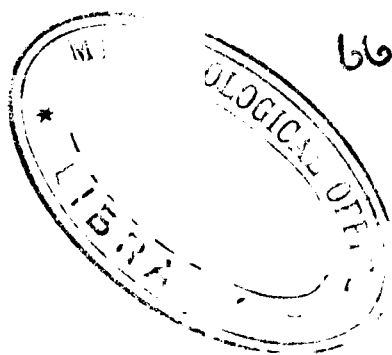
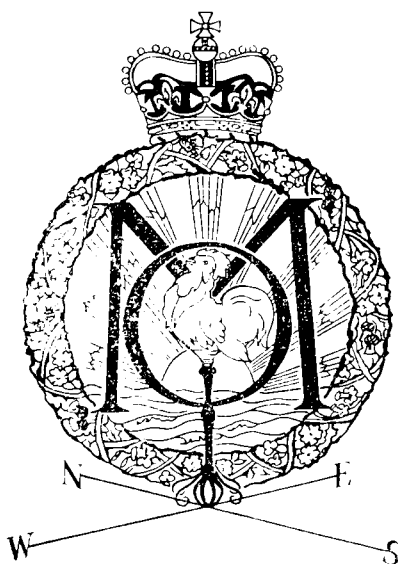


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COMPLETION OF NEW METEOROLOGICAL OFFICE HEADQUARTERS

Eight photographs in this issue show various features of the new Meteorological Office headquarters at Bracknell, Berkshire. The building was formally handed over on 1 November 1961 by Mr. Richard Thompson, M.P., Parliamentary Secretary to the Ministry of Works, to Sir Maurice Dean, Permanent Under-Secretary of State at the Air Ministry by the presentation of an inscribed key. Pointing out that the Ministry of Works does not only build post offices, prisons and telephone exchanges, Mr. Thompson named some of the many buildings which it had provided for scientific work, the latest being for the Meteorological Office at a cost of £600,000.

The building itself consists of three main blocks, arranged to form three sides of a rectangle open to the south. The Napier Shaw Building is the nine-storey block flanked on the east by the Fitzroy Wing and on the west by the Dines Wing. The top floor of the first of these houses the Central Forecasting Office, which is one of the eight master analysis centres of the northern hemisphere. Immediately below it is the Communications Centre which handles almost a million five-figure code groups every day. Below that again one will find the Meteorological Office electronic computer "Meteor". Probably the best known use for such a computer is the objective analysis of weather charts and the numerical prediction of such charts. Indeed "Meteor" is used experimentally for this purpose, thereby permitting a task to be undertaken which could not even be attempted otherwise, because of the vast amount of time such calculations would take if performed by hand. But it has many other applications which save much time. A small example may be quoted in relation to chart production. Previously the computations required to produce the basic grid for a gnomonic projection chart, required for plotting fixes of atmospherics due to

thunderstorms, took a draughtsman about three months. Even then the results contained a degree of approximation. Excluding the time required to write the programme, which once written can be used again for any area merely by inserting the co-ordinates, "Meteor" performs this task in a few minutes—and the answers are precise.

The official guests at the handing-over ceremony were shown the three features mentioned above by the Director-General, Sir Graham Sutton, and then went on to see the high-altitude laboratory, where instruments are being developed to measure the vertical distribution of ozone as part of the United States-United Kingdom satellite experiments. This was followed by a visit to the long-range forecasting section, where the analogue method of forecasting the general weather régime for a month ahead was demonstrated.

The Fitzroy and Dines Wings were not visited by the guests. The former contains the suites occupied by the higher directing staff, the administrative staff and the branches dealing with aviation services, climatological services, climatological research, maritime meteorology, special investigations and services to the general public. It also contains the cartographic drawing office in which the charts used in the Meteorological Office throughout the world are drawn, and in which the diagrams required to illustrate the many Meteorological Office publications are prepared. The national library of meteorology, one of the finest in the world, adjoins the main entrance hall. Some description of this library and its work will appear in the next issue. The Dines Wing contains the Meteorological Office collection of many millions of punched cards, which are so essential to the handy storage and utilization of the vast accumulation of observational data. It also houses the instrumental design and development laboratories and the branch responsible for the control of the Observatories at Kew, Eskdalemuir and Lerwick and for micrometeorological studies.

The new headquarters has been designed in order to provide a common centre of action for the functions previously performed from buildings in London, Harrow and Dunstable. There can be no doubt that the new building will, in the long run, save time and money and add to the efficiency of the Office. Much of the equipment and furniture in some branches has been specially designed by the Ministry of Works to suit the needs of the function. As the photographs show, the architecture is in the modern style, well suited to a New Town. Mr. Thompson put it rather nicely when, in his speech, he said "It is a worthy addition to the image of Bracknell New Town".

Although the main headquarters building is now completed and the great majority of the headquarters staff is working in it, there is a certain amount of building still in progress on a nearby site. This building is expected to be ready in the spring and is intended to house the main instrument store and the archival material of the Office.

The move of a large organization to another location is always an enormous task, attended by a host of problems, both major and minor. Far from the least of these is the re-housing and welfare of the staff. It is most pleasant to be able to record that the Bracknell Development Corporation has given every assistance in the provision of houses and flats and that a hostel has been provided for the use of some of the younger unmarried staff.

NUMERICAL PREDICTION OF TEMPERATURE

By P. GRAYSTONE

The term "numerical prediction" is generally associated with the forecast of a contour field at fixed pressure levels, or of a thickness field. The technique employed, involving the computation of forecast heights and of vertical velocities at time intervals of the order of one hour, is well suited to the prediction of temperature by advective processes. This report describes experiments carried out with a view to predicting the temperature fields at levels between 1000 mb and 500 mb, and hence to predicting the temperature structure in the vertical at any point.

Method.—Temperature forecasts were made using the Sawyer-Bushby¹ two-parameter model atmosphere. With this model, forecast contour heights are derived for 600 mb and thicknesses for the layer 1000–600 mb, on the assumption that the thermal wind between any two pressure levels is constant in direction and proportional in magnitude to the pressure difference between them. It is also assumed that the vertical velocity is zero at 1000 mb and 200 mb, and varies parabolically with pressure, reaching a maximum at 600 mb. These assumptions were adopted in the present investigation while, in addition, the motion was assumed to be adiabatic, humidity effects being excluded, the horizontal motion was taken as geostrophic and temperatures round the boundary of the forecast area were held constant.

Four occasions were chosen for which contour height and thickness forecasts had been made during an earlier series of experiments. To provide a fair test of the temperature prediction method, occasions were chosen which showed some mobility or development in the synoptic pattern and which had yielded reasonably accurate numerical forecasts. Upper air observations for all available radiosonde stations in the forecast area were extracted for each of the four occasions, and temperature charts were plotted at six levels, viz. each 100 mb from 1000 to 500 mb. These charts were analysed, attention being paid to consistency in the vertical and to agreement with the thickness pattern, and values were read off for a grid of 20×16 points, omitting the outer two rings of points from the grid used in the original forecasts.

Two methods of performing the advection presented themselves. The first was to advect the potential temperature field from each grid point, and then re-analyse the field at suitable intervals. The second was to advect temperature to each grid point from positions to be determined at each time step. It was felt that the former presented considerable re-analysis difficulties, particularly if the detailed structure was to be preserved, and in the event the latter technique was adopted. The method employed therefore was to derive the horizontal and vertical velocities at each grid point at time t_n and hence compute positions from which air parcels were presumed to have originated at time t_{n-1} . Interpolated values of the temperature at these positions were then derived, and these values transferred to the appropriate grid points at time t_n .

Interpolation.—24-hour forecast temperature fields were derived by this method for the four chosen situations. Interpolation in the vertical was linear with respect to pressure at levels between 1000 and 500 mb. At 1000 mb the motion was assumed horizontal (or isobaric), while to derive potential temperatures

above 500 mb when this was required during the computation, the lapse rate between 600 and 500 mb was assumed to continue above this level.

Considerable experimentation with artificial temperature fields was required to devise a suitable technique for horizontal interpolation. The simplest assumption tried was that the temperature varied linearly between grid points. With this method, however, the thermal field was progressively smoothed, discontinuities being lost and centres of cold or warm air truncated. A quadratic formula was then tried, involving the fitting of a surface to five grid points nearest the required position. This was successful in maintaining correct values at centres, but gave rise to numerous irregularities near temperature discontinuities.

The method eventually adopted returned to the linear assumption, but took into account also thermal gradients in the vicinity of the required point. The

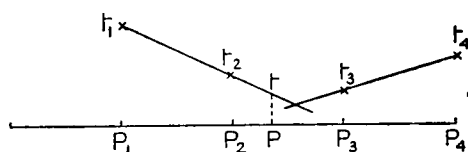


FIGURE 1—INTERPOLATION OF TEMPERATURE (t) AT A POINT p

procedure may be illustrated in one dimension (Figure 1). Let the temperatures be t_1 , t_2 , t_3 and t_4 at points p_1 , p_2 , p_3 and p_4 , where it is required to find the temperature t at a point p between p_2 and p_3 . If the lines t_1t_2 and t_3t_4 intersect between p_2 and p_3 , t is taken to lie on the first or second of these lines depending on whether the intersection is to the right or left of the point p . If the two lines do not so intersect, linear interpolation between t_2 and t_3 is made. This method preserves discontinuities and prevents truncation at thermal troughs, ridges and centres. Tests showed in fact that these features tended to be accentuated somewhat, and a compromise was finally adopted in which the temperature at the required point was taken to be the mean of that derived by the technique just described and that derived by simple linear interpolation. This method, extended to two dimensions, was used in computing the forecast temperature fields described below.

Verification.—24-hour temperature forecasts were derived for four occasions at 100 mb intervals from 1000 mb to 500 mb. They were assessed statistically by a comparison with actual radiosonde observations for nine stations, this being considered preferable to using “actual” temperatures at grid points extracted from a subjectively analysed chart. The stations used were Crawley, Stornoway, Thorshavn, Stockholm, Emden, Bordeaux and ocean weather stations “I”, “J” and “K”.

Since quantitative temperature forecasts are not normally attempted by conventional methods, an assessment of the value of the forecasts is difficult. The statistics in Table I give a comparison between the temperature forecasts made by the method described, persistence forecasts and temperatures derivable from the thickness forecast. The latter are based on a vertical temperature profile, with lapse rate differing from adiabatic by a constant figure of 38°C per 900 mb; a similar value was adopted for the stability parameter in the Sawyer-Bushby model atmosphere during the present series of computations.

Table I lists root-mean-square errors, and correlation coefficients between predicted and actual temperature changes. The root-mean-square values indicate that the forecasts are inferior to persistence forecasts at 1000 mb, but much superior at all other levels. They are also slightly superior to those derivable from the thickness forecasts. The change correlation coefficients are high and are similar in respect of the two temperature forecasts, with the exception of 22 April, when the changes were numerically small and high correlations can be taken as fortuitous.

TABLE I—VERIFICATION STATISTICS FOR TEMPERATURE FORECASTS

	1000 mb					900 mb				
1959	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>
12 March	3.9	2.8	5.3	+0.76	+0.64	3.6	5.6	5.0	+0.83	+0.85
24 March	2.4	3.6	2.7	+0.95	+0.79	2.5	4.9	2.7	+0.88	+0.83
22 April	2.0	2.2	1.3	+0.63	+0.90	2.3	2.7	1.9	+0.30	+0.88
9 November	7.8	2.4	7.0	+0.80	+0.83	3.8	3.0	4.9	+0.77	+0.72
Mean	4.0	2.7	4.1	+0.79	+0.79	3.0	4.1	3.6	+0.69	+0.82

	800 mb					700 mb				
	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>
12 March	3.6	7.4	5.0	+0.91	+0.90	3.9	7.4	5.0	+0.90	+0.89
24 March	1.4	4.4	1.8	+0.94	+0.93	1.7	5.4	2.1	+0.97	+0.96
22 April	2.6	2.9	2.5	+0.44	+0.83	2.4	1.8	2.4	-0.20	+0.29
9 November	3.3	3.3	3.5	+0.48	+0.61	4.4	3.5	3.6	+0.49	+0.47
Mean	2.7	4.5	3.1	+0.69	+0.82	3.1	4.5	3.3	+0.54	+0.65

	600 mb					500 mb				
	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>
12 March	4.4	7.1	4.8	+0.82	+0.86	3.5	6.7	4.6	+0.87	+0.89
24 March	2.2	5.8	2.8	+0.97	+0.94	2.7	6.8	3.8	+0.93	+0.89
22 April	1.9	1.4	1.5	-0.07	+0.82	1.6	1.8	1.4	+0.54	+0.73
9 November	4.9	3.6	3.8	+0.78	+0.74	4.7	4.3	3.8	+0.80	+0.67
Mean	3.4	4.5	3.0	+0.63	+0.84	3.1	4.9	3.4	+0.79	+0.80

- (*a*) Root-mean-square forecast error (°C)
(*b*) Root-mean-square persistence error (°C)
(*c*) Root-mean-square error, temperature derived from forecast thickness (°C)
(*d*) Correlation coefficients between actual temperature change and predicted temperature change
(*e*) Correlation coefficients between actual temperature change and temperature change predicted from thickness

Temperature forecasts.—Results achieved at 1000 mb and 500 mb for two of the occasions are shown in Figures 2 and 3, these two occasions incidentally being the least successful when assessed statistically. The charts shown in each case are:

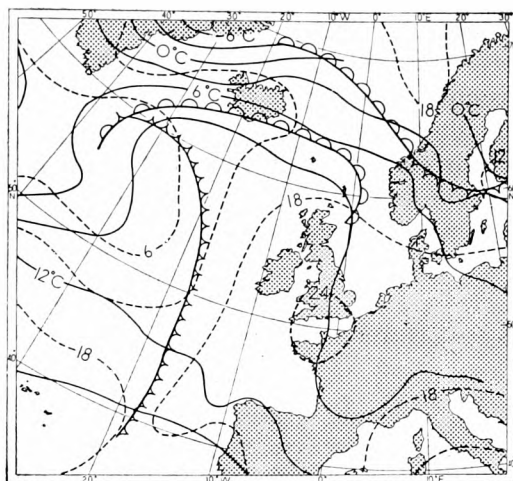
- (*a*) initial 1000 mb temperature and contour chart;
(*b*) actual 1000 mb temperature and contour chart 24 hours later;
(*c*) numerically predicted 1000 mb temperature and contour chart at time corresponding to chart (*b*);
(*d*) to (*f*) corresponding temperature charts for 500 mb.

The numerically predicted temperature fields are discussed briefly below.

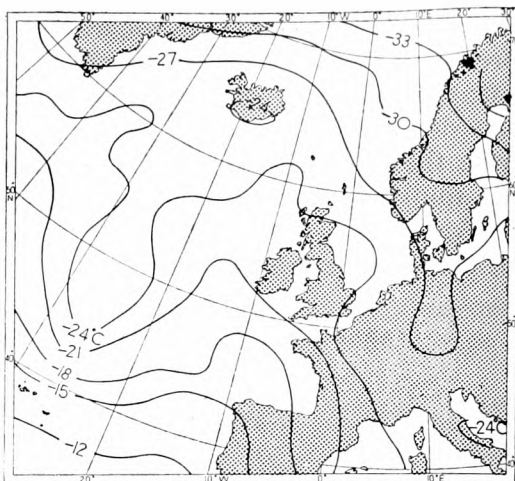
(i) *22 April 1959*—An upper cold trough moved eastwards towards the British Isles, followed by a frontal system on the Atlantic.

1000 mb—Changes over much of the forecast area were small, but the effects of over-advection and of the neglect of changes due to the underlying surface are apparent.

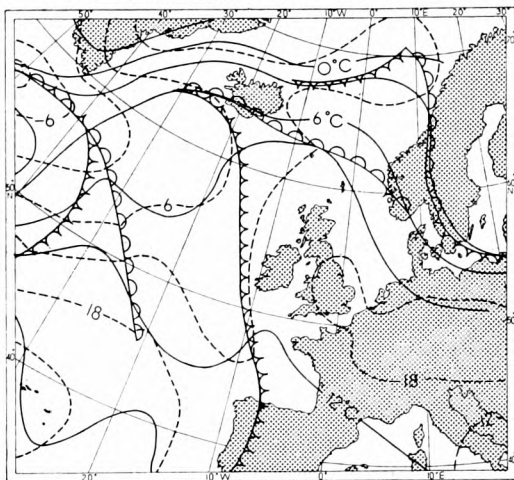
500 mb—The movement of a cold centre over Ireland was well predicted.



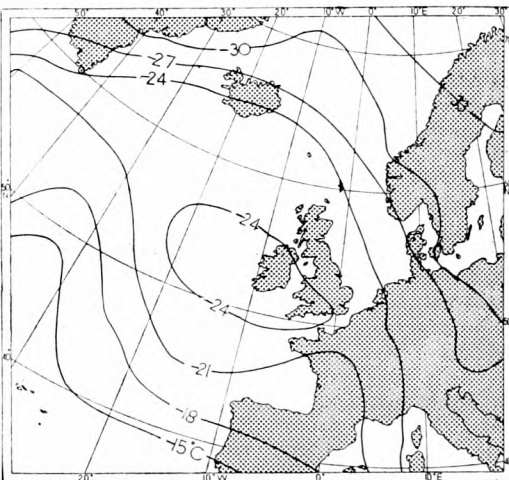
(a) Actual isotherms ($^{\circ}\text{C}$) and contours (decametres) for 1000 mb, 0001 GMT, 22 April 1959



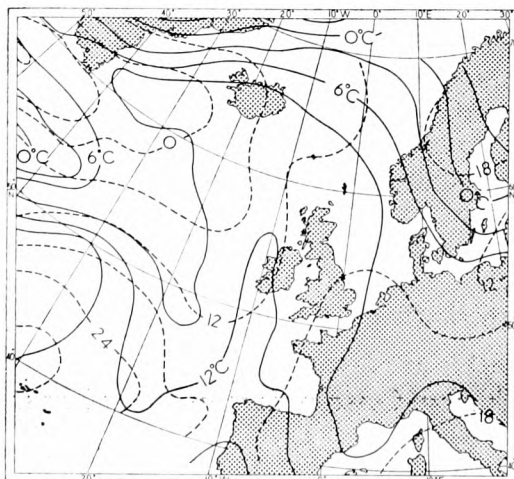
(d) Actual isotherms ($^{\circ}\text{C}$) for 500 mb, 0001 GMT, 22 April 1959



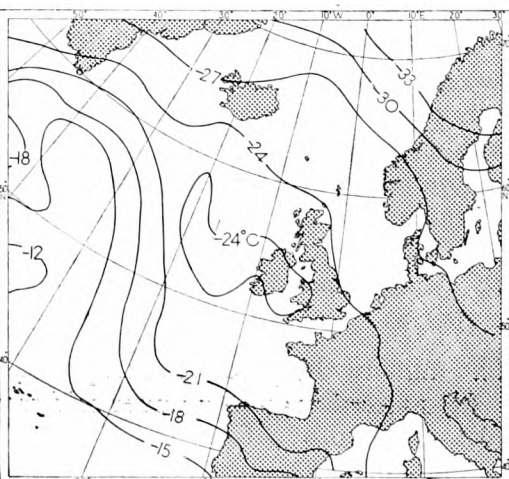
(b) Actual isotherms ($^{\circ}\text{C}$) and contours (decametres) for 1000 mb, 0001 GMT, 23 April 1959



(e) Actual isotherms ($^{\circ}\text{C}$) for 500 mb, 0001 GMT, 23 April 1959

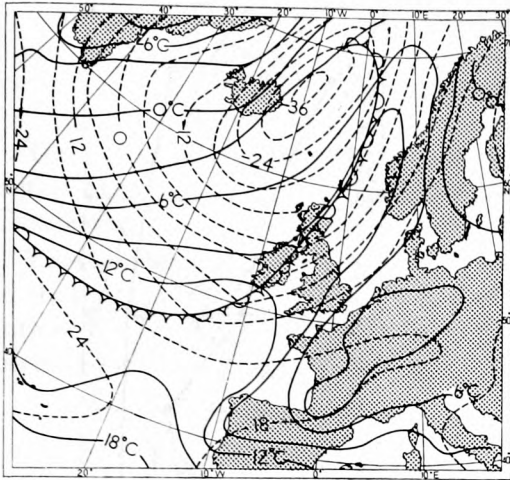


(c) Forecast isotherms ($^{\circ}\text{C}$) and contours (decametres) for 1000 mb, 0001 GMT, 23 April 1959

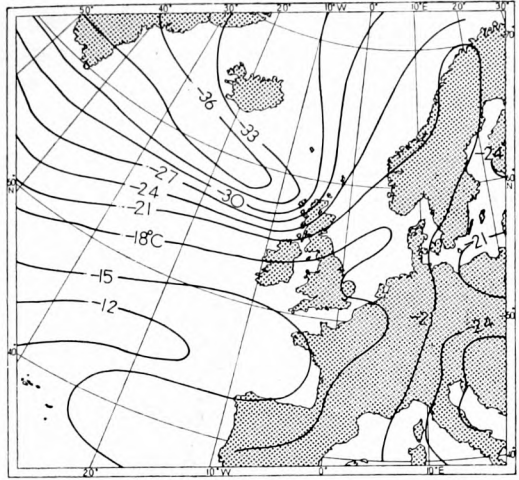


(f) Forecast isotherms ($^{\circ}\text{C}$) for 500 mb, 0001 GMT, 23 April 1959

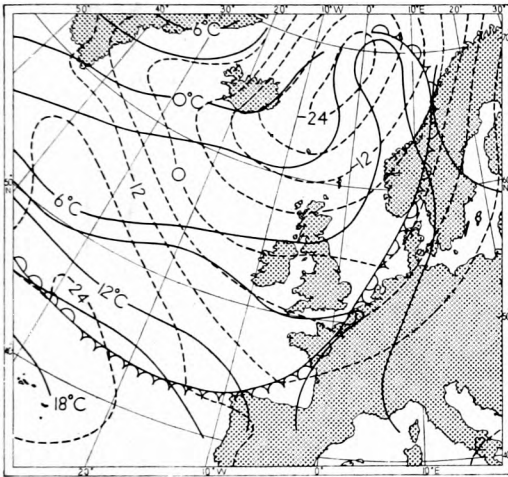
FIGURE 2



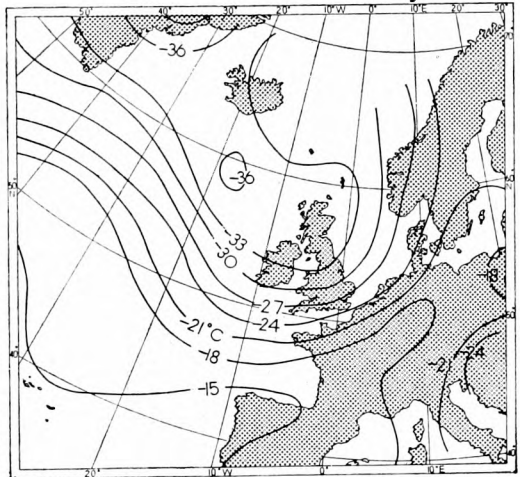
(a) Actual isotherms ($^{\circ}\text{C}$) and contours (decametres) for 1000 mb, 0001 GMT, 9 November 1959



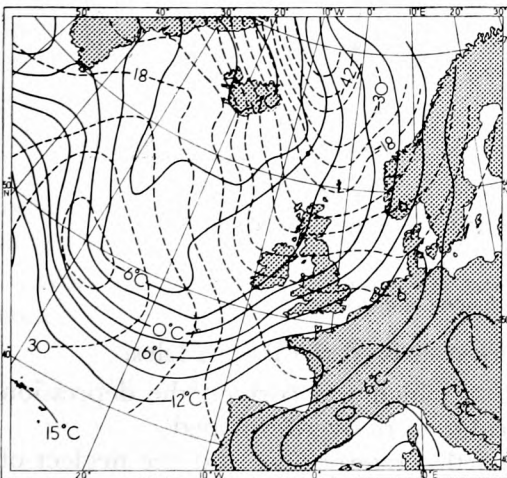
(d) Actual isotherms ($^{\circ}\text{C}$) for 500 mb, 0001 GMT, 9 November 1959



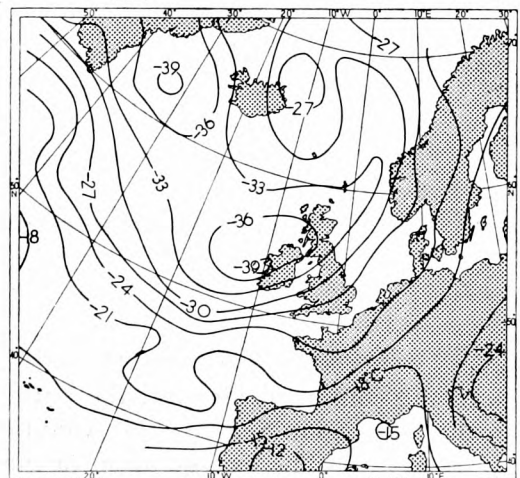
(b) Actual isotherms ($^{\circ}\text{C}$) and contours (decametres) for 1000 mb, 0001 GMT, 10 November 1959



(e) Actual isotherms ($^{\circ}\text{C}$) for 500 mb, 0001 GMT, 10 November 1959

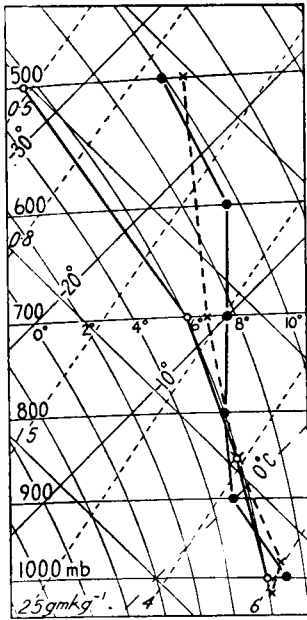


(c) Forecast isotherms ($^{\circ}\text{C}$) and contours (decametres) for 1000 mb, 0001 GMT, 10 November 1959

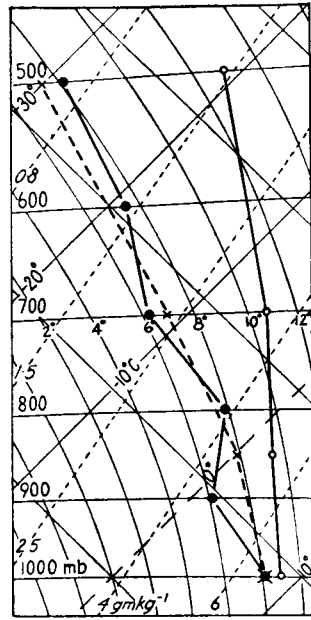


(f) Forecast isotherms ($^{\circ}\text{C}$) for 500 mb, 0001 GMT, 10 November 1959

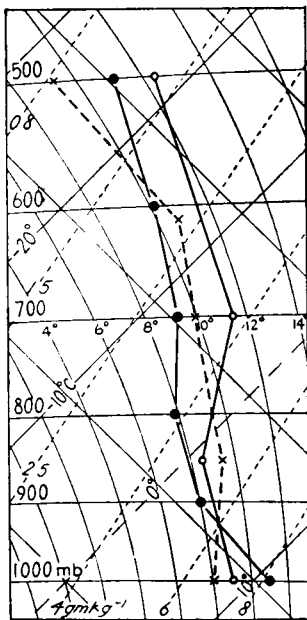
FIGURE 3



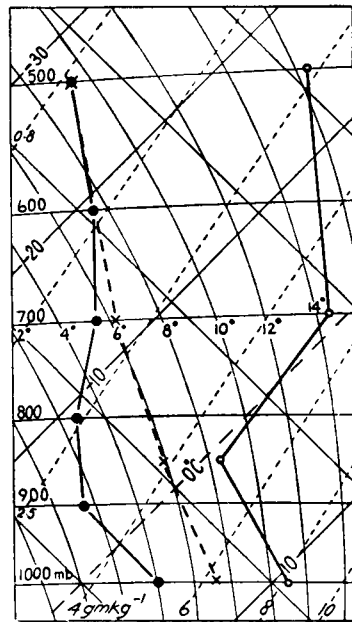
(a) 12 March 1959



(b) 24 March 1959



(c) 22 April 1959



(d) 9 November 1959

FIGURE 4—PREDICTED TEPHIGRAMS FOR CAMBORNE

initial radiosonde ascent
 actual ascent 24 hours later
 predicted ascent 24 hours later

(ii) 9 November 1959—An active cold front cleared the British Isles.

