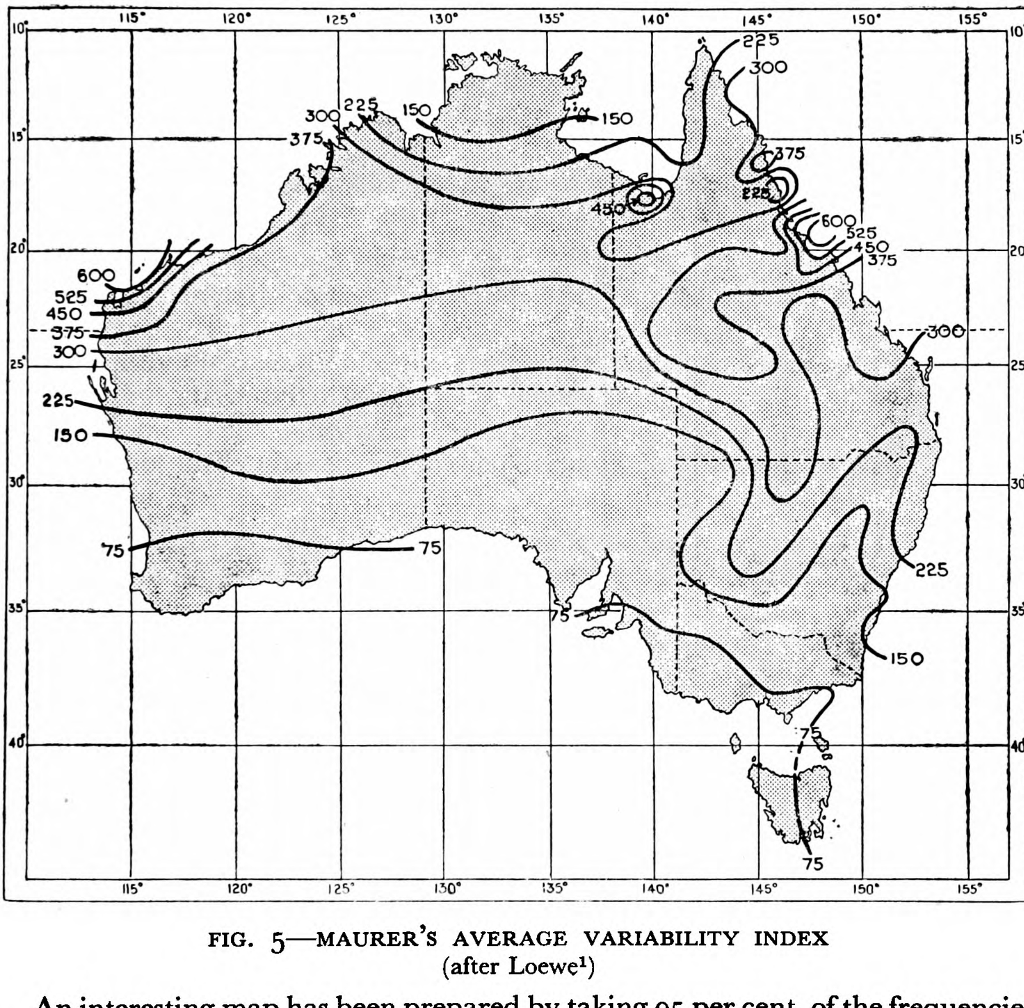

FIG. 5—MAURER'S AVERAGE VARIABILITY INDEX
(after Loewe[1])

An interesting map has been prepared by taking 95 per cent. of the frequencies instead of 50 per cent. as in the former case, and expressing one fourth of the range corresponding to these frequencies as a percentage of the median (Fig. 4).

The general distribution is similar to that of the previous map but with some important differences. The values of the index are generally higher than those of the map previously described. In the north-west of Western Australia they are twice as great and the area of maximum deviation has shifted to the coast between Onslow and Port Hedland. In the south-west of Queensland the variability is over 60 per cent. Areas of lowest variability are western Tasmania, the western and central districts of Victoria and the south-west of Western Australia. The Darwin region, however, compares with the south-west of Western Australia.

The 95 per cent. deviation probably gives a truer picture of the general rainfall experience and has an advantage over the relative variability map in that the disturbing effects of extreme values are largely eliminated. The smoothing of the curve tends to result in a truer frequency distribution.

A map by Loewe, based on Maurer's average variability index, is shown for comparison in Fig. 5. This map shows areas of maximum variability on the north-west coast of Western Australia and between Bowen and Townsville, Queensland. There is also a high local variability around Burketown, Queensland, which is eliminated in the first two maps described. A marked southward dip over south-western Queensland and western New South Wales is also shown, indicating a high variability over this area.

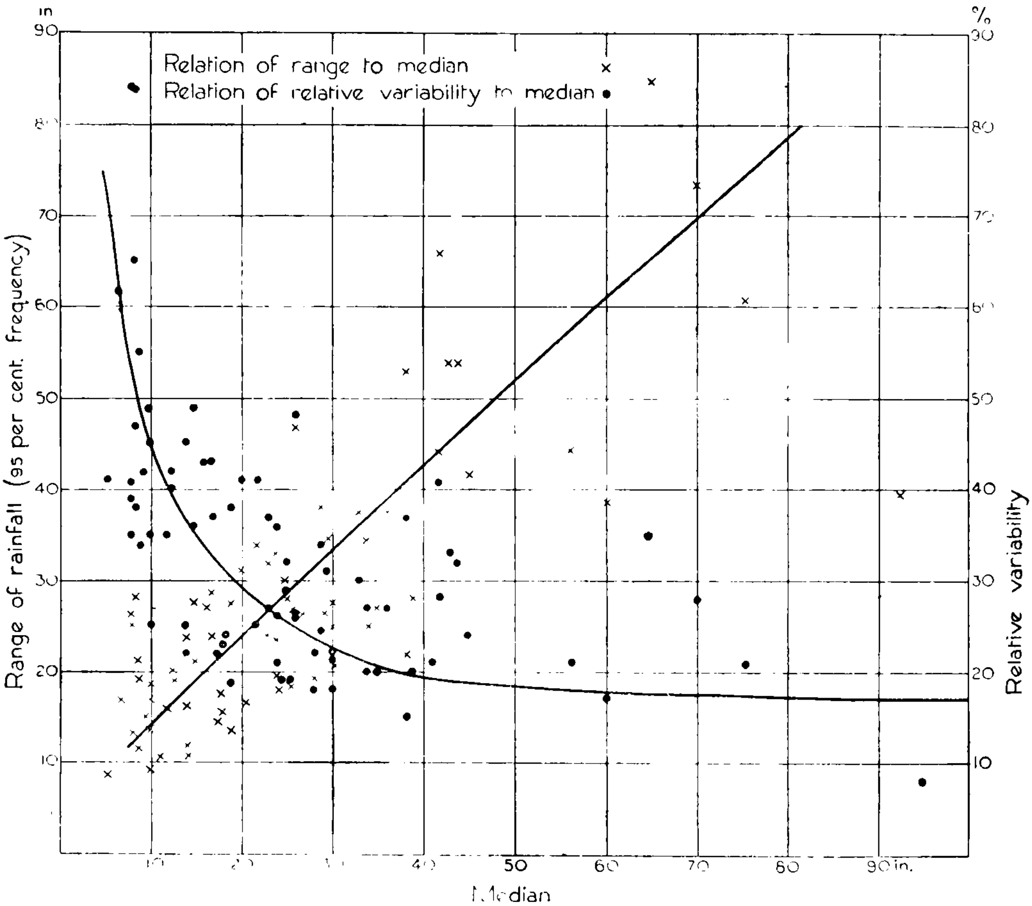

FIG. 6—RELATION OF RANGE OF RAINFALL (95 PER CENT. FREQUENCY) AND RELATIVE VARIABILITY TO MEDIAN RAINFALL

In order to obtain some indication of the change in value of the variability index with increase in the magnitude of the median, spot diagrams have been plotted of range against median for both the quartile deviations and the range of 95 per cent. of the frequencies. In the latter case, shown in Fig. 6, the ratios of range to median are close to unity, but for quartile deviations the ratio is approximately one to three. Some considerable scattering occurs in either case but this may be attributed to actual differences in the variability index. The variability index also is plotted against the median in Fig. 6; and, although there is a suggestion of a hyperbolic distribution, the very high values of the index occurring only with the rainfalls of under 10 in., even here the majority of values are about 40 per cent. or less. The diagram indicates that by taking 95 per cent. of the frequencies and using one fourth of the range to obtain a variability index a good comparison can be obtained between indices for wet and dry regions in Australia. The study has been limited to 77 stations. These stations are, however, fairly representative of various regions of the Commonwealth. Cumulative frequency graphs which have been drawn for all 77 stations indicate that there is a gradual change in the type of curve from one region to another.

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MEAN SEASONAL RESILIENCE OF THE ATMOSPHERE AROUND THE BRITISH ISLES 1948–50

By A. H. GORDON, M.S.

Shaw[1] states that the area on a tephigram between the environment curve and the lifting path curve of a parcel of air represents the surplus of energy developed by the operation of the environment upon unit mass of the working air over and above what is necessary merely to carry it upward through the environment. This information, derivable from the tephigram, shows the "liability" of the environment for the development of energy by the operation of unit mass of air.

When the "liability" of the atmosphere is negative we could re-define the "liability" as the "resilience", that is, the measure of the energy which would be available to restore the original position if a parcel of air were displaced upwards or downwards.

If adjacent vertical layers up to a common level are all lifted to that level then the total of all the areas enclosed by the two curves represents the total resilience of the atmospheric column considered. Values for various stations can be computed and a pattern drawn showing the geographical distribution of the potential energy of resilience. This technique can be applied synoptically to individual ascents, or climatologically to mean values for months, seasons or a period of years. The patterns produced may indicate regions where development is most likely to occur, either synoptically as suggested by Sumner[2] and Mook[3], or climatologically.

An example of the method is illustrated with mean seasonal values for the period 1948–50 inclusive for the ocean weather ship stations JIG* 53°50′N., 18°40′W. and ITEM* 60°00′N., 20°00′W. and the two British land stations Lerwick and Larkhill in order to compare land and ocean values and show their seasonal variation. The environment curves for the four stations have been constructed from mean seasonal values of temperature and humidity.

* Now known as stations JULIETT and INDIA.

It is considered that the use of mean values confined to seasons gives a sufficiently accurate approximation of the resilience of the atmosphere for comparing variations and producing patterns of the horizontal distribution. Each 100-mb. layer from 1000 to 700 mb. was lifted on the upper air diagram to 700 mb., and values of the resilience were obtained for each layer of 100-mb. thickness from the mean of the values for the upper and lower boundary levels of the layer. The areas were computed by planimeter and totalled for the 1000–700-mb. thickness.

Fig. 1 illustrates the seasonal variation of resilience of the 1,000–700-mb. layer at each of the four stations. The units are joules per gramme. In every case the air is stable and the values represent work that must be done on the atmospheric column to lift it to the 700-mb. level. Thus the atmosphere in the mean is stable and resilient at all stations for each season of the year. The curves for the two ocean stations are of similar form. Resilience is least in winter at ITEM and in winter and autumn at JIG and rises to a maximum in summer. Except in autumn ITEM is less resilient than JIG for the same season. L. D. Sawyer[4] has shown, on the basis of a 5-year period, that more depressions form and deepen over the Atlantic Ocean during the winter than during the summer half of the year. A higher liability would be in accordance with this greater frequency and intensity of cyclonic development.

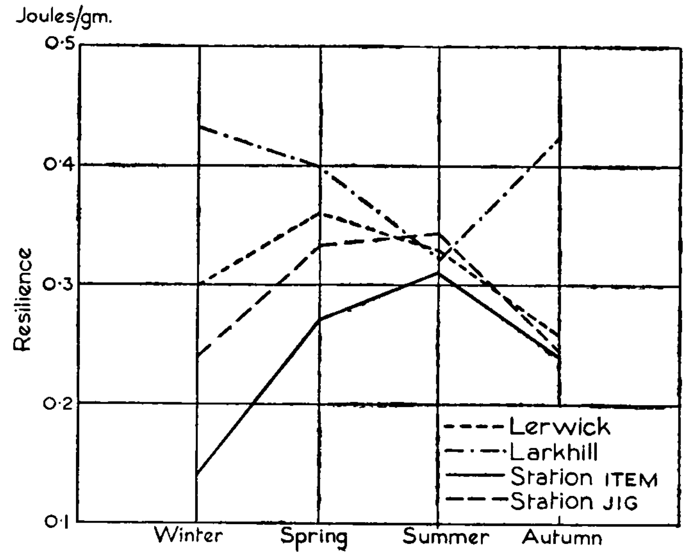

FIG. 1—SEASONAL MEAN VALUES OF RESILIENCE, 1948–50

The curve for Larkhill differs considerably. The resilience reaches a maximum in winter and a minimum in summer. This variation is the reverse of that which occurs over the ocean stations. The minimum value of resilience in summer at Larkhill is approximately the same as the maximum value at JIG in summer.

The curve for Lerwick follows the form of the curves for JIG and ITEM, although the maximum is reached in spring and the minimum in autumn. This might be expected since although Lerwick is on an island it may at times be temporarily influenced by land conditions, as, for example, local heating in summer.

The usefulness of this kind of representation lies in the comparison of the potential energy of the atmosphere from season to season and between land and oceanic climatic regions.

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1. SHAW, SIR N.; Manual of meteorology, Vol. III, Cambridge, 1930.
2. SUMNER, E. J.; Unusual deepening of a frontal depression over the British Isles. *Met. Mag., London*, **80**, 1951, p. 130.
3. MOOK, C. P.; Deepening of frontal depressions. *Met. Mag., London*, **80**, 1951, p. 335.
4. SAWYER, L. D.; Some regions of formation of depressions in the North Atlantic. *Prof. Notes met. Off., London*, **4**, No. 50, 1928.

METEOROLOGICAL RESEARCH COMMITTEE

The 21st meeting of the Physical Sub-Committee of the Meteorological Research Committee was held on June 11. A paper by Mr. E. Knighting[1] dealing with atmospheric turbulence as an aspect of random motion was considered. Two papers dealt with high-level cloud, one, by Mr. Durst[2], containing a report of an extensive sheet of high-level cloud in the tropics, and the other, by A. C. Best[3], presenting three reports of ice accretion in clear air or in cirrus cloud. The last two papers considered, one by Mr. Durst and Mr. Gordon[4] and one by Commander Darlington[5] presented data about the vertical gradient of humidity and temperature over the ocean.

ABSTRACTS

1. KNIGHTING, E.; Random motion and atmospheric turbulence. *Met. Res. Pap., London*, No. 728, S.C. III/130, 1952.

The turbulent motion of marked particles from a point source is compared to random walks of a cluster. As the cluster spreads, larger eddies take effect and the steps are made with increasing velocities. Mathematical discussion leads to the conclusion that turbulence is characterized by this "law of step size".

2. DURST, C. S.; High-level cloud in the tropics. *Met. Res. Pap., London*, No. 727, S.C. III/129, 1952.

In March 1952, in flight from Khartoum to Livingstone, continuous thin cirrus was observed between 10°40′N. and 16°S., at 45,000–50,000 ft. Photographs are given. Cloud is attributed to ice needles from condensation in rising and spreading air near the equator.

3. BEST, A. C.; Ice accretion in cirrus cloud. *Met. Res. Pap., London*, No. 730. S.C. III/131, 1952.

Earlier observations of temperature of spontaneous freezing of water droplets of different sizes are summarized, and suggest that at -50°C. liquid drops must be of diameter 1 μ or less. Three observations of icing in cirrus (one at -54°C.) indicating liquid drops are discussed.

4. DURST, C. S. and GORDON, A. H.; Some observations of vertical temperature and humidity gradients made from ocean weather ships. *Met. Res. Pap., London*, No. 714, S.C. III/125, 1952.

Psychrometer observations in May–September 1951 at JIG (52½°N., 20°W.) and ITEM (59°N., 19°W.), 0–50 ft. above sea surface are tabulated and vertical gradient of dew point compared with sea temperature, wind and weather.

5. DARLINGTON, C. R.; The variation of humidity with height over the ocean. *Met. Res. Pap., London*, No. 725, S.C. III/128, 1952.

During cruises in arctic and northern waters and in the south-west North Atlantic numerous observations of dry- and wet-bulb temperature were made at 0–30 ft. above sea. These are set out in detail with associated wind and weather. Mean profiles of temperature and vapour pressure are shown graphically. The theory of evaporation is set out and Montgomery's "evaporation coefficient" and rate of evaporation are calculated for unstable and stable, rough and smooth conditions, from vapour pressure at 0 and 20 ft. Results are erratic but in general agreement with theory.

ERRATA

July 1952, PAGE 198, line 25; *for* "Able and Baker . . . maturity." *read* "Able occurred off the Bahamas in the second half of May 1951 and Baker over the Atlantic south-east of Bermuda between August 2 and August 5, 1951."

August 1952, PAGE 244, line 42; *for* "June 18, 1952" *read* "January 18, 1952".

OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

Annual Report of the Director of the Meteorological Office presented by the Meteorological Committee to the Secretary of State for Air for the year April 1, 1951 to March 31, 1952.

The Meteorological Office provides meteorological services for the Royal Air Force and Army, civil aviation, other government departments and public utility corporations, agriculture, the Merchant Navy, industrial concerns and the general public. The Report describes the organization by which these services are rendered. New meteorological offices have been opened to meet the needs of the expanding R.A.F., and in other respects also services have been improved or extended. Wherever possible, however, economies have been made, and in particular the programmes of radio-sonde ascents and of special meteorological flights by aircraft have been greatly reduced.

Interest in meteorological conditions at great heights has grown rapidly, largely because of the increasing amount of flying at heights above 40,000 ft. A new Branch of the Office was formed in May 1951 to deal with upper air climatology.

Among the many subjects of research mentioned in the Report are methods of forecasting weather for comparatively long periods, icing on aircraft, and the study of cloud structure by radar. Development work has continued on a number of instruments, particularly the radar theodolite and other radar methods of measuring upper winds.

The geophysical observatories at Kew, Lerwick and Eskdalemuir have maintained their series of observations and automatic records.

The responsibilities of the Office overseas have been slightly reduced by the handing over to local governments of all meteorological services in the West Indies and all services connected with civil aviation in Germany and Ceylon. Political disturbances in Egypt caused inconvenience, but did not interrupt the services provided for the armed forces in the Canal Zone.

Senior members of the staff have attended meetings of the World Meteorological Organization, the International Civil Aviation Organization and other international bodies.

Condensation trails from aircraft. 2nd edition.

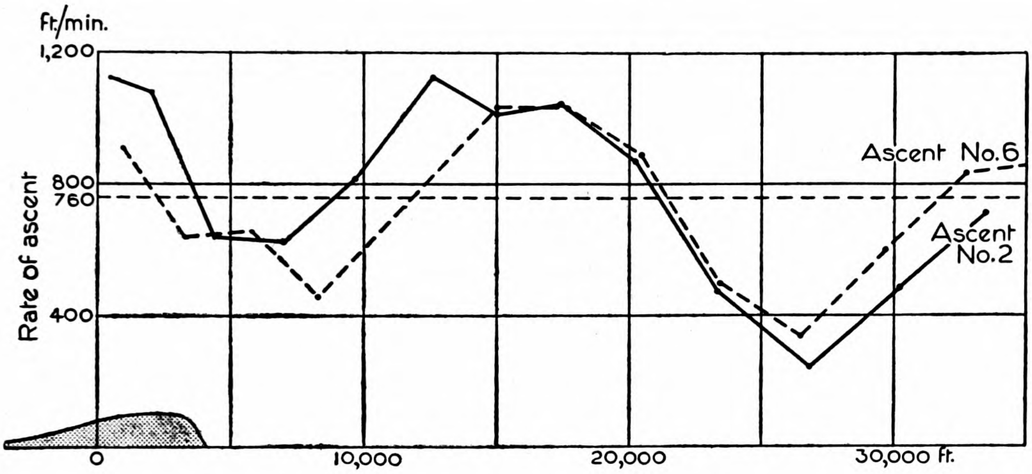
The theory of the formation of condensation trails by aircraft is described in this pamphlet. The most important type of condensation trail is the exhaust trail which forms when the water vapour resulting from combustion of the fuel more than offsets the drying tendency of the heat generated by the engine; this can only occur at low temperatures (below − 11°F. at sea level, below − 34°F. at 30,000 ft.). For a particular height it is important to know the immunity temperature, i.e. the critical temperature above which exhaust condensation trails are unlikely to form even if the atmosphere is saturated. In this second edition of this pamphlet the immunity temperatures for a typical piston-engined aircraft (Spitfire) have been amended in the light of more recent data, and similar figures are also given for a typical jet-engined aircraft (Canberra).

LETTERS TO THE EDITOR

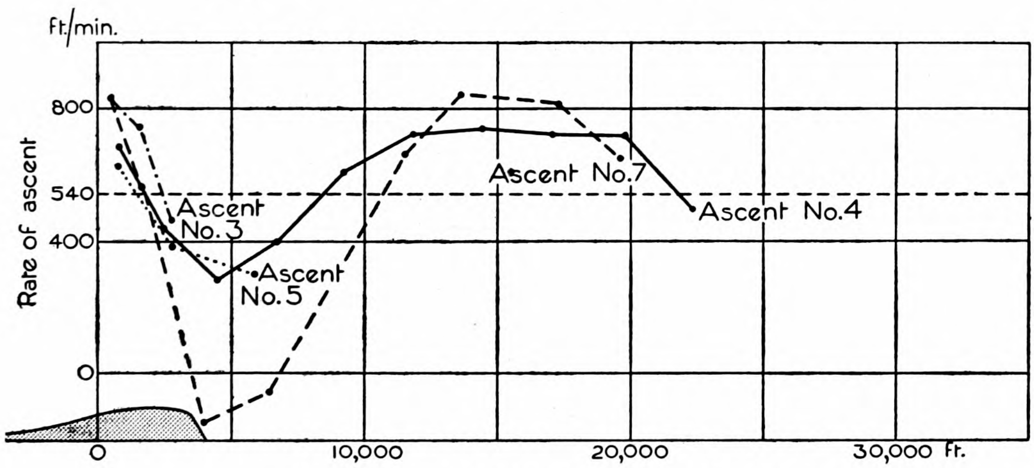
Standing wave at Aberporth

The *Meteorological Magazine* for April 1951 carried a study of standing waves and powered flight[1]. In this, as in similar notes, the lack of quantitative wind measurements was mentioned. It has occurred to me that I may be able to refer you to a good example of reliable wind measurements through a standing wave.

The measurements were made at Aberporth, Cardigan (52°08′N., 04°34′W.) on March 12, 1941, and the regularity of the vertical current was not noticed until later.



(*a*) 150-in. balloons (assumed rate of ascent: 760 ft./min.)



(*b*) 90-in. balloons (assumed rate of ascent: 540 ft./min.)

