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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

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

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 $-0\cdot02$°F. with standard deviation $1\cdot8$°F. (118 occasions); and for the snow type the mean temperature difference is $-0\cdot09$°F. with standard deviation $1\cdot7$°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.

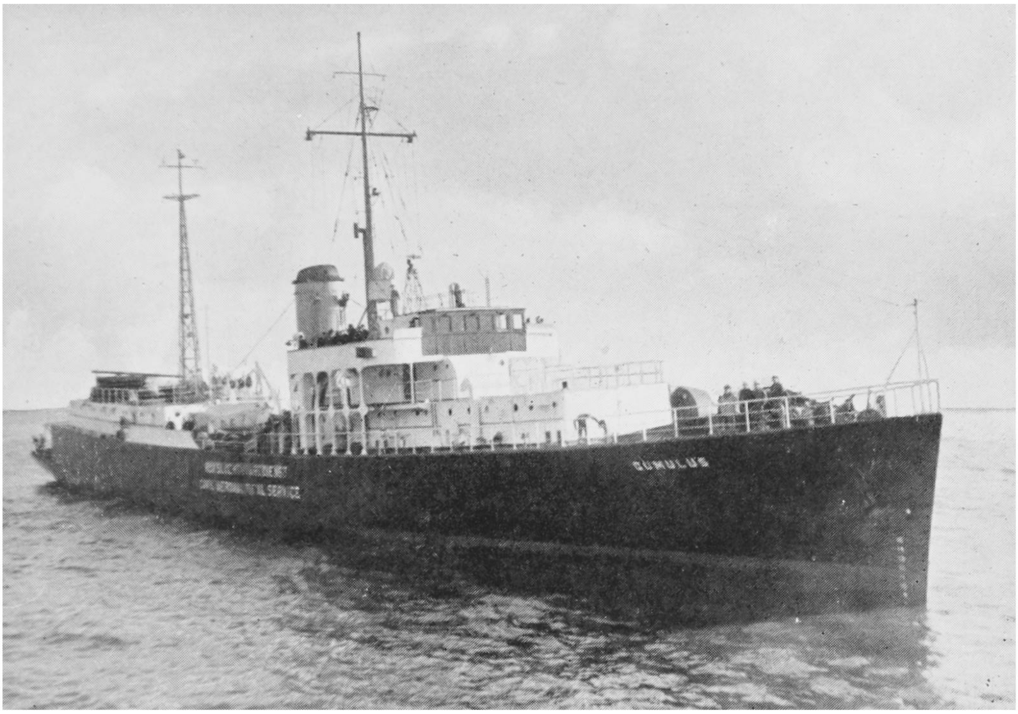
RELATION OF VISIBILITY TO WIND IN CYRENAICA

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.

[To face p. 8



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

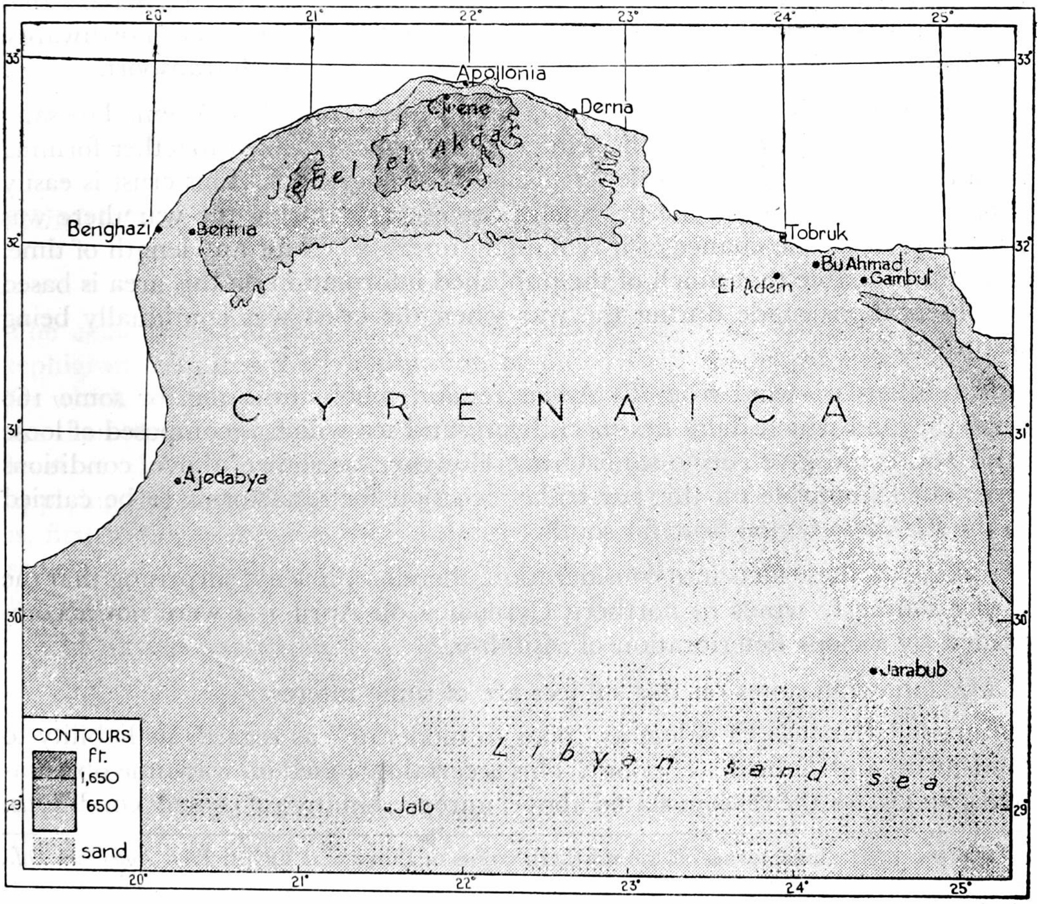
This photograph was taken aboard o.w.s. *Weather Recorder* from near Ailsa Craig in the Firth of Clyde on July 28, 1950, at 1740 G.M.T.