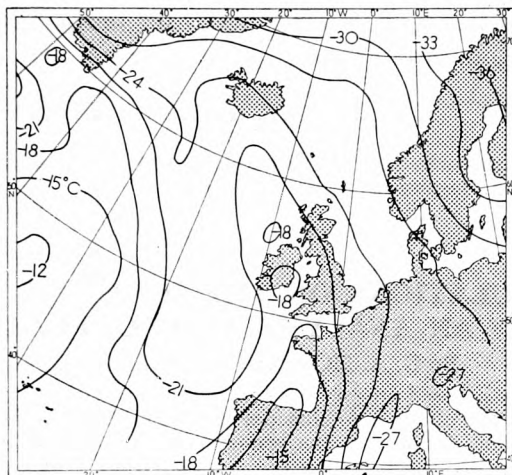
In the computed forecast, the pattern of which was correct, the depression in the Norwegian Sea and the Atlantic ridge were overdeveloped.

1000 mb—The exaggeration of the north-westerly flow and the neglect of surface heating were reflected in the advection of cold air much too far south over the Atlantic. The location of the occluded front is well indicated by the tongue of warm air over the Continent.

500 mb—The advection of cold air into the United Kingdom from the north-west was quite well forecast, the interpolation technique probably being responsible for the exaggeration of the centre off northern Ireland.

Tephigrams for the four occasions are shown in Figure 4. These illustrate the initial and final radiosonde ascents and the predicted temperature curves at Camborne.

Vertical motion.—The allowance for vertical motion was somewhat crude, in that its profile was assumed parabolic, that linear interpolation of temperature was used in the vertical and that humidity effects were excluded. To investigate whether the inclusion of vertical motion was useful, some forecasts



Forecast isotherms ($^{\circ}\text{C}$) for 500 mb, 0001 GMT, 23 April 1959 (omitting vertical velocity)

FIGURE 5

were made omitting the vertical component of velocity of all levels. The 500 mb forecast commencing 0001 GMT, 22 April is shown at Figure 5, for comparison with the original forecast and the verification chart at Figures 2 (*f*) and 2 (*e*) respectively. Clearly in this example, the effect of vertical velocity was considerable and its exclusion resulted in a deterioration in the forecast. Results on other occasions, though less striking, indicated that the allowance for vertical velocity was beneficial.

Discussion.—The 1000 mb forecasts were, not unexpectedly, poor, revealing in particular the effects of over-advection and neglect of surface heating and cooling. At other levels results were promising, while the predicted tephigrams show a useful standard of accuracy.

Errors in the predicted temperature fields may occur for several reasons, namely:

- (i) errors in the numerically predicted contour height pattern;
- (ii) the approximation to the vertical velocity, and the neglect of humidity;
- (iii) errors introduced through interpolation;
- (iv) the neglect of external heating and cooling;
- (v) the geostrophic approximation.

The first of these gave rise to major errors probably on one occasion only, 9 November, when overdevelopment in the forecast gave rise to excessive

gradients. Errors (ii) and (iii) have been considered above; it is probable that computed vertical velocities are too low in regions of saturated air, but the assumption of constant potential temperature, and the correspondingly enhanced effect on temperature of vertical motion, will partly counteract the underestimation of vertical velocity in these regions. Errors (iv) and (v) have clearly contributed most to the poor results at 1000 mb. Formally, however, the introduction of surface heating and allowance for the divergent component of the wind field present no insuperable difficulties, and errors arising from these two factors should thus be greatly reduced.

Conclusion.—It appears that useful forecasts of the temperature field can be made during the process of a numerical forecast using a baroclinic model within the limits of accuracy of the computed forecast. The initial analysis procedure, if carried out by hand, is too lengthy for temperature forecasting to be practical as a routine, and this remains as a further problem in objective analysis.

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SOME SPECULATIONS ON THE 100–200 MB THICKNESS PATTERN AS AN ANALYSIS AND FORECASTING TOOL

By G. A. HOWKINS, M.B.E., B.Sc.

Summary.—This article is based on very limited experience with the 100–200 mb layer during the summer of 1960 and the object is to consider in simple terms a theoretical basis for further work. The emphasis herein is placed on the 100–200 mb thickness as a surface analytical tool and also as a possible means of forecasting the 200 mb wind field without the labour of first forecasting the intervening tropospheric layers.

Statement of observations.—Almost all 100 and 200 mb contour height charts and their associated thickness fields display the following features:

100 mb: a weak field, showing relatively little change in pattern with time and generally slow advection of the features.

200 mb: much larger changes in pattern, with features advected at about the same rate as those on the corresponding surface charts.

100–200 mb thickness: an intense reversed thickness field is closely associated with surface fronts. Tropopause contour height charts have been drawn twice daily at London Airport for the past two years and forecast for one year. Indications so far are that the 100–200 mb thickness may be even more closely associated with the tropopause profile.

Factors controlling the thickness field.—Sutcliffe and Forsdyke¹ showed that the local rate of change in thickness at a point is given by:

$$\frac{\partial h}{\partial t} = R \int_p^{p_0} \left\{ - \left(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right) + \frac{dp}{dt} \left(\frac{\gamma}{g\rho} - \frac{\partial T}{\partial p} \right) + \frac{1}{C_p} \cdot \frac{dq}{dt} \right\} d \log p \quad \dots (1)$$

where the three terms may properly be regarded as describing three processes—advective, dynamical and non-adiabatic. In this equation h is the geopotential thickness of the layer between constant pressure surfaces p and p_0 , q is the heat energy per unit mass given to an element, γ is the dry adiabatic lapse rate and the other symbols have their conventional meanings.

The advective term is of major importance when an air mass is in its source region and it continues to exert the controlling influence in middle latitudes,

but the other terms impose an equatorward limit for low or "cold" thickness and a poleward limit for high or "warm" thickness. Dynamical effects can produce heating or cooling, depending on whether the air is ascending or descending and to a less extent on its moisture content. Neither process is restricted to warm or to cold air and it is probable that the limits on movement of thickness lines are imposed in the main by non-adiabatic effects, for example, by the convective addition of heat to cold unstable air moving equatorwards and the radiative transfer of heat from cloud layers in warm air moving polewards.

In a recent review of the 20–100 km layer, Murgatroyd² states that almost all absorption of solar radiation by ozone takes place at levels above 20 km. Also, absorption of terrestrial radiation by water vapour must be largely restricted to levels below 15 km, while the essentially stable structure of the tropopause must preclude convective transfer of heat upwards from the troposphere into the 100–200 mb layer. Therefore non-adiabatic heating in the 100–200 mb layer should be negligibly small and, if dynamical effects could be temporarily eliminated, all levels between 200 and 100 mb would tend to display flat height contour fields, with a uniform thickness throughout. In fact the 100 mb surface is relatively featureless compared to surfaces within the troposphere, but the stratospheric surfaces below 100 mb become increasingly contoured as the troposphere is approached. This suggests that the contours are introduced by dynamical processes from below, in such a way that the strongest effects are felt in the lower stratosphere and little effect reaches the 100 mb surface which remains relatively flat and undisturbed.

Thickness theory applied to the 100–200 mb layer.—Sutcliffe³ stated that dp/dt , which defines dynamical development and adiabatic processes in the atmosphere, is equal to the isobaric divergence of the velocity above the level under consideration, for example

$$\frac{dp_1}{dt} = - \int_0^{p_1} \text{div}_p \mathbf{V} dp \quad \dots (2)$$

where p_1 is any pressure level.

In a subsequent paper, Sutcliffe and Forsdyke¹ pointed out that, as the 1000–500 mb flow is essentially baroclinic, the thickness field may be regarded as effectively controlling the upper flow. In consequence, they considered the three-dimensional contour field as composed of two parts, the 1000 mb contour pattern, which appears equally at all heights, and the thermal field thus

$$\int_0^{p_0} \text{div} \mathbf{V} dp = \int_0^{p_0} \text{div} \mathbf{V}_0 dp + \int_0^{p_0} \text{div} \mathbf{V}' dp \quad \dots (3)$$

where p_0 and \mathbf{V}_0 are the pressure and wind at 1000 mb and \mathbf{V}' is the thermal wind. Because of the relative constancy of surface pressure, it was argued that

the vertical integral of horizontal divergence $\int_0^{p_0} \text{div} \mathbf{V} dp$

must be approximately zero and hence

$$\int_0^{p_0} \text{div} \mathbf{V}_0 dp = p_0 \text{div} \mathbf{V}_0 \doteq - \int_0^{p_0} \text{div} \mathbf{V}' dp. \quad \dots (4)$$

Turning now to the 100–200 mb layer, Probert-Jones⁴ demonstrated that the 100 mb field is for all practical purposes non-divergent and, since

$$\text{div} \mathbf{V}_{100} = \text{div} \mathbf{V}_{200} + \text{div} \mathbf{V}'_{100-200} \quad \dots (5)$$

it follows that

$$\operatorname{div} \mathbf{V}_{200} = -\operatorname{div} \mathbf{V}_{100-200} \quad \dots (6)$$

In other words, the development at 200 mb should be uniquely determined by the development in the 100–200 mb thickness field. Sutcliffe³ goes on from equation (2) by a series of carefully considered approximations to derive the relationship

$$\operatorname{div}_p \mathbf{V} - \operatorname{div}_p \mathbf{V}_0 = -\frac{1}{l} V' \frac{\partial}{\partial s} (l + \zeta + \zeta_0) \quad \dots (7)$$

where $\partial/\partial s$ represents differentiation along the thickness line, ζ and ζ_0 are the vertical components of the vorticities of \mathbf{V} and \mathbf{V}_0 and l is the Coriolis parameter.

The same detailed investigation would be necessary to establish whether this relationship applies to the 100–200 mb layer. However, there are reasonable grounds for believing that this may be true. It has already been suggested that the 100–200 mb layer is virtually insulated from the non-adiabatic effects which complicate the tropospheric layers and that the thickness field probably derives from vertical motion. Therefore, applying equation (7) to the 100–200 mb layer and remembering that $\operatorname{div} \mathbf{V}_{100} \doteq 0$, we have:

$$-\operatorname{div} \mathbf{V}_{200} = -\frac{1}{l} V'_{100-200} \frac{\partial}{\partial s} (\zeta_{200} + \zeta_{100} + l) \quad \dots (8)$$

$$\text{but } \zeta_{100} = \zeta_{200} + \zeta'_{100-200}$$

$$\therefore \operatorname{div} \mathbf{V}_{200} = \frac{1}{l} V'_{100-200} \frac{\partial}{\partial s} (2\zeta_{100} - \zeta'_{100-200} + l) \quad \dots (9)$$

where the term containing ζ_{100} is the movement term, the term containing $\zeta'_{100-200}$ is the development term due to the thickness and the term containing $\partial l/\partial s$ describes the development due to the variation of the Coriolis force with latitude. Now, the movement term ζ_{100} is certainly no larger than that found at 1000 mb and, because of the relatively conservative pattern at 100 mb, is almost certainly less subject to time changes. In contrast, the thickness field between 100–200 mb is at least as intense as the corresponding field between 1000–500 mb and as distorted, so that a study of the thickness pattern should indicate expected developments in the 200 mb field in much the same way as the 1000–500 mb field is used to indicate developments at the surface. Moreover, since the thickness field between 100–200 mb is believed to be produced dynamically, it will be less subject to the complicated non-adiabatic changes and controls involved in the 1000–500 mb thickness. The $\partial l/\partial s$ term is probably of the same order of importance as in the underlying tropospheric layers.

Possible applications.—If the close relationship between the 100–200 mb thickness and the tropopause profile is confirmed by further work then this raises the possibility that the 200 mb flow can be forecast from the (conservative) flow at 100 mb and the 100–200 mb thickness “advected” with the forecast tropopause. By its nature, the method ought not to introduce vertical inconsistencies between the 200 mb forecast and forecasts for lower levels based on the conventional thickness techniques. It would convey an immediate practical advantage because it would not be necessary to wait for the completion of the 300 mb forecast before work can start on the 200 mb level. It is doubtful whether high-level forecast winds will be required for the supersonic aircraft of the future, but their performance may still be radically affected by the ambient temperature

and it is possible that the 100–200 mb thickness will help to forecast this. Also, if the relationship between the 100–200 mb thickness and the tropopause contours is established, then the thickness should provide an additional analytical tool for use on the surface charts. It should prove valuable in locating frontal features which are inactive near the surface, but which have significance for upper air forecasting, and it ought to prove especially sensitive to surface developments such as warm front waves which are essentially frontal in character. Development of these waves can lead to marked effects on the weather without any great distortion of the surface pressure field and hence they are very difficult to forecast from a consideration of the tropospheric thickness fields. On the other hand, they should be accompanied by a distortion of the tropopause contours and, in turn, of the 100–200 mb thickness field.

Moreover, the 100–200 mb thickness is believed to result from essentially dynamical processes and if, as is implied above, it proves to be a reflection of the tropopause profile, then it should act as a comparatively sensitive indicator of the depth of the underlying troposphere. It should therefore provide a useful additional surface analytical tool and may also prove to have forecasting possibilities, since increasing 100–200 mb thickness gradients should imply increased contouring of the tropopause profile and consequent intensification of the frontal zones. Similar effects should be apparent in the tropopause profile itself and occasions have been noted where the profile charts gave clearer indications of development (especially in warm front waves) than the 1000–500 mb thickness field. However, tropopause charts frequently involve careful assessment of the individual tephigrams whereas thickness charts, although subject to the inherent height errors of the individual ascents, are less subjective in essence than the tropopause height assessments from tephigrams. For this reason, the stratospheric thickness charts (100–200 or 100–300 mb) may prove more tractable. Staff at the Central Forecasting Office, Dunstable, have been working on means of assessing height errors at different levels and in different radiosonde instruments and an assessment of these errors would appear to be an important prerequisite for further work.

In conclusion if, as proposed above, the 100–200 mb thickness is largely a reflection of happenings in the high troposphere, then the suggestion that this thickness may indicate tropospheric developments does not necessarily imply that such developments are being induced by the stratosphere. On energy considerations alone, it would seem improbable that events in the low densities and generally low velocities of the stratosphere could be the prime cause of any significant development in the higher density, higher velocity layers of the troposphere. However, there remains the possibility that the relatively small pressure changes produced in the troposphere, as a result of divergence in the stratosphere, might provide a trigger action if conditions in the troposphere are already ripe for development. Such conditions ought to be indicated by the 1000–500 mb thickness field.

I would like to acknowledge the helpful criticisms and advice offered by Mr. J. S. Sawyer, Mr. V. R. Coles, Mr. N. E. Davis and colleagues at London Airport.

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551.509.323 : 551.524.36

PREDICTION OF MAXIMUM DAY TEMPERATURES AT NICOSIA (CYPRUS)

By R. H. PEDLOW, B.Sc.

Heat balance.—In an attempt to increase the precision of forecasts of maximum day temperatures at Nicosia, it was decided to follow fairly closely the successful approach used by Gold¹ in England.

To restate, briefly, the terms of the heat balance, the ground receives heat from (a) direct solar radiation whose extra-atmospheric intensity has been depleted by mainly high-level absorption and by scattering, and (b) scattered radiation from the sky. Of the incident energy, part is reflected as short-wave radiation to which the atmosphere is transparent, part is reradiated as long-wave radiation approximately according to Stefan's Law, part is used in evaporating water (much of which is transpired through vegetation) and part is used in raising the temperature of the ground. The rest is passed to the lower layers of air by conduction and disseminated by turbulence, and to this portion which is so used in heating the lower air must be added about 70 per cent of the earth's long-wave radiation which is absorbed in transit. The various terms of this budget are considered in turn below.

Short-wave radiation.—The daily quantity of solar radiation entering the atmosphere at latitude 35°N was taken from Shaw² (column 1 of Table I), and following Gold it was assumed that 50 per cent of this total daily radiation (column 1) reaches the ground as direct solar radiation between sunrise and the time of maximum temperature.

Gold's values for diffuse short-wave radiation were taken from measurements at Benson. No such measurements have been made in Cyprus, but Stagg³ gives an empirical curve relating the intensity of diffuse radiation to the sun's altitude on cloudless days at Kew, for solar altitudes between 0° and 60°. This curve was extrapolated by eye to cover solar altitudes up to 77°, and it was assumed that the Cyprus atmosphere was sufficiently like the Kew atmosphere for the same relationship to be valid. Setting dust-haze against smoke and humidity, this is perhaps plausible. Using navigation tables, hourly solar altitudes at Nicosia were computed for the middle day of each month and the corresponding intensities of diffuse radiation plotted against time. The areas under the curves from sunrise to 1400h LMT gave the required values of total diffuse radiation (column 4 of Table I).

We return for a moment to consideration of the direct solar radiation reaching the ground. Gold's estimate of 50 per cent of Shaw's figures may be compared with measurements made by Stagg³. For our present purposes it is sufficiently accurate to use the diagram⁴ which gives the intensity of the vertically downward component of direct radiation plotted against time from sunrise to midday for March, June and December. Extending these curves by symmetry to 1400h, the areas beneath them are a measure of the amounts that Gold estimated. The curves give approximately 250, 465 and 55 gm cal cm⁻² for the three respective months, whereas Gold assumed 265, 490 and 87. Gold's

TABLE I—HEAT BUDGET FOR NICOSIA

	1	2	3	4	5	6	7	8	9	10	11
	Daily insolation outside atmosphere at 35°N	Mean period sunrise to 1400h LMT	Direct insolation at MSL, sunrise to 1400h	Diffuse short-wave radiation, sunrise to 1400h	Total insolation reflected at surface	Effective mean radiating temp of earth	Long-wave radiation from earth, sunrise to 1400h	Daily evaporation	Heat to evaporate 50 per cent of col. 8	Heat available for warming air	Equiv. depth of isothermal-to-adiabatic change
	$gm\ cal\ cm^{-2}$	hr	$gm\ cal\ gm^{-2}$	$gm\ cal\ cm^{-2}$	$gm\ cal\ gm^{-2}$	$^{\circ}A$	$gm\ cal\ cm^{-2}$	mm	$gm\ cal\ cm^{-2}$	$gm\ cal\ cm^{-2}$	mb
Jan. ...	... 425	7	215	60	55	300	280	0.4	10	125	90
Feb. ...	... 555	7.5	275	70	70	302	310	0.6	20	160	100
Mar. ...	... 700	8	350	80	85	305	340	1.0	30	215	115
Apr. ...	... 845	8.5	425	90	105	308	380	1.6	50	245	125
May ...	... 940	9	470	100	95	314	430	2.3	70	276	135
June ...	... 980	9.5	490	100	90	319	500	1.9	55	295	135
July ...	... 965	9.5	485	100	90	325	530	1.1	35	300	140
Aug. ...	... 885	9	445	90	80	325	500	0.6	15	290	135
Sept. ...	... 760	8.5	380	85	70	319	450	0.4	10	250	125
Oct. ...	... 605	8	305	80	65	314	380	0.8	25	180	105
Nov. ...	... 465	7.5	235	70	60	305	320	1.2	35	115	85
Dec. ...	... 400	7	200	60	50	302	290	0.7	20	105	80

assumption is well confirmed for all but the winter months. The discrepancy in December, when the net balance is small, is not negligible.

Confirmation that the same figure of 50 per cent is reasonable for Cyprus was not readily available when the investigation was made. Subsequently comparison was made with figures given by Myers⁵ and Ashbel⁶. Both give hourly means of direct plus diffuse radiation on a horizontal surface for clear days, the former for alternate months over an 18-month period at Nashville, Tennessee, approximately 36°N latitude, the latter for each month over two years at Jerusalem, approximately 32°N latitude. Nicosia lies in latitude 35°N. In Table II below, the totals of incident radiation from sunrise to 1400 LMT at these two places are compared with the month-by-month totals of columns 3 and 4 of Table I. The differences are discussed in the final section below.

TABLE II—COMPARISON OF TOTAL INSOLATION AS MEASURED AT NASHVILLE AND JERUSALEM AND COMPUTED FOR NICOSIA

			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
			<i>gm cal cm⁻²</i>											
Nashville	...	...	—	294	—	464	—	524	—	480	—	310	—	200
Jerusalem	...	...	330	395	465	560	570	595	580	545	490	430	340	320
Nicosia	...	...	275	345	435	515	570	590	585	535	465	385	305	260

The well established value (for grassland) of 0.2 was taken as the effective albedo from November to March. For the period from June to September when large areas are bare of vegetation, the value of 0.15, more appropriate to soil, was used, and 0.17 for the transition months of May and October. Table I column 5 gives the total reflected insolation, that is, the product of the albedo and the total of columns 3 and 4. (Gold appears to neglect the reflexion of diffuse short-wave radiation.)

Long-wave radiation.—There is little information concerning the radiating temperature of the earth's surface day by day. High accuracy is unnecessary (a 10°F error in the assumed mean temperature would produce about a 6 per cent error in the loss of heat by radiation and about half that error in the final net balance of energy) but it is obviously desirable to reduce the uncertainty as far as possible. Mean grass-minimum temperatures and maximum screen temperatures were known, and Mr. K. M. Cripps, lately Cyprus Government Meteorologist, supplied a number of selected high values of black-bulb-in-vacuo maximum temperatures for Nicosia city, ranging from 130°F in January to 160°F in July. Relating these to screen temperatures and assuming a rise of surface temperature after sunrise initially much steeper than that of air temperature, a series of rather subjective curves was drawn to represent hourly variation of surface temperature in each month; fourth-root-mean-fourth-power values were extracted, and the black-body radiation from sunrise to 1400h LMT calculated (Table I, columns 6 and 7).

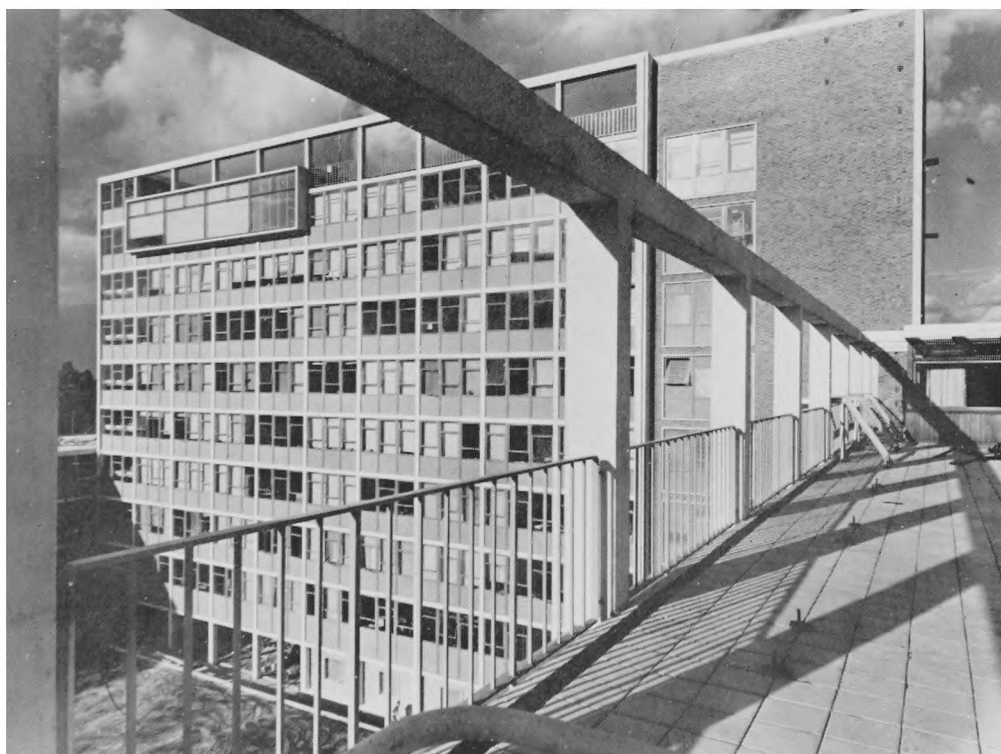
Evapotranspiration.—No evaporimeter measurements have been made in Cyprus. Computations of mean monthly evaporation were made following Thornthwaite and Mather⁷. There was considerable doubt as to the depth of soil that should be assumed to take part in the exchange of water by evapotranspiration. Thornthwaite and Mather, who are concerned with agricultural aspects of the problem, give different effective soil retention figures for each type of soil according to whether the crop is shallow-rooted (peas, beans etc.)



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PLATE I—VIEW OF THE METEOROLOGICAL OFFICE, BRACKNELL,
FROM THE SOUTH-WEST

From left to right: Dines Wing, Napier Shaw Building and Fitzroy Wing



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PLATE II—VIEW OF THE NAPIER SHAW BUILDING FROM THE ROOF
OF THE FITZROY WING
(see p. 1)



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PLATE III—FORECAST ROOM



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PLATE IV—TELEPRINTER ROOM
(see p. 1)



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PLATE V—FACSIMILE ROOM



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PLATE VI—ELECTRONIC COMPUTER “METEOR”
(see p. 1)



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PLATE VII—STAFF RESTAURANT



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PLATE VIII—FITZROY WING
(see p. 1)

moderately deep-rooted (e.g. grain) deep-rooted (pastures, shrubs), orchard or forest. In the present problem we are concerned with a large heating area with varied vegetation. Even along the fertile plain of the Mesaoria over which the prevailing westerly wind approaches Nicosia (and which has a relatively uniform rainfall distribution), the surface varies from bare rock to deep loam; and after the completion of the grain harvest in early May, the cover varies from nil or sparse scrub used for pasture to well irrigated market gardens and deep-rooted olive groves.

A sufficient solution emerged from trial computations. The tables indicate that if the water-holding capacity of the soil were 150 mm or less, then in a year of average rainfall the ground would be waterlogged through most of January, February and March. Even allowing for the inevitable discrepancies resulting from the difference between the island's predominantly shower-type rainfall and the smooth alternation of precipitation and evaporation which is implicit in the use of monthly figures with water-balance tables, the short-lived local flooding which sometimes occurs after heavy rain cannot be reconciled with such a picture. Monthly figures of computed evaporation show little variation with water-holding capacities ranging from 200 to 300 mm, and capacities exceeding 300 mm are appropriate only to forest cover, so the values for 250 mm were taken as valid (Table I, column 8). Gold tacitly assumes that the whole day's evaporation occurs during the heating period. It seemed inadvisable to carry the error involved in this assumption over to Cyprus where, in the Mesaoria, the common pattern is for a quiet morning to be followed by a more or less windy afternoon. As a rough estimate, probably better than no adjustment, half the daily evaporation was ascribed to the heating period (Table I, column 9).