FIG. 1—PILOT BALLOON ASCENTS FROM ABERPORTH, CARDIGAN

Double theodolite ascents, Nos. 2–7, 1045–1445 G.M.T., March 12, 1941. Wind direction south-easterly, speed 17 kt. at 500 ft., 24 kt. at 5,000 ft. and 28 kt. at 10,000 ft. Height of point of release: 420 ft. above M.S.L. Terrain: approximately level downwind for 4,400 ft. and then a 400-ft. cliff to the sea; upwind, river valleys, main bottom 100 ft. above M.S.L. at 1–1¼ miles, followed by ridge rising to 500–700 ft. above M.S.L. at about 3½ miles

Six ascents (Nos. 2–7 of that date) were made between 1045 and 1445 G.M.T., all by the double-theodolite method, but the balloon behaved so erratically that on two occasions it was accidentally lost from sight by one of the observers after the third minute. Even in these ascents such data as were obtained confirmed the constancy of the phenomenon. Of the four complete ascents, two were made using slightly overfilled 90-in. balloons so that the theoretical rates of ascent were more than 500 ft./min., and two using 150-in. balloons filled to rise at about 750 ft./min.

It was immediately obvious from a comparison of the two pairs of balloons that, as might be expected in a standing wave, the areas of ascending and descending currents depended on horizontal distance from the point of release and were independent of height. A plot of the observed rate of ascent against horizontal distance from the point of release is given in Fig. 1. Observations were made and plotted at one-minute intervals. The inset of the profile of the terrain on the same horizontal scale shows how the first down-draught coincides with the cliff drop. The up-draught at the station is presumably due to the upslope of the valley to windward. The wave-length is 4–4½ miles. The downward currents appear to be more concentrated than the upward ones.

Extreme values of the currents were at least 350 ft./min. upward and 650 ft./min. downward, a total range of 1,000 ft./min. over a distance of half a wave-length. There seemed to be no variation with time.

Small sections of streamlines may be calculated from the balloon ascents if it is assumed that any deviation of the observed increases in height per minute from the estimated rate of ascent in still air is due solely to vertical currents. A rate of ascent of 760 ft./min. has been assumed for ascents 2 and 6 and 540 ft./min. for ascents 4 and 7. Fig. 2 was then constructed as follows.

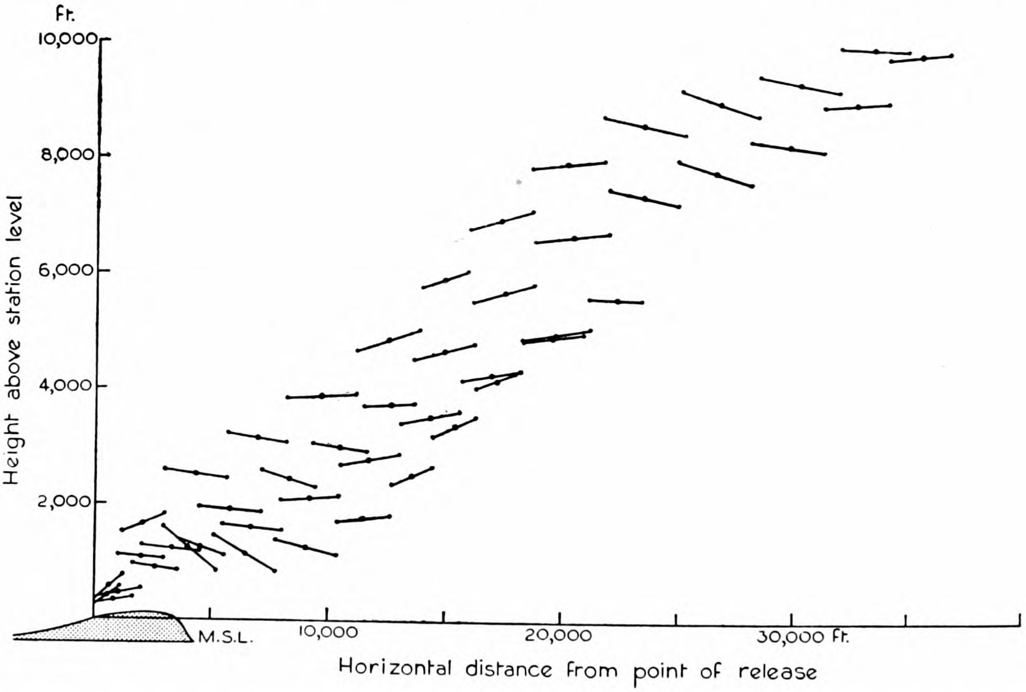


FIG. 2—SECTIONS OF STREAM LINES CALCULATED FROM PILOT-BALLOON ASCENTS

The centre point of each line is the mid height of the balloon above station level in any minute plotted against the mid distance from the station in that minute. The length of the line is the increase of distance from the station in the minute and the difference in height between the ends of the line is the difference between the observed rate of ascent and the estimated rate of ascent in still air. The picture suggested here may be compared with the examples of theoretical streamlines in the lee of an obstruction as given by R. S. Scorer[2].

A. R. LAIRD

Piarco, Trinidad, June 3, 1952

REFERENCES

1. TURNER, H. S.; Standing waves and powered flight. *Met. Mag., London,* **80,** 1951, p. 106.
2. SCORER, R. S.; Theory of waves in the lee of mountains. *Quart. J. R. met. Soc., London,* **75,** 1949, p. 41.

Vertical currents observed at Habbaniya, May 6, 1952

A request from the forecaster on May 6, 1952, for a radar-wind sounding resulted in an ascent being made in very unstable air. The graph in Fig. 1 shows a vertical section of the track of the balloon.

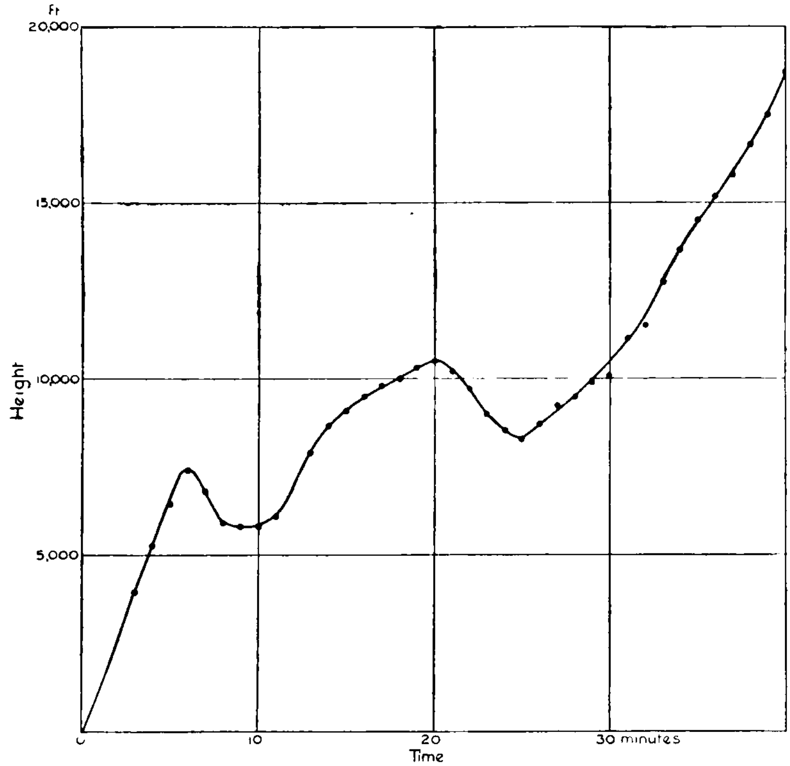


FIG. 1—VERTICAL ASCENT OF RADAR BALLOON AT HABBANIYA, 0630 G.M.T., MAY 6, 1952

Although I have known of balloons being forced down I have never seen a record of one descending so great a distance or for such a length of time. As the balloon was filled to rise at 1,300 ft./min. it will be seen that, with the possible exception of a small period around the 12th minute, the balloon was in a downward current between the 6th and 30th minutes of flight. On two occasions the downward currents were sufficiently strong to force the balloon down through 1,500 ft. The maximum downward current, of the order of 2,100 ft./min., occurred between the 7th and 8th minutes.

The balloon was launched at 0630 G.M.T. The surface wind was 100°, 6 kt. but at 0636 there was a sudden rise to about 16 kt. with a gust of 29 kt. from 330°. The upper wind was about 150°, 15 kt. up to 5,000 ft.; 290°, 6 kt. at 6,000 ft.; 180°, 30 kt. at 8,000 ft.; 200°, 28 kt. at 10,000 ft.; and from there the direction was fairly constant at 190° with the speed increasing to 40 kt. at 20,000 ft.

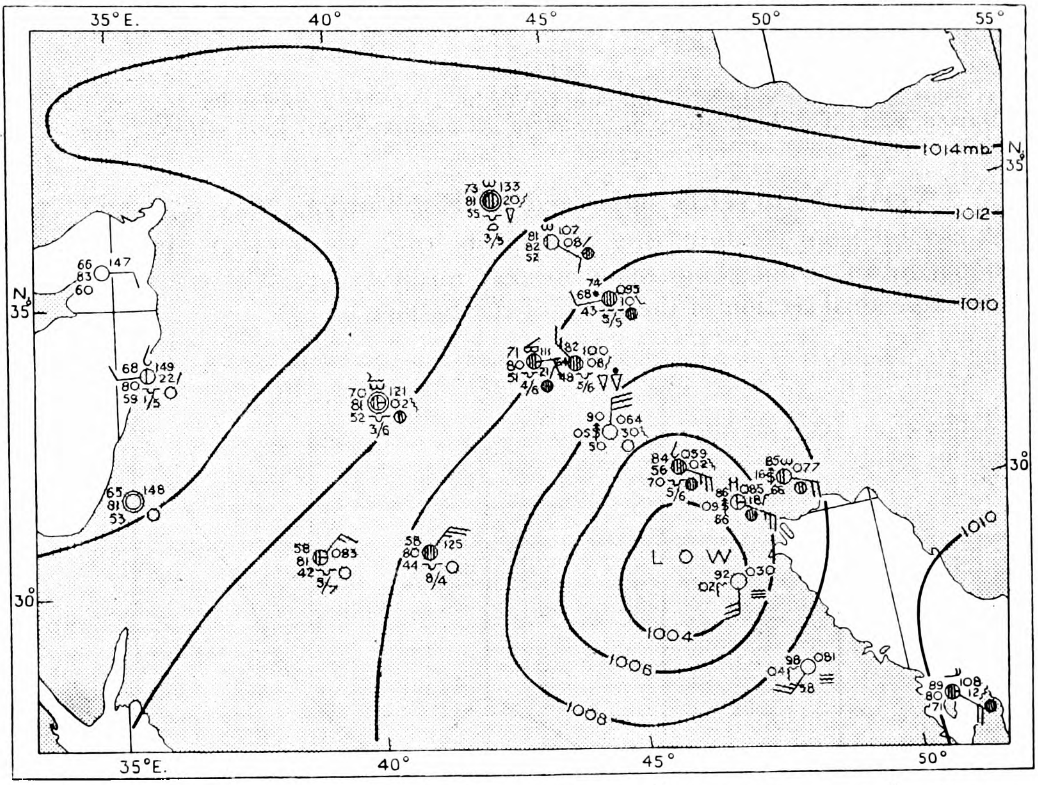


FIG. 2—SYNOPTIC SITUATION, HABBANIYAH, 0600 G.M.T., MAY 6, 1952

At 0630 there were 6 oktas of stratocumulus with base estimated at 5,000 ft. The surface chart for 0600 G.M.T. on May 6 (see Fig. 2) showed a low-pressure system centred at 29°N., 46°E. and the 500-mb. chart for 0300 G.M.T. showed a low-pressure system centred at 35°N., 40°E. From about 0635 G.M.T. there was a drop of about 2 mb. in about 10 min.

H. E. PAINTER

Habbaniya, May 28, 1952

[Venkiteshwaran and Tilakan* describe a more complex occurrence of forced descent of a radio-sonde balloon released at Poona during a thunderstorm on April 26, 1950. On that occasion the fan stopped rotating and the balloon is shown to have been weighted with ice. In the Habbaniya ascent reported by Mr. Painter there seems no doubt that downward currents alone were responsible. Winds calculated on the assumption of constant rate of ascent from observations made in such circumstances would of course be very misleading.—Ed. *M.M.*]

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*VENKITESHWARAN, S. P. and TILAKAN, A. R. B.; Interesting features shown by a radio sonde ascent at Poona on 26 April, 1950, during a thunderstorm. *Indian J. Met. Geophys., New Delhi*, 3, 1952, p. 55.

NOTES AND NEWS

Cloud in the stratosphere

In the note on "Very high cloud layer, August 10, 1951", published in the *Meteorological Magazine* for December 1951, a report from a pilot was quoted of a cloud layer between 46,500 and 47,500 ft. near Preston, Lancashire. It was subsequently ascertained that the cloud extended horizontally at least from north of the Welsh mountains to Brighton. It was so tenuous that it was not possible to be exact as to its base or top. Cloud at such a height implied a frost point of between −50° and −58°F., and it is difficult to understand how air with such a frost point could get into the stratosphere above a tropopause (at 37,000 ft.) with a temperature of −70°F.

Trajectories on the isobaric surfaces of 200 and 100 mb. indicated that air at these levels over Liverpool on August 10, might have originated in the region of Hudson Bay two days earlier. The Controller of the Canadian Meteorological Service was asked if there were any reports of forest fires in this region at the relevant time. He replied that it was extremely unlikely that a smoke cloud could have been produced sufficiently coherent to be observable two days later, so far as the relevant Canadian records showed. The pilot who observed the cloud was in a pressurized cabin, using 100 per cent. oxygen so he was unable to express an opinion as to whether the cloud was composed of smoke particles.

Saturation in the stratosphere.—In his letter of reply the Controller of the Canadian Meteorological Service volunteered the opinion that the cloud could have been composed of ice crystals, having regard to the observations of Barrett, Herndon and Carter*. These were upper air observations up to a height exceeding 28 Km., made on July 1 and August 26, 1949, at Camp Ripley, and on January 7, 1950, at St. Louis, and using automatic frost-point hygrometers. All showed a remarkable layer of saturation, with respect to ice, in the stratosphere, at heights between 150 and 100 mb., well above the level of any British frost-point observations. The frost points at the level of saturation were:—

	July 1, 1949	August 26, 1949		January 7, 1950	
			millibars		
Pressure ...	107	138	125	131	116
			degrees Fahrenheit		
Frost point ...	−54	−74	−77	−71	−71

It is impossible to explain how water vapour can be carried upwards in this way, but the authors of the paper after discussing four possibilities conclude that it is most probably due to vertical transport in convection cells, i.e. to the penetration into the stratosphere of very high cumulonimbus.

When the American observations are plotted they are as shown in Fig. 1, where only portions of the curves are given. In or near the layers of saturation in the stratosphere there is a discontinuity in the temperature curve, there being a marked decrease in temperature above the level of the discontinuity as compared with that below the discontinuity. On July 1 the observed point

* BARRETT, E. W., HERNDON, L. R. and CARTER, H. J.; Some measurements of the distribution of water vapour in the stratosphere. *Tellus, Stockholm,* **2,** 1950, p. 302.

of saturation is at the base of the discontinuity, on August 26 there is a layer of saturation at the top of the discontinuity, and on January 7 the layer of saturation is just above the top of the discontinuity. The wet-bulb potential temperatures at the levels of saturation in the later two observations are about or just over 90°F. while that of the first is over 100°F. It is inconceivable that this last observation could relate to the lifting of surface air under adiabatic conditions and the other two observations are very near the borderline in that regard, on the assumption that the relevant air masses originated in the most humid regions of the earth. A possible explanation is that heat by radiation

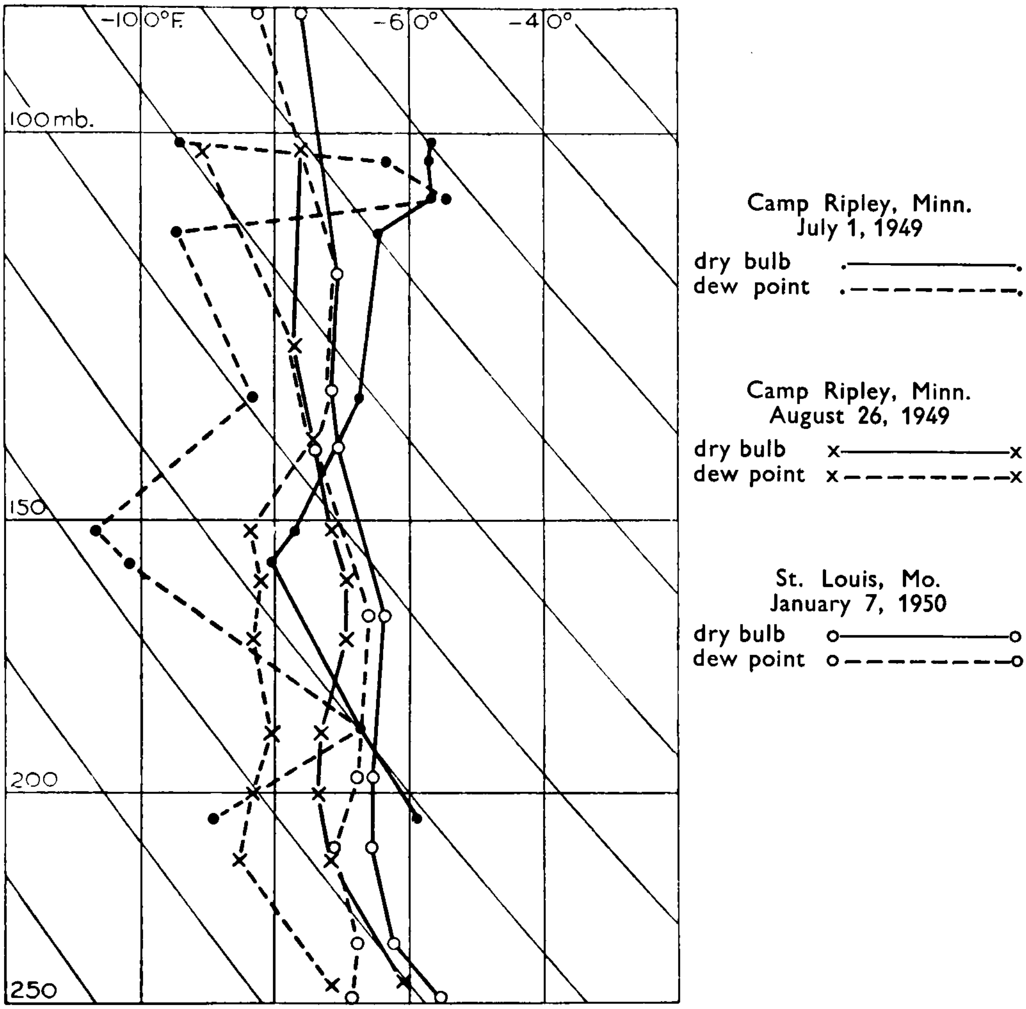


FIG. 1—HIGH-LEVEL TEMPERATURE AND FROST-POINT OBSERVATIONS MADE IN AMERICA

The sloping lines in the background are dry adiabatics

was supplied to the top of a penetrating cumulonimbus cloud, sufficient to evaporate the cloud but insufficient to lower the relative humidity below 100 per cent. One would have expected such a fine adjustment to be rarer than could be encountered on three consecutive chance occasions, but there may be some significance in the fact that the humid layers lay on all occasions between 150 and 100 mb. The authors suggest that such a saturated layer may be a semi-permanent feature of the atmosphere, at least in middle latitudes.

Upper air observations over England and Wales, August 9–10, 1951.—Between 1500 G.M.T. on August 9 and 1500 G.M.T. on August 10, 1951, there was a progressive lifting of the tropopause over Ireland, England and Wales, as shown in Fig. 2. In this figure the isopleths of the change in the pressure level of the tropopause are shown. There is an area of maximum lifting over Wales and south-west England, though the area of absolute maximum lies over north-west France. During the 10th there was a steady encroachment of tropical air in the troposphere over England and Wales, displacing the air of the 9th when there was a pronounced cold pool over the British Isles. The

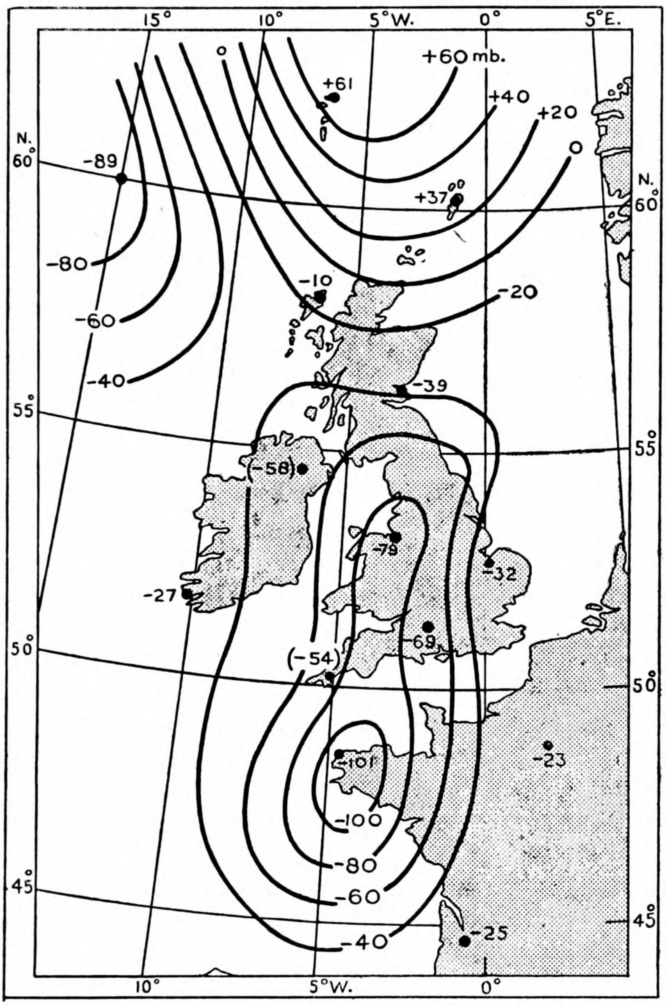


FIG. 2—CHANGE IN LEVEL OF TROPOPAUSE BETWEEN AUGUST 9 AND AUGUST 10, 1951

amount of dry adiabatic lifting required to convert the temperature curve in the stratosphere over Liverpool on the 9th to that over Liverpool on the 10th, would have been approximately that shown in the following table.