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,

$$x = \frac{0{\cdot}622e}{p-e} = \frac{5}{8}\frac{e}{p} \text{ approximately.}$$

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

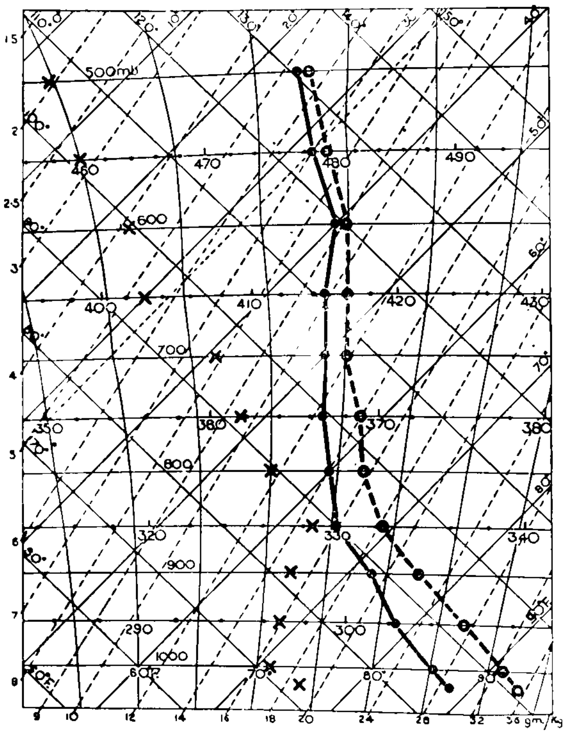
$$= -\frac{gp}{RT}\left(1 - \frac{3}{5}x\right)$$

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

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

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

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

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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6. 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.

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,

$$A - E = \mathcal{N} + \mathcal{Z} - V,$$

where A is the current flowing out of the sea, E is the current flowing in, $\mathcal{N}$ is the rainfall over the sea, $\mathcal{Z}$ 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.

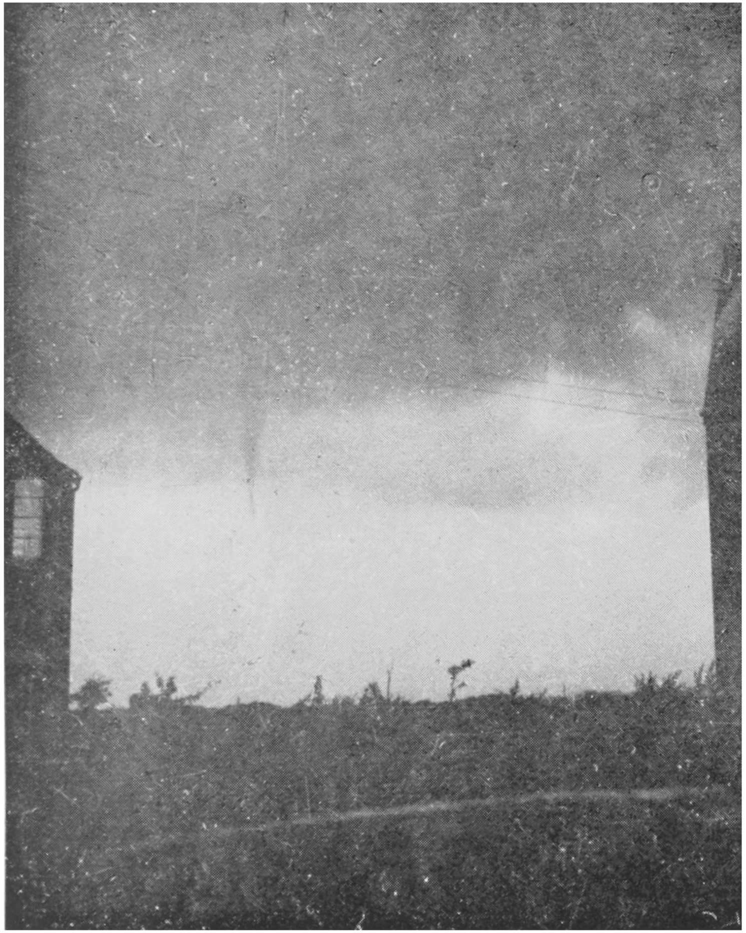
The treatment of the data was very bold and based on strikingly simple assumptions, so that it was rather surprising that good agreement was obtained between calculated and observed mean daily run-off throughout the three-year period. Extension to 1950 and the first part of 1951, after the main work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