In the absence of any relevant records, no serious attempt was made to assess the heat used in raising the temperature of the soil and its contained water. (Myers⁵ prepared curves of heat absorption for dry ground at Nashville which show a net absorption from sunrise to 1400h LMT ranging from about 7 gm cal cm⁻² in December to 13 gm cal cm⁻² in June.)

Results.—In Table I, the energy received by the earth is found by adding columns 3 and 4, that expended in functions other than the heating of air by adding columns 5, 9 and 30 per cent of column 7. The difference between the two totals represents the energy available for air heating and is given in column 10.

Translating Gold's discussion¹ of energy and area on the tephigram into terms of the tephigram now in use in the Office (Form 2810A, 1956 edition), it is easily shown that on the main smaller-scale diagram

$$1 \text{ cm}^2 = 67 \text{ gm cal cm}^{-2} \text{ approximately}$$

and in the lowest 150 mb, a layer $65\sqrt{n}$ mb deep would be changed from an isothermal to a dry-adiabatic lapse rate for an energy input equivalent to n cm², that is, an increase of energy of E gm cal cm⁻² would convert isothermal to adiabatic through a depth of very nearly $8\sqrt{E}$ mb. (This relation holds, of course, on the large-scale inset tephigram on Form 2810A, where $1 \text{ cm}^2 = 17 \text{ gm cal cm}^{-2}$ approximately, and the depth converted is $33\sqrt{n}$ mb.)

The thicknesses so obtained (Table I, column 11) were used to estimate maximum temperatures from 0001h GMT Nicosia radiosonde ascents adjusted for dawn temperatures, using the procedure described by Johnson⁸ appropriate to clear skies. As a preliminary trial, all days in 1957 and 1958 were selected on

which total cloud amount at Nicosia between sunrise and 1400h LMT was 2 oktas or less at all, or all but one, of the hourly observations. Maximum temperatures were forecast from the tephigram without regard to any advection or dynamic processes which might occur after the ascent.

Over the whole period, 63 per cent of the 283 forecasts were within 2°F of the actual maximum, 79 per cent within 3°F and 95 per cent within 5°F. The mean error was -0.4°F or taken without regard to sign, 2.2°F. In each month, over 70 per cent of the forecasts were in error by 3°F or less excepting April (60 per cent) and July (64 per cent).

Occasions with errors in excess of 5°F were investigated. On eight of the nine days, all in the April–August period, when the maximum was from 6° to 12°F below the predicted value, a previously identified cold front or trough had passed through with little or no cloud and/or the westerly breeze had set in unusually early in the day and sometimes with unusual strength. During this season, the sea—only 18 miles to the west-north-west—has a surface temperature of the order of 15°F below the mean maximum air temperature at Nicosia. It appeared that, in general, if a steady run of wind from between west and north-west at Nicosia during the period between sunrise and 1400h LMT exceeded 25 or 30 miles, then the maximum would fall more than 5°F below that predicted by rule. The three occasions when the maximum was 6° or 7°F higher than forecast showed advective or dynamic changes in the midday ascent.

During July–September 1959, with the forecaster adjusting the predicted maximum to allow for wind, cloud, etc., the results shown in Table III were obtained. They are compared with the results of using the previous day's

TABLE III—PERCENTAGE OF FORECAST MAXIMA FALLING WITHIN VARIOUS RANGES OF ACCURACY

Forecast max. temp. within	1	2	3	4	5	°F of actual maximum
Heat-budget forecast (per cent.)	51	70	82	93	96	
Persistence forecast (per cent.)	45	66	76	86	90	

maximum as a forecast. In the long settled spells of the east Mediterranean summer, more than a marginal improvement on 'persistence' forecasts could hardly be expected.

Total insolation.—As shown in Table II, figures for Jerusalem indicate that, neglecting the small difference in latitude, the sums of columns 3 and 4 in Table I are too low by a mean amount of about 30 gm cal cm⁻², whereas those for Nashville indicate a contrary mean error of about 60 gm cal cm⁻². The consequent differences in column 11 of Table I would be reduced by the allowance for reflexion, and further by the dependence of column 11 on the square root of column 10. The changes in predicted maximum temperature would vary with the form of the ascent curve, but would normally be near 1°F and 2°F respectively. Since the tendency is for the forecast temperature to be too low, the use of the Nashville figures would increase the error. The Jerusalem figures would decrease it or give a small over-estimate. It is fortuitous that Gold's 50 per cent estimate referred to above gives so close an approximation to the Nicosia maxima, but it would be worth trying as a first approximation in any area where insolation data are lacking. Residual errors would probably be small enough to be corrected by empirical constants.

Acknowledgements.—Acknowledgements are made to Mr. G. A. Corfield, who suggested the investigation, to Mr. K. L. Cripps, lately Cyprus Government Meteorologist, for certain climatological data, and to colleagues in the Meteorological Office, Nicosia, especially Mr. J. Wallace, for helpful discussions.

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551.501.45:551.524.36:519.2

ESTIMATION OF FREQUENCY DISTRIBUTIONS OF HOURLY TEMPERATURES AT UNITED KINGDOM STATIONS FROM MONTHLY AVERAGES OF DAILY MAXIMA AND MINIMA

By H. C. SHELLARD, B.Sc. and P. B. SARSON, M.A.

Introduction.—Inquiries are frequently received in the Climatological Services Branch for information on the hourly frequencies with which specified temperatures are likely to be exceeded. Such information is often required for places for which hourly observations are not available but for which long-period monthly averages of daily maximum and daily minimum temperatures and temperature extremes are either available or can be readily estimated.

In recent years analyses have been carried out for a number of stations in the United Kingdom of the combined distributions of hourly values of dry-bulb and wet-bulb temperature,¹ based mainly on the 10-year period 1946–55. It was thought, therefore, that the resulting monthly frequency distributions of hourly dry-bulb temperature might be used as the basis for a statistical method of estimating such frequency distributions for any other station at which only daily extremes of temperature had been measured.

This paper presents the relationship that was found and gives the results in the form of monthly graphs on arithmetic probability paper from which, given the appropriate monthly averages of daily maximum and minimum temperature for any station in the United Kingdom, the average number of hours with temperature above or below any desired temperature can be estimated for that station. An indication is given of the accuracy of the method.

Data used.—The basic data consisted of hourly dry-bulb temperature frequency distributions for the following nine stations and periods, together with monthly averages of mean daily maxima and minima and the absolute extremes based on the same periods:

Croydon	1946–55	Stornoway	1946–55
Lympne	1946–53	Aldergrove	1946–55
Boscombe Down	1946–55	Manchester Airport	1946–55
Renfrew	1946–55	Driffild	1946–55
Elmdon Airport	June 1949–May 1957		

It is considered that these stations taken together represent a fairly good cross-section of the United Kingdom although a few large areas such as eastern Scotland, Wales and south-west England are unrepresented.

The data for each station were set out in tabular form, each month's data consisting of the temperatures exceeded on 0.1, 0.5, 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 99, 99.5 and 99.9 per cent of occasions (hours), together with the corresponding averages of mean daily maximum and minimum temperatures and the absolute extreme temperatures. The latter were included for the 0.013 and 99.987 per cent values, that is, they were assumed to have occurred for one hour only during the period and happen also to be the values appropriate to three times the standard deviation. This gave 19 temperatures for each station for each month.

Results.—After several trials, including one on the lines of similar work carried out by W. C. Spreen² on stations representing a wide variety of climates, it was found that the best results were obtained when the data were expressed in the form

$$\frac{(T - \bar{T})}{(T_x - T_n)}$$

where T is the temperature exceeded, \bar{T} ($=\frac{1}{2}(T_x + T_n)$) is the average mean daily temperature for the month and T_x and T_n are the average mean daily maxima and minima for the month, that is, $(T_x - T_n)$ represents the average mean daily range of temperature. The use of this expression gave more consistent results than the use of the absolute extremes of T_x and T_n .

Mean values of $(T - \bar{T})/(T_x - T_n)$ were obtained for the nine stations for each month and were plotted on arithmetic probability paper, the best fitting curves being drawn in. The resulting curves for the 12 months are presented in Figures 1–12, on which the points through which each curve was drawn are also shown. It will be noted that in every case a reasonably smooth curve can be drawn which passes through all 19 points. The winter curves (November–February) show a slight but definite tendency to a platykurtic distribution of frequencies, especially for temperatures greater than the mean. The summer curves (April–September) show negative skewness. In October and especially in March the distributions are almost normal.

Table I gives the actual station values of the expression $(T - \bar{T})/(T_x - T_n)$ and the overall mean values for the months of January, April, July and October and indicates the variations between stations. These variations between stations are small in the middle of the distributions and are only appreciable towards the end of the distributions.

Test of the method.—The method was tested using data for Mildenhall, for which station hourly frequency distributions of dry-bulb temperature were available for the months January–August for the 10-year period 1946–55. Table II sets out the estimated percentage frequencies with which specified temperatures should have been exceeded in this period, together with the actual frequencies for the months January, March, June and August. The agreement between the estimated and observed values is very satisfactory, the largest difference being one of 4.1 per cent for temperatures exceeding 4°C in March, when the average frequency distribution is almost normal and the best estimates would be expected!

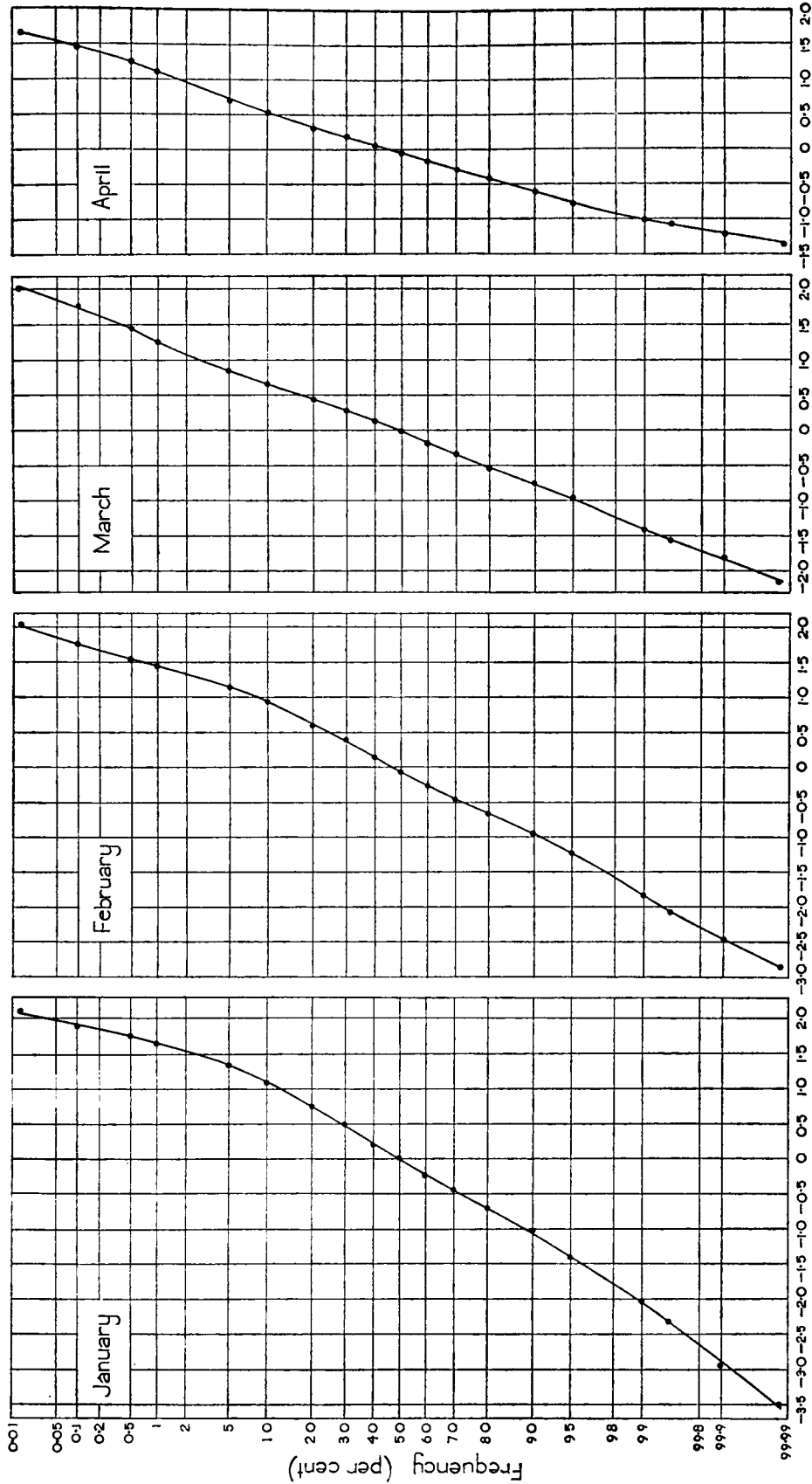


FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

Abscissae: $(T - \bar{T}) / (T_x - T_n)$

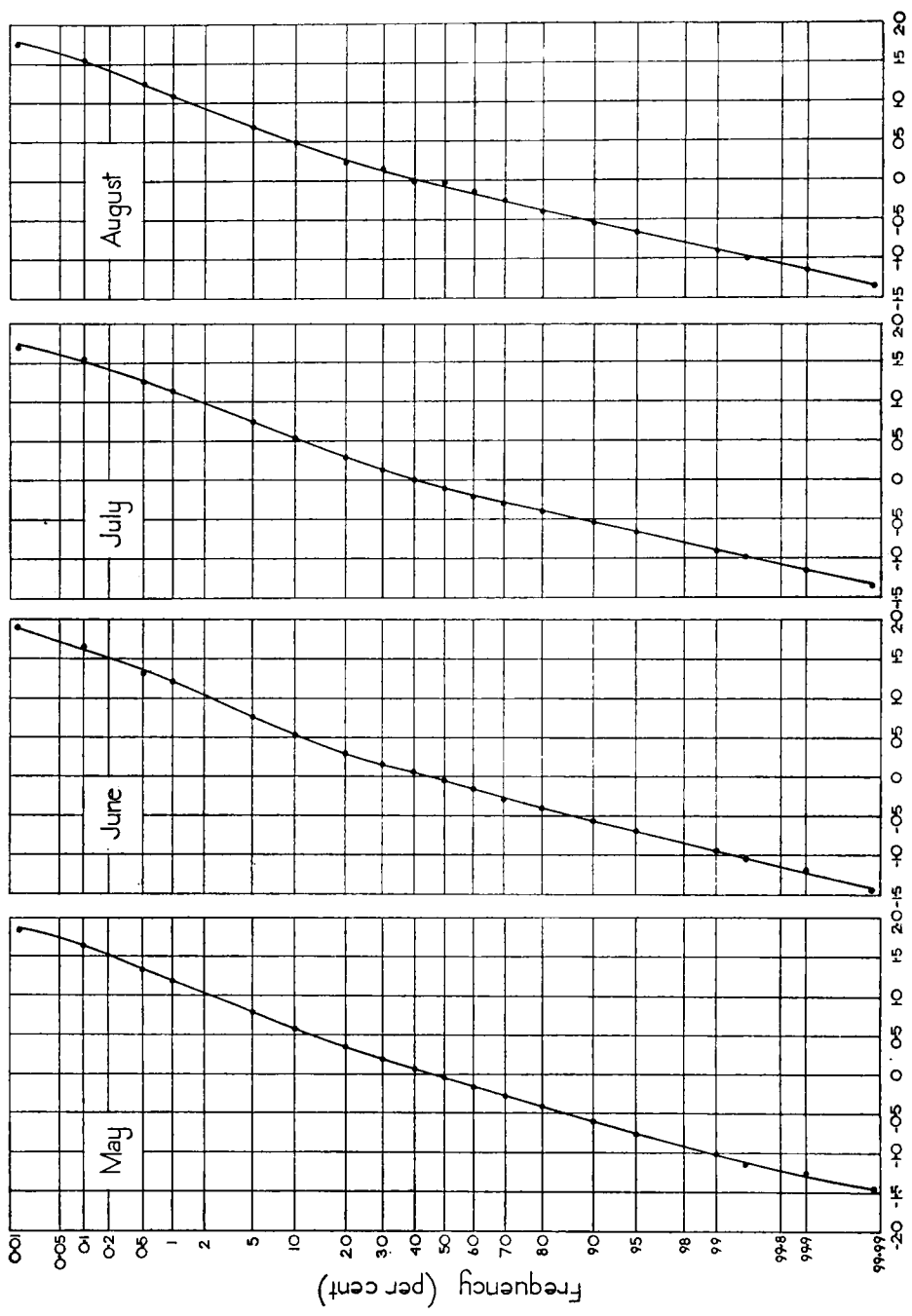


FIGURE 8

FIGURE 7

FIGURE 6

FIGURE 5

Abscissae: $(T - \bar{T}) / (T_x - T_n)$

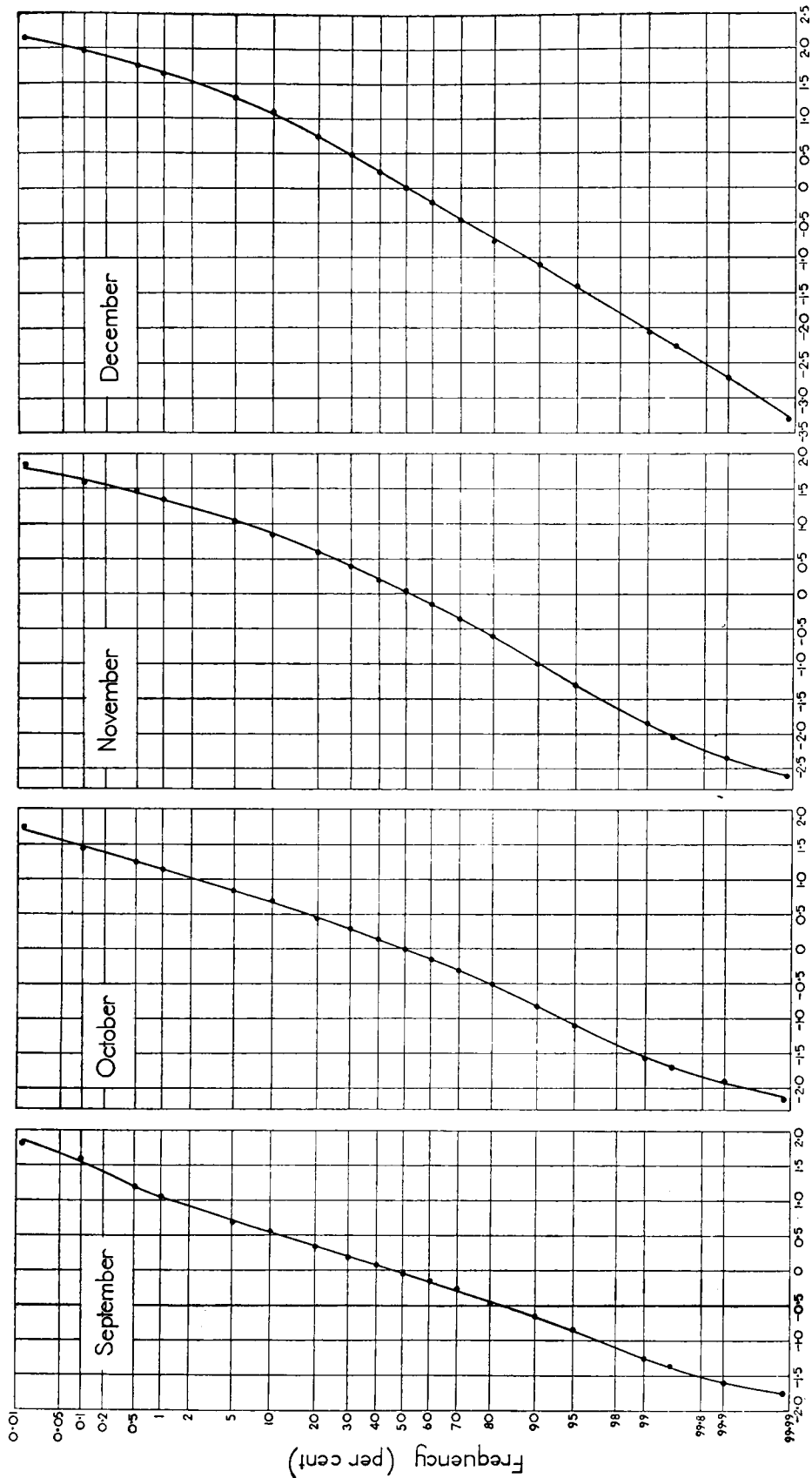


FIGURE 9

FIGURE 10

FIGURE 11

FIGURE 12

Abscissae: $(T - \bar{T}) / (T_x - T_n)$

TABLE I—VALUES OF $(T - \bar{T})(T_x - T_n)$ FOR NINE STATIONS FOR THE MONTHS JANUARY, APRIL, JULY AND OCTOBER BASED MAINLY ON TEN YEARS OF HOURLY OBSERVATIONS, WHERE \bar{T} IS THE TEMPERATURE EXCEEDED WITH THE FREQUENCY SHOWN

January		0.013	0.1	0.5	1	5	10	20	30	40	50	60	70	80	90	95	99	99.5	99.9	99.987
Croydon	Frequency (%)	2.3	2.1	2.0	1.8	1.5	1.2	0.8	0.5	0.3	0	-0.3	-0.5	-0.8	-1.1	-1.5	-2.1	-2.5	-3.4	-4.3
Lympe	..	1.8	1.7	1.5	1.4	1.2	1.0	0.7	0.5	0.3	0	-0.2	-0.4	-0.7	-0.9	-1.2	-1.7	-2.3	-2.5	-3.1
Boscombe Down	..	2.1	1.8	1.7	1.6	1.3	1.1	0.8	0.5	0.2	-0.1	-0.3	-0.5	-0.8	-1.1	-1.4	-2.1	-2.3	-2.7	-3.0
Renfrew	..	2.1	1.9	1.7	1.6	1.3	1.1	0.9	0.5	0.2	0	-0.2	-0.4	-0.7	-1.2	-1.7	-2.3	-2.5	-3.1	-3.6
Stornoway	..	1.9	1.7	1.5	1.4	1.2	1.0	0.7	0.5	0.2	0	-0.1	-0.4	-0.6	-1.1	-1.5	-2.3	-2.4	-3.1	-3.8
Aldergrove	..	2.1	1.9	1.7	1.6	1.3	1.1	0.7	0.5	0.2	0	-0.3	-0.5	-0.7	-1.0	-1.3	-2.2	-2.3	-3.2	-3.5
Manchester	..	2.2	2.1	1.9	1.8	1.5	1.1	0.8	0.5	0.2	0	-0.3	-0.5	-0.7	-1.0	-1.3	-2.2	-2.4	-2.8	-3.3
Driffield	..	2.1	1.8	1.7	1.6	1.3	1.0	0.6	0.3	0.1	-0.1	-0.2	-0.4	-0.5	-0.9	-1.1	-1.7	-1.9	-2.4	-3.1
Elmdon	..	2.3	2.2	2.1	1.9	1.5	1.2	0.8	0.5	0.3	0	-0.3	-0.5	-0.7	-1.1	-1.5	-2.0	-2.2	-3.3	-3.7
Mean	..	2.10	1.90	1.75	1.65	1.35	1.10	0.75	0.50	0.20	0	-0.25	-0.45	-0.70	-1.05	-1.40	-2.05	-2.30	-2.95	-3.50
April																				
Croydon	Frequency (%)	0.013	0.1	0.5	1	5	10	20	30	40	50	60	70	80	90	95	99	99.5	99.9	99.987
Lympe	..	1.9	1.7	1.4	1.3	0.8	0.6	0.4	0.2	0.1	0	-0.1	-0.3	-0.4	-0.6	-0.7	-1.0	-1.1	-1.2	-1.3
Boscombe Down	..	1.7	1.5	1.4	1.3	0.7	0.5	0.3	0.1	0	-0.1	-0.2	-0.3	-0.5	-0.6	-0.7	-0.9	-1.1	-1.2	-1.3
Renfrew	..	1.7	1.5	1.3	1.1	0.7	0.6	0.3	0.2	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.7	-1.1	-1.2	-1.3	-1.4
Stornoway	..	1.6	1.3	1.1	1.0	0.7	0.5	0.3	0.2	0.1	0	-0.1	-0.2	-0.4	-0.5	-0.7	-1.1	-1.2	-1.3	-1.6
Aldergrove	..	1.6	1.3	1.1	0.9	0.7	0.5	0.3	0.2	0.1	0	-0.1	-0.2	-0.4	-0.6	-0.8	-1.0	-1.1	-1.2	-1.5
Manchester	..	1.8	1.6	1.4	1.2	0.7	0.6	0.3	0.2	0	-0.1	-0.2	-0.3	-0.4	-0.6	-0.7	-0.9	-1.0	-1.1	-1.4
Driffield	..	1.8	1.5	1.2	1.1	0.7	0.6	0.4	0.2	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.7	-0.9	-1.0	-1.1	-1.2
Elmdon	..	1.6	1.5	1.3	1.1	0.7	0.5	0.4	0.2	0.1	0	-0.1	-0.2	-0.4	-0.5	-0.7	-0.9	-1.0	-1.1	-1.3
Mean	..	1.70	1.45	1.25	1.10	0.70	0.55	0.35	0.20	0.05	-0.05	-0.15	-0.25	-0.40	-0.60	-0.75	-1.00	-1.05	-1.20	-1.35
July																				
Croydon	Frequency (%)	0.013	0.1	0.5	1	5	10	20	30	40	50	60	70	80	90	95	99	99.5	99.9	99.987
Lympe	..	1.7	1.6	1.3	1.1	0.9	0.6	0.3	0.2	0	-0.1	-0.2	-0.3	-0.4	-0.6	-0.7	-0.9	-1.0	-1.1	-1.2
Boscombe Down	..	1.9	1.7	1.3	1.2	0.7	0.5	0.3	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.9	-1.0	-1.1	-1.2
Renfrew	..	1.7	1.5	1.3	1.1	0.8	0.6	0.3	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.9	-1.0	-1.1	-1.2
Stornoway	..	2.0	1.6	1.3	1.2	0.6	0.5	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.5	-0.7	-1.1	-1.2	-1.5	-1.8
Aldergrove	..	1.7	1.6	1.3	1.2	0.8	0.6	0.3	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.6	-0.7	-0.9	-1.0	-1.2	-1.4
Manchester	..	1.8	1.7	1.4	1.3	0.9	0.6	0.3	0.2	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.9	-1.0	-1.1	-1.3
Driffield	..	1.5	1.3	1.1	1.0	0.7	0.5	0.3	0.2	0.1	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.9	-1.0	-1.1	-1.3
Elmdon	..	1.5	1.4	1.1	1.0	0.7	0.5	0.3	0.1	0	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6	-0.8	-0.9	-1.1	-1.3
Mean	..	1.70	1.55	1.25	1.15	0.75	0.55	0.30	0.15	0	-0.10	-0.20	-0.30	-0.40	-0.55	-0.65	-0.90	-1.00	-1.15	-1.35
October																				
Croydon	Frequency (%)	0.013	0.1	0.5	1	5	10	20	30	40	50	60	70	80	90	95	99	99.5	99.9	99.987
Lympe	..	1.8	1.5	1.3	1.2	0.8	0.7	0.5	0.3	0.2	0	-0.2	-0.3	-0.5	-0.9	-1.1	-1.6	-1.7	-1.9	-2.1
Boscombe Down	..	1.9	1.5	1.3	1.2	0.9	0.7	0.6	0.4	0.3	0.1	-0.2	-0.3	-0.6	-0.9	-1.1	-1.5	-1.7	-1.8	-2.1
Renfrew	..	1.7	1.6	1.2	1.1	0.7	0.6	0.4	0.3	0.1	0	-0.2	-0.3	-0.5	-0.8	-1.0	-1.5	-1.6	-1.7	-2.0
Stornoway	..	1.4	1.3	1.2	1.1	0.9	0.8	0.5	0.3	0.2	0	-0.1	-0.3	-0.5	-0.9	-1.2	-1.7	-1.8	-2.0	-2.1
Aldergrove	..	1.6	1.4	1.2	1.2	0.9	0.7	0.5	0.3	0.2	0	-0.1	-0.3	-0.5	-0.9	-1.2	-1.7	-1.9	-2.3	-2.7
Manchester	..	1.9	1.5	1.3	1.2	0.9	0.7	0.6	0.4	0.3	0.1	-0.2	-0.3	-0.5	-0.8	-1.1	-1.6	-1.7	-1.9	-2.4
Driffield	..	1.9	1.6	1.3	1.2	0.9	0.7	0.5	0.3	0.1	0	-0.2	-0.3	-0.5	-0.7	-1.0	-1.5	-1.7	-1.9	-2.1
Elmdon	..	1.5	1.3	1.1	1.0	0.7	0.6	0.4	0.3	0.1	0	-0.2	-0.3	-0.5	-0.7	-1.0	-1.4	-1.5	-1.7	-1.9
Mean	..	2.0	1.5	1.3	1.1	0.9	0.7	0.5	0.3	0.2	0	-0.1	-0.3	-0.5	-0.7	-1.0	-1.4	-1.5	-1.7	-2.1
Mean	..	1.75	1.45	1.25	1.15	0.85	0.70	0.45	0.30	0.15	0	-0.15	-0.30	-0.50	-0.80	-1.10	-1.55	-1.70	-1.90	-2.15