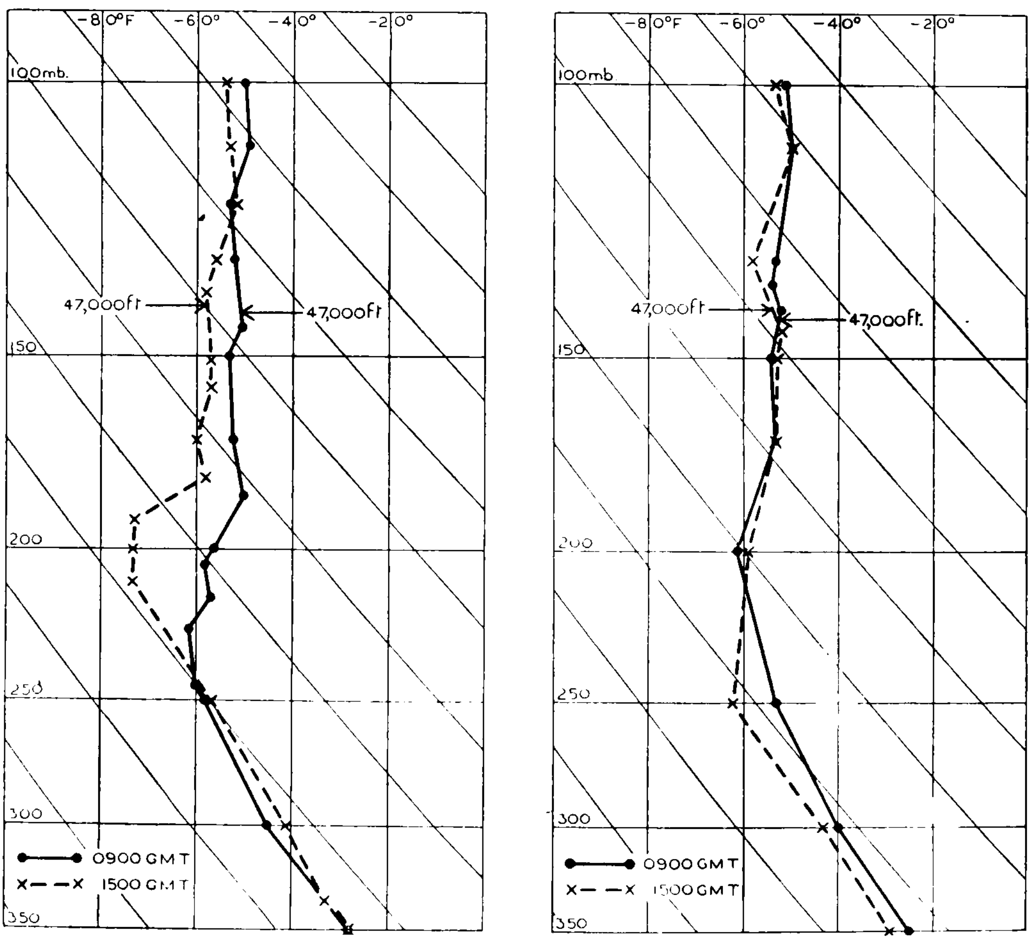
		millibars		
Level of temperature curve { on 9th	277	231	200	160
Level of temperature curve { on 10th	223	203	181	150
Difference between pressure levels (dry adiabatic lifting required)	+54	+28	+19	+10

Examination of the upper air observations over England on August 10 at 0900 and 1500 G.M.T. reveals at a number of stations discontinuities on the temperature curves, in the stratosphere, similar to those shown by the American curves in Fig. 1. One such discontinuity at Liverpool at 0900 G.M.T. occurred between 140 and 135 mb. (about 47,000 ft.) temperature falling 2°F. from the lower to the upper level and the temperature at the base being −52°F. At 1500 G.M.T. this discontinuity had become much more marked, temperature being −52°F. at 144 mb. and −58°F. at 130 mb. Relevant winds were:—

Liverpool	0900 G.M.T.	1500 G.M.T.
150 mb.	338° 30 kt.	316° 27 kt.
130 mb.	336° 22 kt.	318° 19 kt.

These observations show that cooling was occurring throughout the layer within which the cloud formed and at the relevant time. Fig. 3 shows the pressure-temperature curves for Larkhill and Liverpool. These show that the cooling in the stratosphere was more marked at Larkhill than at Liverpool in the period from 0900 to 1500 G.M.T. on August 10, 1951.

An aircraft flying from Edinburgh to Oakington between 0900 and 1000 G.M.T. on Monday, August 25, 1952, observed 8 oktas cirrostratus, base 38,000 ft., top 46,000 ft., over the whole route, the tropopause being at 35,000–36,000 ft. This observation confirms the idea that in disturbed weather



Larkhill Liverpool

FIG. 3—UPPER LEVELS OF RADIO-SONDE ASCENTS OF AUGUST 10, 1951
The sloping lines in the background are dry adiabatics

in summer, vertical movements in the lower stratosphere may lead to condensation in the "semi-permanent layer of saturation" at these heights.

Conclusion.—As indicated in the previous note in the *Meteorological Magazine* the high cloud was the precursor of a vigorous depression associated with prolonged rainfall over the British Isles during a very unsettled period of weather. Probably the intensity of divergence was unusual, and if a saturated layer in the stratosphere between 100 and 150 mb. is a semi-permanent feature of middle latitudes it was probably subject to an unusual degree of cooling. It is suggested that the dynamic cooling of this saturated layer was such as to lead to the cloud observed.

J. S. FARQUHARSON

An example in applied climatology

From inquiries received in the climatological branches of the Meteorological Office it has been apparent for many years that there is an ever-increasing demand for meteorological data for use in industry and other fields of applied science. A first impression from any comprehensive survey of such inquiries must be that their great diversity makes it almost impossible to undertake any concise analysis or exhaustive classification; and this is equally true whether they are looked at mainly with the range of applications in mind, or with the types of data and required methods of presentation to the fore. It also appears that the economic value of the applied data, when this can be assessed with any confidence, bears no consistent relationship to the effort which is needed for their collection and preparation, or to the purely meteorological interest of the information sought.

It follows that the climatologist cannot arrive unaided at any valid conclusions about what can most usefully be done in his field to aid economic development. The needs of the situation can be fully met only by close liaison between climatologists and the appropriate experts in industry and research. This is to some extent realized in present practice; but there is room for an indefinite expansion of what has already been achieved.

An example illustrating these generalizations is furnished by the position regarding information about atmospheric humidity. In the older tradition of climatology emphasis was often placed on relative humidity at the expense of other measures of moisture content, and this was reflected, for instance, in the lay-out of the *Observatories' Year Book*, and in the climatological tables given in various publications. In synoptic meteorology greater emphasis is placed, for obvious reasons, on dew-point temperature. The distribution of vapour pressure has also received attention. But among the more insistent demands in applied climatology there have recently been repeated calls for detailed information about the space-time distribution of wet-bulb temperature. It is not the object of this note to deal with the difficulties of providing this information, from available material, in the form in which it is required, but to discuss two items of current literature[1,2] concerned with a particular field, which explain a great part of the need for wet-bulb temperature data. It will be seen how far some of the general principles which should govern applied climatology can be and are observed.

Wet-bulb temperature data are required mainly in connexion with problems of cooling, air conditioning and comfort, and the literature now under review is concerned with the important sub-section of such problems covering the use of cooling towers in industrial processes. The first item by Jackson[1] is an approach to a general handbook on the subject. The present writer is not competent to discuss the work on the technical side, but finds nothing to conflict with the assurance, given to him by an expert in this field, that it is a very commendable effort containing information of much value, especially with regard to test-data and the economics of cooling. It is perhaps too one-sided in the relative prominence given to one type of tower and to a particular theoretical approach (due to Merkel[3]); against this, however, it is understood that it is the only book of its kind at present available, and it must also be said that its one-sidedness is frankly declared and in part corrected by references to other available literature.

Meteorological interest arises, directly or indirectly, at a number of points:—

(i) the process of evaporative cooling and the importance of atmospheric wet-bulb temperature;

(ii) the quantities of water required in different cooling processes, and the water-supply problem;

(iii) the possible effects, with different processes, on river flow and river temperatures; and

(iv) the possible effects on local atmospheric conditions, including temperature, humidity, visibility and precipitation.

Whilst the greatest interest lies in (i), a few other points connected with (ii) to (iv) may be noted in passing. The water-supply problem (coupled with effects on rivers) is of course a major reason for the existence of cooling towers in that they enable the same water to be used over and over again, with but a small percentage loss for each cycle. With regard to river temperature, an example quoted by Townend and Richards[2] is that throughout the year the Thames is warmer at Battersea than at Teddington (with a difference of about 7°F. in summer), largely, it is supposed, because of the intervening power stations which make direct use of river water for cooling (this supposition probably requires a quantitative check before it can be completely accepted). Finally, the precipitation nuisance in the neighbourhood of cooling towers has been definitely established to be due to the carry-over of spray droplets, and not to condensation as was formerly believed (methods of eliminating it are still under investigation).

On the approach to any meteorological question Jackson's book is weaker than it need be—though perhaps with a deliberate aim. In Appendix B, for example, there appears the statement: "wet-bulb and river-water temperatures are normally approximately equal, but the discharge of hot effluents into rivers in industrial areas raises the temperature of the river water." Evidence for the second part of this statement is given, but not for the first, and examples have been found of river temperatures in non-industrial areas exceeding dry-bulb temperatures (mean values) for part of the year. Although a recent paper by Eckel and Reuter[4] could not have been available to the author at the time of writing, he could surely, with a moment's reflection, have appreciated the role of some of the many factors whose influence these writers discuss.

Similarly, there seems to have been little attempt to find out exactly what information could have been obtained to determine optimum values for design wet-bulb temperatures in different parts of the country. A standard value of 62·8°F. is assumed, "as a reasonable compromise between peak and average summer conditions" (aspirated wet bulb, with dry bulb 68°F. and relative humidity 75 per cent.). It is true that consideration is given to the performance of cooling towers under other atmospheric wet-bulb temperatures, but it is at the design stage that the chosen value is all-important. It would have been useful to supplement the economic comparisons provided in the Appendices with a careful calculation of the saving which would be affected if, for instance, the design wet-bulb temperature could be lowered with confidence from 63°F. to 62°F.

Such information can be obtained from Townend and Richards. Their paper is narrower in its scope but much more satisfactory in its treatment of meteorological and allied data. Some dissatisfaction can be sensed in the statement that "unfortunately, meteorological stations observing wet-bulb temperatures are not numerous in this country" (which should, of course, read "... stations for which data are available in suitable form are not numerous ..."). But the information which has been obtained from the Meteorological Office for six stations near important industrial areas has been most thoroughly and carefully used, and made the basis of important conclusions. It appears that with design wet-bulb temperatures in the neighbourhood of 63–66°F., which are suggested as reasonable values for areas between Glasgow and London, there may well be a saving of 5 or 6 per cent. in the necessary size of a tower, and in corresponding capital costs, for every degree Fahrenheit by which the design wet-bulb temperature can be safely reduced. This surely justifies the authors' contention: "The problem of how often high wet-bulb temperatures occur in various parts of the country and what wet-bulb should be specified to tower makers has not so far received much attention. With modern high-performance mechanical-draught towers, however, it becomes acute". It gives force to the implication that hourly values of wet-bulb temperature should be available for a good number of stations throughout the country in order to meet their desire "to suggest a basis for choosing design wet-bulb temperatures which will enable the process operator to predict how long in an average year any particular water temperature will be exceeded with a given plant or to choose his equipment so that a specified water temperature is only surpassed on a limited number of occasions." The requirement is in fact receiving attention to meet this and other needs.

A. BLEASDALE

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Vertical currents over northern England

A report of vertical currents, apparently associated with lee waves, encountered near Newcastle on November 27, 1951, is published in the *Meteorological Magazine* for May 1952.

Vertical currents were again encountered over Newcastle between 0600 and 0700 G.M.T. on July 11, 1952. The pilot of an aircraft flying on a north-westerly track at 140 kt. at 13,000 ft. encountered an upward current lasting for between 5 and 10 min., which corresponds to a distance of between 14 and 28 miles, of speed estimated at 400–500 ft./min. The speed is estimated from the fact that by maintaining constant altitude airspeed rose from 140 to 160 kt. Down-currents were then experienced for a short period followed by less pronounced up- and down-currents. Another aircraft flying at 10,000 ft. encountered vertical currents producing a rise of air speed from 135 to 165 kt. in the up-currents and a fall to 125 kt. in the down-currents. A third aircraft flying at 13,000 ft., but some 8 miles further east, experienced a slight effect only.

The aircraft were flying over "corrugated" stratocumulus clouds. The tops of the cloud rolls were at 6,000–8,000 ft. and the "valley" bottoms at 3,000–4,000 ft. The corrugations were across the track of the aircraft and apparently roughly along the wind.

The aircraft encountered a wind of 240° 50 kt. at 13,000 ft. The relevant upper wind observations are tabulated below; they are all radar observations. Aldergrove is 170 miles distant to west-south-west, roughly up wind at the time, Liverpool 120 miles to south-south-west and Leuchars 110 miles to north.

	ALDERGROVE				LIVERPOOL		LEUCHARS					
	0300		0900		0900		0300*			0900	
ft.	°	kt.	°	kt.	°	kt.	ft.	°	kt.	°	kt.
24,000	253	52	247	86	256	37	(24,120)	238	61	235	83
18,000	248	46	247	70	255	41	(18,600)	241	63	235	76
14,000	255	44	240	61	254	41	(13,940)	245	57	243	63
10,000	254	47	257	50	247	39	(9,910)	252	58	247	51
6,000	254	40	252	39	252	31	(6,380)	251	43	235	35
2,000	244	25	252	28	243	22	(1,800)	235	33	252	27

* Winds only reported at fixed pressure levels.

It seems probable from these observations that the wind increased with height up to at least 13,000 ft. over Newcastle. The 0300 upper air temperature observations showed the presence of isothermal layers over Aldergrove at 5,000 and 12,000 ft. and of inversions over Liverpool at 3,500 and 8,000 ft. and over Leuchars at 8,000 and 16,000 ft.

The lapse rate above the inversion at 8,000 ft. over Liverpool and Leuchars was small. The increase of wind with height and the presence of the inversions agree with the theoretical requirements for the occurrence of standing waves, but a large lapse rate above the inversion would have been more favourable than the small one. It is however by no means certain that any of these ascents is representative of the temperature over Newcastle at 0600–0700 G.M.T. on July 11, 1952.

REVIEW

Tropical revolving storms and windstorm insurance. By M. C. Hart. *J. chart. Insur. Inst., London,* **48**, 1952, p. 89. *Illus.*, Chartered Insurance Institute, London, 1952. Price: 2*s.*

The literature on insurance against damage on land by wind or precipitation is not large and Mr. Hart's pamphlet, which is written for the instruction of insurance staff, provides, to the meteorologist, an interesting example of the economic importance of meteorological information.

Insurance against damage by hurricanes is a more difficult problem than insurance against fire. Fire claims vary relatively little from year to year; hurricane damage is infrequent but when it does occur produces claims which far exceed the total annual premiums for hurricane insurance.

The pamphlet advises the insurer on the use of meteorological information in the assessment of the liability to damage by hurricanes, tornadoes, strong winds in general, and fire following storm, rain and flood. It is interesting to see that the author, writing in 1948, recommends *Geophysical Memoirs* No. 19 as the most comprehensive study of the incidence of tropical storms*.

G. A. BULL

NEWS IN BRIEF

The L. G. Groves Memorial Prize for Meteorology has been awarded this year to Mr. A. C. Best, M.Sc., Principal Scientific Officer, Meteorological Office, London, who has made a special study of the physical conditions and processes occurring in clouds, and has made important contributions to our knowledge of this subject. Studies have been made of the size-distribution of water droplets in clouds, their rate of coagulation and their rate of evaporation when falling through the atmosphere. The results of these investigations have particular significance in connexion with the development of cloud and fog, the radar detection of cloud and precipitation and the complex problem of ice accretion on aircraft, and are thus of great practical importance to aviation.

Mr. Best's researches provide a coherent picture of a subject which has hitherto been largely a matter of conjecture and uncertainty.

The L.G. Groves Memorial Award for Meteorological Air Observers has been awarded this year to Sergeant J. L. Smith (3039145), Royal Air Force, Meteorological Air Observer, for meritorious work and devotion to duty with No. 1301 Meteorological Flight at Negombo, Ceylon. He has completed over 120 meteorological sorties totalling 660 hours, the majority of the flying having been carried out over sea areas unfrequented by shipping and where navigational aids are very limited. He combined the duties of navigator and meteorological air observer, and displayed technical ability of a high order. His visual observations and his conscientious recording of scientific data have always been of a very high standard, and he has shown a keen appreciation of the forecasters' requirements.

METEOROLOGICAL OFFICE NEWS

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

London B.Sc.(Special) pass: W. C. Reynolds

London B.Sc.(General) pass: P. D. Borrett, R. P. Chandler

Intermediate B.Sc.: T. Lockwood.

General Certificate of Education (*Advanced Level*) pass in one, two or three subjects: C. F. Bell, G. F. D. Cooper, S. G. Cornford, D. K. E. Crome, Miss E. A. Harris,

*NEWNHAM, MRS. E. V.; Tropical hurricanes and revolving storms. *Geophys. Mem., London,* **2**, No. 19, 1922.

Miss A. Hart, S. Hunter, E. B. Jefferies, J. N. Lain, P. Menmuir, P. G. Payne, J. A. Smith, M. Waines, R. R. Warner, Miss H. Woods.

Higher National Certificate: S. I. Nute, D. F. Winter.

City and Guilds. Radio I and II: first class pass: A. F. Hope.

Sport and Athletics.—The "Ariel" cricket team, representing the Air Ministry and the Ministry of Civil Aviation, have won the Curtis-Bennett (Cricket) Shield and so become the Civil Service cricket champions of 1952. Messrs. C. L. Hawson (Dunstable) and J. B. Shaw (Victory House) were members of the team.

In the Civil Service swimming championship races Miss D. S. Cook gained third place in the ladies' breast-stroke and Mr. S. W. Lewis third place in the men's 220 yards.

For the second year in succession, the Meteorological Office (Gloucester) team, came third in the Annual Sports of the Gloucester and District Civil Service Association which was held on August 9. Mr. E. B. Jefferies was first in the 120 yards hurdles and second in the 440 yards, in which Mr. Gallimore was third. The veterans, who scored points last year, were most disappointed that no veterans' race was held this year.

Christmas Party.—The Meteorological Office Social and Sports Committee announce that the Christmas Party will be held in the Air Ministry Refreshment Club "B" Block, Adastral House, on Tuesday, December 16. In addition to games and dancing, there will be a one-act play by staff from Harrow.

WEATHER OF SEPTEMBER 1952

Mean pressure was generally below normal over the whole of Europe and above normal over the Atlantic Ocean north of 45°N. The mean pressure in northern Scandinavia fell to 1004 mb., about 8 mb. below normal, and in western Europe where the mean pressure was generally 1015 mb., the deficit of pressure was about 3 mb. Mean pressure at the Azores was normal at 1020 mb., but northwards from the Azores, mean pressure in 50°N. reached 1022 mb. which was 7 mb. above normal and 1018 mb. in 60°N. which was as much as 11 mb. above normal.

Mean temperature was below normal over Europe the deficit generally being 4°F.; the mean temperature varied from 40°F. in Scandinavia, 50–60°F. in west Europe and 65–75°F. in the western Mediterranean.

In the British Isles the month was exceptionally cold for the time of year; at some stations with long records it was the coldest September and at others it equalled the previous cold September of 1912. At Oxford it was the coldest September in a record going back to 1815. It was mainly drier than the average in Ireland, most of Scotland except the north, and in part of the English Midlands and south-west Wales; on the other hand it was very wet in the North and East Ridings of Yorkshire, Dorset and locally on the south-east coast from Calshot to Felixstowe. Sunshine was mostly below the average except in some western districts.

In the opening days of the month pressure was high off our south-west coasts with a ridge extending across France, while a depression off east Iceland moved slowly east and turned north-east. Warm, rather sunny weather prevailed for the most part though showers occurred, chiefly in the north and west. In the early hours of the 3rd a small depression moved across south Scotland giving moderate rain in south Scotland, north England and north Ireland. In the rear of this depression cold northerly winds, with showers and local thunderstorms, prevailed for some days. Slight air frost occurred locally in Scotland and Ireland on the 7th and ground frost occurred fairly widely even in the south in the early morning on the 6th, 7th and 8th, while the maximum temperature at Dunstable on the 7th was only 47°F. On the 7th a shallow depression formed over the western English Channel and moved east causing widespread thunderstorms in the south (2·49 in. of rain was registered at Deal Water Works). Subsequently a depression north of the Faeroes moved south over the western part of Great Britain giving considerable rain, particularly in the south-west (3·09 in. at Beaminster, Dorset, on the 9th). Further rain or showers occurred in England and Wales on the 11th and 12th. Meanwhile an anticyclone was situated off our north-west coasts, and this system maintained dry weather over most of the country from the 13th to the 15th. On the 16th a depression near Iceland moved east to west Norway and by the 17th cold northerly winds were renewed over the British Isles, with showers and bright periods. There was more ground frost on the mornings of the 18th to the 20th. On the 20th and 21st a depression off south-east Iceland moved east-south-east, while a trough moved south-east over the British Isles giving rain generally, but on the 22nd and 23rd an anticyclone off our south-west coasts was associated with a short fair spell over England and Wales, temperature reaching 70°F. locally on the 23rd. On the 24th a very deep depression approached north-west Scotland and on the 25th it moved east-south-east to the North Sea. Heavy rain fell locally in Scotland on the 23rd and more widely on the 24th and 25th, while rain or showers occurred on the 26th (3·98 in. at Erracht, Glenhoy on the 23rd, 3·67 in. at Glenquoich on the 24th, 3·60 in. at Kinlochquoich and 2·39 in. at Thirlmere, Cumberland, on the 25th, and 3·65 in. at Kinlochquoich on the 26th). Gales were recorded at exposed stations especially in the west and north on the 24th to 26th and strong winds were general. Behind this depression north-westerly winds again prevailed and cool, unsettled weather was maintained until the end of the month. A depression moved north-east over England on the 28th and 29th; rainfall was heavy in places (2·28 in. at Kildale Gardens, Yorkshire, on the 28th) and thunder occurred locally. Another depression over Brittany on the 30th moving north-east gave widespread and prolonged rain in the south.