Reproduced by courtesy of H. W. Pemberton

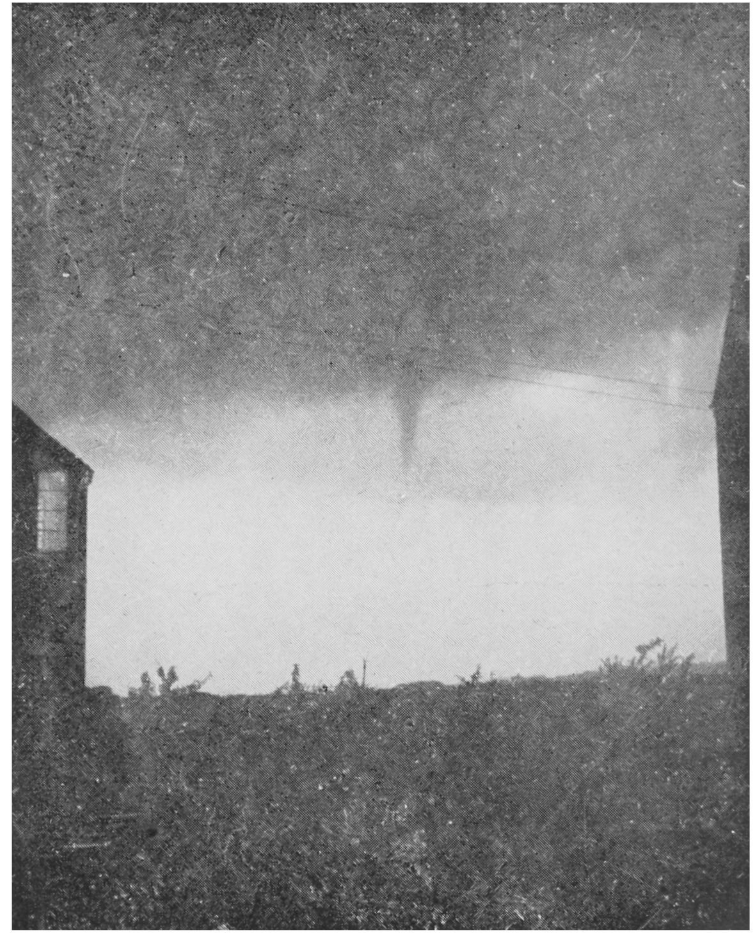
FUNNEL CLOUD AT BRAUNSTONE, LEICESTER

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.

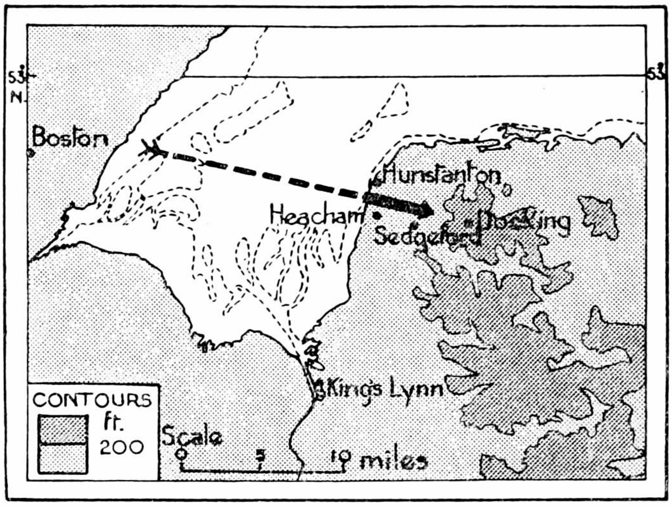
LETTERS TO THE EDITOR

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