TABLE II—ACTUAL AND ESTIMATED PERCENTAGE FREQUENCY WITH WHICH
SPECIFIED TEMPERATURES WERE EXCEEDED

Mildenhall, 1946-55

Temperature exceeded °C	January		March		June		August	
	Actual	Esti- mated	Actual	Esti- mated	Actual	Esti- mated	Actual	Esti- mated
			<i>percentage frequency</i>		<i>(hours)</i>			
-8	99.8	99.7	99.9	99.8				
-4	97.2	97.3	99.5	98.0				
0	82.4	82.4	88.3	90.2				
4	44.1	46.2	58.9	63.0	99.8	99.8		
8	16.1	14.4	30.4	31.9	95.8	96.0	99.2	98.9
12	1.5	0.4	8.3	7.0	72.0	72.3	87.4	87.5
16	0	0	1.0	1.0	36.6	35.2	51.8	50.9
20			0.05	0.1	12.3	10.7	19.2	18.9
24					3.2	2.8	5.8	5.0
28					0.9	0.5	0.7	1.0
32					0.1	0.03	0.04	0.1

Plymouth, 1946-60

Temperature exceeded °C	January		April		July		October	
	Actual*	Esti- mated	Actual*	Esti- mated	Actual*	Esti- mated	Actual*	Esti- mated
			<i>percentage frequency</i>		<i>(hours)</i>			
-8	99.9	99.7						
-4	99.7	99.6						
0	95.7	95.4	99.8	100				
4	71.1	72.0	96.6	96.2			97.9	98.5
8	36.1	32.0	70.0	64.0	99.95	99.97	89.1	88.0
12	0.4	4.5	12.4	15.0	95.6	95.0	56.4	50.0
16			1.5	1.3	42.5	42.0	6.4	8.0
20			0.1	0.03	7.4	8.0	0.2	0.1
24					1.4	0.7		
28					0.2	0		

* Actual values for Plymouth based on only four observations per day, namely 3 h, 9 h, 15 h and 21 h GMT.

Table II also includes actual and estimated frequencies for Plymouth (Mount Batten) for 1946-60. These are included because, as mentioned earlier, original data were missing for south-west England. Unfortunately the actual frequencies available for Plymouth are based on observations for four hours per day only, namely 3 h, 9 h, 15 h and 21 h GMT. For this reason it was not to be expected that the estimated and observed frequencies would agree very well, particularly as the sampling hours used would miss many of the extreme daily values. Bearing this in mind the agreement is on the whole remarkably good, the only large differences being one of 6.0 per cent for temperatures exceeding 8°C in April and one of 6.4 per cent for temperatures exceeding 12°C in October.

Practical application.—Suppose that it is desired to obtain an estimate of the annual average percentage frequency with which temperature falls below 0°C (32°F) at a place X . If long-period averages of mean daily maximum and minimum temperature are available for X , then $(T_x - T_n)$ is known and $\bar{T} = \frac{1}{2}(T_x + T_n)$ is also known. Putting $T = 0^\circ\text{C}$ the value of $(T - \bar{T})/(T_x - T_n)$ may be calculated for each of the 12 months. These values are then entered on the appropriate monthly graphs to obtain the estimated percentage of time that 0°C is exceeded in each month. By combining these and subtracting from 100 the required annual average percentage frequency that temperature falls below 0°C is obtained.

If long-period averages of mean daily maximum and minimum temperatures for X are not available but a short-period record is available, then the required

long-period records may be estimated with reference to the nearest long-period station in the usual way.³ If no records are available then as a last resort values might be estimated from average sea-level temperature maps making appropriate allowance for the variation of temperature with height, depending of course on the exposure at *X*.

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2. SPREEN, W. C.; Empirically determined distributions of hourly temperatures. *J. Met., Boston, Mass.*, **13**, 1956, p. 351.
3. London, Meteorological Office; Averages of temperature for Great Britain and Northern Ireland, 1921-50. London, 1953, p. 1.

METEOROLOGICAL OFFICE DISCUSSION

The jet stream

The first Meteorological Office discussion of the winter season was held at the Royal Society of Arts on 16 October 1961. The subject was "The jet stream".

Mr. A. H. Gordon opened the discussion with a brief summary of current knowledge about this significant meteorological phenomenon; casting back through the years, he said that the creation of the name "jet stream" in the mid 1940's created an impact, an air of excitement of a new discovery. This simile with hydrodynamics helped to give recognition to the wholly new aspect of meteorology which had been opened up by the routine operational use of the radiosonde. Mr. Gordon's remarks focussed attention on the tropospheric polar front jet, and also on the subtropical jet. The other jet forms—the polar night stratospheric jet, the tropical easterly and the high atmosphere jets—were only mentioned in passing. He pointed out that the jet stream is important synoptically as an essential feature of weather chart analysis; it is important climatically as an integral part of the general circulation; it is important dynamically as a mechanism for producing pronounced development of pressure systems.

Slides were shown illustrating each of these aspects of the subject. In addition a display of several 300 mb synoptic charts portraying jet analyses was referred to during the discussion.

Mr. A. F. Crossley subsequently presented the results of some work he had done on the distribution of jet streams over the North Atlantic, Europe and the Mediterranean. The frequency of occurrence of jet streams was displayed by isopleths indicating the average number of days per season when a jet axis traversed each sub-area. In each season there is a maximum frequency in the western Atlantic near or to the south of Newfoundland; this maximum is greatest in autumn and least in spring. Tongues of high frequency extend from these maxima eastwards across the Atlantic in summer, autumn and winter. In summer the area over which 10 days per season is exceeded is remarkably concentrated within 12 degrees of latitude all the way from 60°W to about 10°W, whereas in the other seasons the 10-day isopleths are separated by about 25 degrees of latitude. Another maximum frequency occurs in the south-east Mediterranean and is most marked in winter, but is entirely absent in summer. This is associated with the subtropical jet stream, augmented from time to time by the strong winds of the polar front as it moves into this area.

Mr. Briggs then gave the results of a preliminary analysis based on a series of flights through jet streams by aircraft of the Meteorological Research Flight. Slides were shown illustrating the distribution of observations of ozone content, water vapour content, wind and temperature for cross-sections across the jet.

The discussion was a lively one. Mr. Miles exchanged comment with Mr. Hawson about the behaviour of jet streams in North America as compared with their behaviour in western Europe. Mr. Matthewman mentioned the conflicting practices in connecting the frontal surface with the tropopause. Mr. Lamb talked about the climatological positions of jets and Mr. Davis was concerned about the stratosphere. Finally, Mr. Sawyer repeated a suggestion emanating from the recent session of the Commission for Aerology that the subtropical jet should be given another name.

REVIEWS

The climates of the continents (5th Edn.), by W. G. Kendrew. 8½ in. × 5¾ in., pp. 608, illus., Oxford University Press, Amen House, London, E.C.4, 1961. Price: 55s.

To those acquainted with the earlier editions, this latest edition of Kendrew's well known book will need no introduction. It remains the English classic of world climate. The principal changes introduced lie in the inclusion of more recent climatic data, mainly in the numerous tables, but these changes are mostly small, as the author says, a pleasing tribute to the earlier observers. One may justifiably ask however whether climatic change may be involved—a subject not dealt with by the author.

For new readers some description of the book is desirable. After a short introductory section about the nature of climatic data and the broad pattern of pressure and wind systems over the earth's surface, there are seven sections each dealing with a separate continent, Antarctica included, and the respective groups of off-lying islands. Each section has an introductory chapter on the climate of the continent as a whole, followed by chapters on sub-divisions of the continental areas; the sub-divisions are made on a climatic rather than a political basis.

In a book of this size and nature exhaustive detailed treatments of the climates of particular places or small regions are not to be expected. Neither perhaps should the reader look for a treatment more advanced than one based on annual and monthly means of the basic elements of weather, so that questions of year-to-year changes, including the important one of rainfall reliability are but lightly touched upon. However, the author's accounts of the general climatic features of the various areas and their effects on living conditions and habits are lucid and informative. In conjunction with the climatic tables given in the book and the fuller tables available elsewhere these accounts provide valuable material both for students and for practical users in the fields of commerce, engineering, industry and agriculture.

The book abounds in lively descriptions of climates which from one point of view or another have outstanding and sometimes unexpected features. The reviewer is impressed by the vivid descriptions of the climates of those overseas areas with which he is acquainted. Some of these descriptions however are reproduced word for word from the work of much earlier writers, for example that by Merk on the Punjab, written towards the end of the last century (pages 187–190). Though the climate has probably changed little since then its effects

can now have been ameliorated by air conditioning, and improved irrigation; the ravages of diseases formerly thought of as necessarily endemic in some tropical climates have been much diminished by improved hygiene and advances in medicine. Perhaps therefore these transcribed accounts paint too dark a picture for present-day conditions.

Far from being a stodgy work of reference the book provides interesting and entertaining reading for the leisure hours of all interested in weather. The standard of production is high, the diagrams clear and simple, errors and misprints are hard to find. It is a worthy successor to the earlier editions.

A. G. FORSDYKE

Maritime meteorology, by Captain G. E. Earl and Captain N. L. Peter. 8½ in. × 5½ in., pp. vii+122, *illus.*, The Maritime Press Limited, 30 Fleet Street, London, E.C.4, 1961. Price: 10s. 6d.

In the preface, the authors state that "The contents are designed in particular to assist candidates preparing for the Ministry of Transport examinations". In pursuit of this aim, the subject has been stripped to the bare bones, and the book has both the merits and defects of such an approach. Most of the tables and diagrams are very good, setting out clearly all essential information, but much of the text is very dull, the aim being to pack the greatest possible number of facts into the smallest possible space. Also there are several loose unqualified statements where accuracy has been sacrificed for the sake of brevity, for example "Over the sea evaporation increases with a rise of air temperature" (page 4), or "Where there is convergence the characteristic of barometric tendency over the region will be 'falling'" (page 23), or in reference to swell waves "Length and speed remain the same, but the height diminishes as they proceed" (page 71).

Much of the chapter on meteorological instruments is superfluous. It would have been sufficient to deal with the marine barometer, the barograph, dry- and wet-bulb thermometers and the sea temperature bucket, that is those instruments which are in regular use by voluntary marine observers. Measurement of sea temperature by the bucket method is not discussed at all, which is unfortunate, since this is not the simplest of measurements to make accurately.

This book will no doubt be of help to the reluctant examinee who needs to brush up his "Met" the night before the examination, but it is not recommended to anyone who has a genuine interest in maritime meteorology for its own sake.

F. E. LUMB

LETTER TO THE EDITOR

Seasonally induced meridional flux of momentum in the atmosphere

It has been pointed out that the eddy flux term is actually larger than $\partial U/\partial t$ in the equation for the meridional velocity (not smaller as stated on page 242 of the September 1961 *Meteorological Magazine*). However, the calculations and patterns show the seasonally induced motion which is due to the contribution of $\partial U/\partial t$ alone. The actual meridional motion is, as stated, considerably greater than the seasonally induced contribution; the latter term depends on seasonal changes in the heat balance. It is thought that it is dynamically important to divorce this term from the eddy stress and non-geostrophic drift terms which have been calculated from actual or geostrophic winds for a given month or season by a number of workers in this field.

A. H. GORDON

Meteorological Office Training School, Stanmore

OBITUARIES

Mr. H. J. Masters.—We regret to report the death, on 9 November 1961, in the Port Meteorological Office, London, of Mr. H. J. Masters, Temporary Assistant Scientific, at the age of 62. Henry James Masters joined the Meteorological Office as a locally engaged Clerk at Heliopolis, Egypt, in January 1928 on leaving the R.A.F. Meteorological Section. Until he was transferred to the United Kingdom in April 1940 he served at various stations in Egypt, Palestine and Trans-Jordan performing outstation observer duties. He was regraded as Observer (unestablished) on 1 April 1937.

Continuing his outstation duties he served successively at Thorney Island, Cranwell, Shawbury, Sealand and Aberdeen, being promoted to Assistant III (temporary) in October 1940. In January 1948, he took up duty at the Port Meteorological Office at London Docks and remained there until his death, having been regraded as Assistant Scientific (temporary) in April 1951. Whilst at London he was engaged mainly on the administrative duties of the office but occasional visits to British merchant ships to inspect the meteorological instruments loaned to the ship to enable them to make and transmit weather reports to appropriate shore stations were also undertaken.

Henry Masters was a bachelor and to his only brother we extend our sympathy.

G.C.F.

Mr. W. T. Stiles.—It is with deep regret that we record the sudden death in his office at the age of 53 of an old friend and colleague, Mr. W. T. Stiles (Senior Experimental Officer).

Walter Stiles finished his education at Bristol University where he obtained the B.Sc. degree in mathematics and physics in 1929. He also obtained a diploma in education and was a schoolmaster until joining the staff of the Meteorological Office in 1937. Much of his career was devoted to forecasting for aviation and much of his time was spent in East Anglia. He became very expert in East Anglian conditions and his forecasts of the occurrence of the troublesome North Sea stratus clouds were unusually reliable.

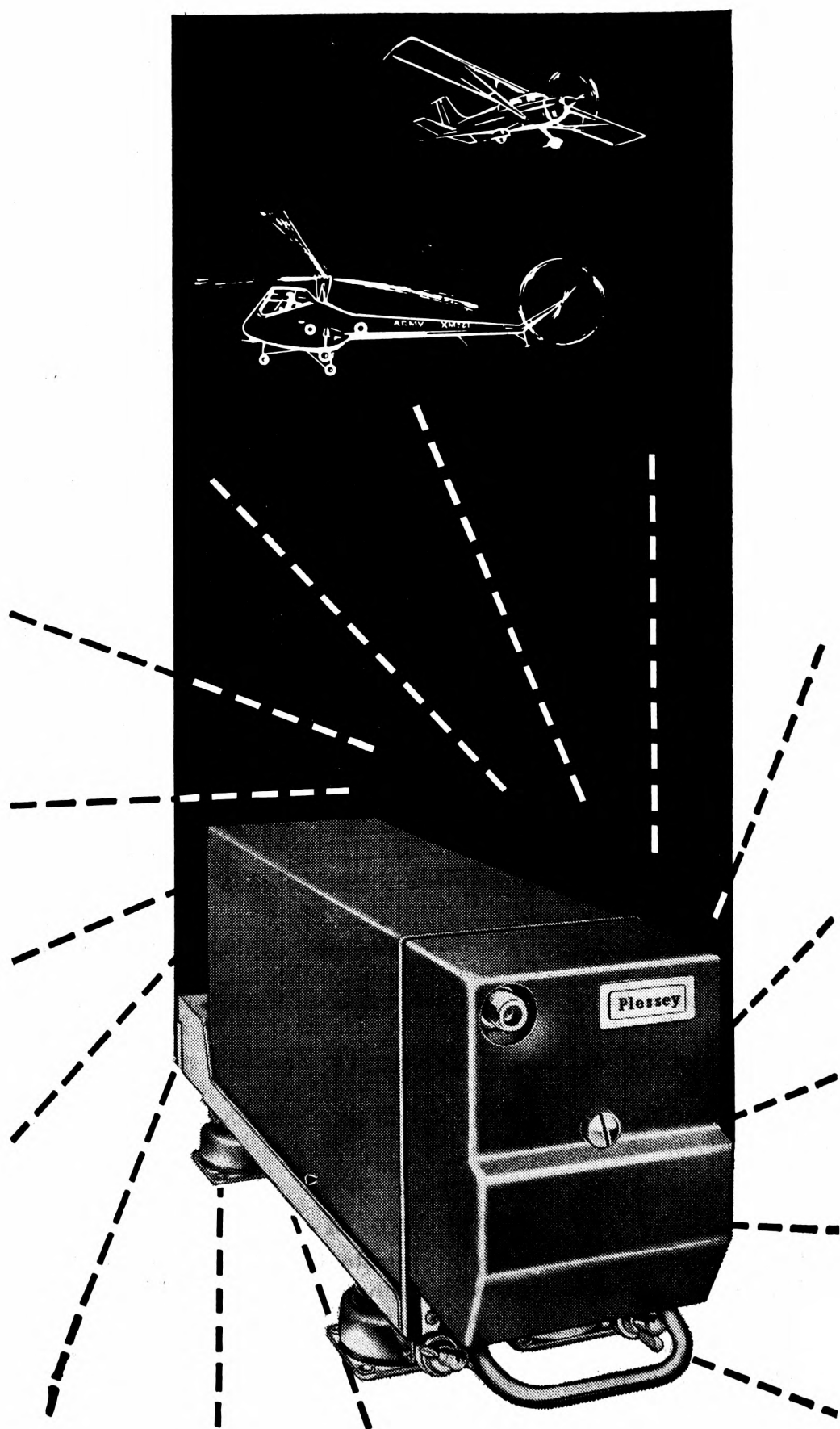
He was commissioned in the R.A.F.V.R. as a Flight Lieutenant in 1943 and served with R.A.F. formations both at home and in Iceland. After demobilization he served for a while in Gibraltar and then returned again to East Anglia, where he remained for several years before undertaking a tour of duty at Singapore, eventually returning to the Communications Branch at Headquarters.

Stiles was naturally reserved in character, but once the reserve was broken through he was a staunch and true friend. His health had not been robust for some years, but his sudden death has come as a great shock, and we extend our deepest sympathy to his widow and two daughters.—*Ed.*

CORRIGENDUM

A preliminary note on early meteorological observations in the London region, 1680–1717, with estimates of the monthly mean temperatures, 1680–1706

In Table II on page 309 of the November 1961 *Meteorological Magazine*, the value for February, 1701–10, should read 39.5.

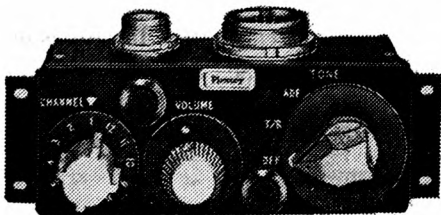


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THE FALL OF HAIL ALONGSIDE CLOUD

By A. F. CROSSLEY, M.A.

Introduction.—Hail is occasionally encountered by aircraft when flying in clear air alongside a cumulonimbus cloud, so that if hail is to be avoided in flight these clouds should not be approached within a few miles. For supersonic aircraft considerable stresses arise in making the required turns and it is important for their design and operation to know by how much the clouds should be avoided in order to make sure of missing all hail greater than some specified size. There are few observations on the occurrence of hail alongside cloud and none are known to the writer in which the size of hail has been estimated in these circumstances. It is consequently of some interest to calculate the horizontal displacement of hail from the parent cloud, the object being to find how great the displacement can be in favourable conditions. The displacement is attributed to the effects of wind shear as explained in the next section; the calculations follow (p. 34), and finally there is a general discussion including a comparison with observed values (p. 37).

Vertical shear of wind.—It has become recognized within the last few years that the development and maintenance of an intense thundercloud can take place in the presence of a pronounced increase of wind with height¹. In these conditions, hail formed in the narrow funnel of strong updraught may, on reaching the upper part of the cloud, be carried sideways into the anvil and afterwards fall down through clear air alongside the main tower of cloud.

The thundercloud is known to maintain its existence on occasions for several hours while drifting with the wind but without being appreciably deformed by the shear except in the anvil itself. The cloud is a thermodynamic structure and the updraughts and downdraughts taking place enable its form to remain on the whole unchanged in spite of the variation of wind with height. Alternatively the cloud may be regarded as repeatedly renewing itself as a nearly vertical tower while drifting along with a speed equal to that of the wind at some intermediate level. If this level is denoted by h_1 and if the wind speed increases with height from the ground up to the top of the cloud, the effect of the shear will be to carry hail and other precipitation away from the cloud at heights greater than h_1 while below this height the precipitation would be carried back towards

the cloud. The greatest horizontal displacement of hail from the cloud on the downwind side therefore occurs at approximately the height h_1 , but a closer estimate will be given later. The distance travelled by hail horizontally relative to the cloud will be calculated on the basis of these simple assumptions. It will be assumed that the wind increases uniformly from a value V_0 at the surface, h_0 , to a value V_2 at a height h_2 near the upper part of the cloud. The wind speed at any intermediate height z is then given by

$$V = V_0 + a(z - h_0)$$

where a , the vertical shear, is given by

$$a = \frac{V_2 - V_0}{h_2 - h_0}.$$

Further, if the cloud as a whole is moving with speed V_1 equal to that of the wind at height h_1 then the wind speed relative to the cloud at height z is given by

$$V' = V - V_1 = a(z - h_1). \quad \dots (1)$$

Some information on vertical shear during falls of hail is given by Beck² who states that in two out of 24 encounters with hail of diameter 0.5 inch or larger above 20,000 feet, the wind shear exceeded 40 knots through a layer from 10,000 feet to the level of the encounter; also for encounters between 10,000 and 20,000 feet, four out of six cases in clear air were associated with a shear in excess of 50 knots between 10,000 feet and the level of the encounter. In a storm over south-east England on 9 July 1959 discussed by Ludlam¹ the shear was about 70 knots between the surface and 10 km, above which the wind decreased; on this occasion hail of 2 inch diameter was observed at the ground. A uniform shear of 50 m sec⁻¹ (100 kt) between the ground and 12 km will be taken as representing a rather large value, but probably not an extreme one, when hail is present; this gives a value of a equal to 4.167×10^{-3} sec⁻¹. (The value quoted from Ludlam is equivalent to 3.6×10^{-3} up to 10 km.)

The height h_1 is usually about 3 km, which with the assumed shear implies that the storm system moves at a speed of 25 knots relative to the wind at the surface, a not unreasonable value. The height at which the hail is released from the updraught, h_2 , will be taken as 12 km, again a large but not an extreme value, at least for stones up to about 3 cm diameter.

First stage: hail accelerated away from the cloud.—If a hailstone has a horizontal velocity u relative to the cloud, then the wind has velocity $V' - u$ relative to the hailstone. So long as $V' > u$, the stone is being accelerated away from the cloud and its horizontal motion is determined by equation (2) which relates the drag to the product of the mass of the hailstone and its acceleration,

$$\frac{1}{6} \pi d^3 \sigma \frac{du}{dt} = \frac{1}{4} \pi d^2 \rho C_D (V' - u)^2, \quad V' \geq u, \quad \dots (2)$$

where d is the diameter and σ the density of the hailstone, ρ the air density and C_D the drag coefficient. A similar equation for vertical motion³ gives an expression for the terminal velocity,

$$v^2 = \frac{2}{3} \cdot \frac{\sigma}{\rho} \cdot \frac{g}{C_D} d, \quad \dots (3)$$

by which equation (2) may be written

$$\frac{du}{dt} = \frac{g}{v^2} (V' - u)^2. \quad \dots (4)$$

The terminal velocity will be assumed constant for a given diameter, so that if z is the height reached at time t after falling from the level h_2 , then

$$h_2 - z = vt. \quad \dots (5)$$

On substituting for V' from equation (1) and for z from equation (5), equation (4) becomes

$$\frac{du}{dt} = \frac{g}{v^2} [a(h_2 - h_1 - vt) - u]^2.$$

Write

$$\xi = a(h_2 - h_1 - vt) - u$$

then

$$\frac{d\xi}{dt} + \frac{g}{v^2} \xi^2 = -av \quad \dots (6)$$

the solution of which is

$$\xi = \frac{av}{k} \tan(A - kt), \quad k = \sqrt{\frac{ag}{v}} \quad \dots (7)$$

where A is an arbitrary constant. Therefore

$$u = a(h_2 - h_1) - avt - \frac{av}{k} \tan(A - kt). \quad \dots (8)$$

Initially the hailstone is considered to be moving horizontally with the speed of the cloud so that

$$\tan A = (h_2 - h_1) \frac{k}{v}. \quad \dots (9)$$

ξ is the horizontal velocity of the air relative to that of the hailstone and equation (6) applies only while $\xi \geq 0$. From equation (7), ξ becomes zero at time A/k , a time which (on the assumptions made) is found to vary from about 30 to 50 seconds according to the diameter of the hailstone. The horizontal displacement (x') from the cloud at this time is obtained by integration of equation (8),

$$x' = \int_0^{A/k} u dt = a(h_2 - h_1) \frac{A}{k} - \frac{1}{2} av \frac{A^2}{k^2} + \frac{av}{k^2} \log_e \cos A \quad \dots (10)$$

and the corresponding height ζ is given by

$$\zeta = h_2 - \frac{vA}{k}. \quad \dots (11)$$

The terminal velocity is calculated from equation (3) for stones of diameter 1, 2, 4, 6 and 8 cm. C_D is about 0.6 for these diameters⁴. σ is taken as 0.9, ρ is for a first approximation given its value at 12 km in the international standard atmosphere, k is given by equation (7) and A by equation (9). The estimated distance fallen in the whole of this stage, vA/k , is found to vary from about $\frac{1}{2}$ km for hail of diameter 1 cm, to 2 km for hail of diameter 8 cm. A second approximation is then obtained by using a value of v appropriate to the

mean height ($h_2 - Av/2k$) obtained from the first approximation. The relevant data and results are given in Table I.