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 ...	75	27	−3·9	148	+5	86
Scotland	69	27	−3·2	98	+1	91
Northern Ireland ...	68	30	−3·7	74	+1	92

RAINFALL OF SEPTEMBER 1952

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·76	152	*Glam.*	Cardiff, Penylan ...	4·53	149
Kent	Folkestone, Cherry Gdn.	5·13	216	*Pemb.*	Tenby, The Priory ...	2·45	78
,,	Edenbridge, Falconhurst	3·15	139	*Radnor*	Tyrmynydd	4·48	116
Sussex	Compton, Compton Ho.	4·43	159	*Mont.*	Lake Vyrnwy	4·10	114
,,	Worthing, Beach Ho. Pk.	4·60	215	*Mer.*	Blaenau Festiniog ...	8·89	113
Hants.	Ventnor Cemetery ...	5·20	205	,,	Aberdovey	2·56	80
,,	Southampton, (East Pk.)	3·92	180	*Carn.*	Llandudno	3·86	181
,,	Sherborne St. John ...	3·48	170	*Angl.*	Llanerchymedd ...	4·49	153
Herts.	Royston, Therfield Rec.	3·12	166	*I. Man*	Douglas, Borough Cem.	4·28	131
Bucks.	Slough, Upton	3·06	174	*Wigtown*	Newton Stewart ...	2·86	84
Oxford	Oxford, Radcliffe ...	1·68	98	*Dumf.*	Dumfries, Crichton R.I.	1·62	60
N'hants.	Wellingboro' Swanspool	2·33	129	,,	Eskdalemuir Obsy. ...	2·35	64
Essex	Shoeburyness	3·50	210	*Roxb.*	Kelso, Floors	2·26	119
,,	Dovercourt	4·48	250	*Peebles*	Stobo Castle	2·18	87
Suffolk	Lowestoft Sec. School ...	2·79	142	*Berwick*	Marchmont House ...	2·43	101
,,	Bury St. Ed., Westley H.	2·73	137	*E. Loth.*	North Berwick Res. ...	1·95	93
Norfolk	Sandringham Ho. Gdns.	3·35	162	*Midl'n.*	Edinburgh, Blackf'd. H.	1·88	92
Wilts.	Aldbourne	2·36	118	*Lanark*	Hamilton W. W., T'nhill	2·36	88
Dorset	Creech Grange... ...	6·55	239	*Ayr*	Colmonell, Knockdolian	2·83	82
,,	Beaminster, East St. ...	6·58	258	,,	Glen Afton, Ayr San. ...	2·93	75
Devon	Teignmouth, Den Gdns.	2·81	143	*Renfrew*	Greenock, Prospect Hill	4·43	99
,,	Cullompton	3·48	155	*Bute*	Rothesay, Ardencraig ...	3·39	84
,,	Ilfracombe	3·59	133	*Argyll*	Morven (Drimnin) ...	5·00	88
,,	Okehampton Uplands...	5·00	154	,,	Poltalloch	5·27	115
Cornwall	Bude, School House ...	3·32	134	,,	Inveraray Castle ...	5·96	93
,,	Penzance, Morrab Gdns.	4·29	146	,,	Islay, Eallabus	3·78	90
,,	St. Austell	5·11	160	,,	Tiree	3·45	93
,,	Scilly, Tresco Abbey ...	4·67	182	*Kinross*	Loch Leven Sluice ...	2·46	96
Glos.	Cirencester	1·43	65	*Fife*	Leuchars Airfield ...	0·77	40
Salop	Church Stretton ...	2·53	120	*Perth*	Loch Dhu	4·55	79
,,	Shrewsbury, Monksmore	1·41	87	,,	Crieff, Strathearn Hyd.	1·37	48
Worcs.	Malvern, Free Library...	1·29	67	,,	Pitlochry, Fincastle ...	1·12	45
Warwick	Birmingham, Edgbaston	1·74	97	*Angus*	Montrose, Sunnyside ...	0·89	45
Leics.	Thornton Reservoir ...	1·64	91	*Aberd.*	Braemar	1·73	69
Lincs.	Boston, Skirbeck ...	2·21	126	,,	Dyce, Craibstone ...	2·05	85
,,	Skegness, Marine Gdns.	2·67	148	,,	New Deer School House	4·22	167
Notts.	Mansfield, Carr Bank ...	1·98	108	*Moray*	Gordon Castle	3·93	157
Derby	Buxton, Terrace Slopes	4·61	142	*Nairn*	Nairn, Achareidh ...	1·50	71
Ches.	Bidston Observatory ...	3·70	154	*Inverness*	Loch Ness, Garthbeg ...	3·96	128
,,	Manchester, Ringway...	2·88	127	,,	Glenquoich	11·87	137
Lancs.	Stonyhurst College ...	5·13	134	,,	Fort William, Teviot ...	6·37	100
,,	Squires Gate	4·61	170	,,	Skye, Duntuilm ...	5·82	127
Yorks.	Wakefield, Clarence Pk.	1·45	91	,,	Skye, Broadford ...	7·08	102
,,	Hull, Pearson Park ...	3·63	211	*R. & C.*	Tain, Tarlogie House ...	1·32	58
,,	Felixkirk, Mt. St. John...	4·23	232	,,	Inverbroom, Glackour...	6·30	143
,,	York Museum	3·72	228	,,	Achnashellach	9·34	136
,,	Scarborough	5·33	298	*Suth.*	Lochinver, Bank Ho. ...	6·14	177
,,	Middlesbrough... ...	4·66	281	*Caith.*	Wick Airfield	2·45	98
,,	Baldersdale, Hury Res.	3·60	141	*Shetland*	Lerwick Observatory ...	4·03	134
Norl'd.	Newcastle, Leazes Pk....	3·51	177	*Ferm.*	Crom Castle	1·50	54
,,	Bellingham, High Green	3·06	127	*Armagh*	Armagh Observatory ...	1·23	50
,,	Lilburn Tower Gdns. ...	4·31	183	*Down*	Seaforde	1·63	59
Cumb.	Geltsdale	3·88	139	*Antrim*	Aldergrove Airfield ...	1·39	56
,,	Keswick, High Hill ...	6·01	142	,,	Ballymena, Harryville...	2·90	93
,,	Ravenglass, The Grove	3·05	91	*L'derry*	Garvagh, Moneydig ...	3·49	117
Mon.	Abergavenny, Larchfield	3·28	140	,,	Londonderry, Creggan	3·35	102
Glam.	Ystalyfera, Wern House	3·09	71	*Tyrone*	Omagh, Edenfel ...	1·78	58

M.O. 559 AIR MINISTRY

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STORM OVER EXMOOR ON AUGUST 15, 1952

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

The rainfall over Exmoor which caused the Lynmouth flood disaster of August 15, 1952, produced one of the three heaviest falls in 24 hr. which have ever been recorded in the British Isles. In a Meteorological Office rain-gauge set up as recently as August 27, 1951, near Longstone Barrow on the ridge running from west to east about five miles south of the coast, a voluntary observer, Mr. C. H. Archer of Wootton Courtenay, near Minehead, measured 9·00 in. for the 24 hr. beginning at 0900 G.M.T. on the 15th.

The Longstone Barrow fall and its place in the records.—To explain the authenticity of this reading it needs to be said that it was not strictly a 24-hr. measurement in the usual sense. A standard rain-gauge is read daily at 0900 G.M.T., a practice which gives rise to the definition of a "rainfall day" as the period of 24 hr. beginning at this time on the date specified. But the gauge near Longstone Barrow is in a very remote spot at an altitude of 1,550 ft. above mean sea level, and it could scarcely be visited every day even by one of the few inhabitants of the moorland neighbourhood. It is in fact a monthly gauge intended to be read only on the first day of each month. Fortunately the observer makes additional readings of this and other monthly gauges for which he is responsible, and had made one such observation at about 1500 G.M.T. on August 14. On the 16th, appreciating the significance of what had occurred, he made a very difficult journey through Simonsbath along roads made almost impassable by flood debris, and then across the moor on foot, to take another reading at about 1130 G.M.T. on that day. The total rainfall for the intervening $44\frac{1}{2}$ hr. was 9·04 in., and there is ample reason to suppose that 0·04 in. is a generous allowance for the meagre falls which must be credited to the rainfall days 14th and 16th. The reading of 9·00 in. for the 15th may therefore be accepted and considered as reliable as the usual daily observation at a rainfall station. It is probably accurate within one or two per cent. Two other measurements made with standard gauges for the 15th approached this fall in magnitude. They were 7·58 in. at Challacombe and 7·35 in. at Honeymead, near Simonsbath, both on lower ground within a few miles of Longstone Barrow. There was abundant supporting evidence as will appear.

A total of 9·00 in. in 24 hr. has been surpassed only twice in the records of the British Rainfall Organization, which now go back, with fair cover for most of the British Isles, over a period of 80 or 90 years. There was a fall of 9·56 in. on June 28, 1917, at Bruton and one of 9·40 in. on August 18, 1924, at Cannington, in each case for the rainfall day. It is rather odd that these two outstanding falls both occurred in Somerset, and that the third highest now added to the

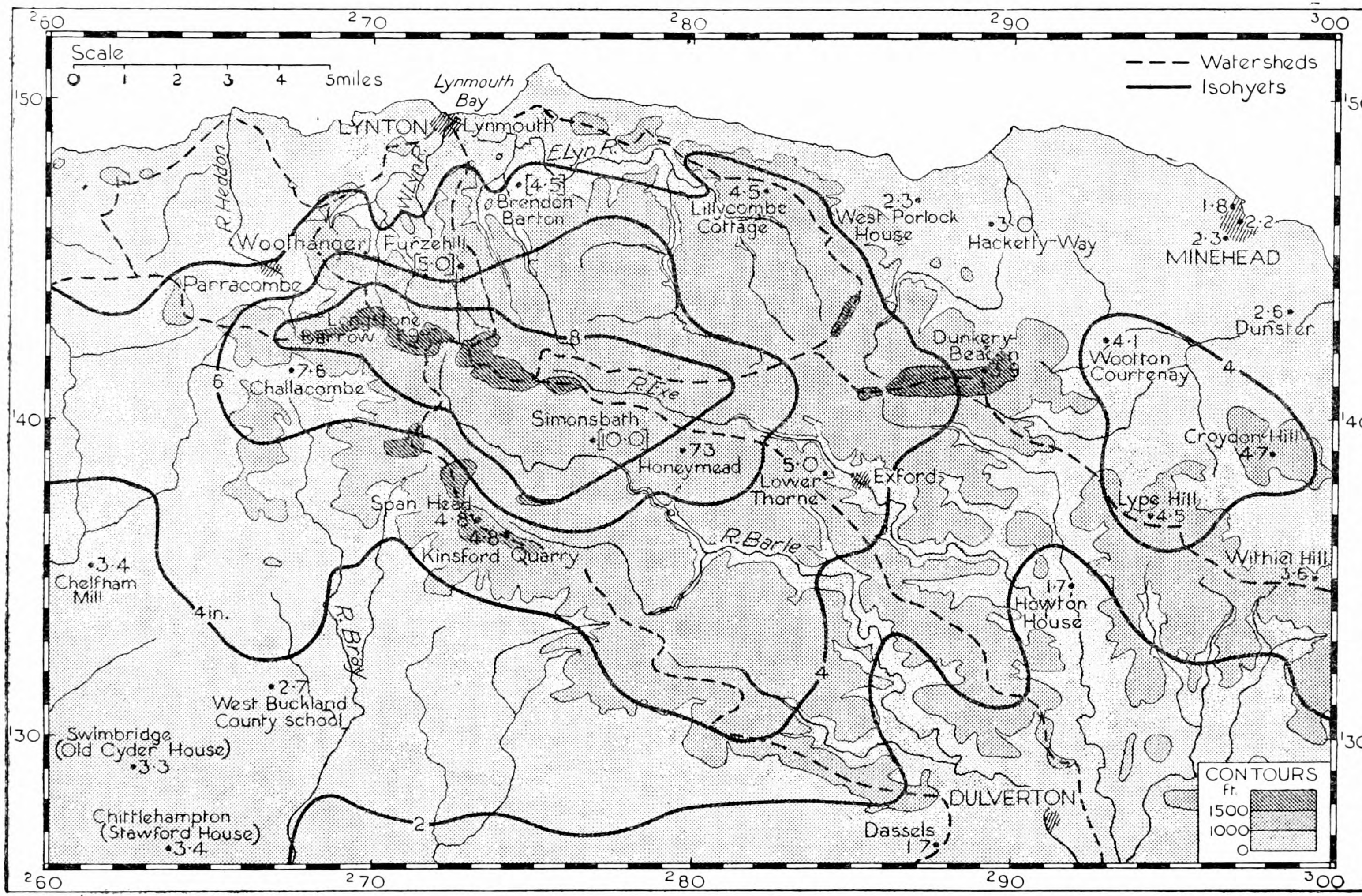


FIG. 1—RAINFALL DISTRIBUTION OVER EXMOOR, AUGUST 15, 1952

list was recorded in Devon at a point only about half a mile from the Somerset border. But the data so far available do not justify the conclusion that other parts of the country are relatively immune from such intense rains.

Investigation of the storm.—Within a few days of the storm special efforts were made to collect all the routine rainfall data from the district, with any additional information which the observers were able to give, so that a provisional assessment could be available at once. At the same time Mr. Archer began a thorough exploration, sponsored by the Meteorological Office, of all the headstreams draining down from the area which received the most intense rain. His own investigations continued for very nearly two months including a period during the first month when he conducted Mr. Bleasdale round many of the most impressive scenes on the moor and photographs were taken. Contact was made with other investigators, and photographs and other information were requested from the public. The large amount of data which has thus been collected is still increasing, but the main features of the storm are already clear and are summarized below.

Distribution of the rainfall in space.—The distribution of rainfall for the rainfall day of August 15 is shown in broad outline on the map of the Exmoor district shown in Fig. 1. Values plotted to the nearest tenth of an inch are for the most part from recognized rainfall stations. Three exceptional values are inserted in square brackets; these are approximate readings obtained by unorthodox methods. That at Brendon Barton came from a well exposed camp site where chance catches were made in an almost cylindrical pressure cooker and in an ordinary bucket. The actual rainfall may have been a little more than 5 in. and the value plotted is a cautious estimate. An amount corresponding to about 4 in. of rain was caught in an old and worn bucket in a seriously over-sheltered site at Furzehill; it seems unlikely that the true fall there was greater than 5 in. The most interesting of the three estimates was due to the fortunate circumstance that at 1845 G.M.T. on the 15th an accurately cylindrical bucket graduated in quarts, and in excellent condition, was left out in the middle of a field at Simonsbath. The general exposure was very good and the conditions required of a standard rain-gauge were almost observed except that the bucket did not have a sharp rim and that there must have been some loss from splashing when the water rose towards the top. Careful measurement and calculation showed that the catch observed the next morning was equivalent to 9·1 in. of rain. From relevant reports it seems hardly possible that less than 1 in. of rain fell at Simonsbath before 1845 G.M.T. and the value plotted on the map is very cautious. The true fall for the day may have been as much as 11 or even nearly 12 in., though it may also be true that such a large fall was very local. The possibility of using certain reservoir data as a further check on the heaviest falls is being pursued.

Isohyets are drawn on the map at intervals of 2 in. It would be unreasonable to attempt much greater detail, and the lines as they stand are rather generalized. There was evidence on the moor of seeming variations from place to place in the intensity and total amount of rainfall, but owing to the complexity of the country in soil and vegetation cover, in the nature of the underlying strata, and above all perhaps in the gradients encountered near the headstreams, it would be difficult if not impossible to carry through a valid analysis of all the variations suspected. The most notable example was a small area about three-quarters of a mile north of the gauge at Span Head which appeared to have received a heavier fall than the 6 in. suggested by the map, unless perhaps the intensity of the rain was at that point very high for a relatively short time. It is also probable that some parts of the coastal ridge running east-south-east from Lynmouth Bay received more than 4 in. where the map indicates rather less. The isohyets were originally drawn on the basis of standard rain-gauge readings alone, and information supplied at an early date to certain official bodies was derived in part from this provisional map. It has now been slightly modified to take account of the value for Lillycombe Cottage near Culbone which was received late, of the estimates for Furzehill and Brendon Barton, and of the results of the investigations in the central district, which roughly coincides with the area enclosed by the 8-in. isohyet, and includes the estimate of 10 in. or more for Simonsbath. If the attempt were made to add a 9-in. isohyet it would be advisable to limit this to two separate small areas east or east-south-east from Longstone Barrow and north-west from Simonsbath with a very small area enclosed by a 10-in. isohyet within the latter. The modifications have not greatly changed the original estimates of the general rainfall over the drainage areas of the West Lyn and East Lyn rivers, which are of importance in connexion with the Lynmouth flood. They show an increase on any previous estimates which could have been made for the areas draining down the Exe valley to Exford and down the Barle and its tributaries to Simonsbath and subsequently to Dulverton. The investigations have shown, at least in part, the cause of the sudden high flood at Exford, which might not at first have been apparent from the rainfall readings alone except by a very bold extrapolation from the reading at Honeymead.

TABLE I—GENERAL RAINFALL AND TOTAL VOLUME OR WEIGHT OF WATER RECEIVED IN VARIOUS DRAINAGE AREAS

Drainage area	Area		General rainfall	Volume or weight of water received		
	sq. miles	acres	in.	cu. ft. $\times 10^6$	gallons $\times 10^6$	tons $\times 10^6$
West Lyn	9·1	5,800	5·87	124	773	3·45
East Lyn	30·1	19,300	5·56	389	2,422	10·81
Combined area above Lynmouth	39·2	25,100	5·63	513	3,195	14·26
Exe above Exford	7·3	4,650	6·71	114	709	3·16
Barle above Simonsbath	8·2	5,200	8·00	152	949	4·24
Heddon down to sea	12·2	7,800	4·27	121	754	3·37
Heddon above Parracombe ...	2·3	1,500	6·49	35	216	0·96

Revised estimates of the general rainfall over certain drainage areas and of the volume of water to which these estimates correspond are set out in Table I. The number of significant figures given for these values goes beyond the attainable accuracy which, for general rainfall and dependent calculations, may be taken as about $\pm$ 5 per cent., or at the very worst $\pm$ 10 per cent. Approximate estimates of the total areas which received falls above given limits are:—

	sq. miles
more than 8 in.	17·0
more than 6 in.	42·5
more than 4 in.	
(i) main area	140·0
(ii) small area to the east	13·3

Over the area represented by the map (Fig. 1) the general rainfall was about 3·7 in., equivalent to an amount of water falling over this tract of country of the order of 90 million tons.

One feature of the distribution which is worthy of note is that it appears to consist of a pattern determined largely by orographical influences upon which are superimposed irregularities due to the thundery characteristics of the storm. The separate enclosed area to the east which received more than 4 in. may have been due to an additional thundery shower which occurred in the early hours of the 16th and appeared prominently on the chart of the recording rain-gauge at Wootton Courtenay, but probably did not occur over most parts of Exmoor. In conformity with the mainly orographical pattern an area on the northern side of Dartmoor, perhaps 50 sq. miles in extent, also received more than 4 in., and high ground in south Wales received amounts ranging up to 3 in. Another irregularity occurred in the Torridge valley about 10 miles south of Barnstaple and 15 miles south-west of the centre of the Exmoor storm, where a relatively low-lying area round Torrington received more than 4 in.

Distribution of the rainfall in time.—Unfortunately there are no recording rain-gauges in the heart of Exmoor. The two nearest are at Chivenor, about 14 miles west-south-west of Longstone Barrow, and at Wootton Courtenay, the same distance east. The two records have been carefully analysed using intervals of 6 min. along the time-scale, and the results are shown diagrammatically in Fig. 2. Each 6-min. fall is represented as a rate of rainfall in inches per hour. It cannot be confidently stated that the accuracy aimed at in this fine-scale analysis, indicated by the method of drawing the diagram, has actually been achieved, but an independent check produced very similar results. The totals obtained from the data shown differ by less than 8 per cent. from the accepted 24-hr. falls recorded by standard gauges at the two stations, and there is little doubt that the diagram is substantially correct.

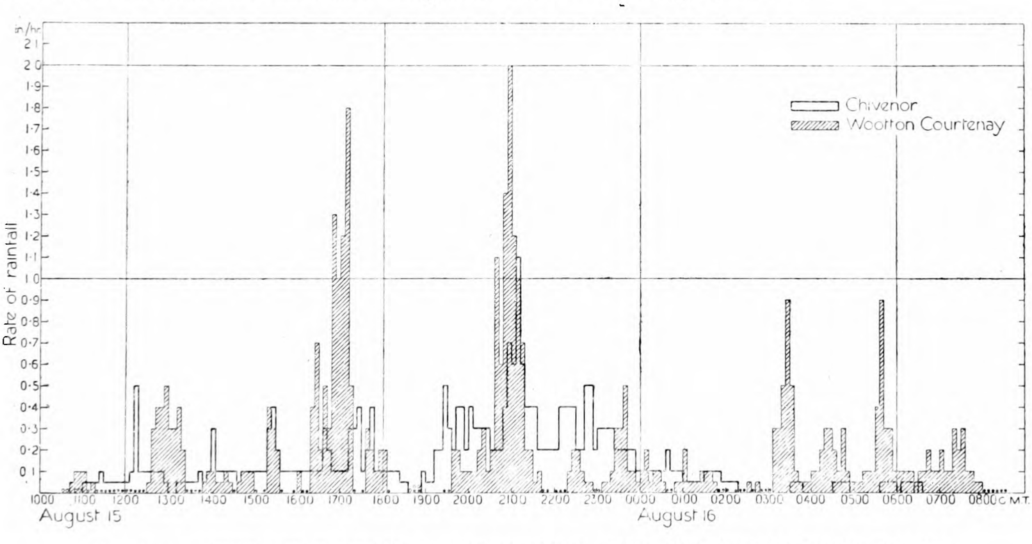


FIG. 2—RATES OF RAINFALL, CHIVENOR AND WOOTTON COURTENAY, AUGUST 15–16, 1952

Despite the distance between the two stations there is a degree of agreement, particularly in the timing of the most intense fall of the day, where the difference is a matter of a few minutes, and in the quieter period which preceded it. It does not immediately follow that the same timing is valid for the whole of Exmoor, and in fact there is some evidence against this, but the agreement provides a basis for the interpretation of eye-witness accounts which are not entirely in harmony even where there is reason to expect that they should be. An analysis of the data in hourly periods centred on the full hour and adjusted to give agreement with the standard-gauge reading is set out in Table II. Eliminating the heavy fall in the early morning of the 16th at Wootton Courtenay, which, it has been suggested, corresponds with the small enclosed 4-in. isohyet on the rainfall map, the amounts for the two stations up to 0230 G.M.T. are 2·61 in. at Chivenor and 3·03 in. at Wootton Courtenay. Of these amounts the falls during the 7 hr. beginning at 1630 G.M.T. were 1·77 in. and 2·05 in. respectively, very nearly 68 per cent. at each station. It is in this 7-hr. period that the main interest of the storm over Exmoor is concentrated, and the general pattern of the rainfall day may be considered to be: rain starting before midday and continuing throughout the afternoon, becoming heavy at times and building up to a downpour in the late afternoon or early evening, then a brief respite followed by a torrential downpour lasting for three or four hours up to about midnight during which very roughly half the total for the rainfall day came down, thereafter gradually ceasing during the early hours except for minor sporadic outbursts.

TABLE II—HOURLY RAINFALL AT CHIVENOR AND WOOTTON COURTENAY, AUGUST 15–16, 1952

	Chivenor	Wootton Courtenay		Chivenor	Wootton Courtenay		Chivenor	Wootton Courtenay
G.M.T.	in.	in.	G.M.T.	in.	in.	G.M.T.	in.	in.
0930–1030	0·00	0·00	1830–1930	0·11	0·01	0330–0430	0·01	0·19
1030–1130	0·03	0·05	1930–2030	0·30	0·13	0430–0530	0·02	0·13
1130–1230	0·11	0·02	2030–2130	0·46	0·92	0530–0630	0·03	0·27
1230–1330	0·07	0·31	2130–2230	0·29	0·05	0630–0730	trace	0·16
1330–1430	0·10	0·05	2230–2330	0·29	0·10	0730–0830	0·00	0·07
1430–1530	0·14	0·12	2330–0030	0·14	0·17	0830–0930	0·00	trace
1530–1630	0·11	0·16	0030–0130	0·08	0·06	0930–1030	0·00	0·00
1630–1730	0·19	0·73	0130–0230	0·06	0·04			
1730–1830	0·13	0·11	0230–0330	0·00	0·23	Standard gauge*	2·67	4·08

* 0900 G.M.T. 15th to 0900 G.M.T. 16th.