TABLE I—FALL OF HAIL IN FIRST STAGE

Diameter, d cm	1	2	4	6	8
Air density, $\rho \times 10^6$ gm cm ⁻³ ..	325	335	350	364	373
Fall-velocity, v cm sec ⁻¹ ..	1740	2420	3350	4020	4590
Displacement, x' km	1.0	1.1	1.2	1.2	1.2
Final height, ζ km	11.5	11.1	10.6	10.2	9.9

An alternative procedure would have been to assume that the hail starts to fall from rest at height h_2 . This reduces the average velocity in the first stage by 5 to 10 per cent according to the diameter of the hail, and it also makes a slight reduction in the depth of this stage. After pursuing the calculations through the second stage, the result is to increase the total horizontal displacement as given in the last line of Table II by 0.1 to 0.2 km, an amount which is hardly significant.

Second stage: hail accelerated towards the cloud.—In the second stage the hail falls through air moving horizontally more slowly than the hail itself. Although the hail is still moving away from the cloud, the horizontal drag is now towards the cloud. The sign of the right-hand sides of equations (2) and (4) needs to be reversed to represent these conditions, giving

$$\frac{du}{dt} = -\frac{g}{v^2}(u - V')^2, \quad V' \leq u. \quad \dots (12)$$

In this stage t will be measured from the time of passing through the level ζ , so that we now write

$$\xi = u - V' = u - a(\zeta - vt - h_1)$$

whence equation (12) becomes

$$\frac{d\xi}{dt} + \frac{g}{v^2}\xi^2 = av. \quad \dots (13)$$

The solution is

$$\xi = \frac{av}{k} \cdot \frac{Be^{2kt} - 1}{Be^{2kt} + 1}$$

where k is as defined previously (equation (7)) and B is an arbitrary constant. At $t = 0$, $\xi = 0$, hence $B = 1$ and

$$\xi = \frac{av}{k} \tanh kt.$$

Therefore
$$u = a(\zeta - vt - h_1) + \frac{av}{k} \tanh kt \quad \dots (14)$$

and the contribution (x'') to the horizontal displacement after time t in this stage is given by integration of equation (14),

$$x'' = a(\zeta - h_1)t - \frac{1}{2}avt^2 + \frac{av}{k} \log_e \cosh kt. \quad \dots (15)$$

The greatest horizontal displacement from the cloud occurs when the relative

velocity u vanishes. At this point t is large enough to make $\tanh kt$ practically unity, hence from equation (14)

$$t = \frac{\zeta - h_1}{v} + \frac{1}{k}. \quad \dots (16)$$

This shows that the hailstone continues to move away from the cloud for a time $1/k$ after falling through the level h_1 , below which the relative wind is towards the cloud. The duration of the part of the fall below h_1 amounts to about 20 to 30 seconds, and it may be shown that in this time the hail falls a distance varying from about 0.2 km to 1 km according to its size. Since h_1 is taken as 3 km, the maximum horizontal displacement from the cloud therefore occurs at a height above the ground varying from nearly 3 km for stones of diameter 1 cm, to 2 km for stones of diameter 8 cm.

The computation of the maximum horizontal displacement in this stage, from equation (15) with t given by equation (16), begins by assuming a fall-velocity appropriate to a height half-way between h_1 and ζ , the height at the end of the first stage. This gives an estimated time of fall from equation (16), and hence a revised fall-distance vt and a revised mean height $(\zeta - vt/2)$, from which point the calculations are re-started with a value of v appropriate to this level. The results are given in Table II. The total displacement x in this table is the sum of the respective displacements x' in the first stage (Table I) and x'' in the second stage.

TABLE II—FALL OF HAIL IN SECOND STAGE

Diameter, d cm	1	2	4	6	8
Air density, $\rho \times 10^6$ gm cm ⁻³	582	599	625	647	667
Fall-velocity, v cm sec ⁻¹	1300	1810	2510	3020	3430
Displacement, x'' km	11.5	7.6	4.8	3.6	2.8
Final height, km	2.8	2.6	2.4	2.2	2.0
Total displacement, x km	12.5	8.7	6.0	4.7	4.0

Discussion.—A method has been described for estimating the extent to which hail of various sizes may be displaced laterally from the thundercloud which gives birth to it. Values of the various parameters have been chosen with the object of arriving at figures for a large, but not an extreme, displacement. Comparison with the few observations available show that the results are at least of the right order of magnitude, although no observations are available to the author on the *size* of hail "outside cloud. Beck², describing a summary of observations made on flights by the United States Air Force, mentions encounters up to 6 miles (10 km) from the parent thunderstorm in the height range 10,000 to 20,000 feet. Also Lehr⁵ states without amplification that encounters may occur up to 2 to 3 miles in any direction from the intense radar echo and up to 10 miles (16 km) on the downwind side. Beck's statement regarding hail in clear air is worth quoting at length:

"Encounters below 10,000 feet exhibited a completely random distribution insofar as the relative location of the aircraft and thunderstorm was concerned. The encounters in clear air alongside the thunderstorm, in rain below the thunderstorm and within the thunderstorm were about equally divided. The fact that more than 90 per cent of these low-level encounters were within two miles or less or were actually within or below the thunderstorm is considered vitally significant to flight operations.

“Encounters in the range 10,000 to 20,000 feet were distributed approximately 60 per cent within the thunderstorm and 40 per cent in the clear air alongside the thunderstorm. The clear-air encounters in this group showed a distribution from 100 feet to six miles from the parent thunderstorm with 82 per cent being under an overhanging cloud from the thunderstorm.

“Encounters in the range above 20,000 feet were distributed approximately 80 per cent within the thunderstorm and 20 per cent in the clear air, with all clear-air cases occurring beneath the anvil or other cloud extending from the parent thunderstorm.”

The frequency of encounters with hail is not necessarily the same as the frequency of occurrence of hail, since it is not known how the flights were conducted in the presence of cumulonimbus clouds. Moreover, the “random” distribution mentioned in the first sentence of the quotation presumably implies nothing more than what is stated in the second sentence regarding the equal frequency of encounters below 10,000 feet in clear air, in precipitation, or within the storm itself. The actual distribution of falls of hail would be expected to be biased towards the direction of the vertical shear.

Several factors which might influence the calculated results have had to be ignored. The air motion in and near the cloud is complicated by the vertical circulation of the cloud itself and by the necessity of preserving hydrodynamic continuity. The hail is assumed to fall without change of size; this is true enough in clear air at temperatures less than 0°C , moreover melting would not usually become appreciable until below 3 km except in low latitudes; if part of the fall takes place through cloud, then growth would occur where the temperature is less than 0°C . The terminal velocity of a hailstone varies with its shape. The fall of hail from 12 to 2 km takes about 5 to 12 minutes, and in this time changes taking place in the cloud may affect the distance between hail and the visual cloud, although distance between hail and core is perhaps less likely to be appreciably modified. The height at which hail is released from the cloud may not be independent of hail size; if the larger hail falls out sooner than the smaller hail, then the larger hail would come down relatively more closely to the cloud than the calculated figures suggest. The variation of wind shear with height is not necessarily uniform; if it is distributed to give a steeper shear in the middle and lower levels than in the upper levels, then the horizontal displacements would be greater than those calculated for a uniform shear, since the fall-velocity is less at lower heights. It is to be noted from equations (10) and (15) that with a uniform shear, the total displacement is proportional to the shear.

In view of the various uncertainties, it is considered that the displacements calculated for a given total shear may be in error by perhaps ± 2 km. The distances so calculated are in principle measurements from the main updraught or core of the cloud, not from the visual edge of the cloud. Finally, the estimates do not imply the existence of hail of the given diameters in any particular cloud, but state only the distance from cloud at which hail of a specified size is likely to be found when it does occur in the given conditions of shear. It should be noted that any large displacements are necessarily confined to the downwind side of the cloud.

Acknowledgement.—The author is indebted to Mr. J. K. Bannon for suggestions made during the course of this work.

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EXTREME WIND SPEEDS OVER THE UNITED KINGDOM FOR PERIODS ENDING 1959

By H. C. SHELLARD, B.Sc.

Introduction.—This paper is an extension of an earlier investigation by the author¹ and in it account has been taken of anemograph records for an additional five years, 1955–59. The same procedure has been adopted, that is, the statistical theory of extreme values² has been applied to the annual maximum mean hourly wind speeds and the annual maximum gust speeds recorded at all anemograph stations in the United Kingdom for which records for ten years or more are available. The number of stations for which data can now be presented is thus increased from 48 to 56. This includes 8 new stations and 35 stations for which the available record has been lengthened by from three to five years.

Results.—Tables I and II set out the results of the new computations for mean hourly wind speeds and for gusts respectively. For each station are given the number of years and period of the record, the speeds likely to be exceeded on the average only once in 10, 20, 50 and 100 years, the highest recorded speed up to December 1959 and the mean annual maximum, the speed likely to be reached or exceeded on the average once in two years. In every case the speeds refer to a height of 10 metres (33 feet) above the ground and have been reduced to that level, as in the previous paper, using the formulae

$$v_{10} = v_h \left(\frac{10}{h} \right)^{0.17} \quad \text{for mean hourly speeds}$$

$$v_{10} = v_h \left(\frac{10}{h} \right)^{0.085} \quad \text{for gusts}$$

where h is the “effective height” of the anemograph in metres.

The highest mean hourly speeds at 10 metres likely to be exceeded only once in 50 years are plotted in Figure 1 on a map of the British Isles and tentative isopleths at intervals of 10 m.p.h. have been drawn in. Figure 2 is a similar map showing the distribution of maximum gust speeds on a once in 50 years basis.

Discussion.—It must again be emphasized that Figures 1 and 2 give only a broad picture of the distribution of maximum wind speeds over the United Kingdom and are based on observations from stations which are, generally speaking, on open level sites and which in most cases are below 500 feet above sea level. Since extreme wind speeds are greatly affected by local topography such maps must be used with great caution, as values interpolated from them may need considerable adjustment depending on the actual exposure of any specified location for which estimated extremes are required. This applies particularly to sites on hill tops, in valleys or in heavily built-up areas.

TABLE I—MAXIMUM MEAN HOURLY WIND SPEEDS (M.P.H.)
AT 33 FEET ABOVE THE GROUND

Station	No. of years of record	Period of record used	Speeds likely to be exceeded only once in stated number of years				Highest on record	Mean annual maxi- mum
			10	20	50	100		
			<i>miles per hour</i>					
Lerwick	29	1931-59	67	70	75	78	73	58.0
Kirkwall	14	1930-43	58	61	65	69	59	50.1
Stornoway	23	1937-59	69	74	79	84	73	58.4
Aberdeen	15	1933-47	44	47	52	55	44	35.5
Balmakewan	21	1915-35	45	48	53	56	51	36.8
Bell Rock	28	1930-55, 58-59	56	59	63	66	60	49.2
Leuchars	11	1949-59	48	51	55	57	46	41.7
Edinburgh	43	1915-33, 36-59	56	58	62	65	59	49.3
Tiree	33	1927-59	64	69	75	80	66	52.7
Paisley	46	1914-59	42	45	48	50	46	36.2
Renfrew	14	1946-59	50	54	59	62	51	41.2
Prestwick	16	1944-59	51	54	58	61	49	43.8
Eskdalemuir	36	1914-45, 56-59	54	57	61	64	56	46.3
Point of Ayre	24	1936-59	58	61	66	69	63	49.2
Durham	22	1938-59	48	51	54	57	50	39.6
South Shields	26	1934-59	55	58	64	69	61	44.0
Catterick	10	1933-42	51	56	62	67	49	38.8
Spurn Head	32	1922-46, 48-50, 54, 56-58	56	58	62	64	59	49.9
Cranwell	28	1928-42, 44, 47-48, 50-59	45	49	53	56	49	38.0
Gorleston	39	1913-31, 34-39, 41-46, 48, 51-57	50	53	57	59	55	44.0
Mildenhall	22	1938-59	47	50	55	59	56	37.2
Felixstowe	22	1931-35, 37-38, 44-52, 54-59	45	48	51	53	45	39.0
Dunstable	14	1944-48, 51-59	46	49	54	57	48	37.4
Cardington	28	1932-59	45	48	53	56	50	36.9
Stevenage	10	1950-59	40	43	46	50	39	34.0
Shoburyness	34	1926-59	47	50	54	57	51	40.4
Leicester	10	1938-40, 43-45, 47-50	45	50	56	61	42	33.0
Birmingham	36	1924-59	37	40	43	45	38	31.2
London (Kingsway)	11	1944-54	37	40	43	46	34	29.7
Hampton	10	1950-59	33	35	38	40	31	27.9
Croydon	27	1928-39, 44-58	41	43	46	49	45	34.7
Kew Observatory	29	1931-59	33	35	37	38	34	29.0
Dover	26	1924-39, 48-50, 53-59	44	46	48	50	46	39.3
Lympne	27	1923-29, 31-43, 45-51	48	50	54	56	52	42.0
Manston	12	1943-54	46	48	51	54	45	39.6
Thorney Island	17	1943-59	43	46	49	52	45	36.2
Calshot	24	1920, 22-41, 50-52	51	54	58	61	50	43.0
South Farnborough	15	1945-59	46	50	56	60	49	35.5
Abingdon	13	1944-45, 49-59	38	41	44	46	38	32.7
Larkhill	29	1931-59	45	48	50	53	46	40.1
Boscombe Down	27	1933-59	48	51	56	59	49	40.1
Sellafield	10	1950-59	50	53	57	60	50	42.0
Fleetwood	32	1924-43, 46-57	61	65	69	72	62	52.6
Southport	45	1913-54, 57-59	59	63	67	71	65	50.8
Liverpool (Speke)	11	1948-50, 52-59	47	49	52	54	47	42.3
Bidston Observatory	30	1929-44, 46-59	56	59	63	67	62	47.4
Manchester Airport	15	1942-50, 54-59	50	55	59	62	54	42.5
Sealand	19	1928-41, 43-47	49	52	56	59	53	41.4
Holyhead	19	1933-51	61	64	69	73	64	51.7
Aberporth	15	1945-59	56	60	64	68	56	46.6
St. Ann's Head	14	1935-46, 48-49	69	75	83	89	70	54.9
Plymouth	35	1921-43, 47-48, 50-59	53	56	60	63	58	45.7
Scilly	33	1927-59	62	65	70	74	63	52.9
Lizard	22	1935-42, 45-47, 49-59	62	65	69	72	67	54.7
Pendennis Castle	20	1929-38, 41-50	65	68	72	75	67	58.2
Aldergrove	30	1928-46, 49-59	47	50	54	56	49	39.9

TABLE II—MAXIMUM GUST SPEEDS (M.P.H.)

AT 33 FEET ABOVE THE GROUND

Station	No. of years of record	Period of record used	Speeds likely to be exceeded only once in stated number of years				Highest on record	Mean annual maxi- mum
			10	20	50	100		
			miles per hour					
Lerwick	29	1931-59	98	103	109	114	103	87.2
Kirkwall	14	1930-43	92	97	102	106	100	82.3
Stornoway	23	1937-59	106	113	123	130	110	88.2
Aberdeen	15	1933-47	78	83	89	93	83	67.8
Balmakewan	21	1915-35	76	82	89	94	87	62.8
Bell Rock	28	1930-55, 58-59	89	94	101	106	91	76.6
Leuchars	11	1949-59	82	87	95	100	82	68.0
Edinburgh	43	1915-33, 36-59	87	91	97	101	89	77.0
Tiree	33	1927-59	100	107	117	124	110	81.6
Paisley	46	1914-59	87	93	100	105	105	74.7
Renfrew	14	1946-59	94	101	110	117	97	76.2
Prestwick	16	1944-59	86	91	97	101	89	75.1
Eskdalemuir	36	1914-45, 56-59	87	92	98	103	91	74.7
Point of Ayre	24	1936-59	87	91	97	102	90	75.5
Durham	22	1938-59	89	94	100	105	95	77.4
South Shields	26	1934-59	83	88	95	101	86	69.3
Catterick	10	1933-42	86	92	99	105	88	71.1
Spurn Head	32	1922-46, 48-50, 54, 56-58	85	90	96	101	91	73.1
Cranwell	29	1928-44, 47-48, 50-59	85	92	101	109	108	67.2
Gorleston	39	1914-31, 34-39, 41-48, 51-57	77	81	86	90	82	66.6
Mildenhall	22	1938-59	86	93	101	107	94	70.4
Felixstowe	22	1931-35, 37-38, 44-52, 54-59	80	86	93	98	85	66.5
Dunstable	14	1944-48, 51-59	79	86	95	102	82	62.1
Cardington	28	1932-59	77	82	90	95	83	63.6
Stevenage	10	1950-59	75	80	87	91	73	63.2
Shoeburyness	34	1926-59	74	78	84	88	79	63.8
Leicester	10	1938-40, 43-45, 47-50	83	91	101	108	84	65.2
Birmingham	36	1924-59	74	79	86	90	79	62.7
London (Kingsway)	11	1944-54	79	86	95	102	77	61.3
Hampton	10	1950-59	69	74	80	84	69	58.4
Croydon	27	1928-39, 44-58	74	78	84	88	77	64.0
Kew Observatory	29	1931-59	70	73	78	81	71	61.6
Dover	26	1924-39, 48-50, 53-59	79	84	92	97	87	65.2
Lympne	27	1923-29, 31-43, 45-51	80	84	89	93	84	69.8
Manston	12	1943-54	78	82	87	91	80	68.1
Thorney Island	17	1943-59	78	82	87	91	81	68.0
Calshot	24	1920, 22-41, 50-52	80	85	92	98	86	67.2
South Farnborough	15	1945-59	75	79	84	87	79	65.6
Abingdon	13	1944-45, 49-59	74	80	87	92	77	60.8
Larkhill	29	1931-59	79	82	87	90	80	70.8
Boscombe Down	27	1933-59	80	85	92	97	86	66.2
Sellafield	10	1950-59	85	90	97	102	87	73.0
Fleetwood	32	1924-43, 46-57	88	93	100	106	91	76.0
Southport	45	1913-54, 57-59	89	94	101	106	93	76.5
Liverpool (Speke)	11	1948-50, 52-59	84	90	96	101	84	71.8
Bidston Observatory	30	1929-44, 46-59	93	98	105	110	100	81.2
Manchester Airport	15	1942-50, 54-59	85	90	97	102	90	73.5
Sealand	18	1928-41, 44-47	82	87	93	97	86	70.7
Holyhead	19	1933-51	94	100	107	113	107	79.1
Aberporth	15	1945-59	91	97	104	110	92	76.5
St. Ann's Head	13	1935-45, 48-49	105	112	122	128	> 107	88.3
Plymouth	35	1921-43, 47-48, 50-59	80	85	92	97	91	67.4
Scilly	33	1927-59	96	102	109	114	107	83.3
Lizard	22	1935-42, 45-47, 49-59	92	96	100	103	94	83.7
Pendennis Castle	20	1929-38, 41-50	100	106	114	120	102	85.2
Aldergrove	30	1928-46, 49-59	82	87	93	97	87	71.3

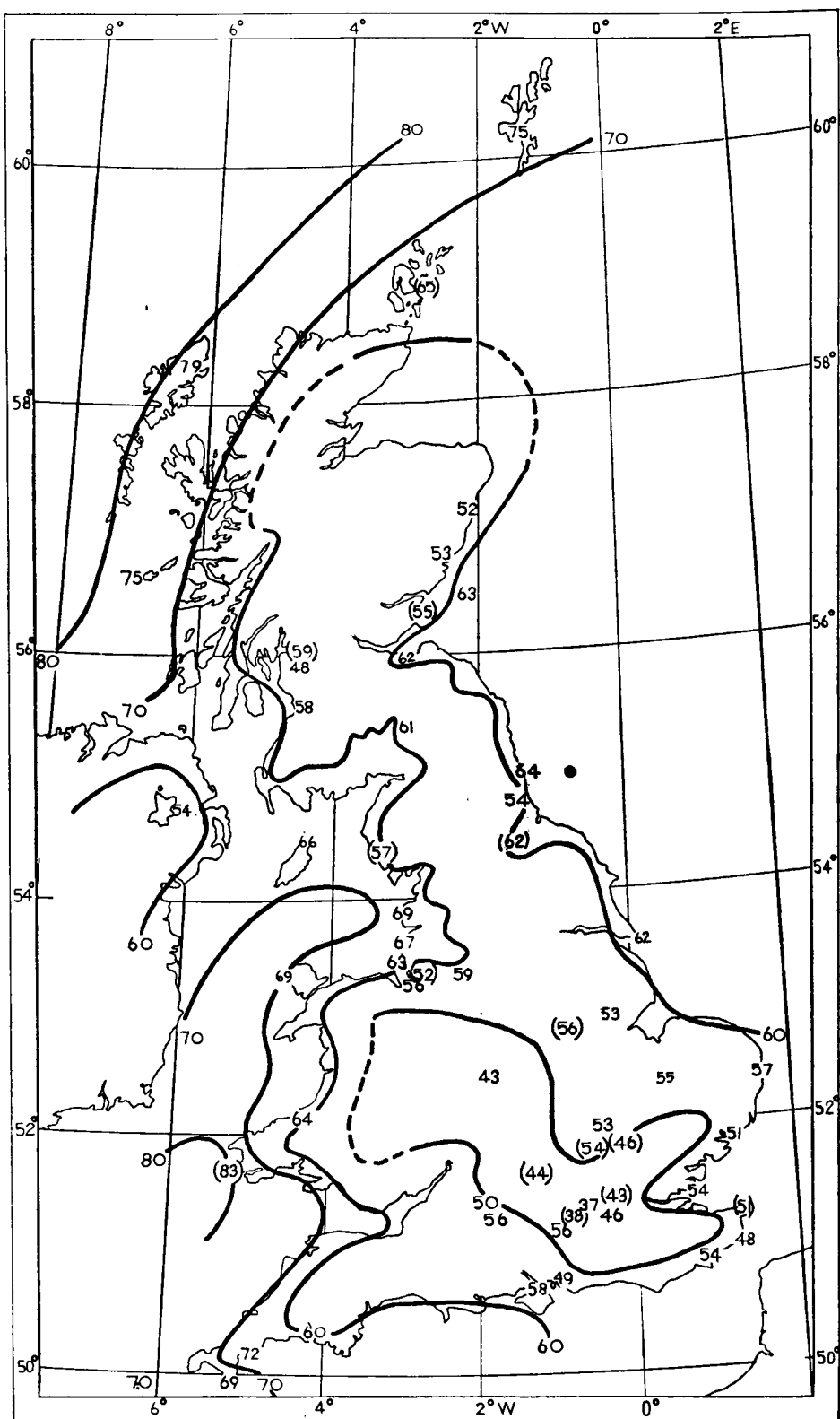


FIGURE 1—HIGHEST MEAN HOURLY WIND SPEED (M.P.H.) AT 33 FEET LIKELY TO BE EXCEEDED ONLY ONCE IN 50 YEARS
Values based on less than 15 years of record are bracketed.

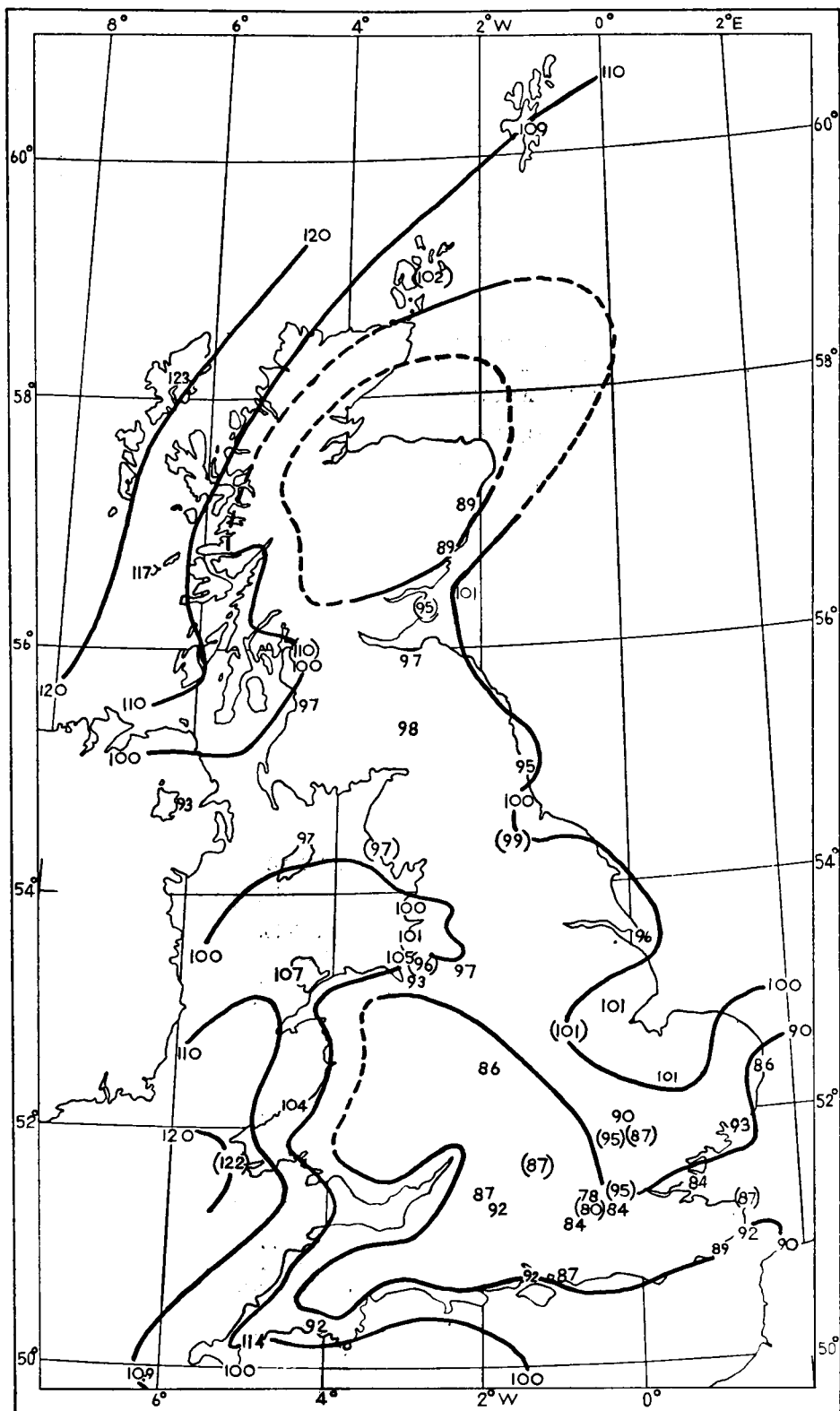


FIGURE 2—HIGHEST GUST SPEED (M.P.H.) AT 33 FEET LIKELY TO BE EXCEEDED
ONLY ONCE IN 50 YEARS

Values based on less than 15 years of record are bracketed.

When Figures 1 and 2 are compared with the corresponding maps of the author's earlier paper¹ (Figures 2 and 3 respectively) it will be noted that most of the changes are relatively minor ones, perhaps the most noteworthy difference being an increase in expected maximum speeds by a few miles per hour in the north and west of Scotland. For the 35 stations for which the new values may be compared with the old values the frequency distributions of the speed differences for mean hourly and gust speeds on a once in 50 years basis are given in Table III.

TABLE III—FREQUENCY DISTRIBUTIONS OF CHANGES (NEW MINUS OLD) IN MAXIMUM SPEEDS ON A ONCE IN 50 YEARS BASIS RESULTING FROM THE ADDITION OF THREE TO FIVE YEARS' ADDITIONAL RECORDS (35 STATIONS)

Differences* <i>m.p.h.</i>	Max. mean hourly speeds <i>No. of stations</i>	Maximum gust speeds	Differences <i>m.p.h.</i>	Max. mean hourly speeds <i>No. of stations</i>	Maximum gust speeds
+8		1	-1	12	7
+7			-2	4	10
+6		1	-3		
+5			-4	1	
+4		1	-5		2
+3	1	1	-6	1	1
+2	5		-7		
+1	3	4	-8		1
0	8	6			

* Differences = new values minus old values.

TABLE IV—RATIO OF MAXIMUM GUST SPEED (g) TO MAXIMUM MEAN HOURLY SPEED (v), ON ONCE IN 50 YEARS BASIS, FOR 56 STATIONS, AT 33 FEET ABOVE THE GROUND

Station	g/v	Station	g/v
Lerwick	1.45	London (Kingsway)	2.21
Kirkwall	1.57	Hampton	2.11
Stornoway	1.56	Croydon	1.83
Aberdeen	1.71	Kew Observatory	2.11
Balmakewan	1.68	Dover	1.92
Bell Rock	1.60	Lympne	1.65
Leuchars	1.73	Manston	1.71
Edinburgh	1.56	Thorney Island	1.78
Tiree	1.56	Calshot	1.59
Paisley	2.08	South Farnborough	1.50
Renfrew	1.86	Abingdon	1.98
Prestwick	1.67	Larkhill	1.74
Eskdalemuir	1.61	Boscombe Down	1.64
Point of Ayre	1.47	Sellafeld	1.70
Durham	1.85	Fleetwood	1.45
South Shields	1.48	Southport	1.51
Catterick	1.60	Liverpool (Speke)	1.85
Spurn Head	1.55	Bidston	1.67
Cranwell	1.91	Manchester Airport	1.64
Gorleston	1.51	Sealand	1.66
Mildenhall	1.84	Holyhead	1.55
Felixstowe	1.82	Aberporth	1.63
Dunstable	1.76	St. Ann's Head	1.47
Cardington	1.70	Plymouth	1.53
Stevenage	1.89	Scilly	1.56
Shoeburyness	1.56	Lizard	1.45
Leicester	1.80	Pendennis Castle	1.58
Birmingham	2.00	Aldergrove	1.72



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PLATE I—VIEW OF METEOROLOGICAL OFFICE LIBRARY FROM ENTRANCE

(see p. 47)



Crown Copyright

PLATE II—LIBRARY LOAN AND ISSUE COUNTER

(see p. 47)



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PLATE III—MAIN LIBRARY

(see p. 47)



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PLATE IV—STOCK ROOM IN “THE TOWER”

(see p. 47)

Nearly all the changes are of 2 m.p.h. or less. The majority of the differences greater than 2 m.p.h. occurred at stations with short records (15 years only) or at stations in the west and north-west where some exceptional gusts have occurred in the last few years.

The ratios of the maximum gust speeds to the maximum mean hourly speeds are of some interest and these are set out in Table IV, using once in 50 years estimates.

These "gust factors" range from 1.45 to 2.21 with an average value of 1.70. The lowest values are found where the anemographs are on well exposed sites, usually near the sea, and the highest ones in cities and well built-up areas. There are, however, a number of stations such as Kew Observatory, Durham, Mildenhall, Stevenage, Leicester, Hampton, Croydon and Liverpool (Speke) where the "gust factor" is 1.80 or higher although the exposures were reasonably open, and this may be at least partly due to the fact that the anemographs at these stations were mounted on fairly large buildings.

Davenport³ has made use of the values of u and $1/a$ in the expression for the reduced variate,

$$y = a(x - u)$$

where a is the scale factor, x the maximum wind speed and u the mode of the extreme value data, to estimate corresponding values referring to the gradient wind speed, after making allowances for the influence of surface roughness. Therefore it may be useful to list the values of u and $1/a$ which have been obtained in this study and they are given in Table V, for maximum mean hourly speeds and for maximum gusts. These parameters may also be used to calculate the maximum speeds for return periods other than those listed in Tables I and II from

$$x = u + \frac{1}{a} \cdot y$$

where

$$y = -\log_e (-\log_e p)$$

and the return period T is equal to $1/(1-p)$ years.

Values of y corresponding to various values of T are as follows:

T years	y	T years	y
2	0.37	60	4.09
5	1.50	70	4.24
10	2.25	80	4.38
20	2.97	90	4.49
25	3.20	100	4.60
30	3.38	120	4.82
40	3.68	150	5.01
50	3.90	200	5.30
		500	6.21

It should be mentioned that the values of u given in Table V have not been reduced to the standard height of 33 feet, as have the values in Tables I and II. The effective height allotted to each anemograph has therefore been included in Table V.

The British Standard Code of Practice on wind loading⁴ is undergoing revision, but the current code still requires the highest maximum mean wind

TABLE V—VALUES OF u AND $1/a$ FOR MAXIMUM MEAN HOURLY SPEEDS
AND MAXIMUM GUST SPEEDS AT 56 STATIONS

Station	Effective height	Maximum mean hourly speeds		Maximum gusts	
		<i>u</i>	$\frac{1}{a}$	<i>u</i>	$\frac{1}{a}$
		<i>feet</i>	<i>m.p.h.</i>	<i>m.p.h.</i>	
Lerwick	39	56·8	5·06	84·6	6·69
Kirkwall	35	48·3	4·54	79·7	5·88
Stornoway	36	55·7	6·33	83·3	10·30
Aberdeen	32	32·9	4·69	64·4	6·17
Balmakewan	20	31·6	4·38	57·1	7·51
Bell Rock	124	59·2	5·14	81·4	7·98
Leuchars	35	40·2	3·81	64·5	7·88
Edinburgh	23	44·2	3·62	71·6	5·63
Tiree	42	51·2	6·97	77·6	10·68
Paisley	31	33·9	3·35	70·3	7·44
Renfrew	35	39·0	5·15	71·4	10·06
Prestwick	35	42·0	4·33	72·2	6·43
Eskdalemuir	35	44·4	4·40	71·3	7·00
Point of Ayre	35	47·1	4·88	72·5	6·48
Durham	33	39·6	3·70	73·8	6·71
South Shields	44	42·9	6·28	66·7	7·96
Catterick	33	35·4	6·80	67·0	8·33
Spurn Head	34	48·3	3·48	69·5	6·86
Cranwell	47	37·9	4·56	63·5	10·51
Gorleston	34	42·2	3·73	63·5	5·86
Mildenhall	60	38·1	5·95	69·1	9·52
Felixstowe	65	41·6	4·02	66·1	8·27
Dunstable	33	35·0	4·80	57·2	9·70
Cardington	135	43·6	6·17	67·3	8·62
Stevenage	33	32·2	3·66	59·8	6·84
Shoeburyness	89	45·2	4·97	65·3	6·72
Leicester	33	29·6	6·81	60·1	10·41
Birmingham	73	33·6	4·02	63·1	7·32
London (Kingsway)	40	27·5	3·70	57·7	10·26
Hampton	100	31·9	3·57	60·7	6·93
Croydon	70	37·3	3·96	64·9	6·20
Kew Observatory	50	29·9	2·39	61·2	4·91
Dover	60	42·0	2·84	64·1	8·25
Lympne	48	42·7	3·72	68·5	5·97
Manston	46	39·9	3·70	66·8	5·68
Thorney Island	42	35·6	4·04	66·5	5·68
Calshot	42	42·3	4·55	64·2	7·65
South Farnborough	35	32·8	5·98	63·0	5·40
Abingdon	40	32·2	3·28	57·9	7·73
Larkhill	36	39·0	3·08	68·7	4·77
Boscombe Down	33	37·6	4·59	62·1	7·74
Sellafield	35	40·2	4·46	69·9	7·07
Fleetwood	31	49·5	4·77	71·7	7·14
Southport	33	48·1	4·95	72·6	7·27
Liverpool (Speke)	65	45·8	3·32	72·3	7·56
Bidston	39	46·2	4·85	78·5	7·16
Manchester Airport	40	41·4	5·01	70·8	7·56
Sealand	42	40·8	4·41	68·6	6·60
Holyhead	35	49·4	5·28	75·1	8·39
Aberporth	41	45·8	5·35	73·7	8·40
St. Ann's Head	70	57·8	9·51	88·1	10·34
Plymouth	65	48·7	4·73	67·2	7·66
Scilly	57	55·0	5·65	82·9	8·02
Lizard	60	58·2	4·65	85·4	5·09
Pendennis Castle	42	58·2	4·30	82·2	8·65
Aldergrove	42	39·3	4·20	69·3	6·53

speed over a period of one minute to be specified. The records from standard anemographs have too close a time scale for means to be measured over such a short period and, in the absence of any other evidence, it is recommended that the results obtained by Durst⁵ from his statistical analysis of the “ultra-quick runs” made at Cardington, should be used. These indicate that the probable value of the maximum wind speed averaged over one minute is about 1·24 times the maximum mean hourly wind speed. Corresponding factors for mean values over other short periods, based on Durst’s Table VIII, are as follows:

Period	10 min	1 min	30 sec	20 sec	10 sec	5 sec
Factor	1·06	1·24	1·33	1·36	1·43	1·47

As Durst has emphasized, these values strictly refer only to sites where the wind is unobstructed and the topography is flat, although they can also be reasonably applied to sites where the countryside is undulating and slopes are not too steep. There is a need for similar data which would be applicable to the more common case where the site is obstructed by buildings or trees, that is, to built-up areas. To meet this requirement a series of open-scale recordings in moderate and strong winds are needed from a typical site in a city such as London.

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551.5:026:06

NEW ACCOMMODATION FOR THE METEOROLOGICAL OFFICE LIBRARY

By R. F. ZOBEL, O.B.E.

The Meteorological Office Library has now been transferred from its former home at Harrow to the new Meteorological Office Headquarters at Bracknell, Berkshire. This library is, of course, primarily intended to provide the books, papers and data, in addition to those available at outstations, required for study and research by the Office staff. But it is more than that, as it constitutes a national library of meteorology and allied subjects. The reference facilities provided are available to the general public and documents may be lent to approved institutions and individuals.

The accommodation at Harrow to which the Library was moved at the end of World War II suffered from a number of defects. The new accommodation at Bracknell was specifically designed to house this major British special library and it is now in keeping with that status. It comprises two main parts, that housing the open shelves of the Library, and the stock rooms to which borrowers are not normally admitted.

The Library itself is a large, pleasant room containing the main collection of documents for lending. The bookcases and much of the panelling are faced in polished chestnut, relieved here and there by the darker tones of Australian walnut. The impression of quiet elegance as one enters from the Main Hall (Plate I) is undoubtedly pleasing and conducive to study. The lending counter

(Plate II), specially designed for convenience in handling loans and returned documents, is on the left and the "author catalogue" is contained in an array of card cabinets built into the wall on the right.

Ample space has been provided in good lighting conditions at the ends of the bookcases and elsewhere for quiet study and browsing amongst the documents (Plate III). This space includes a separate room in which hand-operated calculating machines, for example, may be used without annoyance to other library users. Under-floor heating has been used with the object of providing a reasonably uniform circulation of air around the bookcases.

The stock rooms consist of a six-storey steel structure built within the hollow brick and masonry tower at the far end of the main library. These rooms are the repository of much of the older and less frequently used material and they are air-conditioned. Plate IV shows part of the interior of one of the stock rooms.

The work of the Library has been described previously in this Magazine¹, but after a lapse of 14 years some recapitulation may not be out of place. Its aim is still largely the same—"to be of the utmost assistance to all members of the Meteorological Office, by acting not only as a repository of books, but also as an information bureau". The first requirement in meeting this objective is a steady flow of new literature. This is achieved mainly by the exchange, mostly of an international character, of Meteorological Office publications with those of other institutions. Nearly 400 such exchange arrangements are in being at the present time. However, not all documents of value to the Library are published by institutions with whom we have exchange arrangements, so that such deficiencies are made good by purchase. The second requirement, equally essential, is that the system of cataloguing shall be such that an inquirer can speedily find any document he wants, or can be given lists of references to papers on the subject in which he is interested. The cataloguing system adopted is very complete. The "author catalogue", already referred to, is an alphabetically arranged card index. There is a separate card under each author's name for every book, paper, etc., he has written, whether it appeared as a separate publication, or was one of a number of articles in a journal. Cards are duplicated or triplicated in the event that a document had two or three joint authors. This index also contains cards in relation to series issues of the various publishing bodies. The "author catalogue" therefore shows all the papers by a given author held in the Library, what institution was responsible for publication and where to find it on the shelves. The number of cards in the index is now about 120,000.

In addition, all books and papers are entered in at least one "subject catalogue", or permanent bibliography of meteorological and allied literature. Entries are made in chronological order under Universal Decimal Classification headings. Thus an inquirer asking what literature is available in the Library on the subject of, say, noctilucent clouds, would be referred to the entry 551.593.653 in the permanent bibliography, where he would find the author and title of every paper held on the subject. Special geographically arranged catalogues are also maintained for some of the more important subjects, i.e. climatology, synoptic climatology and upper air conditions.

Abstracts are not, at present, prepared in the Library, but short descriptive notes are added to many of the entries in the monthly bibliography which is a classified list of accessions to the Library in the particular month and which has a wide circulation.

There is only one full-time translator on the staff, engaged wholly on translating from the Russian. But translating is also done by a number of volunteers and paid linguists, whilst a number of translations are bought or exchanged, so that members of the staff may request the translation of papers in almost any language with the reasonable expectation that it will be done. This service cannot, of course, be provided for other than Office staff, but translations already held can be loaned in the same way as the original text.

But not all available literature is in normal printed form. There is therefore a room set aside for viewing microfilm, microcards and films. There is also a good collection of lantern and colour slides and of photographs in the Library for illustrating lectures or articles. All visual aids are available for loan to members of the staff and some may be hired by non-members for bona fide purposes.

So if you have a problem in which you think the literature or other facilities of the Library can be of assistance, do not hesitate to ask. It is the purpose of the Library not only to collect meteorological papers and information, but also to ensure that the greatest amount of information may be obtained from them.

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MATHEMATICS AND METEOROLOGY

By E. KNIGHTING, B.Sc.

The journals of applied mathematics and meteorology have always contained papers written about meteorology and using mathematics; in the nineteenth century Helmholtz, Kelvin and Bjerknes spring to mind. And yet meteorology was not in the main a quantitative science and there was no coherent mathematical theory. Of course, special branches employed quantitative reasoning, such as turbulence theory which in the two decades following World War I was expressed in the form of differential equations. Nevertheless, the meteorological journals of twenty years ago were mainly descriptive. In the last two decades meteorology has emerged as a quantitative science in nearly all its aspects, and this is reflected in the journals where it is now almost impossible to pick up a current number which does not contain articles which are formidably mathematical in content. The scope of the mathematics is wide, ranging through matrix theory, tensor analysis, differential equations, etc. Additionally, the use of electronic computers has become commonplace in meteorological research and a knowledge of computational methods, not only in the solution of differential equations but also in statistics and many other branches, has become part of the meteorologist's equipment. This emergence as a quantitative science has made it necessary for meteorologists to note books which are not primarily of meteorological interest; in the case of the two books under review,* they are primarily of mathematical interest, the first being a text on differential equations and the second on computational methods. Both of these subjects are currently of great interest to meteorologists.

* *Differential equations for engineers and scientists*, by C. G. Lambe and C. J. Tranter. 8 $\frac{3}{4}$ in. \times 5 $\frac{1}{2}$ in., pp. xii + 372, *illus.*, English Universities Press Ltd., London, 1961. Price: 30s.

An introduction to computational methods, by K. A. Redish. 10 in. \times 7 $\frac{1}{2}$ in., pp. xii + 211, *illus.*, English Universities Press Ltd., London, 1961. Price: 30s.

Differential equations abound in the literature of meteorology and it would scarcely be possible to read much of the modern work without a considerable background knowledge of the subject. Certain books acquire a "classical" reputation and among general texts on differential equations Piaggio's book has this reputation. Any book which seeks to cover much the same field must invite comparison. Moreover, the field covered by such books must have a common content, for there is a body of knowledge common to most of the physical sciences which essentially expresses the balance between forces and accelerations and therefore gives rise to second order differential equations. It is no accident, then, that books on differential equations written for engineers and scientists should be largely concerned with second order equations, whether ordinary or partial. The first two chapters of Lambe and Tranter's text probably have less physical content than the remainder because they deal with preliminary ideas and first order equations. The third and fourth chapters deal with linear differential equations with constant coefficients and the methods of integration are the classical ones stemming from Euler with the particular integrals obtained by inversion of the linear differential operator. The first parts of each of these chapters are, of course, simply mathematical and provided with plenty of exercises. The later parts are much more physical in content and deal with the sort of problems which give rise to these second order equations, such as vibrations of elastic springs, electric circuits and a good explanatory section on servomechanisms. These sections are more extended than the corresponding examples on physical systems in Piaggio, which are confined to the end-of-chapter exercises. The meteorological applications of these chapters will probably be mostly in instrument theory.

When the second order differential equations do not have constant coefficients the operator methods of solution are rarely practical and recourse is usually made to solutions in series. The systematic use of such methods is due to Frobenius and Fuchs (*c.* 1870), although series solutions had been used much earlier. Many of the well known functions in mathematics are definable by series (e.g. $\cos x = 1 - x^2/2! + x^4/4! \dots$) and this important chapter is well presented and includes a sketch of the hypergeometric function. It is difficult to assess where such knowledge will be required, but as examples the confluent hypergeometric function arises in considering the statistics of winds and the hypergeometric function in the vertical transfer of energy in the atmosphere. Not having included a chapter on miscellaneous methods of solving such equations, for example by the method of variation of parameters, the authors have inserted in this chapter almost irrelevantly, the Wronskian theorem. It must be exceedingly difficult to collate the material for a text on differential equations and both this text and Piaggio's have information which belongs to no particular part of the development scattered about in odd places.

Lambe and Tranter devote a complete chapter to some special functions and in it they treat Legendre, Bessel and various Jacobi polynomials as well as those of Hermite and Laguerre—a much more complete treatment than that of Piaggio, whose information is mainly scattered in examples. The meteorological necessity for such information is too varied to more than indicate Legendre functions in representing a field over the earth's surface (although one will want more than is given here to follow the development) while Bessel functions, like elliptic integrals, are ubiquitous and both occur in the statistics of winds.

Čebyčev* polynomials are also now creeping into various statistical and representational problems, to say nothing of computational mathematics. This is a very good chapter and an excellent introduction to the more specialized texts. It is also the basis for the text in the following chapter dealing with partial differential equations.

Meteorology naturally gives rise to partial differential equations since one of the central sets of equations is the Navier-Stokes set, expressing the dynamics of fluid motion. The chapter given here deals only with second order linear partial differential equations arising from physical problems. One may regret the omission of first order partial differential equations, which are basic for thermodynamical considerations, but selection of material must be judicious and the large number of worked physical examples is valuable; the way in which special functions arise in the solution of Laplace's equation and its generalizations is made clear.

The use of integral transforms in solving differential equations is one of the most powerful methods developed over the last sixty years and is the subject of a vast literature. In meteorology the method has been used with increasing frequency in recent years, the Fourier transform in problems concerning gravity waves, the Laplace transform in problems of micrometeorology and the Bessel transform in some considerations of the optimum distribution of observing stations. Dr. Tranter is a well known expert in this field and as expected the chapter is clear and concise. One notes, however, that there is no mention of treating two point boundary problems by use of the Laplace transform. Would it be too revolutionary to sweep away the differential operator methods given earlier and replace them by a consistent use of the Laplace transform? One notes also with regret that the authors decided against including the use of Laplace transforms in the solution of partial differential equations, because the list of transforms would be excessively long: Carslaw and Jaeger (*Operational methods in applied mathematics*) used a quite short list, in solving numerous problems.

The formal methods of solving differential equations, expressing the answer in some closed form or as a series of identifiable functions, can really only be applied to simple equations; the equations that one wishes to solve in practice are rarely simple. Moreover, the formal solution itself may in practice be very difficult to evaluate numerically, or may indeed be in an unsuitable form for computation. In many cases the only practical way of solving the differential equation, or indeed any equation, may be by direct numerical methods. This has, of course, long been recognized and one of the earliest examples in meteorology is that of computing corrections to ballistic range tables due to the departures of wind and temperature from some standard state. The current uses of numerical methods in meteorology are too numerous to mention, but it is well known that the equations predicting the pressure distribution are solved numerically and that no other way is possible. Mr. Redish's book deals, among other subjects, with the numerical solution of differential equations as does the book of Drs. Lambe and Tranter. It should be said at once that the treatment given by Lambe and Tranter is adequate as an introduction and rounds off their text apart from a valuable chapter on non-linear equations.

*[Often written Tchebychev, or other variants, in mathematical texts. *Ed.*]

The problems of numerical integration of differential equations are more complicated when one deals with partial differential equations. Ordinary differential equations, say of the second order, may have boundary conditions all given at the same point or some given at one point and some at another. If all the boundary values are given at one point the problem is a "marching problem" and reduces to constructing the solution near the boundary point for say four or five neighbouring points in order to get a start and then using these values to extrapolate a new value; the extrapolated value is then corrected by using the differential equation itself. This is precisely the process used in the meteorological ballistic problem. A variety of methods have been constructed for each of these processes, the crux lying in constructing an extrapolated value which requires little correction. Redish deals with a selection of these methods and illustrates them numerically. The author and publishers are to be congratulated upon the page size adopted for this book, which allows the numerical computations to be beautifully displayed without any crowding together.

If the boundary values are given at two different points then one has a "jury" problem, that is the solution must satisfy conditions at a set of points. One way of solving the problem is to guess another boundary condition at the first point and see how well the solution computed using this guess fits the boundary value at the second point, followed by a refined guess at the boundary condition; a meteorological application of this method lies in estimating the wavelength and amplitude of gravity waves. Perhaps the most obvious way is simply to make the differential equation in difference form and solve the simultaneous equations which arise and Redish deals well, if briefly, with this method of solution, which replaces the problem by that of selecting the best method of solving sets of linear equations.

It is the chapter on functions of two variables that will most interest meteorologists, who are likely to meet partial differential equations of the second order. Here the treatment is limited to elliptic equations and the method of solution to that of relaxation. This is, of course, a most effective method if the computations are to be carried out by hand and the number of equations is small. If the number of equations is large, that is the number of grid points at which the solution is to be obtained is large, then the work is prohibitive, even for experienced computers and to solve a pair of simultaneous equations may take months. The impact of the electronic computer on such computations is enormous. The methods used for the solution of partial differential equations are more elementary and would be time-wasting if used by hand; for example, a Liebmann-type process is far preferable to a relaxation process and perhaps one could complain that the author does not deal with such methods.

The first part of the book deals with the standard formulae of finite differences, interpolation, differentiation and integration. They are very clear, but do not present any new material. The author is careful in his warnings but does not draw attention to the dangers of using experimental information, for example in forming a derivative. One might have expected some discussion of smoothing of experimental data in a practical text, especially if aimed at the "occasional" computer. Additionally, there are chapters on simultaneous and non-linear equations, and a final chapter on miscellaneous methods.

One wonders what the ultimate impact of electronic computers will be on textbooks of mathematics. Even now one can solve a second order differential equation numerically without knowing anything about the methodology of either

differential equations or computing. Standard programmes exist for the solution of sets of first order differential equations which automatically suit the interval to the accuracy required; they also exist for many other processes such as solving sets of simultaneous equations or obtaining eigenvalues and eigenvectors. In the future, mathematical functions may no longer be tabulated in book form except in the description of the best method to use for computing over a given interval. Facilities for using electronic computers will undoubtedly spread to everyone at university level. Perhaps then the flow of new books will shrink as has that of books on geometry.

Both books are well produced. That of Drs. Lambe and Tranter is a serious rival to that of Piaggio, having a more physical outlook although it is less of a mathematicians' book and one would miss the useful results given in the latter's miscellaneous examples. One would also miss the references and perhaps the authors could be persuaded to add a bibliography to the next edition. It is not apparent from the text that books by Ince, Kamke, Von Mises, Courant-Hilbert, Bateman, to mention but a few, exist. I found Mr. Redish's book to be rather in the nature of lecture notes with a few irritating obscurities, for example on p. 174 "the nature of the equation may vary from point to point" and not "will vary". The printer has not been consistent in his symbols for partial derivatives. Nevertheless, it is a good, practical and useful book.

REVIEW

Das Klima der Vorzeit, by M. Schwarzbach, 9½ in. × 6½ in., pp. xi + 275, *illus.*, Ferdinand Enke Verlag, Hasenbergsteige 3, Stuttgart, 1961 (2nd edition). Price: geheftet DM 53.50, ganzleinen DM 57.

This book is an admirable guide to palaeoclimatology, handy in size, full of data presented wherever possible in figures (temperatures, rainfall, etc.) of direct significance to meteorology, illustrated by 134 aptly chosen pictures, maps and diagrams, succinctly written (in places in note form), yet with room for many a wise caution about sources of error and misinterpretation and more than a few shafts of humour. Though a second edition, it contains so much that is new that possessors of the 1950 edition will want the new one. The need for rewriting so soon of what had quickly become a standard work arises largely from the burgeoning of the subject brought about by the development of so many new tools—the O^{18}/O^{16} method of determining palaeotemperatures, C^{14} dating, palaeomagnetism studies and the sampling of cores taken from the ocean bed. It is still true, however, as the author says, that "no really satisfying explanation of climatic history can yet be given; though the theoretical hypotheses are interesting, and their numbers continue to mount, the main interest must still be focussed on the facts—or what geology counts as facts—that is to say the traces left by past climates".

The work starts with a few pages indicating the history of knowledge and ideas about palaeoclimatology from 1686, when from the finding of fossil tortoises in England Robert Hooke deduced the former existence of a warm climate and the possibility that the Earth's axis had shifted. The second chapter is on present-day climate and its relevance to palaeoclimatology. Here, in eight pages including several world maps, nothing more than a sketch of the basic framework of world weather and ocean currents is attempted and extra space might,

with advantage, have been given to introducing such elements as the role of the upper westerlies with their ridges and troughs and the variations of thermal stability and instability. Successive chapters are devoted to characteristic traces left by warm climates, cold climates, dry climates and wet climates, evidences of former average pressure and wind distribution, of regular seasonal changes and of climatic oscillations of various period lengths in the geological and more recent past. The middle section of the book (from p. 93 to 193) gives the known facts of climate and its distribution in successive geological epochs from the pre-Cambrian to the Quaternary, including a few pages on the post-glacial or Holocene. The final chapters survey the numerous, and often conflicting, theories with shrewd notes pro and con in each case, mustering a remarkable breadth of knowledge and a critical insight which does not fail to detect the fanciful and the far-fetched even in fields remote from the author's own (geology). Two pages at the end are devoted to an attempted synthesis which accepts as a probability that some variations of the radiation from the sun do occur and allows many secondary (terrestrial) influences affecting the receipt and redistribution of solar energy, especially through the relief and extent of land and sea; moreover, the author believes that the climatic history of epochs before the Tertiary cannot be explained without the assumption of shifting poles and drifting continents.

On a thorough reading the reviewer learnt a lot and found little to criticize and few misprints—perhaps the only confusing misprint is on p. 70 where the prevailing winds at the foot and top of Mt. Erebus have got interchanged. On p. 8 the extreme high temperature at Death Valley should be 56° not 50°C .