The combined evidence of more than a dozen eye-witnesses who were in various parts of Exmoor during the storm is very confused, and there is as much disagreement within some groups of reports from neighbouring localities as there is between those from widely separated points. It is of course very understandable that this should be so. Most of the witnesses were extremely busy for a good part of the time because of the effects of the storm and flood; largely as a result of this there were instances of a failure to distinguish clearly between rain precipitated in the immediate neighbourhood and the torrents rushing downstream or downhill, in many places through previously dry or non-existent channels. Several witnesses said that the torrential rain was uniformly heavy for a number of hours, an observation which is most unlikely to have been valid. A few failed to remember any distinct easing of the fall in the early evening, and of the majority who spoke of two heavy falls some thought that the earlier was the heavier. There was no clear statement that there were more than two exceptionally heavy falls. Two independent reports of thunder and lightning were in disagreement, one stating definitely that it was severest just before the torrential evening fall and the other that it occurred mainly during this period. Though these witnesses were separated by only 2 miles it is just possible that both reports are valid; of the two the former is probably the more reliable. There was no report of hail.

In the circumstances it is best to take all the accounts together and form a composite picture of the storm as a whole with two qualifications: (i) that the heaviest rain may have occurred somewhat earlier toward the north and north-east, and a little later toward the south and south-west (the accounts suggest this but are not sufficiently accurate for any such difference to be determined with precision); and (ii) that the relationship of the two heaviest bursts may perhaps have been inverted near the coastal ridge east of Lynmouth. The description which then emerges is in substantial agreement with the combined pattern from the recording rain-gauges at Chivenor and Wootton Courtenay. Rain started at some time during the morning, probably towards 1100 or 1200 G.M.T. in many places. It was heavy at times during the afternoon with brighter intervals locally, and the first exceptionally heavy downpour occurred, after unusual darkening of the sky and peculiar colour effects, between 1530 and 1730 G.M.T., thereafter easing. Torrential rain occurred between 1830 and 2230 G.M.T., accounts of the precise timing differing slightly and very erratically from place to place; it slowly eased off with little rain of importance in most places after about 0200 G.M.T. on the 16th, though there were some reports of rain or showers throughout the night and until well into the next morning. There is little doubt that over most of Exmoor the phenomenal rain during the main evening fall was more prolonged than the Wootton-Courtenay record suggests, and was very much heavier than the first burst. It is therefore necessary to give more weight to the Chivenor record, though with a shift of the rainfall pattern in time to about one hour earlier. On such a basis Table III may be taken as giving an approximation to the percentage distribution of rainfall in time for Exmoor as a whole.

TABLE III—DISTRIBUTION IN TIME OF RAINFALL OVER EXMOOR, AUGUST 15–16, 1952

Time	Rainfall	Time	Rainfall
G.M.T.	per cent.	G.M.T.	per cent.
0900–1530	15	1930–2030	18
		2030–2130	18
1530–1630	8	2130–2230	10
1630–1730	8		
1730–1830	3	2230–0900	10
1830–1930	10		

In using this distribution the two qualifications mentioned above must be taken into account, and the possibility of certain other modifications must be considered: (i) on the eastern flank of Exmoor in particular a greater percentage should be allotted to the final period after 2230 G.M.T.; (ii) the distribution as it stands may apply fairly accurately to most places elsewhere which received about 5 in., though a possible shift in time should be allowed for; (iii) in places which received much less than 5 in. there should probably be a decrease in the percentages for the heaviest fall, to correspond more closely with the Chivenor record, and *vice versa;* and (iv) for areas of a few square miles upwards a smoothing of the percentages to take account of local variations in timing is probably desirable. Some accounts of the flooding show that in places it occurred with extraordinary suddenness, but it is unnecessary to suppose that the heaviest fall began with a sudden burst, even locally, as no direct evidence for this was found, and satisfactory alternative explanations of the flooding can be advanced. With the adjustments suggested it will probably be safe to apply this distribution in time to the general rainfall for the drainage areas listed in Table I, though for individual localities the need for caution is shown by the report from Lower Thorne near Exford. Out of a 24-hr. total of 4·96 in. separate measurements gave 2·37 in. from 1815 to 2020 G.M.T., and 0·77 in. from 2020 to 2040 G.M.T.

Synoptic situation.—The outbreak of thunderstorms and phenomenal rainfall was the culmination of a four-month period in which there was a high incidence of heavy thunderstorms, especially in south-western districts and the west Midlands, with notably severe thunderstorms on April 16, May 19, June 13, and July 1 and 6. Though the regions affected are liable to heavy storms, it must be unusual to have six in one year. Naturally their worst incidence was not exactly in the same region, but Exmoor was badly affected on April 16.

The small depression responsible for the great rainstorm was first clearly shown over the Atlantic at 1200 G.M.T. on August 12, centred at about 47°N., 34°W. with central pressure about 1016 mb. It first moved east-south-east to a position near 43°N., 19°W. at 0000 on the 14th when its central pressure was 1007 mb. After that time it rounded an upper trough and then moved slowly north-east parallel to the general thermal gradient and the 500-mb. contours, not very far from the thermal trough. The track on 15th–16th is shown on Fig. 3; between 1500 and 1800 the centre moved north to near Exeter, and very soon afterwards it became occluded and subsequently drifted east-north-east as a dying system. No fronts were identified in its earlier stages, and the warm front shown on Fig. 3 (the 1500 G.M.T. chart on the 15th) was originally quite separate from the depression. It can probably be identified with the old Cold front marked H on the *Daily Weather Reports* for August 10–13, and as a quasi-stationary front over France and north-west Spain on the morning of the 14th. As the new depression approached, a small low developed over south-west France, and a warm front (largely superficial) moved north-west from France to southern England, entering the depression in the western English Channel. The origin of the cold front is not known; it was comparatively weak and it made a large angle with the mean thermal gradient up to both 700 and 500 mb., but the upper winds backed as it swept round the depression and finally occluded the warm sector.

A ship in the Bay of Biscay at 47½°N., 8°W. reported continuous drizzle at 1800 on the 14th, and by 2100 there was continuous slight rain at Scilly. The rain spread north-eastward, but the thundery outbreak which led up to the exceptionally heavy rainfall appears to have started in and near Brittany and crossed the English Channel. The sources of atmospherics were so far apart—there was an isolated "sferic" location in the Bay of Biscay on the 14th and only some scattered ones in France—that no important source could have escaped location. There was thunder during the evening at Brest, and also at Rennes at 2100 near the warm front. At 0430 on the 15th there was a group of "sferics" south of Plymouth and a few near the Brittany coast. The 700-mb. wind at Brest at 0300 was SSE., which favoured the movement of thunderstorms across the English Channel. Earlier in the night there was some thunder in the Bristol-Channel area, but the main outbreak reached Plymouth shortly before 0700 and moved slowly northwards, and by 1500 (Fig. 3) it was mostly confined to north Devon and the Bristol-Channel area. To the west of the belt of heavy thundery rain there was a fairly large area of non-thundery rain, and to the east of it there were many more or less separate thunderstorms, in some cases severe but of a normal type. Over most of Cornwall and Devon the rain lasted all day and well into the night, and by midnight it had spread across Wales and the west Midlands.

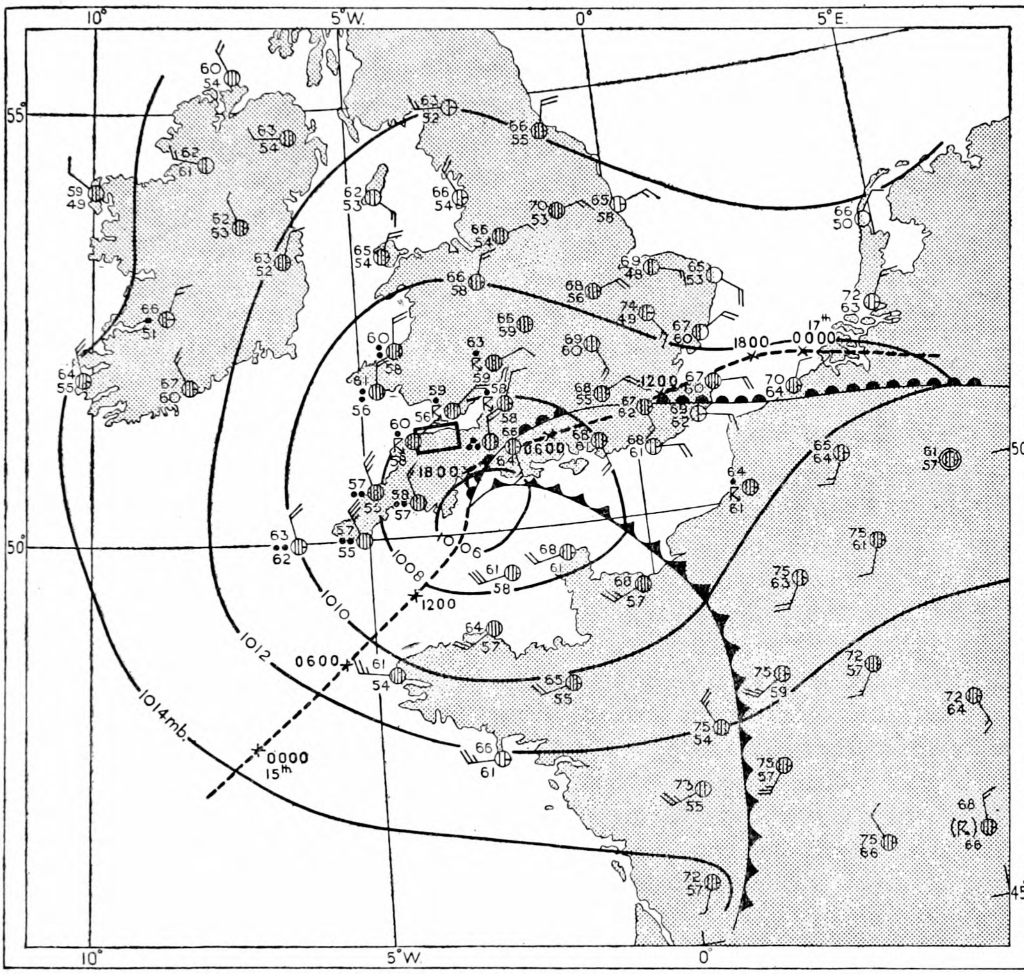


FIG. 3—SYNOPTIC CHART, 1500 G.M.T., AUGUST 15, 1952

The area covered by Fig. 1 is indicated by the small rectangle. The dew points are plotted below the temperature

Fig. 4 shows the 1400 G.M.T. soundings at Larkhill and Camborne. The amount of instability was much less than in many depressions which do not give exceptional rainfall. Table IV gives the upper-wind soundings in the area during the day. The two parts of the table may be compared from the following rough equivalents: 700 mb., 10,000 ft.; 500 mb., 18,000 ft.; 300 mb., 30,000 ft.

Any estimate of wind structure over the area of heaviest rainfall is necessarily rather speculative. The 700-mb. trough was quite close to that area in the evening, but probably just west of the rainfall maximum. There was a north-easterly geostrophic wind of 20 kt. in the Exmoor region during the evening,

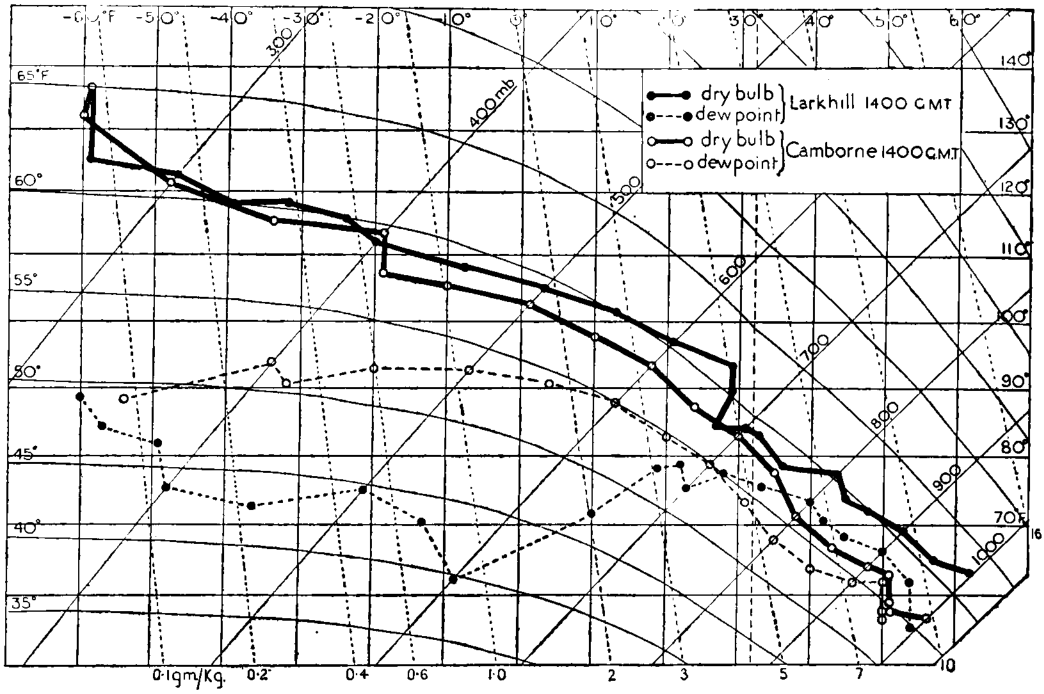


FIG. 4—PRESSURE AND TEMPERATURE SOUNDINGS, AUGUST 15, 1952

and it is fairly certain the wind veered with height, and was in the south-east quadrant in a fairly thick layer from 3,000 or 4,000 ft. up to 10,000 ft. or a little higher. This would allow the rain area to be fed from the warm sector air which held the most moisture. At 1500 (Fig. 3) the warm front was north-west of Henstridge (ten miles east of Yeovil) and about 50 miles from Longstone Barrow. At 1800 the distance from the front was probably 40 miles or even less. There was a difference of 160° in wind direction in the 25 miles between Henstridge and Merryfield (ten miles east-south-east of Taunton). The dew point was 64°F. at Henstridge and 65°F. at Hurn (near Bournemouth) at 1500, so that the surface reading on the Larkhill sounding was not representative of much of the warm-sector air. Probably the front had not quite reached Larkhill at 1400. The sustained heavy rain in Devon showed that ascent was taking place on a colossal scale, even over the low ground, and this ascending current could only have been supplied from the warm sector. The very damp

TABLE IV—UPPER WINDS ON AUGUST 15, 1952

	Brest 0300 G.M.T.		Larkhill 0300 G.M.T.		Larkhill 1400 G.M.T.		Camborne 1400 G.M.T.			Larkhill 0800 G.M.T.		Camborne 0800 G.M.T.		Larkhill 2000 G.M.T.	
mb.	°true	kt.	°true	kt.	°true	kt.	°true	kt.	ft.	°true	kt.	°true	kt.	°true	kt.
300	220	50	222	40	189	16	187	21	30,000	220	36	180	32	100	16
400	...	...	214	28	186	17	185	15	24,000	210	23	180	17	140	14
500	230	30	232	25	183	20	227	4	18,000	210	12	210	5	180	14
600	...	...	223	26	183	20	254	10	14,000	200	14	120	7	190	19
700	160	19	215	13	157	24	284	6	10,000	180	11	90	8	160	13
750	...	...	182	7	146	23	333	7	8,000	160	9	70	13	140	13
800	...	...	140	7	141	18	351	9	6,000	120	7	70	14	130	14
850	...	...	125	10	130	15	352	14	4,000	100	12	50	15	140	14
900	...	...	114	8	119	15	342	22	2,000	90	16	30	14	140	12
950	150	18	105	7	104	17	332	25	1,000	90	15	10	15	150	12

The data on the left-hand side are compiled from radio-sonde ascents; those on the right from radar wind observations only.

surface air could have been piled up by convergence, and it is fairly certain that a deep layer was formed with a wet-bulb potential temperature appreciably above 60°F. Fig. 4 shows that this air could have risen to the tropopause.

The rainfall distribution shows that non-orographic rain ranged up to 4·45 in. at Torrington, about half that at Longstone Barrow. The surface NE. wind striking the steep northern slope of Exmoor would necessarily increase the ascending motion through a deep column of already saturated air. The lowest layers would make some direct contribution to the orographic rain since the surface dew point had risen to 58°F. by afternoon owing to the rain over the Bristol Channel.

The favourable combination of factors inevitably led to substantial rainfall, but in the present state of knowledge we cannot differentiate between very exceptional rain and heavy prolonged rain of a more normal type which is often accompanied by thunder. Most heavy rainfall is associated with a new and recent phase of development and with some kind of occlusion process. Even when there are no clearly defined fronts there is evidence that the warmest and dampest air has ascended. In the present case there was a new warm sector which was quickly occluded, and though the warm front was feeble except near the ground over Dorset and Somerset, it was of great importance in relation to the moisture supply. The process of occlusion may affect the track of a depression; it was long ago pointed out by Dr. H. R. Mill that after exceptional rainfall a depression often turns to the right.

Some earlier exceptional rainstorms.—The record daily rainfall for the British Isles, at Bruton, Somerset, fell mostly in the night of June 28–29, 1917. The area with over 4 in., though not a record, was very much larger than in the rainstorm of August 15, 1952. It also was associated with a depression in the English Channel, and there were thunderstorms in an area of continuous rain. There were, however, points of difference from the August 1952 occurrence. The belt of heaviest rain was orientated east-to-west, and had a southern boundary 100 miles from the centre of the depression, which became complex. The belt of heavy rainfall developed in a diffuse frontal zone with colder air spreading slowly south, while a cold front moved east over France but, except in the south-east well away from the heaviest rain, there was no evidence of related trigger action in France, such as happens before most big outbreaks of thundery rain in southern England.

The next largest rainfall, that at Cannington, Somerset, on the night of August 18–19, 1924, was a local fall of a magnitude quite unique in the conditions prevailing. There was a WNW. geostrophic wind of 35 kt. and a dew point a little above 50°F. The heavy hail and rain lasted 4½ hr., and during that time a strip of air about 180 miles long at 2,000 ft. must have crossed the area. Heavy orographic rain requires a suitable initial condition of the air mass, so that there was probably a long chain of showers or at least of large cumulus from the sea. The charts show plenty of showers but no front or trough.

Another notable rainfall in the south-west occurred on the morning of August 4, 1938, when 6 in. fell at some places from Torquay to Dartmoor, in a chain of very violent thunderstorms moving north-west. Temperature exceeded 90°F. in Brittany on the previous day, which is much higher than those associated with the three rainstorms already mentioned.

Discussion of photographs.—Most of the photographs reproduced in the centre of this magazine can be fully appreciated only if they are examined in relation to the 1 : 25,000 Ordnance-Survey map with their positions and subjects accurately identified. It is then possible from the contours to judge the drainage areas and gradients which produced the effects. The national-grid reference* and direction of view of the camera is given directly beneath each photograph. The 1 in. to the mile Ordnance-Survey map is not quite adequate but can be used for a general survey. A very rough idea of the positions and significance of the photographs may be obtained by using the national-grid-reference border which has been added to Fig. 1. Even on the 1 : 25,000 map (approximately $2\frac{1}{2}$ in. to the mile) a number of the combes which were visited and photographed are not named, so that the references are necessary to identify them. For convenience names derived from other place names in their localities have been attached to these anonymous combes.

On the relatively level ground of the high moor the rainfall had left few marks except for some small patches of flattened vegetation, usually long tough bog grass, and occasional slight erosion or deepening occurring in an old drainage channel or by the side of an embanked hedge. At the heads of the combes the usual ground formation is a shallow trough on the moor leading to a sudden descent into the steep-sided valley, and in these places it was normal for the flattening of the grass in the trough to be very pronounced, with disintegration of the stream-bed in the combe often beginning very high up immediately below the edge of the moorland plateau. Thereafter there was increasing evidence of large volumes of surface water having poured off the moor and rushed down the valleys, deeply eroding the central channel and leaving a high-water mark of flattened or shorn-off vegetation on the banks. The photographs are arranged in approximate order with downstream effects as far as possible toward the end.

Fig. 5.—A general view looking up Woodbarrow Combe, a headstream of a tributary of the West Lyn. Drainage area less than 100 acres.

Fig. 6.—Landslip in Gammon's Combe, a headstream of the most westerly tributary of the East Lyn. The disintegration of the stream-bed begins very high up and the flattening of bog grass in the channel can be discerned. Drainage area less than 100 acres.

Fig. 7.—Erosion partly induced by human activities, about three-quarters of a mile south-west of Simonsbath. Water draining from the upper slopes flowed down a metalled road into the mouth of an old quarry and then overflowed across the road down the hill-side, slope about 1 in 3. The scar on the left seems to be due to water, which percolated through the quarry bottom under the road, emerging because of impermeable strata below.

Fig. 8.—Deep scouring of a moorland cart-track on the eastern side of Shallowford Farm. The second photograph is a close-up of the furthest of the three holes in the general view, and the hump in the foreground obscures a deep depression going down another foot or more. The cart-track runs along a well-defined ridge, and there was virtually no drainage area contributing water other than the track itself.

*All photographs reproduced were taken at points shown on the rainfall map (Fig. 1). This forms part of the 100-Km. square 21 = SS (see "The projection for Ordnance Survey maps and plans and the national reference system", published for the Ordnance Survey, London, in 1951). The remaining figures given below each photograph, four for eastings followed by four for northings, in each case identify a 10m. square within which lies the point from which the photograph was taken, subject to the qualification that the accuracy of any fourth figure is open to slight doubt. The direction of view of the camera is given to the nearest 5° with a similar qualification about the accuracy of the final figure.

Fig. 9.—Disintegration of stream-bed seen from the head of a combe below Dure Down, about $1\frac{1}{2}$ miles north-west of Simonsbath. Dark lumps of peat rubble on the banks indicate the height reached by the flood discharge. Drainage area about 60 acres.

Fig. 10.—The Exe valley looking east from a point about a mile below Exe Head. The width of the valley is about $\frac{1}{2}$ mile, so that along the line of view of the photograph the drainage area ranges upwards from about half a square mile. As the slope of the valley bottom going downstream is much smaller than that for other Exmoor streams disintegration of the channel was not pronounced. The high-water mark of the flood can be seen as the edge of a light patch of flattened vegetation on the left bank of the stream.

Fig. 11.—A spring emerging from beneath the soil at the head of a combe (Tang's Bottom) about two miles north-west of Simonsbath. This sub soil channel, lying immediately above impermeable shale, had carried a very large volume of water and the roof had collapsed for several yards. Overground flow had been even greater, and the combe downstream was one of the most impressive examples of disintegration to be found on the moor. Drainage area above the spring about 50 acres.

Figs. 12 and 13.—Scenes in Cannon Hill Combe, a tributary of the West Lyn, running directly down from the moor near Longstone Barrow. Fig. 12 shows what appeared to be an almost entirely new gorge and waterfall, about one mile north-north-west of the Barrow. Drainage area less than 150 acres. Fig. 13, about 200 yd. further upstream, shows how storm and stream action had breached a footpath over a length and width of more than 12 ft. to a depth of 3–4 ft. The small waterfall in the second photograph enters the pool at the left edge of the first.

Figs. 14 and 15.—Examples of rubble deposited by the floods. Fig. 14 shows Mr. Archer standing on the original stream bank at the side of a mass of peaty earth about 40 ft. × 18 ft. × 5 ft. thick, which had been carried downstream for several hundred yards near the head of Shallowford Combe. About a mile downstream, near Shallowford Farm, was an enormous mass of stone rubble covering a length of about 500 yd. and a maximum width of 70 yd. The second photograph is a general view of the lowest part of this deposit.

Fig. 16.—Discharge of water from a tributary into Long Chains Combe. The torrent indicated by the first photograph had to turn through a right angle on reaching the main combe and in doing so surged in a great curve over the steeply ascending hillside, as shown in the second photograph. Undercutting produced an incipient landslip, and there is a deep fissure which by chance nearly coincides with the top of the high-water mark. Drainage area to this point less than 50 acres.

Fig. 17.—Scenes in Cannon Hill Combe near Woolhanger where there was formerly a small reservoir of capacity 1,500,000 gallons, drained during the flood. The photographs were taken just below the dam (Fig. 17(*a*)), near the dam breached by the flood (Fig. 17(*b*)), and just above the site of the reservoir (Fig. 17(*c*)). Comparison of Figs. 17(*a*) and 17(*c*) shows little to suggest that the draining of the reservoir added much to the volume of water pouring down towards Lynmouth. Calculation of the rainfall, more than 45,000,000 gallons, received above this point (drainage area just over 250 acres) supports this view. Probably not more than 10 per cent. was added to the flow through the reservoir.

Note on drainage.—To interpret data such as those given in Tables I and III in terms of actual flood flow in the streams draining from Exmoor it would be necessary to derive relationships between rainfall and run-off, for the various drainage areas, applicable to the conditions which existed on August 15. It would be out of place to try to develop such relationships in the present note or to attempt any detailed study of the soil, vegetation, topography, and geology of the area which would be a necessary basis. But the investigation brought to light some interesting observations which have a bearing on the problem.

It is apparent from some of the photographs, and was impressively obvious from various points on the moor, that during the period of most intense rain there was a tremendous volume of water pouring from the high ground and raging down the combes. Without going into details it was clear that deep percolation and underground flow were negligible, and that subsoil drainage, though of unusual volume and sufficient to produce upland landslips or contribute to the disintegration of the surface in some of the valleys, did not represent a high proportion of the total run-off. At some point during the evening of the 15th large tracts of Exmoor must have been literally awash to a depth of several inches, the water pouring directly into any convenient depression or trough, to be conveyed very rapidly to the main channels. This was the impression increasingly forced to the mind as more and more of the central area was explored, and it was later confirmed in reports from Pinkworthy Farm, about 1½ miles south-east of Longstone Barrow, and from the high ground near the Exe valley. From the farm it was stated that over the neighbouring slopes the fields were flooded to a depth of 6–8 in. soon after the torrential rain began. It seems beyond doubt that this happened in many parts of the moor, with sheet-flow over extensive surfaces. Normally dormant springs had already burst into activity, according to several accounts, during the heavy falls of the afternoon and early evening, and it seems that this earlier rain, added to substantial falls during the previous fortnight, had been quite sufficient to saturate the land very thoroughly, whilst the brief respite in the early evening with little rain or only moderate falls had not been long enough to ease the situation in this respect. When the torrential rain started it fell on ground which could absorb no more. For this reason alone there is no need to postulate a sudden burst for the outbreak of the main evening fall as the cause of the remarkably sudden floods which descended on Exford and other places. Even with a comparatively gradual build-up in the intensity of this fall the ground probably began to adapt itself to ever more rapid run-off, the channels themselves being improved by the bending or flattening of impeding vegetation and the scouring of all stream-beds. By the time the rain reached its fiercest intensity the rate of run-off was probably almost equivalent to the rate of rainfall over much of the high ground, a state which may have been maintained for some hours with greatly increased rates of travel from the moor into the main channels.

The reports mentioned also support this view in another way. In times of rain since the storm the streams have risen noticeably more rapidly, risen to higher levels, and fallen again more rapidly than before the flood. These observations are consistent with the view that all channels, over ground and beneath the soil, have been cleared and improved by the storm and that rainfall now gathers more quickly into the main streams, only to flow away again more quickly because of similar channel improvement downstream.

It was also reported that on the high ground north-east of Pinkworthy Farm bogs previously impassable by pony had become firm enough to permit passage. The observation is again consistent with the view that drainage has become more efficient as a result of the storm. For any valid assessment of the flood run-off from the rainfall data it is necessary to suppose that drainage was becoming increasingly efficient and rapid during the storm, and especially from the beginning of the four hours or so which were covered by the main evening fall. Such an allowance leads to an appreciably higher estimate of the maximum flood discharge through Lynmouth than any which has so far been put forward.

Acknowledgement.—Discussion of the material available from investigations took place with Mrs. Joyce Gifford, University of Southampton, and Mr. C. Kidson, University College of the South-West, Exeter. The voluntary rainfall observers, within and beyond the area of the rainfall map of this report, contributed many useful data in addition to their routine records, and the general appeal for photographs and other information received a very generous response. Finally the work of Mr. C. H. Archer of Wootton Courtenay, who was assisted by his two brothers, must again be brought to notice.

WORLD METEOROLOGICAL ORGANIZATION

Conference of the Commission for Maritime Meteorology

The first Conference of the Commission for Maritime Meteorology of the World Meteorological Organization was held, appropriately enough, in the lecture hall of the Royal Geographical Society in London. The Conference lasted from July 14 to 29, 1952, and was attended by the delegates and advisers of 21 countries which are Member States of the World Meteorological Organization.

Mr. George Ward, Under Secretary of State for Air, welcomed the delegates on behalf of the British Government, and mentioned, in his address, the important contribution which voluntary observers in merchant ships of many nations make to the science of meteorology by providing observations from the oceans. He added that this voluntary work had been going on for nearly a century, and emphasized its importance not only to the shipping industry but also to all other forms of transport, as well as in connexion with the present world food problems and in its application to other fields of human activity. It was appropriate that this maritime Conference should be held in the ancient Port of London, and Mr. Ward stressed the part which British shipping had played in the peaceful development of world trade.

In his reply the President, Commander C. E. N. Frankcom, said that international maritime meteorology originated in 1854 when Maury organized the first International Meteorological Conference in Brussels. The Commission for Maritime Meteorology of the former International Meteorological Organization held its first meeting in London in 1909. There were at present 2,300 "selected" ships of all nations voluntarily making meteorological observations at sea.

Sir Nelson Johnson, Director of the Meteorological Office, and Dr. Swoboda, Secretary General of the World Meteorological Organization, were present at the opening meeting. The British members of the Commission were Commander J. Hennessy and Captain P. Bracelin. Admiral Termijtelen (Netherlands) was elected Vice-President for the Conference. Representatives of the International Telecommunications Union and International Air Transport Association were present as observers. Probably the most important task of the Commission was to review and improve, where possible, the network of observations from shipping in all oceans. Prior to the Conference, maps had been prepared showing the known positions of all "selected" ships on a stated day and also the positions from which reports had been received from ships at various meteorological centres throughout the world. During the Conference another map was prepared, with the assistance of the G.P.O. and Lloyd's, showing the known density of shipping in the various oceans. From a study of these three maps it became evident that there are areas where the network is adequate; there are areas where the network is at present inadequate but can be improved; and there are other areas where ships very rarely go and little improvement is possible.

The Commission made recommendations whereby maritime countries should be asked to state whether they could recruit more "selected" ships, particularly in areas where shipping is sparse, and other recommendations were made to rationalize the network generally and improve it.

The Southern Ocean is one area which is of great meteorological importance and in which shipping is always rather sparse. Whaling ships are a fruitful source of information from this ocean, but these ships are always reluctant to disclose their positions to their rivals. A recommendation, proposed by South Africa, was made whereby the whaling ships are supplied with cyphers so that their positions are not disclosed in their radio weather messages. The whaling ships will send their messages to South Africa or Australia, as convenient, and the receiving country, when preparing the message for rebroadcast, will recypher the position and omit the name of the ship in the collective message. All countries in the southern hemisphere will hold the recypher, and will thereby be able to plot the position of the ship without knowing her name, and nobody intercepting the message who does not hold the recypher will be able to know the position of the vessel. By this means it is hoped that Services in the southern hemisphere will have more adequate meteorological information and will be able to issue suitable forecasts for shipping and other purposes. Problems concerning the reception and transmission of radio messages from ships were also considered, and recommendations made with a view to effecting improvements.

The Commission gave considerable study to problems connected with methods of making observations at sea, the exposure and type of instruments used, bearing in mind the special difficulties inherent in a voluntary system of observations aboard ship. Recommendations were made concerning improvements in observational practice. The use of weather ships for making special observations and instrumental experiments was realized, and recommendations were made as to further studies which should be made aboard such ships into such problems as rainfall observation, evaporation, radiation, sea and air temperature, humidity and meteorological factors affecting radio propagation.

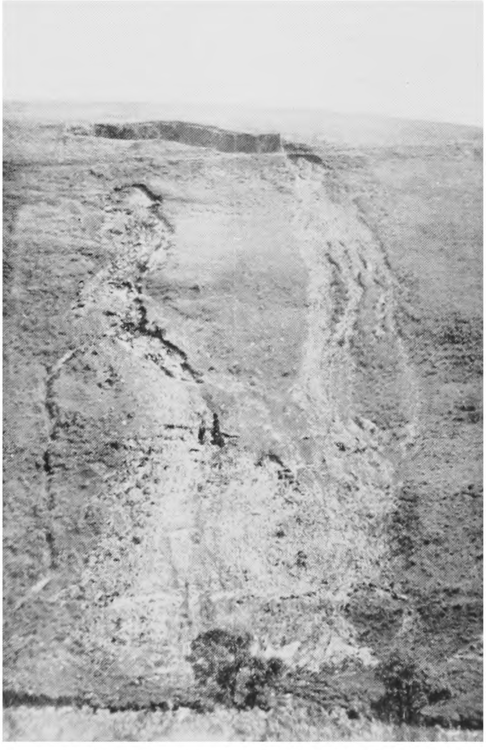
The Commission considered that, in general, meteorological information issued for shipping is reasonably comprehensive, but suggestions were made for special radio storm-warning advice in tropical-hurricane areas, and also for additional visual storm warnings at night in these areas. A new international

Ref.: 7120 4297, 030°

FIG. 5—WOODBARROW COMBE

Ref.: 7413 4298, 190°

FIG. 6—LANDSLIP IN GAMMON'S COMBE



Ref.: 7609 3888, 135°

Reproduced by courtesy of Joyce Gifford

FIG. 7—HILLSIDE NEAR SIMONSBATH

STORM DAMAGE ON EXMOOR, AUGUST 1952

(see p. 353)

Ref.: 7140 4495, 165°

General view along track

Ref.: 7140 4492, 165°

Close-up of furthest hole

FIG. 8.—CART-TRACK NEAR SHALLOWFORD FARM

Ref.: 7543 4080, 260°

FIG. 9—DURE DOWN COMBE

Ref.: 7676 4111, 090°

Reproduced by courtesy of F. Tattersall

FIG. 10—EXE VALLEY NEAR THE HEAD

STORM DAMAGE ON EXMOOR, AUGUST 1952

(see p. 353)

Ref.: 7510 4109, 040°

FIG. 11—SPRING FROM SUBSOIL DRAINAGE (TANG'S BOTTOM)

Ref. 7007 4420, 180°

FIG. 12—NEW GORGE AND WATERFALL (CANNON HILL COMBE)

Ref.: 7021 4400, 260°

View along the path

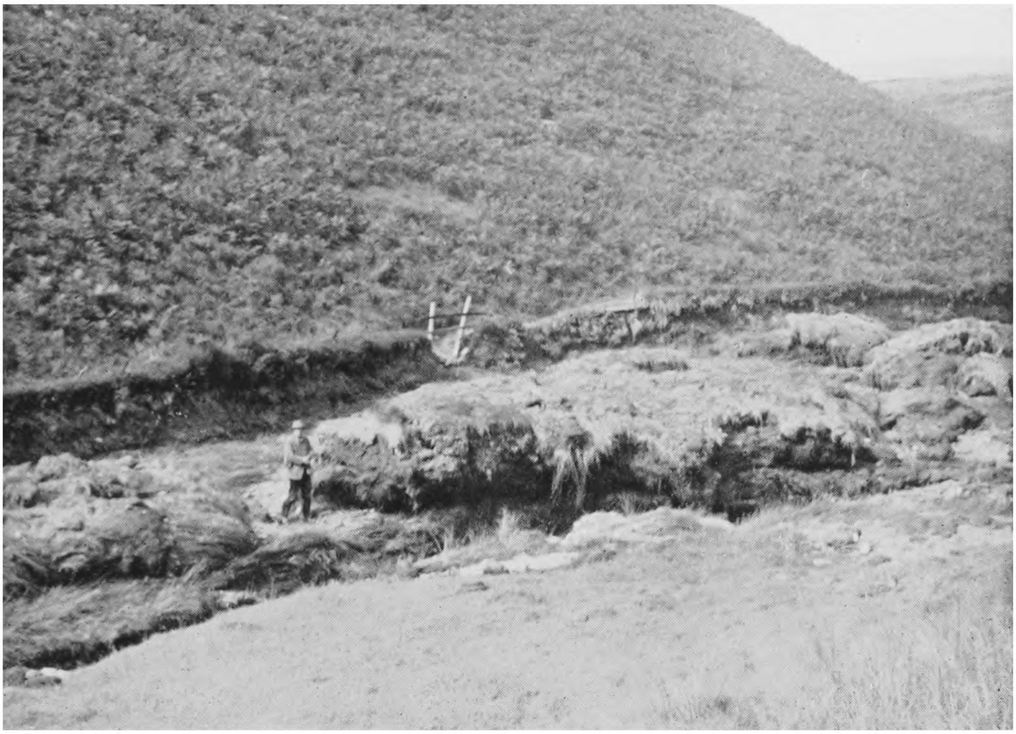
Ref.: 7021 4400, 130°

View upstream

FIG. 13—STREAM DAMAGE ACROSS A FOOTPATH (CANNON HILL COMBE)

STORM DAMAGE ON EXMOOR, AUGUST 1952

(see p. 353)



Ref.: 7130 4316, 335°

FIG. 14—PEAT RUBBLE IN SHALLOWFORD COMBE

Ref.: 7124 4472, 030°

FIG. 15—STONE RUBBLE ABOVE SHALLOWFORD FARM

STORM DAMAGE ON EXMOOR, AUGUST 1952

(see p. 353)

Ref.: 7447 4220, 190°

Looking up the tributary

Ref.: 7447 4220, 190°

Bank of the main stream opposite the tributary

FIG. 16—TRIBUTARY DISCHARGE IN LONG CHAINS COMBE

Ref.: 7016 4508, 175°
(*a*) Below Southdown Pond

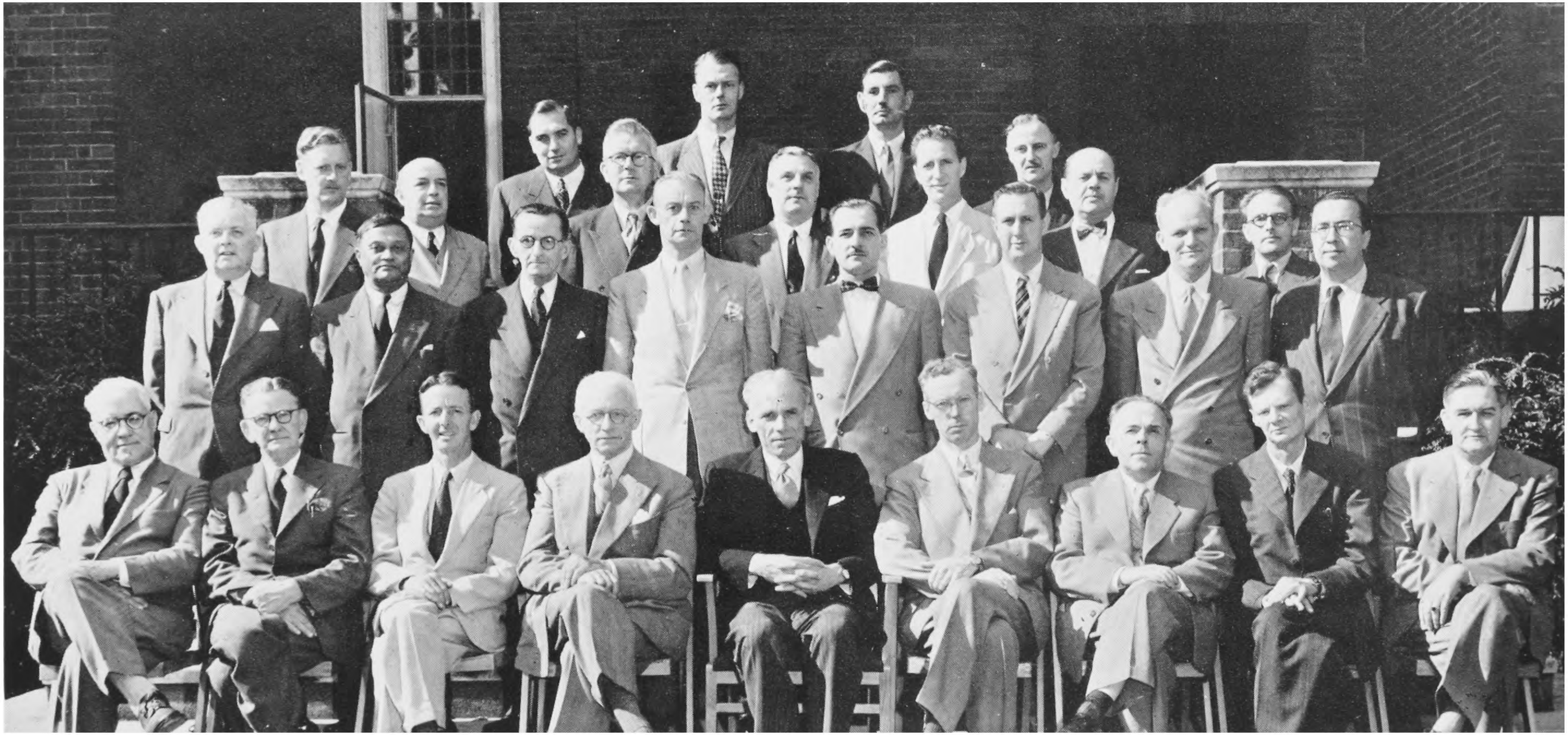
Ref.: 7015 4501, 185°
(*b*) Breach in the dam

Ref.: 7012 4477, 175°
(*c*) Above Southdown Pond

FIG. 17—SCENES IN CANNON HILL COMBE NEAR WOOLHANGER

STORM DAMAGE ON EXMOOR, AUGUST 1952

(see p. 353)



CONFERENCE OF MARITIME METEOROLOGY, LONDON, JULY 1952

Back row.—Capt. B. F. Benesch (Argentine), R. F. M. Hay (U.K.), J. R. Clackson (B.W. Africa), C. A. S. Lowndes. *Second row.*—H. Thomsen (Denmark), Prof. M. Tenani (Italy), P. M. A. Bourke (Eire), F. Balén García (Spain), J. B. L. Cayetano (Spain), Capt. S. Turcio (Uruguay), Dr. R. Frith (U.K.). *Third row.*—W. Blow (I.T.U.), Dr. B. N. Desai (India), E. Bruzon (France), J. A. Van Duijnen Montijn (Netherlands), Capt. D. Gamez-Calcano (Venezuela), Lieut. C. R. Lluberas (Uruguay), A. Sik (U.S.A.), J. B. de Portugal (Portugal). *Front row.*—W. F. McDonald (U.S.A.), Cmdr. J. Hennessy (U.K.), G. S. P. Heywood (Hongkong), Vice-Adm. J. K. Termijtelen (Netherlands), Cmdr. C. E. N. Frankcom (President), K. T. McCleod (Canada), F. Spinnangr (Norway), A. H. Gordon (W.M.O. Secretariat), Capt. R. O. Minter (U.S.A.).

ice nomenclature was drawn up by a committee of polar experts and recommended for adoption.

A major task was the preparation of general technical regulations of the World Meteorological Organization in the field of maritime meteorology. The preparation of these required the study of innumerable resolutions which had been passed by the International Meteorological Organization and its predecessors since 1872.

In the climatological field the Commission recommended more uniformity in the matter of ships' logbooks in order to facilitate punching the observations on to the new international maritime punch card. A working group was set up to consider improvements which might be effected in the way of international co-ordination in the preparation of maritime climatological atlases.

The application of meteorology to the carriage of goods at sea was considered, bearing in mind the considerable hygroscopic damage which can be caused to cargo in a ship's hold as the vessel encounters varying air and sea temperature and humidity during her voyage. It was felt that this is an important question at present in view of world shortages of food and raw material and rising costs, and the Commission set up a working group to study the question and make recommendations accordingly.

At the conclusion of the Conference, Commander Frankcom and Admiral Termijtelen were elected President and Vice-President respectively.

Members of the Commission expressed great satisfaction with the facilities provided for the Conference. In the way of relaxation the Commission was entertained at a reception given by the British Government at which the Secretary of State for Air was present, and by the Honourable Company of Master Mariners aboard the *Wellington*. Through the kindness of Lord Waverley the Port of London Authority launch *St. Katherine* took the delegates on a trip down the Thames and through the London Docks, where they were able to appreciate at first hand some of the problems associated with instrumental exposure aboard merchant ships. Two British instrument firms also entertained the Commission very hospitably.

The recommendations of the Commission were, for the most part, approved by the Executive Committee of the World Meteorological Organization at their Session in Geneva in September. Steps are now being taken to put the recommendations into effect, and it is hoped that these will make meteorological information from the oceans both more adequate and more accurate.

AERODYNAMIC NUMBERS

Three numbers associated respectively with the names of Mach, Reynolds and Richardson, figure prominently in present-day aeronautical and meteorological literature. These notes have been written to explain as simply as possible the significance of these three numbers to those who have not made a special study of hydrodynamics.

They are all pure numbers, and so differ from quantities such as velocity, to a numerical value of which it is always necessary to add units of measurement such as miles per hour or feet per minute, or lapse-rate of temperature which must be specified in so many degrees Centigrade per kilometre or degrees Fahrenheit per thousand feet.