From the evidence presented, it appears that the meteorologist must take stock not only of warm and cold epochs in the Earth's history, but of some which were generally moist and others which were generally dry, of times of only low relief and others of high relief, of epochs when both poles were in an oceanic environment (maps pp. 113 and 135) and possibly of shorter epochs (geologically speaking) when both poles were on land. By now one is amazed at the extraordinary lengths to which Brooks was driven (pp. 201–2) to explain the Permo-Carboniferous glaciation without resort to changes in the positions of the poles. The traces of this glaciation are all in low latitudes today, and Brooks's explanation was based on very high plateau levels, combined with a geography that diverted the equatorial ocean currents towards the (warm) poles. The theory seems in any case at variance with the observed role of extensive high plateaux (for example, Tibet, Bolivia) in low latitudes today as raised heating surfaces. From this point it is reassuring to come to the much broader range of evidence in favour of polar wandering, etc. One notes (with Schwarzbach) the most obvious virtue of Ewing and Donn's ice-age theory in stressing the importance of the peculiar Arctic geography of the Quaternary with the pole in an almost enclosed sea.

Meteorological theories of climatic variations on shorter time-scales from the separate Quaternary ice ages and interglacials downwards are presented. These give an impression of a chartless maze until one comes to the radiation curves calculated by Milankovitch, and others since, on the basis of astronomical variables. But one is reminded that here too the firmest evidence (C^{14} dating) both before and since the last ice age does not clearly confirm the theory. "No one enjoys more peace of mind than he who has no opinion"—as one might translate a remark quoted by the author at this point!

The book is well indexed and has a 21-page bibliography which includes full titles—a valuable guide to further studies of the geological, botanical and other evidence and its interpretation. The work will be found very valuable by theoreticians who know nothing of the facts of past climates and by geologists and others working in the field who wish to know more of the picture so far built up.

H. H. LAMB

HONOUR

The following award was announced in the New Year Honours List, 1962:

B.E.M.

H. F. Clifton, Boatswain, Ocean Weather Ship *Weather Reporter*.

OBITUARIES

Charles Sumner Durst, O.B.E., B.A.—The news of the sudden death of Mr. C. S. Durst on Christmas Day, 1961, was a great shock to his many friends. Born in 1888, Durst graduated in mathematics at Pembroke College, Cambridge, in 1910. During the next nine years he served as a surveyor in the Malay States and, during the First World War, in the Royal Engineers in Gallipoli, Palestine and the Western Desert. In 1919 Durst joined the Meteorological Office and so started a career as a research worker which was to be distinguished by a steady output of original work, up to the time of his death. His field of interest was extraordinarily wide, ranging from aerial navigation to the efflux of gas in mines; it is described in more detail in the notice of his retirement from the Office in the issue of this Magazine for November 1957. During his service in the Meteorological Office his work earned him many marks of public recognition, the Buchan Prize of the Royal Meteorological Society in 1937, the award of the O.B.E. in 1946, a Groves Memorial Prize in 1949 and the Bronze Medal of the Institute of Navigation in both 1950 and 1956. Perhaps just as important as these prizes was the affection and respect he inspired in his colleagues. In 1953 Durst retired from his post as Assistant Director in the Office but remained on the staff for a further four years to continue his research work. In 1957 his official connexion with the Office came to an end. At an age at which most men are content to rest on their laurels Durst then started a career as an independent meteorological consultant which continued up to the time of his death.

During his lifetime Durst earned our respect for his wisdom, his wide range of knowledge and for his ever active mind. Combined with this respect was a deep affection for a man who was always ready to use his talents to help others.

In 1921 Mr. Durst married Miss Mary Helen Blakiston. To his widow and to their son and daughter goes the sympathy of his colleagues.

A. C. BEST

Mr. William Shannon.—It is with deep regret that we learn of the death on 5 January 1961 of Mr. W. Shannon, Senior Scientific Assistant, at the age of fifty-one. He joined the Office in October 1938 as a Technical Assistant, Grade III, and his first three and a half years were spent in the Forecast Division at Headquarters. From 1941 he served at numerous aviation outstations, mainly in the north of England and in Scotland. He also undertook tours of duty in Germany and Gan Island. At the time of his death he was

serving at Turnhouse. He is survived by a widow and three sons to whom the sympathy of all who knew him is extended.

Mr. Michael John Samways.—It is with deep regret that we learn of the death on 22 December 1961, as a result of a car accident, of Mr. M. J. Samways, Scientific Assistant, at the age of twenty-four. He joined the Office in October 1954, and all his service was spent at aviation outstations, including a tour of duty in Germany. At the time of his death he was serving at Upavon. He is survived by a widow and two children to whom the sympathy of all who knew him is extended.

Mr. Christopher James Oxley.—It is with deep regret that we record the death on 21 December 1961, as a result of a car accident, of Mr. C. J. Oxley, Scientific Assistant, at the age of twenty-one. He joined the Office in October 1959 and, apart from a short spell at Headquarters in the Observations and Communications Division, his service was spent at an aviation outstation, Scampton, where he was stationed at the time of his death. The sympathy of all who knew him is extended to his parents.

HONORARY DEGREE

We note with pleasure the award of the degree of D.Sc. *honoris causa* by the University of British Columbia to Mr. P. D. McTaggart-Cowan, M.B.E., Director of the Meteorological Service of Canada.

BOOK RECEIVED

Annual Meteorological Tables 1958, Falkland Islands and Dependencies Meteorological Service. 13 in. \times 8½ in., pp. iii + 167, Falkland Islands Dependencies Survey, Stanley, 1960. Price: £1.

METEOROLOGICAL OFFICE NEWS

Following a meeting of the Meteorological Research Committee at Bracknell on 21 November 1961, Professor H. Bondi gave a lecture on "Special Relativity". This was the first lecture to be given in the new lecture theatre, which was filled to capacity by members of the staff from headquarters and outstations.

CORRIGENDA

The key to Figure 4 on page 8 of the January 1962 *Meteorological Magazine* is incorrect. It should read:

○————○	initial radiosonde ascent
x-----x	actual ascent 24 hours later
●————●	predicted ascent 24 hours later

THE METEOROLOGICAL MAGAZINE

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551.555.3

OCCURRENCE OF FÖHN WINDS IN THE BRITISH ISLES

By J. G. LOCKWOOD, Ph.D.

Introduction.—The föhn is a warm dry wind that sometimes blows down Alpine valleys. The word has come to have a wider meaning to meteorologists, who use it to refer to any wind that has recently come across a mountain range, and in so doing has been warmed. Reports of the occurrence of föhn winds within the British Isles have been made by Mossman¹, McCaffery², Lawrence³ and Manley⁴. These authors have shown that föhn winds do occur in this country, but they do not attempt any detailed investigations into the problem of the nature and distribution of föhn winds. This paper gives the results of a small investigation into British föhn winds. In particular it is suggested that föhn winds in this country can arise from downcurrents associated with large-amplitude lee waves.

The problems associated with föhn winds.—The first tenable explanation of föhn was given by Hann⁵ in 1866, this being his now classic thermodynamic föhn theory. Moist air traversing a mountain range precipitates moisture while ascending the windward slopes and gains the latent heat released; subsequent descent of the air down the lee slopes takes place dry adiabatically and the air arrives at lower altitudes drier and warmer than it was at corresponding elevations during the ascent. This explanation is found today in many textbooks. The difficulty with Hann's theory is that in a stable atmosphere there is no reason why warm air having ascended a mountain range should descend and displace cold air on the lee side, moreover in cases of föhn there is by no means always evidence that precipitation occurred on the windward slope.

The descent of the warm föhn air, in a stable atmosphere, is the central problem concerning föhn. Although various theories⁷ have been advanced to explain the descent of warm föhn air, no satisfactory explanation has yet been achieved. The Austrian researchers, Hann⁵ and von Ficker⁸, simply considered, in the case of Alpine föhn, that the descent was an immediate consequence of the withdrawal of the cold surface air from the lee valleys, the mass of the Alps to the south preventing replacement from anywhere except aloft. Kuttner⁹, basing his conclusions on the results of sailplane flight data in Germany, stated that warmer air penetrates to the valley floors when, under certain conditions, standing waves are set up in the airflow downwind from the barrier and these attain sufficiently great amplitudes.

Hoinkes¹⁰ considers that northerly föhn can arise in the Alps when a cold front approaches from the north and comes to lie along the northern edge of the range. The föhn is regarded as due to flow down the upper surface of the cold front, the subsiding air carrying on across the mountain range and reaching the surface on the lee side. Scorer and Klieforth¹¹ suggest that föhn winds will occur if an airstream reaches a mountain, say on the arrival of a cold front, whose height exceeds the value of π/l in the airstream. In this expression l is the Scorer¹² stability parameter*.

The evidence for British föhn winds.—In this investigation a föhn wind was considered to be blowing if unusually high temperatures for the season of the year were reported from the immediate lee of an upland area. The high temperatures were normally restricted to the immediate lee of the upland area, and were considerably higher than those reported from the neighbouring lowlands. Using this criterion, it was possible to select six situations between 1944 and 1958, when föhn occurred with enough data to justify investigation. The dates selected are given in Table I. The number of föhn occurrences found was small because of the erratic nature of the phenomenon and the small number of observing stations in suitable mountainous locations. To these six examples was added an example of a föhn wind in 1901, in Glen Nevis, which was described by Mossman¹. Because of insufficient observational data, it was impossible to make any use of the two föhn examples described by McCaffery² and Lawrence³.

It is seen from Table I that föhn winds in the British Isles are most frequently observed to the north of the Cairngorms, in the counties of Nairn, Morayshire and Banffshire. There are few reports from the Lake District or from the Pennines, but this is probably due to lack of suitably placed observing stations rather than a real lack of föhn winds. It is from Scotland and North Wales that the data used in the investigation were mostly drawn. The data mostly consisted of hourly observations from airfields (such as Kinloss and Lossiemouth) and daily observations from climatological stations. Brief descriptions of the föhn winds used in the investigation are contained in Table I and descriptions of two typical examples of föhn are given below.

(i) *The föhn of 24 March 1945 in North Wales.*—A warm anticyclone was situated to the east of the British Isles, while a deep southerly airstream covered the country. This airstream was warm, dry and nearly cloudless. Föhn winds were reported along the North Wales coast. In Table II are reproduced hourly observations from some of the airfields in North Wales (see also Figure 1).

*The Scorer stability parameter, l , is defined by:

$$l^2 = \frac{g\beta}{U^2} - \frac{1}{U} \cdot \frac{\partial^2 U}{\partial Z^2}$$

where g = acceleration due to gravity

U = horizontal wind perpendicular to the mountain ridge

Z = the height measured upwards

$\beta = \frac{1}{\theta} \cdot \frac{\partial \theta}{\partial Z}$, where θ is the potential temperature.

Unless the wind shear is changing rapidly with height, $\frac{1}{U} \cdot \frac{\partial^2 U}{\partial Z^2}$ is small, and is usually ignored when calculating l^2 .

TABLE I—LIST OF BRITISH FÖHN WINDS BETWEEN 1944 AND 1958
USED IN INVESTIGATION

Date	Area	Notes on occurrence	Approx. value of π/l in the inversion layer* nautical miles	Average height of mountain range* nautical miles
23/3/45	North Wales and Scotland	Warm anticyclone situated to east of British Isles. Stable SE'ly airstream over North Wales, stable SW'ly airstream over Scotland. Föhn winds along North Wales coast and to north of Scottish Highlands.	0.6 (N. Wales)	0.5 (N. Wales)
24/3/45	North Wales	Warm anticyclone situated to east of British Isles. Stable SE'ly airstream over North Wales. Föhn winds along North Wales coast.	0.75	0.5
6/3/53	Aberdeenshire	Anticyclone centred over southern Britain. W'ly airstream over Scotland. Föhn wind at Huntly in morning.	0.8	0.7
12/3/54	Morayshire	Anticyclone over Scandinavia, low over Biscay. SE'ly airstream over Scotland. Föhn winds reported along Moray coast.	Wind speed in lower levels of Leuchars ascent too low to make it typical of airstream over Scottish Highlands. 0.6	0.7
15/10/56	Morayshire	Anticyclone over Scandinavia, low over Biscay. SSW'ly airstream over Scotland. Föhn winds reported along Moray coast.		
12/3/57	Morayshire	Anticyclone over Germany, low to SW of Ireland. S'ly airstream over Scotland. Föhn winds reported along Moray coast.	1.0	0.7

* See page 63.

Typical föhn characteristics are reported from the airfield at Llandwrog to leeward of Snowdonia. The start of the föhn on the morning of the 24th is very similar to the start of a föhn in an Alpine valley. At 0600 GMT there is calm, the temperature is 53°F and the relative humidity is 49 per cent; at 0700 GMT the

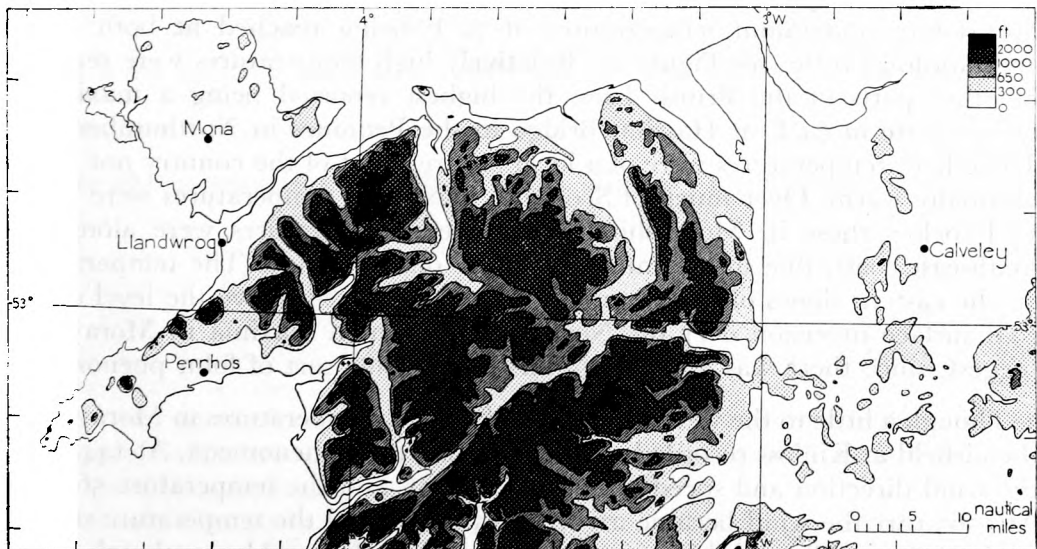


FIGURE I—LOCATION OF AIRFIELDS IN TABLE II

TABLE II—METEOROLOGICAL OBSERVATIONS FROM AIRFIELDS IN NORTH WALES
FOR 24 MARCH 1945

Llandwrog				Mona		
Time	Temperature	Relative humidity	Wind	Temperature	Relative humidity	Wind
GMT	°F	%	m.p.h.	°F	%	
0001	61	42	SSE 18	53	64	SE force 2
0100	61	42	SSE 18	52	63	SSE force 2
0200	59	38	SSE 15	52	74	SSE force 2
0300	58	42	SE 6	54	55	SSE force 2
0400	52	54	NE 9	51	56	SSE force 1
0500	52	55	NNW 4	52	56	SSE force 1
0600	53	49	Calm	48	60	SE force 2
0700	63	23	SSE 26	56	39	E'S force 2
0800	62	33	SSW 16	59	41	SW force 2
0900	64	34	S 26	63	42	S force 3

Penrhos				Calveley		
Time	Temperature	Relative humidity	Wind	Temperature	Relative humidity	Wind
GMT	°F	%		°F	%	
0001	53	71	SE force 4	51	82	SE force 2
0100	53	70	ESE force 4	48	86	SE force 2
0200	52	73	ESE force 4	48	84	SE force 2
0300	51	72	ESE force 3	48	86	SE force 3
0400	51	72	ESE force 2	47	85	SSE force 2
0500	51	73	ENE force 2	46	85	SE force 3
0600	52	63	NNE force 2	44	89	SE force 3
0700	50	73	Calm	46	87	SSE force 4
0800	56	57	E force 4	50	73	SSE force 4
0900	57	64	E'S force 5	54	61	SSE force 4

The term "force" in this table refers to Beaufort force.

wind speed is 26 miles per hour, the temperature has risen by 10°F to 63°F, and the relative humidity has fallen to 23 per cent. The suddenness of the arrival of the warm, dry air is one of the characteristics of Alpine föhn.

(ii) *The föhn of 12 March 1957 in north-east Scotland.*—On this occasion the highest temperatures in Scotland were recorded along the coast of Morayshire, maximum temperatures of 72°F being reached at both Elgin and Gordon Castle (see Figure 2). Relatively high temperatures were reached in other parts of the British Isles, the highest reported being a maximum temperature of 74°F at Haydon Bridge in the Pennines in Northumberland. These high temperatures were of a local nature, most of the country not being unusually warm. Over much of Scotland, maximum temperatures were up to 15°F below those in Morayshire. The lowest temperatures were along the south-east coast, due to the influence of the onshore wind. The temperatures on the eastern slopes of the Cairngorms were measured above the level of the cold surface inversion over the North Sea. The high maxima in Morayshire suggest, since there was a southerly airstream, some sort of föhn phenomena.

Though a little to the west of the zone of highest temperatures in Morayshire, the airfield at Kinloss recorded some interesting föhn phenomena. At 1444 GMT the wind direction and speed were 360°, 1 knot, and the temperature 56·1°F. At 1505 GMT the wind became 210°, 10–15 knots, and the temperature started to rise very rapidly, reaching 68·1°F at 1515 GMT. The sudden outbreak of the föhn so impressed the meteorological observers that they noted the above details

in the airfield meteorological logbook. The autographic records (see Figure 3) from Kinloss airfield provide further evidence for the suddenness of the arrival of the föhn.

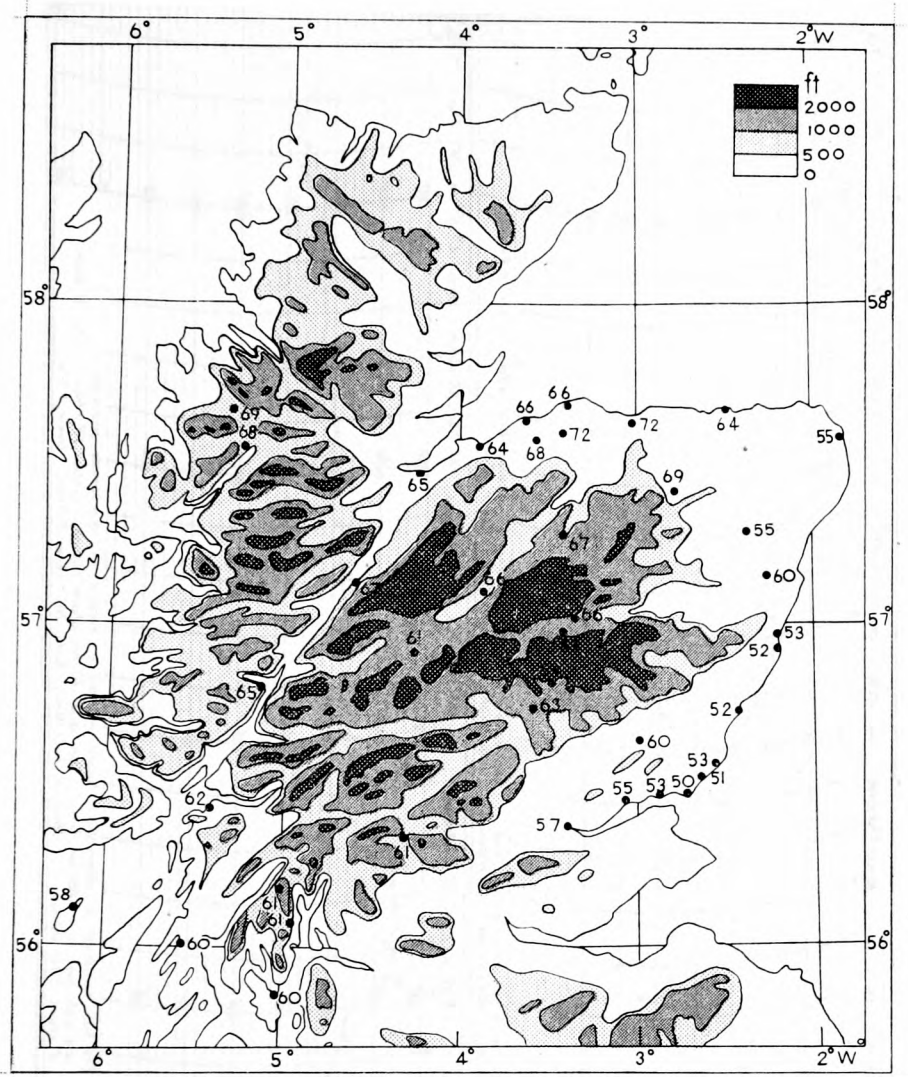


FIGURE 2—DISTRIBUTION OF MAXIMUM TEMPERATURES, 12 MARCH 1957

The characteristics of British föhn winds.—Investigation showed (see Table I) that the six British föhn winds considered were mainly associated with warm, dry, stable airstreams, there often being a warm anticyclone in the neighbourhood of the British Isles. In the six föhn winds considered and also in the föhn wind described by Mossman¹ in Glen Nevis, there was either nil or negligible rainfall over the mountain ranges to windward. Therefore föhn theories, such as the 1866 theory due to Hann⁵, involving thermodynamic heating due to condensation and rainfall over the mountains to windward, do not apply. This is not a new discovery; many recent writers^{9, 10, 11} on föhn winds have come to a similar conclusion.

In the six föhn airstreams described in Table I there was to windward of the mountain ranges marked stability from the surface to near a level corresponding to the top of the generating mountain range (see Figures 4, 5 and 6). Above this

layer there was a marked decrease in the stability. Scorer and Klieforth¹⁰ have suggested that föhn winds might occur if an airstream reaches a mountain whose height exceeds the value of π/l in the airstream. To test this theory the values of π/l were calculated for the surface inversion layer in five föhn airstreams (see Figure 4). The results are given in Table I.

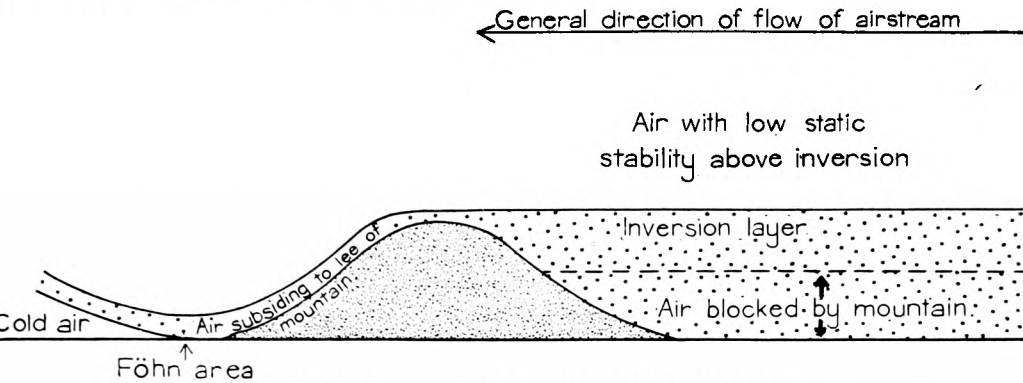


FIGURE 4—A TYPICAL FÖHN AIRSTREAM

The method used to calculate the values of l was that suggested by Corby¹³. The average value of $g\beta$ through a layer of suitable thickness (normally 50 mb) was measured using a scale. The average value of l^2 through the layer was then obtained by dividing $g\beta$ by the square of the average wind speed through the layer. The process is then repeated for the remaining layers. Unless the wind shear is changing rapidly with height, the value of $\frac{1}{U} \frac{\partial^2 U}{\partial z^2}$ is small and is usually

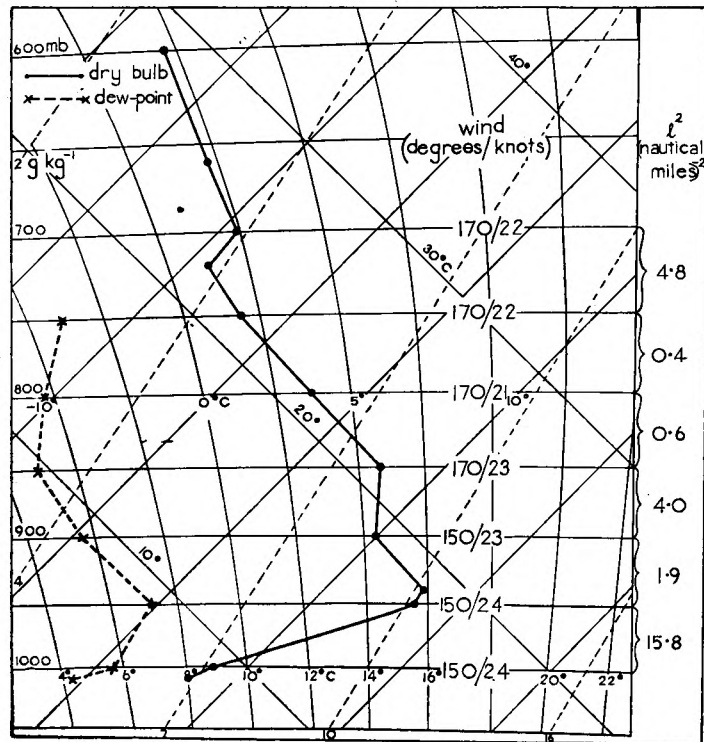


FIGURE 5—TEPHIGRAM FOR LIVERPOOL, 0600 GMT, 24 MARCH 1945, WITH WIND AND VALUES OF l^2

neglected in calculating l . To calculate l a radiosonde ascent near to the area of föhn winds was used and where possible was chosen upwind of the mountains. The Liverpool ascent was used for the North Wales föhn and Leuchars for the Morayshire föhns. Because of the distance of Leuchars from Morayshire, the ascent cannot be regarded as being completely typical of the airstream over the Cairngorms, but it is the best available.

It is seen from Table I that the values of π/l are usually approximately equal to or slightly greater than the height of the generating mountain range. With the mountain height greater than π/l , Scorer and Klieforth¹¹ suggest that the lower layers of the airstream might be blocked and become stationary with the upper layers descending to the surface on the lee side of the mountain. There is some evidence from the observations that even when the heights of the mountains are slightly less than π/l the lowest layers of the inversions considered did not flow across their respective mountain ranges.

The l^2 profiles to windward of the mountains in five föhn airstreams were examined. Two examples are shown in Figures 5 and 6. In each case the value of l^2 decreased with height. The value of l^2 is always greatest in the inversion layer and low in the layer immediately above. Now according to Corby and Wallington¹⁴ these conditions could be suitable for large-amplitude lee waves in the inversion layer. It is known from aircraft reports that very large-amplitude lee waves can occur in inversion layers. Kuttner⁹, using sailplane flight data, has already suggested that föhn winds might be partly due to large-amplitude lee waves.