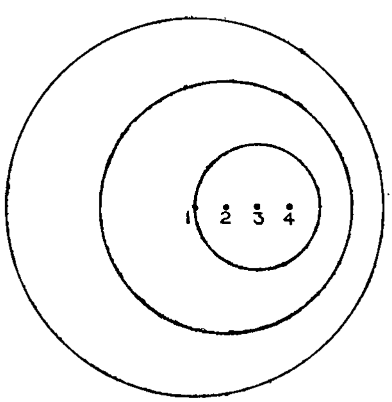
Mach number.—The Mach number is a number of importance in the movement of aeroplanes or projectiles through the air. It is the ratio of the airspeed of the object to the speed of sound. It has always been important in ballistics—the study of projectiles—because bullets and shells move at speeds considerably greater than the speed of sound, and it has become important in aerodynamics with the development of jet-propelled aircraft which can reach airspeeds of over 600 m.p.h. As it is the ratio of two velocities it is obviously a pure number.

Because air is compressible, changes of pressure which are small compared with the total pressure are transmitted at a finite speed. This speed was first measured in connexion with sound and is known as the speed of sound. The speed of sound depends on the temperature, and at temperatures experienced ordinarily at sea level is about 760 m.p.h.

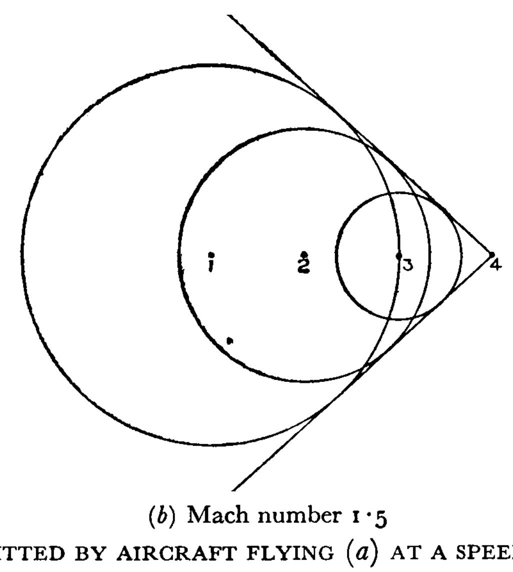
An aeroplane presses on the air ahead which, if the speed of the aeroplane is small compared with the speed of sound, is readily able to adjust itself with only small changes of density or pressure. At such speeds the maximum change of pressure near the aeroplane is approximately equal to ρv^2 where ρ is the air density and v the speed of the aeroplane. From this formula it is easy to calculate that at a speed of 100 m.p.h. the maximum pressure change is approximately 26 mb., that is 2·5 per cent. of the normal atmospheric pressure at sea level.

The air flows round a slow aeroplane in very nearly the same flow pattern as would an incompressible fluid. When an aeroplane is moving at high speeds this easy adjustment of the air to the aeroplane's motion is no longer possible, and the pattern of flow of the air is different from what it is at low speeds.

A useful way of looking at the matter is to think of the aircraft as sending out at every instant a pressure wave spreading out in all directions at the speed of sound. Fig. 1 (*a*) shows the situation with a slow-speed aircraft. Points 1, 2, 3, 4 represent the position of the aircraft at successive seconds, and the circles show where the pressure changes, emitted at time 1, 2, 3, respectively, and moving with the speed of sound, have arrived at time 4. The circle for 4 is, of course, a point. It will be seen that, so long as the aeroplane is moving at a



(*a*) Mach number 0·5



(*b*) Mach number 1·5

FIG. 1—FRONTS OF PRESSURE WAVES EMITTED BY AIRCRAFT FLYING (*a*) AT A SPEED LESS THAN THAT OF SOUND, (*b*) AT A SPEED GREATER THAN THAT OF SOUND

lower speed than the speed of sound, the circles, though closer together on the side towards which the aeroplane is moving, will never overlap. If, however, the aeroplane is moving at more than the speed of sound (Mach number greater than 1) the situation takes on the very different complexion shown in Fig. 1(*b*). The circles then overlap, and at any instant they all touch a wedge moving with the aircraft and having its vertex at the leading edge. The pressure changes set up by the motion of the aircraft cannot reach the air ahead so that air is unaffected by the motion. The result is a very different flow pattern from the one prevailing at low aircraft speeds. A surface of compressed air and pressure discontinuity situated along the wedge travels with the aircraft just as a surface wave set up by the bows accompanies a ship. It is easily seen that the sine of half the angle of the wedge equals the reciprocal of the Mach number.

The change in the pattern of flow causes changes in the lift of the wings and in the resistance of the air to the aircraft. The lift and drag are respectively proportional to $C_L v^2$ and $C_D v^2$ where C_L and C_D are quantities called the lift and drag coefficients. They are not constants, but vary very little with airspeed so long as the type of flow does not appreciably change. When the Mach number exceeds about two-thirds, the lift coefficient starts to decrease and the drag coefficient to increase at rates which get larger and larger as the speed increases, so that eventually the lift actually decreases with increasing speed. These changes in the lift and drag coefficients affect the stability of the aircraft and its reaction to the controls. It is vital for the pilots of aircraft which are powerful enough to reach speeds approaching the speed of sound to be warned when the Mach number reaches a high value, because the aircraft may become uncontrollable if it travels too fast. The warning is given by a meter on the instrument board which indicates the Mach number. The dial of the machmeter is shown in Fig. 2. A needle moves over the face in the usual way to indicate the Mach number as a decimal fraction. Special marks are placed on the dial to indicate to the pilot the Mach number he must not exceed.

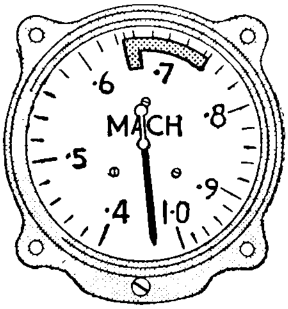


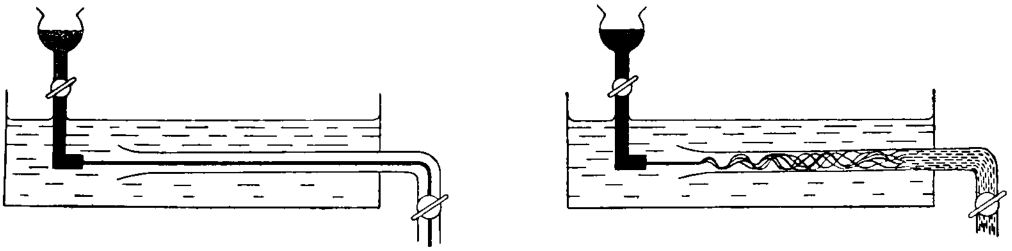
FIG. 2—MACHMETER, MK. I

As already mentioned the speed of sound depends on the temperature. In fact, neglecting the minute effects of water vapour, the speed of sound is proportional to the square root of the absolute temperature of the air. In the international standard atmosphere the speed of sound at zero height (temperature 15°C.) is 762 m.p.h. and at 37,000 ft. (−56·5°C.) it is 660 m.p.h. The machmeter had necessarily to be designed to take account of the change of speed with temperature. This was done by using the fact that the Mach number is nearly proportional to the square root of the ratio of the difference between pitot-head pressure and static pressure to the static pressure. For a full description of the instrument reference should be made to the "Instrument manual (navigational instruments)"[1].

Reynolds number.—The Reynolds number is also important in connexion with the flow pattern of a fluid or gas but at very much lower speeds than those for which the Mach number is important. It is concerned with the transition from stream-line, or laminar, flow to turbulent flow in a fluid without an appreciable temperature gradient.

It originated in experiments made in 1883 by Osborne Reynolds on the flow of water in a narrow tube. Reynolds set water flowing in a horizontal glass tube projecting from a reservoir. A subsidiary thin tube opening into the main one along its centre was arranged to make a thin stream of coloured dye enter the centre of the tube, as shown in Fig. 3.

At low speeds of flow, as shown in Fig. 3(*a*), the dye made a thin steady line along the centre of the tube. The speed of flow was increased by small steps until, quite suddenly, the nature of the flow changed drastically so that instead of the dye forming a steady line it spread out to mix with the water to form a dilute coloured mass filling the tube—Fig. 3(*b*). For a given diameter of tube and fluid Reynolds found there was a critical speed of flow for which the flow pattern changed from laminar to turbulent. Further experiments revealed that the critical speed depends on the liquid and on the size of the tube. Turbulent flow in a given fluid sets in at a lower speed in a wide tube than in a narrow one.



(*a*) Laminar flow (*b*) Turbulent flow

FIG. 3—APPARATUS USED BY OSBORNE REYNOLDS IN 1883 TO STUDY TURBULENT FLOW IN A LIQUID

These experiments led Reynolds to define the number: $ud\rho/\mu$ in which u, ρ, μ are the speed, density and viscosity of the fluid and d is the diameter of the tube. It can be shown from the theory of dimensions, for which reference should be made to standard textbooks[2,3], that the Reynolds number is a pure number. The symbols employed for the Reynolds number are R or R_e.

Reynolds found that turbulent flow in smooth tubes carefully insulated from external disturbances set in spontaneously when the Reynolds number reached a value of about 2,000. The actual value in any case depends on the shaping of the entry pipe. Thus in a tube of 1 cm. diameter the flow of water at temperature 15°C. ($\mu = 0{\cdot}01142$ gm./sec./cm.) changes from laminar to turbulent at a speed of 23 cm./sec.

Further experiments showed that there is a critical Reynolds number defining the speed at which turbulent flow sets in when a fluid flows past any smooth body such as a sphere or transverse cylinder. The diameter of the sphere or the cylinder replaces the diameter of the tube in the formula for the Reynolds number. The critical range of values of the Reynolds number for transition to turbulent flow is 2×10^5 to 4×10^5 for flow round a sphere or cylinder and is thus higher than for flow in a tube.

The transition to turbulent flow has repercussions on the resistance of a fluid to a body moving through it as the speed increases through the critical value. The change to turbulent flow produces a sharp drop in the value of the drag coefficient C_D in the formula $C_D v^2$ mainly because turbulence reduces the fall of pressure immediately behind the body.

Meteorological applications of the change in drag coefficient at a critical speed occur in the ascent of balloons and the fall of hailstones. In balloon work the decrease in density of the air with height produces for a given rate of ascent a decrease in Reynolds number with height. Many meteorological balloons have diameters and rates of ascent such that at some parts of the ascent the Reynolds number lies within the critical range for change of flow from turbulent to laminar, and this fact makes it impossible to derive a simple general formula connecting the rate of ascent of the balloon with its weight and free lift. Scrase showed, in an unpublished report, that high-altitude 2-Kg. balloons pass through the critical value of Reynolds number at heights between 10 and 15 Km. The Reynolds number decreases so that turbulent flow round the balloon is replaced by laminar flow, and the rate of ascent decreases because of the rise in drag coefficient. The change from a value of Reynolds number of $6 \cdot 7 \times 10^5$ at 10 Km. to one of $1 \cdot 7 \times 10^5$ at 20 Km. is associated with a fall in speed of ascent from about 1,500 to 1,000 ft./min. Bilham and Relf[4] have studied the fall of hailstones and shown by equating the weight to the drag that the change in drag coefficient of a sphere in the critical range of Reynolds numbers makes it possible for hailstones, within certain ranges of size depending on the density of the hail, to have two terminal speeds. The higher of these two speeds is associated with the lower drag coefficient but is so great, at 300–400 ft./sec., that it is considered very unlikely that it ever occurs. It is concluded that there is an upper limit of about 200 ft./sec. to the rate of fall of a hailstone. This occurs with one of mass about 1·5 lb. which is considered to be the largest possible size.

Richardson number.—Turbulence in a fluid may be generated by motion over solid bodies to which the Reynolds number theory applies. In a compressible fluid it is also possible for turbulence to arise spontaneously when there are variations of speed of flow, or of density, or both, within the fluid. A theory of the development of spontaneous turbulence was put forward by L. F. Richardson in 1920, and this theory introduces a non-dimensional quantity now called Richardson's number and usually designated by R_i.

In an atmosphere in which temperature falls with height at a rate greater than the adiabatic value, the ordinary theory shows that a "bubble" once starting to move vertically will be accelerated by buoyancy, because at any level it will be lighter than the surrounding air if moving upwards and heavier than the surrounding air if moving down. In such an atmosphere turbulence readily arises.

In an atmosphere of lapse rate less than the adiabatic value a "bubble" set moving vertically will be slowed down by buoyancy and it is not clear at first sight how turbulence can be spontaneously generated. Spontaneous generation of turbulence is possible, however, if there is a sufficient variation of horizontal wind speed with height. Suppose the horizontal speed increases with height as it nearly always does in the lower layers of the atmosphere. Then an upward-moving eddy will carry up slower-moving air and so tend to produce a local reduction of speed as it mixes with air higher up. Similarly a downward-moving eddy will tend to produce a local increase in speed. These local irregular reductions or increases of the general flow constitute turbulence.

We have to consider the kinetic energy of turbulence which, per unit volume, is proportional to $\rho(u - \bar{u})^2$ where u is the actual horizontal speed and $\bar{u}$ the mean horizontal speed at the height considered. As an eddy moves up or down in a stable layer it loses energy because it has to move against the buoyancy, but if the gain in the kinetic energy of turbulence produced by the movement into a layer of different mean speed exceeds the energy lost by the movement of the eddy against buoyancy, then turbulence will tend to increase.

It can be shown that the mean rate of gain of turbulent kinetic energy by a large number of eddies is, per unit volume, proportional to $K_M \, \rho(d\bar{u}/dz)^2$ in which K_M is the coefficient of turbulent diffusion of momentum and $d\bar{u}/dz$ is the rate of increase in mean speed with height. The usual adiabatic convection theory shows that a "bubble" rising through a small distance l will be at a temperature lower than the temperature of its surroundings by the amount $l(dT/dz + \Gamma)$ where dT/dz is the rate of increase of temperature with height and Γ is the adiabatic lapse rate. From this it follows that the density of the "bubble" is greater than the density of the environment by the amount

$$\frac{l\rho}{T}\left(\frac{dT}{dz} + \Gamma\right),$$

whence Archimedes' theorem shows that the downward force per unit volume on it is

$$\frac{gl\rho}{T}\left(\frac{dT}{dz} + \Gamma\right).$$

If w is the vertical velocity, the amount of work done against buoyancy in the upward flow is thus

$$\frac{g}{T}\left(\frac{dT}{dz} + \Gamma\right)\overline{wl}$$

for unit horizontal area per second taking the mean over many eddies. The mean value of vertical velocity multiplied by distance travelled by the eddy $\overline{wl}$, is the coefficient K_T of turbulent diffusion of heat. The ratio K_T/K_M is believed not to differ appreciably from unity in the atmosphere. The ratio of the rate of loss of potential energy to the rate of gain of turbulent kinetic energy is the Richardson number, and is given by the ratio,

$$g\left(\frac{dT}{dz} + \Gamma\right) \Big/ T\left(\frac{d\bar{u}}{dz}\right)^2.$$

It is easily proved from dimensional theory that the Richardson number is a pure number. This theory suggests that turbulence will tend to increase in intensity if R_i is less than unity and decrease if it is greater than unity.

Laboratory investigations suggest a critical value of R_i as low as 0·04. On the meteorological scale it is difficult to determine R_i and decide whether turbulence is increasing or decreasing. Critical values of between 0·04 and 1·0 have been given for the lower atmosphere by various workers. In the free atmosphere calculation is possible only from observations over rather large height ranges. Bannon's data[5] suggest that the maximum of the frequency distribution of R_i is about 10, and that values of over 1,000 are by no means infrequent. No definite information is available on the critical value of R_i in the free atmosphere, but it is significant that Bannon[6,7] found that bumpiness encountered by aircraft in clear air at great heights is often associated with a large vertical wind shear (i.e. large du/dz) and with correspondingly low values of R_i in the range from 1 to 5.

For further study on the subjects of these notes, readers could hardly do better than turn in the first place to the two small books by O. G. Sutton[8,9] listed below. "The science of flight" is the more elementary of the two.

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PILOT-BALLOON OBSERVATIONS IN THE SUDAN

By U. C. W. RATH

The opening of regular jet-plane passenger services over the Sudan in May 1952 made upper wind observations necessary to heights of 30,000–40,000 ft. in a country over which, it was believed until a few years ago, duststorms, haze and strong upper winds, as well as tropical thunderstorms, made direct observations by means of pilot-balloon ascents to such high levels impossible.

In "Upper winds over the world"[1], the reasons why pilot balloons are lost were investigated for a number of stations all over the world, and it was considered that Khartoum was a typical example of a hazy and dusty atmosphere. In their paper the authors chose Khartoum (November 1935–October 1936) as an example of difficult atmospheric conditions where the observed frequencies of upper wind would require large corrections for balloons lost because of poor visibility and strong upper winds[1]. Actually 49 per cent. of all balloons were lost below 10,000 ft. during the period investigated by Brooks. Since then the mean height reached by pilot balloons has increased steadily. Table I gives some typical examples for the period 1939–51.

The improving standard of observations shown in Table I is not due to climatic changes but to the better training and longer experience of the

TABLE I—MEAN HEIGHT OF PILOT BALLOON ASCENTS AT KHARTOUM

	Number of ascents	Mean height at which balloons were lost by all observers	by the best 3 observers
		ft.	ft.
1935–36	623	10,000	...
1939–40	730	13,000	16,000
1944–45	730	11,500	13,000
1950	1,039	16,500	22,500
1951	1,160	18,000	23,500

observers, who have to follow balloons without protection against the sun or the wind at temperatures often exceeding 100–110°F.

Nevertheless only a few of the 40 daily ascents from 14 Sudan stations reach the required heights, and the reasons for the loss of balloons at lower levels are not always easy to detect. Observations of the oblique visibility of the ground from aircraft would be one measure of the haziness but very few are available, and even these few are not considered very reliable because of the scarcity of visibility marks and fixed points for navigation over the desert. Table II gives the best data for Khartoum based upon observations made during regular twice-daily aeroplane ascents in the winter of 1945–46.

TABLE II—VISIBILITY REPORTED FROM REGULAR AIRCRAFT ASCENTS OVER KHARTOUM, WINTER 1945–46

Height of aircraft (ft.)	6,000	10,000	14,000
Approximate mean visibility (miles) ...	20	30	40

The observations are in fair agreement with reports from the pilots of commercial aircraft and with observations by meteorologists during occasional flights over the Sudan in such aircraft. It is interesting to compare these normally very good slant visibilities with the mean distances up to which high-level pilot balloons would have to be followed to obtain wind data to heights of 10,000, 20,000, 30,000 and 40,000 ft. In the third column of Table III the horizontal components of the distances from the balloon to its point of release are given, while the last column states the actual slant distances. It will be seen that on the average the difference between the horizontal component and the actual slant range, i.e. the difference between columns 3 and 4, is of the order of 0·5–1·3 miles only.

TABLE III—APPROXIMATE MEAN DISTANCES OF PILOT BALLOONS WHEN OBSERVED AT DIFFERENT HEIGHTS OVER KHARTOUM

Period: 1950–51

Height	Time since release	Mean horizontal distance	Mean slant distance
ft.	min.	miles	miles
40,000	80	21	22·3
30,000	60	13	14·2
20,000	40	8	8·9
10,000	20	3	3·5

Table III is based on a preliminary analysis of upper winds at Khartoum. It is hoped that full details of this analysis will be published in the near future.

Even if allowance is made for the inevitable inaccuracies of both visual observations from aircraft in flight and of pilot-balloon observations, Tables II and III suggest that the limitations of visibility by dust and haze are normally not nearly as bad as was thought in former years. In fact, with good theodolites and balloons of suitable size and quality, atmospheric conditions over Khartoum normally make it possible to follow pilot balloons to distances two or three times those hitherto attained.

An analysis of the results of all 14 Sudan pilot-balloon stations has shown that three main factors are of considerable influence on the heights attained:—

(i) Seasonal variation with a pronounced maximum during the clear and comparatively cool winter months and with a minimum during the cloudier as well as very hot and trying summer months. As an example records from Wadi Halfa (21°55′N., 31°20′E., height 410 ft.), Khartoum (15°37′N., 32°32′E., height 1,247 ft.) and Juba (4°51′N., 31°37′E., height 1,509 ft.) for 1950 and 1951 are shown in Fig. 1. Since all stations are of about the same longitude this graph may be regarded as a meridional cross-section through the Sudan from 5°N. to 22° N.

(ii) Time of day.—The 0300 G.M.T. and 0900 G.M.T. (0500 and 1100 Sudan time) balloons show the best results, while during the very hot and (in summer) cloudier afternoons the mean heights show a marked decrease. The lowest results are obtained at night (2100 G.M.T. or 2300 Sudan time) when most of the balloons reach about 10,000 ft. and only a few exceed 15,000 ft.

(iii) Superimposed on these seasonal and diurnal variations is a wide scatter from station to station and generally from observer to observer. It has been found very difficult, so far, to separate the decrease in the heights attained during the summer months or in the afternoon due to weather (such as thunderstorms and duststorms, cloud, thick haze and strong winds) from that due to other random causes.

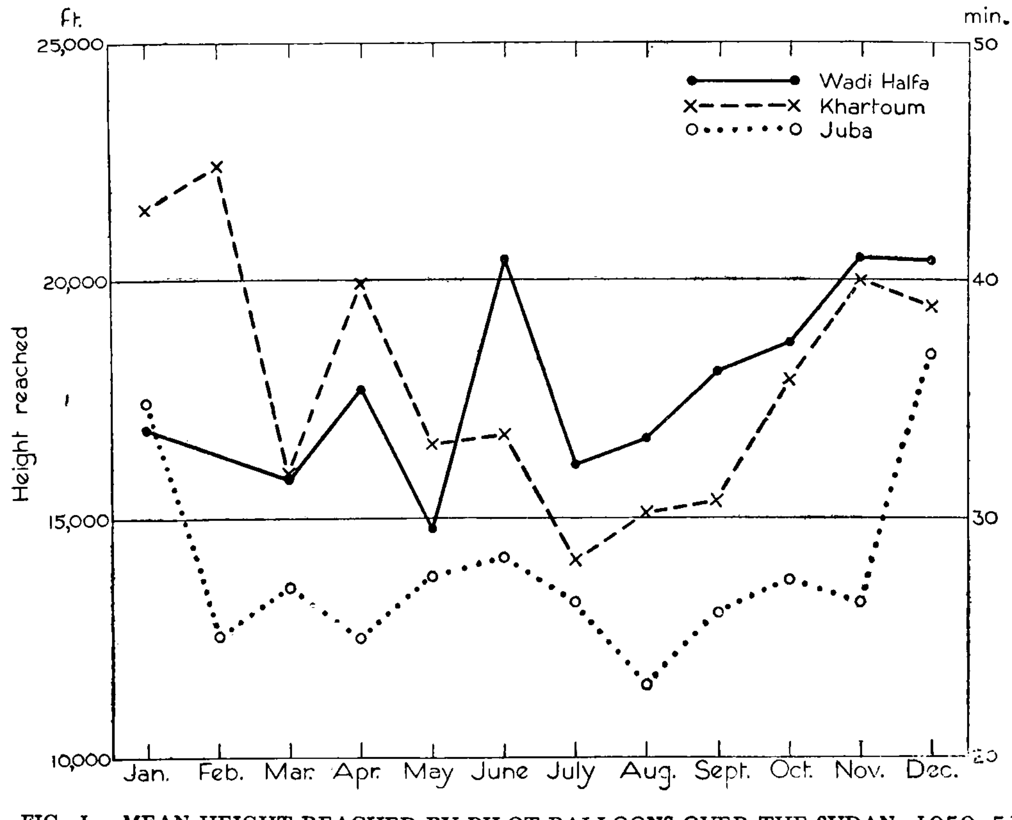

FIG. 1—MEAN HEIGHT REACHED BY PILOT BALLOONS OVER THE SUDAN, 1950–51

Since the frequency of duststorms, thick haze and thunderstorms, is less than 5 per cent. at Khartoum and in the arid and desert zones of the country (i.e. north of about 13°N.), even during the worst times of the year, it is hoped that with better equipment, faster-rising and bigger balloons, and improved training of observers, a further substantial improvement in the number of upper wind observations at the required heights of 30,000–40,000 ft. will be possible.

The writer is indebted to the Sudan Government Meteorologist for permission to publish this note and for his valuable suggestions during the preparation of it.

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LETTER TO THE EDITOR

Ageostrophic mean flow

Mr. Crossley's demonstration[1] that the spatial mean ageostrophic departure is related to the vector variance is as important as it is elegant. That a normal wind distribution is assumed should not be regarded as too limiting, for we can at least be satisfied with knowing the magnitude of these ageostrophic flows. Sooner or later the problem of ageostrophic flows arising from skewed wind distributions will have to be faced, but the "normal" assumption is obviously the first step.

Mr. Crossley's work emphasizes again the great importance of the vector wind variance as a meteorological parameter. This quantity was first measured by Brooks and co-workers[2] as a model of wind structure alternative to the ungainly wind-rose. The aim was largely practical, connected with flight planning, safe fuel loads, etc., but the value of σ is by no means confined to these fields.

In the present application it is possible to measure simply one component of ageostrophic mean flow. The measurement of ageostrophic flows is of obvious importance in dynamic meteorology, particularly in connexion with the global circulation.

The wind variance may also be applied to the mean kinetic energy per unit mass at a point. Over a period this is given by

$$\tfrac{1}{2}\overline{\mathbf{V}^2} = \tfrac{1}{2}\mathbf{V}_m{}^2 + \tfrac{1}{2}\sigma^2.$$

For a number of perturbations in a steady flow, $\frac{1}{2}\mathbf{V}_m{}^2$ represents the kinetic energy inhering in the general flow, and $\frac{1}{2}\sigma^2$ the kinetic energy of the perturbations. The vector wind variance is thus a measure of the "activity" of migrating disturbances in a given area. We may distinguish a high-index situation as one in which most of the kinetic energy derives from the general flow, or $|\mathbf{V}_m|/\sigma$ is large, whilst in a very low-index situation most of the kinetic energy will be derived from the perturbations, and $|\mathbf{V}_m|/\sigma$ will be small. This suggests that we might take $|\mathbf{V}_m|/\sigma$ as an index of the general flow rather than a mean wind between two latitudes. It is, in general, advantageous to have a dimensionless parameter for an "index".

Another application of the wind variance is to the vertical structure of perturbations. The way in which σ varies with height tells us something about the mean vertical structure of disturbances[3].

Whether such applications would prove of value to the practical forecaster or not, it is apparent that many problems, particularly in connexion with the mean global flow, can be formulated simply and elegantly with the aid of the vector variance.

R. W. JAMES

27 Dora Road, S.W.19, September 4, 1952

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NOTES AND NEWS

Thunderstorm of November 19, 1950, at Singapore

During the early hours of November 19, 1950, a good example of the more active type of equatorial thunderstorm was observed from Tengah, Singapore. This storm gave heavy rain, a total fall of 111·3 mm.* occurring between 0100 and 0700 zone time (G.M.T. + 7) of which 73 mm. fell between 0300 and 0400, and 102·2 mm. between 0300 and 0500. Zone time is half an hour behind local time.

This storm produced extensive flooding over Singapore island, mainly in the northern and western parts.

Of five other heavy falls of rain at Tengah since January 1, 1950, which each gave 60 mm. or more over a period of 5 hr., the mean fall in 5 hr. was 69 mm. and the maximum 82 mm., whereas the storm under review in this note gave 110 mm. during a corresponding period.

Lightning was first observed to the south from Tengah at 1900, together with a lunar halo. Lightning continued to the south and south-west during the following hours, becoming quite vivid and very frequent by 2300. During this period stratocumulus cloud was spreading into the Tengah area from the south-west. Although by midnight the lightning had become less frequent, the storm cells were steadily advancing towards the airfield and thunder was heard at 0028. Cumulonimbus clouds were now visible to the south-west.

	Weather	Surface wind		Temperature	Relative humidity	Rainfall during previous hour	
		° true	kt.	° F.	%	mm.	in.
0000	cl	040	1	74·7	96	—	—
0100	ctl	240	2	74·3	96	—	—
0200	tlr_0	250	2	74·0	98	1·3	0·05
0300	tlr_0	250	1	74·1	99	0·1	0·004
0400	TLR	240	4	73·5	100	73·0	2·87
0500	TLR	250	6	73·3	100	29·2	1·15
0600	rr	230	4	73·8	97	5·8	0·23
0700	r_0r_0	260	1	74·1	100	1·9	0·07

By 0100 a storm cell to the west-south-west was again giving very frequent lightning, accompanied by thunder, and rain commenced at 0106. This proved to be only a light fall, the storm centre passing to the west of the station, with the lightning becoming less frequent. The rain shower ceased at 0220. Upper cloud, associated with cumulonimbus, increased to 4 oktas of alto-cumulus.

* 25·4 mm. = 1 in.

More thunderstorm cells were lying to windward, however, and the rain recommenced at 0257, intensifying to moderate by 0306. This fall probably came from the leading edge of a multi-cell storm of fairly extensive proportions, which was extremely active and passed slowly over Tengah. The rain became very heavy by 0315, with almost continuous, and vivid, lightning in all directions.

Heavy rain, with lightning, continued until 0510 and then eased to moderate intensity, as the main storm centre moved slowly away towards the north. By 0700 there was only continuous light rain falling from altostratus cloud.

The surface wind throughout was from 240–250°, 2–6 kt., but with a gust to 18 kt. at 0515.

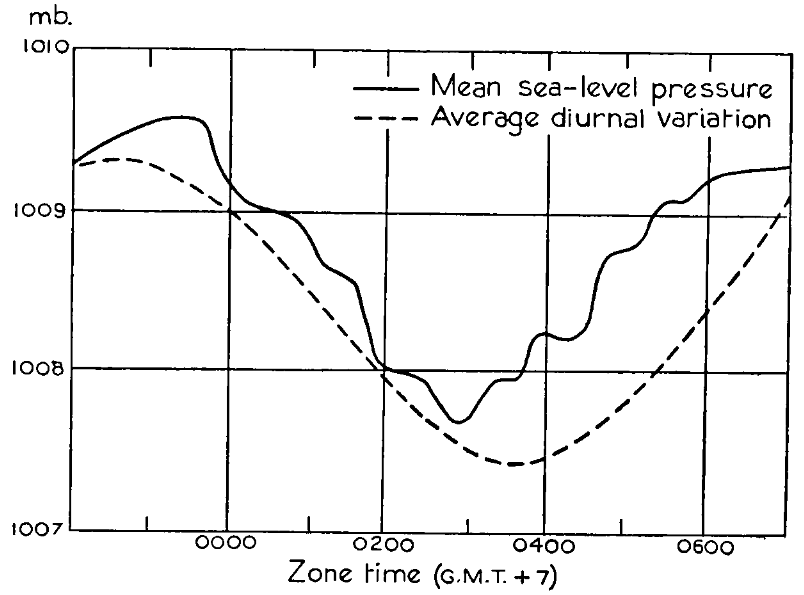

FIG. 1—BAROGRAM FOR TENGAH, NOVEMBER 18–19, 1950

Fig. 1 is a reproduction of the actual barogram during the period, the lower curve representing the average diurnal pressure variation. Fluctuations associated with the passage of individual storm cells are well marked.

This storm was associated with the intertropical convergence line, which, after lying to the south-west of Singapore, had moved quickly north-eastwards on November 18. Activity was probably intensified as the convergence line traversed the Malacca Straits to cross the island in the early hours of November 19.

The southern half of the Straits of Malacca is a notorious area of local nocturnal convergence and thunderstorm activity. The Straits seem to exercise a "booster" effect at night time upon transient cumulonimbus clouds.

P. G. RACKLIFF

REVIEWS

Soviet plans for irrigation and power: a geographical assessment. By A. A. Grigoryev. *Geogr. J., London,* **118,** 1952, pp. 168–179.

Academician Grigoryev's article in the June 1952 number of the *Geographical Journal* is concerned mainly with plans for the utilization of the water of the great rivers of the U.S.S.R. for irrigation and the generation of electric power.

He includes a short note on the climatic effect of wind-breaks, which shows that in the areas of the U.S.S.R. which, as in the lower Volga region, are arid but not desert, the main advantages expected from wind-breaks lie in a reduced outflow of snow-melt water and more uniform distribution of soil moisture produced by a more uniform distribution of snow cover. For this reason the wind-breaks in these areas are arranged to provide appreciable penetrability to the wind. Impenetrable wind-breaks produce a very uneven distribution of snow. In the desert areas wind-breaks are of use only in irrigated areas and are planted round oases to reduce the influx of dry desert air. In the irrigated and sheltered oases evaporation gives a July mean temperature 3°C. lower than over the desert, but more important is the reduction in the midday July surface-soil temperature from 65°C. in the desert to 35°C. in the irrigated fields of the oasis.

G. A. BULL

Report on the Snow Survey of Great Britain for the season 1950–51. By E. L. Hawke and D. L. Champion. *J. Glaciol., London,* **2,** 1952, pp. 25–38.

This report by Mr. E. L. Hawke and Mr. D. L. Champion, Directors of the Snow Survey, describes the snow condition of the snowiest winter since the one of 1946–47. Observations made from Banavie of the snow cover on Ben Nevis are included for the first time, and reveal that there was continuous snow cover above 3,500 ft. on that mountain from October 30 to May 30. The higher summits of the Snowdon group were continuously covered from November 12 to May 31. Snow showers occurred as late as May 15 on Dartmoor. The report is illustrated with excellent photographs of a snowfield on Ben Macdhui in the Cairngorms in late July 1951 and of very heavy rime during April on a snowfield in the Cairngorms.

G. A. BULL

OBITUARY

Francis James Chaplin.—We regret to record the death of Mr. F. J. Chaplin on October 25, 1952.

Mr. Chaplin joined the staff of the meteorological office attached to the Artillery Ranges at Shoeburyness in April 1921 and remained there for more than eleven years. In 1932 he transferred to synoptic work at the civil aerodrome at Croydon and from 1936 to 1938 he served in the Climatological Branch at Headquarters. After further service at civil aviation stations he went to Canada in March 1942 to serve with the meteorological unit attached to an Advanced Navigation School. On return to England in the autumn of 1943 he filled successively a number of administrative posts at R.A.F. Groups until he went to Morton Hall in 1947 on the inception of No. 21 Group, Flying Training Command. Beginning with a small nucleus of stations in eastern England, he saw the Group expand to treble its original size.

Mr. Chaplin was particularly suited for administrative work at a Group Headquarters. He lightened the load of Senior Meteorological Officers by his close attention to detail and the good relations he maintained with staff at the subsidiary offices.

Mr. Chaplin enjoyed country life. He was a great walker and cyclist, swam often, and had latterly renewed an early interest in riding. This interest followed on from his service in a Yeomanry Regiment during the 1914–18 war. His sudden illness and unexpected death came as a great shock to all who had known him.

METEOROLOGICAL OFFICE NEWS

Courses for climatological observers.—Two courses for climatological observers were held in October 1952, each attended by twenty-five observers from amongst the crop weather stations, health resort stations and normal climatological stations. Lectures were given by the staff of the Meteorological Office Training School, Stanmore, on making and recording observations and on the lay-out, care and maintenance of instruments. Attention was also given to the particular interests of the crop weather stations and health resorts. Finally the observers spent a day at the meteorological office at Harrow where the procedures for dealing with returns in the Climatological Branch and of testing instruments by the Instruments Branch were explained to them.

This is the third successive year that such courses have been held, to the mutual advantage of the observers and the Office.

Swimming.—At the Air Ministry swimming gala held at Marshall Street Baths on October 22, the Meteorological Office won the departmental relay race for the fifth consecutive year.

Miss D. M. Vinney, a newcomer to the Office, was second in the Ladies' Championship.

WEATHER OF OCTOBER 1952

Mean pressure was below normal over the North Atlantic and west Europe but above normal over north Scandinavia, the Arctic Ocean and most of the United States except the extreme east. The lowest mean pressure, 998 mb., occurred south-east of Greenland and was 7 mb. below normal, while the mean pressure at the Azores, 1017 mb., was 4 mb. below normal. Mean pressure over north Finland reached the high value of 1021 mb., as much as 11 mb. above normal; over the United States mean pressure was uniform around 1020 mb. and generally 3 mb. above normal.

Mean temperature was 30°F. in Finland (5°F. below normal), 40–50°F. in Europe (2–3°F. below normal) but in the Mediterranean region the mean temperatures between 60° and 70°F. were about 2°F. above normal. In the United States, mean temperature was high in the west and south-west; in Arizona it exceeded 70°F. and was 5°F. above normal.

In the British Isles the cold weather experienced in September persisted during the first three weeks of October, while the last ten days were unsettled and rather mild. Broadly speaking rainfall was less than the average over most of the east of Great Britain and at many places on or near the west coast, while more than the average occurred in central districts of Great Britain and in Ireland.

On the 1st a depression moved north-east from the Strait of Dover to the southern North Sea giving rain, chiefly in the southern and eastern districts of Great Britain. Thereafter a ridge of high pressure off our north-west coasts moved south-east and was followed by a trough. Showers occurred, chiefly in the north and west, but there were long bright periods locally, particularly in the west. On the 5th a ridge extending from an anticyclone on the Atlantic moved south over our southern districts and bright weather prevailed for the most part in England, Wales and Ireland, while a trough gave cloudy, showery weather in Scotland. On the 6th a deep depression centred north of Scotland moved east and later turned south-east to the Skagerrak and a short spell of westerly to northerly winds ensued with scattered rain or showers but long, sunny periods in many places. By the 8th an anticyclone was situated over southern Ireland giving a mainly sunny day over southern districts but a trough, associated with a depression moving east from Iceland to Norway, caused rain in northern districts on the 8th and slight scattered rain or showers on the 9th. Subsequently an anticyclone moved from westward of Ireland to Scandinavia and a short cold, fair spell occurred with some low minimum temperatures; air temperature fell to 24°F. at Shawbury on the morning of the 11th and at Elmdon on the 12th. A trough gave considerable rain in the west on the 12th, while a deep depression crossing southern England on the 13th was associated with heavy rainfall over a large area and a gale in places. Another ridge of high pressure followed with further widespread early morning frost and fog. Temperature fell to 23°F. at Eskdalemuir on the 15th and to 24°F. at Elmdon on the 16th. Weather continued mainly fair in the east until the 18th with some rise in temperature. On the 18th and 19th a trough of low pressure off our south-west coasts moved slowly east giving rain in most parts; winds backed to south-east and the 19th was a cold, mainly wet day. Meanwhile the anticyclone over Scandinavia persisted and mainly dull, cold weather prevailed on the 20th and 21st. A spell of unsettled, milder weather ensued which lasted until the end of the month. On the 22nd and 23rd a deep Atlantic depression approached our north-west coasts, while troughs moved north-east across the country giving rain and local thunderstorms; gales occurred in places in the north and north-west. At Ternageeragh, near Upperlands, Co. Londonderry, a tornado caused considerable damage on the 23rd. Subsequently the main depression moved east-north-east to the north of Scotland and filled; widespread thunderstorms occurred on the 24th and showers on the 25th and 26th. On the 27th a trough associated with an intense depression on the Atlantic (pressure at the centre about 940 mb.) moved north-east over England giving heavy rain in the west on the night of the 26th–27th and more generally on the 27th (2·61 in. at Thirlmere, Cumberland, 2·53 in. at Llyn-y-fan Fach, Carmarthenshire, and 2·45 in. at Halifax, Yorkshire, on the 27th). The main depression subsequently moved north-east off our north-west seaboard causing widespread rain and gales, which were severe on our north-west coasts (3·48 in. of rain fell at Glenquoich, Inverness-shire, on the 28th). The rain was followed by showers, local thunderstorms and sunny periods. Further rain spread into the west on the 31st and right across the country during the night.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	64	21	−1·4	105	−1	104
Scotland	66	22	−1·0	106	0	116
Northern Ireland ...	61	27	−0·6	133	+1	133

RAINFALL OF OCTOBER 1952

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·61	99	*Glam.*	Cardiff, Penylan ...	5·71	[illegible]
Kent	Folkestone, Cherry Gdn.	3·05	76	*Pemb.*	Tenby	4·18	
,,	Edenbridge, Falconhurst	2·91	81	*Mer.*	Aberdovey	5·80	[illegible]
Sussex	Compton, Compton Ho.	6·68	146	*Radnor*	Tyrmynydd	6·87	[illegible]
,,	Worthing, Beach Ho. Pk.	3·16	87	*Mont.*	Lake Vyrnwy	10·63	[illegible]
Hants.	Ventnor Cemetery ...	4·29	107	*Mer.*	Blaenau Festiniog ...	8·25	[illegible]
,,	Southampton (East Pk.)	5·03	128	*Carn.*	Llandudno	3·89	[illegible]
,,	Sherborne St. John ...	4·18	119	*Angl.*	Llanerchymedd ...	4·37	[illegible]
Herts.	Royston, Therfield Rec.	2·16	79	*I. Man*	Douglas, Borough Cem.	4·86	[illegible]
Bucks.	Slough, Upton... ...	2·84	101	*Wigtown*	Newton Stewart ...	4·24	
Oxford	Oxford, Radcliffe ...	3·76	130	*Dumf.*	Dumfries, Crichton R.I.	5·40	[illegible]
N'hants.	Wellingboro' Swanspool	2·69	107	,,	Eskdalemuir Obsy. ...	5·07	
Essex	Shoeburyness	1·30	55	*Roxb.*	Kelso, Floors	3·21	[illegible]
,,	Dovercourt	1·61	67	*Peebles*	Stobo Castle	3·91	[illegible]
Suffolk	Lowestoft Sec. School...	1·76	63	*Berwick*	Marchmont House ...	3·47	
,,	Bury St. Ed., Westley H.	2·83	104	*E. Loth.*	North Berwick Res. ...	1·30	
Norfolk	Sandringham Ho. Gdns.	2·22	73	*Midl'n.*	Edinburgh, Blackf'd. H.	1·46	
Wilts.	Aldbourne	4·64	137	*Lanark*	Hamilton W. W., T'nhill	2·04	
Dorset	Creech Grange... ...	5·59	110	*Ayr*	Colmonell, Knockdolian	4·57	[illegible]
,,	Beaminster, East St. ...	5·32	120	,,	Glen Afton, Ayr San. ...	6·25	[illegible]
Devon	Teignmouth, Den Gdns.	5·36	139	*Renfrew.*	Greenock, Prospect Hill	6·64	[illegible]
,,	Cullompton	4·86	118	*Bute*	Rothesay, Ardencraig...	5·50	[illegible]
,,	Ilfracombe	4·90	107	*Argyll*	Morven (Drimnin) ...	7·14	[illegible]
,,	Okehampton Uplands...	5·92	98	,,	Poltalloch	6·80	[illegible]
Cornwall	Bude, School House ...	5·07	125	,,	Inveraray Castle ...	8·43	[illegible]
,,	Penzance, Morrab Gdns.	4·42	95	,,	Islay, Eallabus... ...	4·55	
,,	St. Austell	7·63	145	,,	Tiree	4·56	[illegible]
,,	Scilly, Tresco Abbey ...	3·02	79	*Kinross*	Loch Leven Sluice ...	2·86	
Glos.	Cirencester	4·65	140	*Fife*	Leuchars Airfield ...	2·60	[illegible]
Salop	Church Stretton ...	4·92	134	*Perth*	Loch Dhu	7·96	[illegible]
,,	Shrewsbury, Monksmore	3·57	127	,,	Crieff, Strathearn Hyd.	3·88	
Worcs.	Malvern, Free Library...	4·77	160	,,	Pitlochry, Fincastle ...	4·34	[illegible]
Warwick	Birmingham, Edgbaston	4·19	151	*Angus*	Montrose, Sunnyside ...	2·09	
Leics.	Thornton Reservoir ...	2·88	102	*Aberd.*	Braemar	5·34	[illegible]
Lincs.	Boston, Skirbeck ...	1·93	70	,,	Dyce, Craibstone ...	2·67	
,,	Skegness, Marine Gdns.	2·06	75	,,	New Deer School House	2·67	
Notts.	Mansfield, Carr Bank...	3·66	120	*Moray*	Gordon Castle	2·28	
Derby	Buxton, Terrace Slopes	5·69	116	*Nairn*	Nairn, Achareidh ...	1·58	
Ches.	Bidston Observatory ...	3·20	98	*Inverness*	Loch Ness, Garthbeg ...	4·76	
,,	Manchester, Ringway...	3·35	108	,,	Glenquoich	15·30	
Lancs.	Stonyhurst College ...	3·53	79	,,	Fort William, Teviot ...	8·77	
,,	Squires Gate	3·36	95	,,	Skye, Broadford ...	7·93	
Yorks.	Wakefield, Clarence Pk.	3·55	124	,,	Skye, Duntuilm ...	6·43	
,,	Hull, Pearson Park ...	2·42	81	*R. & C.*	Tain, Tarlogie House ...	2·13	
,,	Felixkirk, Mt. St. John...	4·14	144	,,	Inverbroom, Glackour...	8·81	
,,	York Museum	2·44	91	,,	Achnashellach	9·88	
,,	Scarborough	2·14	68	*Suth.*	Lochinver, Bank Ho. ...	4·24	
,,	Middlesbrough... ...	2·21	74	*Caith.*	Wick Airfield	3·49	
,,	Baldersdale, Hury Res.	3·65	98	*Shetland*	Lerwick Observatory ...	3·75	
Norl'd.	Newcastle, Leazes Pk....	2·77	90	*Ferm.*	Crom Castle	3·95	
,,	Bellingham, High Green	3·05	78	*Armagh*	Armagh Observatory ...	3·87	
,,	Lilburn Tower Gdns. ...	3·63	98	*Down*	Seaforde	6·13	
Cumb.	Geltsdale	2·85	77	*Antrim*	Aldergrove Airfield ...	3·11	
,,	Keswick, High Hill ...	5·67	101	,,	Ballymena, Harryville...	4·10	
,,	Ravenglass, The Grove	4·77	110	*L'derry*	Garvagh, Moneydig ...	5·03	
Mon.	Abergavenny, Larchfield	6·27	150	,,	Londonderry, Creggan	4·45	
Glam.	Ystalyfera, Wern House	6·10	89	*Tyrone*	Omagh, Edenfel ...	5·61	

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