It is suggested therefore that föhn winds in this country arise from two main causes. Firstly, there is some subsidence of the upper layers to the surface, in the lee of the mountains, due to the blocking of the lower layers of the airstream by the mountain range. Secondly, the subsidence to leeward is probably aided by the downcurrents arising from the presence of large-amplitude lee waves in the upper part of the low-level inversion layer. From the six föhn winds examined, it appears that a wind speed of at least 15 knots throughout the first 10,000 feet of the atmosphere is necessary for the production of marked föhn winds. The maximum temperatures reached in the föhn winds were usually about equal to the potential temperature just below the top of the stable surface layer.

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STRATOSPHERIC WIND REVERSALS OVER NANDI, FIJI

551.557.33

By E. FARKAS

New Zealand Meteorological Service

Introduction.—The wind régime of the equatorial stratosphere has recently received some attention^{1,2,3} in conjunction with the discovery of an apparent two-yearly fluctuation in the zonal component of wind at various equatorial stations. At some of these stations the change-over from easterly to westerly wind components, and vice versa, occurred first at the highest levels and appeared progressively later at lower levels, the phenomena becoming less distinct and regular in the low stratosphere. The purpose of this note is to draw attention to a similar apparent periodicity in the stratospheric zonal wind components at Nandi, Fiji ($17^{\circ}45'S$, $177^{\circ}27'E$).

Data.—The period covered by the observations commences in October 1951 for the 50 mb level, in January 1953 for the 30 mb level and in June 1957 for the 20 and 15 mb levels. Data have been analysed up to July 1961 for all levels except the 15 mb level, for which satisfactory data are not available beyond April 1961. The number of observations above the 30 mb level falls off rather rapidly with height and in most cases monthly averages at the highest level are based on less than 10 observations. However, it appears that in the high stratosphere even these sparse data are sufficient to give a reasonably adequate indication of the magnitude and direction of the average zonal component of wind in each month. Figure 1 shows monthly mean zonal wind components for several stratospheric levels (50 mb and above) for the above period. Monthly means based on less than 10 observations are marked by crosses. Figure 1 also shows 12-monthly running means of the monthly mean zonal wind components. This serves the purpose of filtering out of the record the seasonal and annual variations. These are more pronounced at a subtropical station such as Nandi than they are in the equatorial regions³.

Discussion.—The following points may be seen from Figure 1.

- (i) At all levels analysed an approximate two-yearly fluctuation of the monthly mean zonal winds existed during the period covered by the observations. This fluctuation is manifest at the 15 and 20 mb levels in the alternation between easterly and marked westerly wind components during every second (southern hemisphere) winter from 1957 onwards. Westerly zonal wind components occurred during one or two winter months in 1953, 1955, 1957, 1959 and 1961 at the 30 and 50 mb levels also, but at these lower levels westerly components also occurred in July 1958 and June 1960. However, even at these levels an approximate two-yearly periodicity in the magnitude of the (southern hemisphere) late summer easterly components may be seen from January 1955 onwards.
- (ii) No significant phase shift of the zonal wind fluctuations appeared between the levels analysed.
- (iii) At levels above 30 mb the occurrence of the wintertime westerly components at Nandi coincided with the occurrence of westerly wind régimes in the equatorial stratosphere,^{1,2,3} while in the years when easterlies prevailed over the equator, only a decrease in magnitude of the mean easterly wind components during the winter months was observed at Nandi.

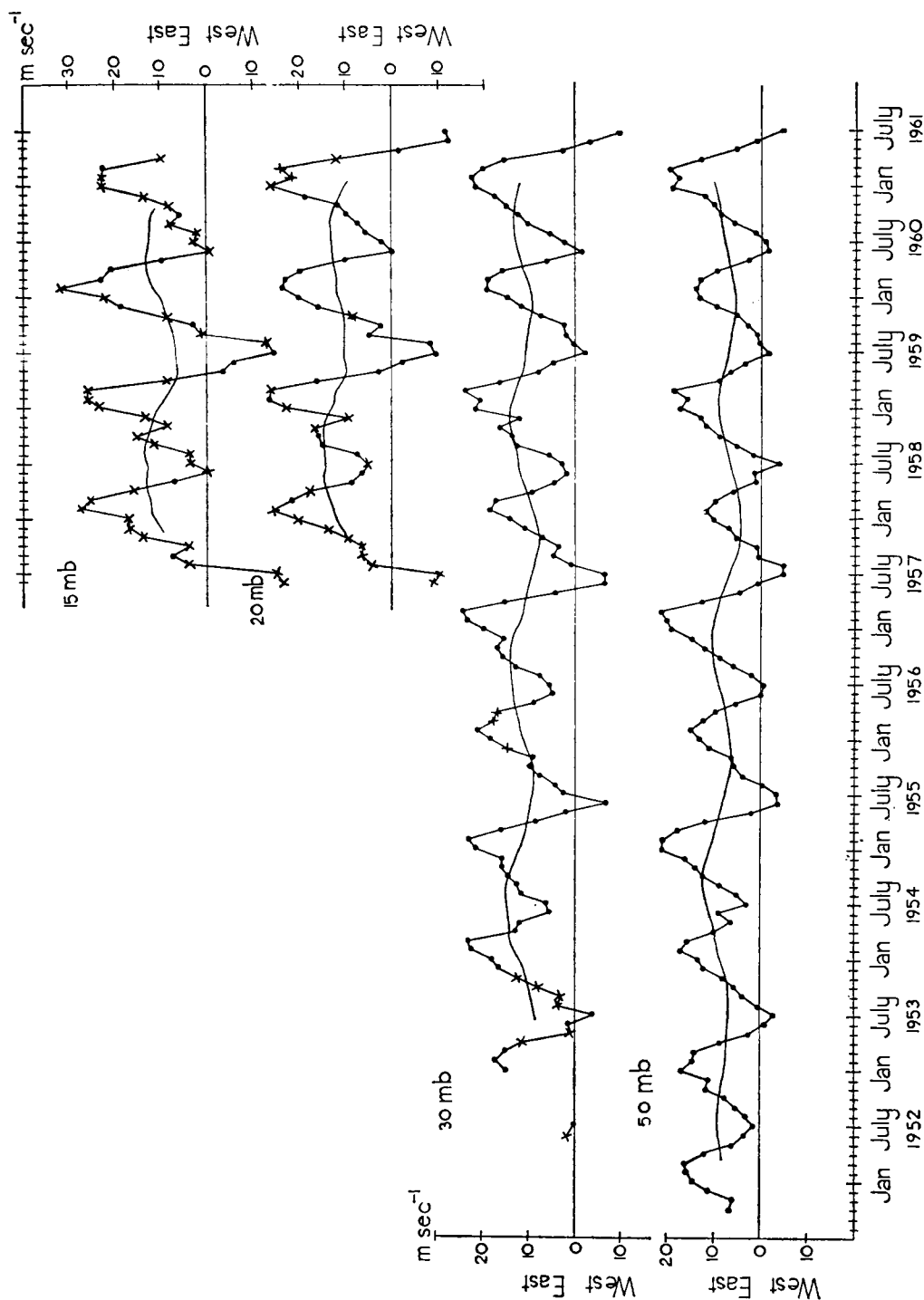


FIGURE 1—MONTHLY MEAN ZONAL WIND COMPONENTS AND THEIR 12-MONTHLY RUNNING MEANS FOR NANDI, FIJI
 Monthly means based on less than 10 observations are marked by crosses.

Conclusion.—At Nandi the analysis of nearly 10 years of wind observations for the 50 and 30 mb levels and $4\frac{1}{2}$ years for the 20 and 15 mb levels shows that the two-yearly zonal wind fluctuation found in the equatorial stratosphere also exists in the stratosphere over Nandi. However, at Nandi, the small amplitude of the two-yearly fluctuations of the mean zonal wind components at all levels analysed, as compared with the corresponding amplitudes observed in the equatorial regions, makes it likely that Nandi, although clearly influenced by the prevailing equatorial wind régime, lies fairly close to its southern boundary.

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551.5:526.8

CONSTRUCTION OF MAPS AND CHARTS USED IN METEOROLOGY

By P. B. SARSON, M.A.

The standard projections of maps and charts recommended for meteorological use¹ are

Mercator projection (for maps near the equator) with scale true in latitude $22\frac{1}{2}^\circ$.

Lambert's conformal conic projection with two standard parallels at 30° and 60° or 10° and 40° .

Polar stereographic projection (circumpolar maps) with scale true in latitude 60° .

All these projections are orthomorphic so that, even though the scale varies with latitude, the scale at any individual point is the same in all directions thus preserving shape over small areas with no distortion of direction locally. Since meridians and parallels are both straight lines intersecting at right-angles, the normal Mercator projection has the additional property that all straight lines are rhumb lines, that is, lines of constant bearing. Construction of the charts on Mercator and stereographic projections offers little difficulty when once the distances between different parallels of latitude have been calculated. In constructing a conic projection, however, particularly those on a larger scale, it is usually necessary to calculate the intercepts of the meridians with the borders of the chart (because even a beam compass has limitations in size and accuracy) and also the intercepts of the parallels along the meridians. The scale at each latitude is also required.

If s is the scale at the standard latitude (s) of each chart, ϕ the latitude, R the earth's radius, s_ϕ the scale at latitude ϕ , d_ϕ the distance (on the chart) from the equator in Mercator projections, and from the pole in the other projections, and ϕ_1 the latitude of the standard parallel in the Mercator, ϕ_2 and ϕ_3 the latitudes of the standard parallels in the conic and ϕ_4 the latitude of the standard parallel in the stereographic projections, then the required formulae are:

Mercator projection

$$s_\phi = \frac{\cos \phi_1}{\cos \phi} s$$

$$d_\phi = R s \cos \phi_1 \log_e \tan \left(\frac{\pi}{4} + \frac{\phi}{2} \right)$$

Lambert's conformal conic projection

k is the constant of cone (semi-vertical angle = A), that is

$$k = \sin A = \frac{\log_e (\cos \phi_2 / \cos \phi_3)}{\log_e \left\{ \tan \left(\frac{\pi}{4} - \frac{\phi_2}{2} \right) / \tan \left(\frac{\pi}{4} - \frac{\phi_3}{2} \right) \right\}}$$

$$s_\phi = \frac{\cos \phi_2}{\cos \phi} \left\{ \frac{\tan \left(\frac{\pi}{4} - \frac{\phi}{2} \right)}{\tan \left(\frac{\pi}{4} - \frac{\phi_2}{2} \right)} \right\}^k = \frac{\cos \phi_3}{\cos \phi} \left\{ \frac{\tan \left(\frac{\pi}{4} - \frac{\phi}{2} \right)}{\tan \left(\frac{\pi}{4} - \frac{\phi_3}{2} \right)} \right\}^k$$

$$d_\phi = \frac{\cos \phi_2}{k} \left\{ \frac{\tan \left(\frac{\pi}{4} - \frac{\phi}{2} \right)}{\tan \left(\frac{\pi}{4} - \frac{\phi_2}{2} \right)} \right\}^k = \frac{\cos \phi_3}{k} \left\{ \frac{\tan \left(\frac{\pi}{4} - \frac{\phi}{2} \right)}{\tan \left(\frac{\pi}{4} - \frac{\phi_3}{2} \right)} \right\}^k.$$

The angle on the chart between longitudes λ_1 and λ_2 is

$$(\lambda_1 - \lambda_2) \sin A = k (\lambda_1 - \lambda_2).$$

Polar stereographic projection

$$s_\phi = \frac{1 + \sin \phi_4}{1 + \sin \phi} s$$

$$d_\phi = R s \tan \left(\frac{\pi}{4} - \frac{\phi}{2} \right) (1 + \sin \phi_4).$$

Gnomonic projection.—One further projection is used meteorologically. This is the gnomonic projection with the valuable property that all great circles on the globe are reproduced as straight lines and vice versa. This is a perspective projection from the centre of the earth on to a tangential plane. The chart is seen as if from the side of the plane opposite to the centre of the globe. The chart is quite easy to construct if the tangential plane touches the earth's surface at the pole. However, in practice, for use in thunderstorm location, the oblique case is required and the tangential point (O in Figure 1) may be anywhere on the earth's surface. Meridians (being great circles) are reproduced as straight lines through the pole, the equator is a straight line at right-angles to the meridian through the tangential point and all other parallels are either ellipses or hyperbolae.

The scale of a gnomonic chart increases with distance from the tangential point, becoming infinite at a distance equal to a quarter of the globe's circumference. Figure 1 shows some of the triangles used to determine the more

important formulae needed to construct a gnomonic chart. C is the centre of the earth and O is the tangential point of the projection on which P is the pole and EE_λ is the equator on the chart. The co-ordinates of O are ϕ_0 and λ_0 . For any general point G (ϕ , λ) the projected point is G' . α is the angle on the chart

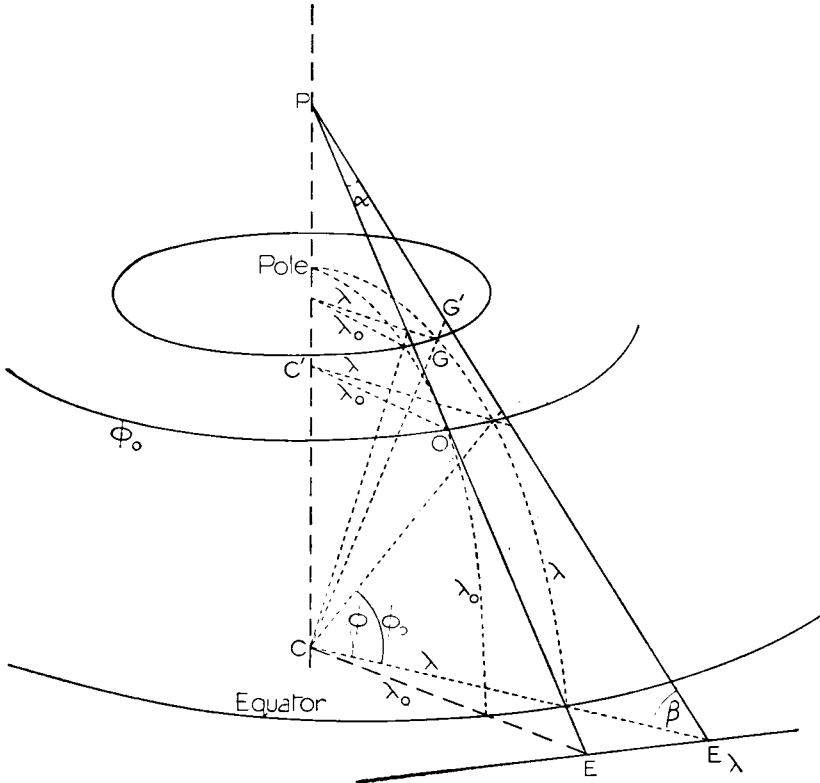


FIGURE I

between longitudes λ and λ_0 ; β is the angle between the longitude λ (on the chart) and the line drawn from latitude 0° on longitude λ to the centre of the earth. The formulae are:

$$\begin{aligned}
 PE &= 2Rs \operatorname{cosec} 2\phi_0 \\
 \tan \alpha &= \tan (\lambda - \lambda_0) \sin \phi_0 \\
 \tan \beta &= \cos (\lambda - \lambda_0) \cot \phi_0 \\
 PE_\lambda &= \frac{Rs}{\sin \beta \sin \phi_0} \\
 PG' &= \frac{Rs \cos \phi}{\sin \phi_0 \sin (\phi + \beta)} \quad \dots (1) \\
 G'E_\lambda &= \frac{Rs \sin \phi}{\sin (\phi + \beta) \cos \phi_0 \cos (\lambda - \lambda_0)} \quad \dots (2)
 \end{aligned}$$

Formula (1) leads to inaccuracies for tangential points near the equator; formula (2) leads to inaccuracies for tangential points near the pole; and it is best to use one or the other formula, depending on the position of the tangential point.



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PLATE I—METEOROLOGICAL OFFICE, ROYAL AIR FORCE, FELIXSTOWE

The wooden building on the left is the earliest office from 1918–28. The brick building on the right was used from 1929–37.

(see p. 81)



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PLATE II—METEOROLOGICAL OFFICE, ROYAL AIR FORCE, FELIXSTOWE

This office was occupied from 1937–61.

(see p. 81)

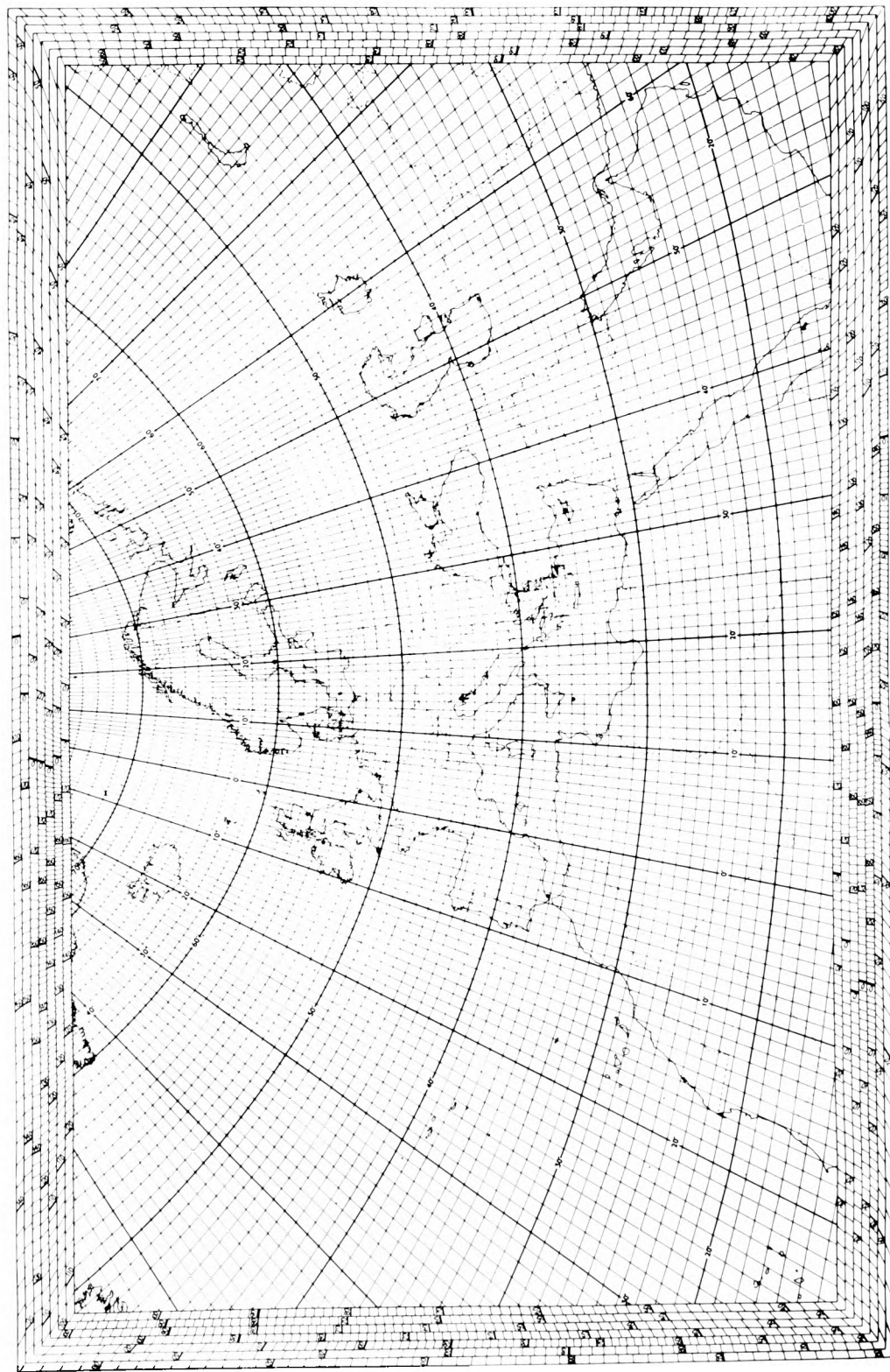


FIGURE 2—OBLIQUE GNOMONIC PROJECTION

The tangential point is at the centre of the chart (45° 48' N, 15° 58' E). The direction roses, in succession outwards from the edge of the chart, are centred on: Hemsby 52° 41' N, 1° 41' E; Shanwell 56° 26½' N, 2° 52' W; Longkesh 54° 29' N, 6° 06' W; Camborne 50° 13' N, 5° 19' W; Gibraltar 36° 09' N, 5° 21' W; Malta 35° 50' N, 14° 27' E; Nicosia 35° 09' N, 33° 17' E

For SFLOCS use, the bearings of a lightning flash from several points on the chart are plotted almost instantaneously. It is therefore necessary to draw direction roses round the borders of the chart, one for each SFLOCS station, as in Figure 2. The chart is not orthomorphic, and therefore the angles between the corresponding bearing and the sides of the chart have to be calculated for every required bearing round the compass. If e and e' are the chart distances of the SFLOCS station from the polar and western edges of the chart, a' and b' are the similar distances for the tangential point, and δ is the angle between the bearing required and the meridian through the SFLOCS station, the formulae are:

$$\left. \begin{aligned} e &= \frac{Rs \cos \phi \sin \alpha}{\sin \phi_0 \sin (\phi + \beta)} + a' \\ e' &= Rs \left\{ \frac{\cos \phi \cos \alpha}{\sin \phi_0 \sin (\phi + \beta)} - \cot \phi_0 \right\} + b' \end{aligned} \right\} \begin{array}{l} \text{for stations} \\ \text{not near} \\ \text{the equator} \end{array}$$

or

$$\left. \begin{aligned} e &= Rs \left\{ \frac{\tan (\lambda - \lambda_0)}{\cos \phi_0} - \frac{\sin \phi \sin \alpha}{\cos \phi_0 \cos (\lambda - \lambda_0) \sin (\phi + \beta)} \right\} + a' \\ e' &= Rs \left\{ \tan \phi_0 - \frac{\sin \phi \cos \alpha}{\sin (\phi + \beta) \cos \phi_0 \cos (\lambda - \lambda_0)} \right\} + b' \end{aligned} \right\} \begin{array}{l} \text{for stations} \\ \text{not near} \\ \text{the pole} \end{array}$$

and the angle δ is given by:

$$\tan (\delta - \alpha) = \frac{\{\cos \phi_0 \cos \phi + \cos (\lambda - \lambda_0) \sin \phi_0 \sin \phi\} \sin T - \sin \phi_0 \sin (\lambda - \lambda_0) \cos T}{\cos T \cos (\lambda - \lambda_0) + \sin (\lambda - \lambda_0) \sin \phi \sin T}$$

where T is the true bearing of the lightning flash from the SFLOCS station.

These formulae are rather cumbersome to work out by hand and, before the use of electronic computers, the direction roses never were calculated. By choosing the tangential point near the centre of the network of SFLOCS stations the chart was assumed to be orthomorphic at each station. With stations in so small an area as the British Isles the errors are not large. With stations farther afield the errors may easily be as much as 10° . The graticule of such a chart as Figure 2 might take as much as three or four months' solid work to calculate using, as it is found necessary, six-figure mathematical tables. With METEOR the co-ordinates for each graticule on a map such as Figure 2 can be calculated and printed by the machine in a matter of 15 minutes, including the direction-rose borders.

REFERENCE

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551.509.317:551.509.324.2

DEVELOPMENT OF RAIN AHEAD OF AN UPPER TROUGH

By T. A. M. BRADBURY

Introduction.—During the afternoon of 7 April 1961 there was a rapid development of rain over England ahead of an upper trough which moved eastwards across the country. The rear edge of the rain area coincided approximately with the upper trough line. It is suggested that the movement of this

trough controlled the development and subsequent movement of the rain area. The 300 mb contour chart is advocated as a useful guide to the probability of this kind of development.

Descriptive account of the outbreak of rain.—The surface chart for 1200 GMT on 7 April 1961 is shown in Figure 1. The main features are the

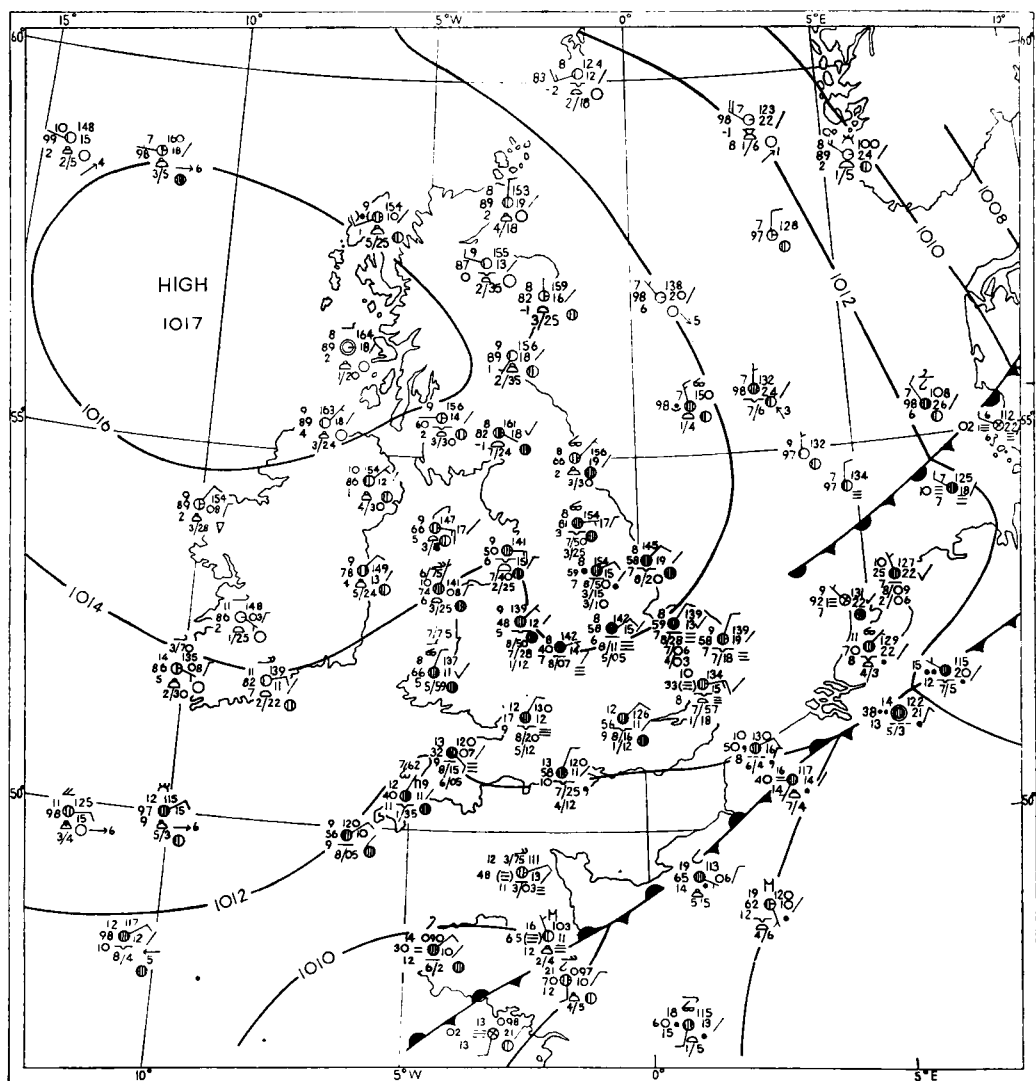


FIGURE 1—SURFACE CHART FOR 1200 GMT, 7 APRIL 1961

developing anticyclone approaching Scotland from the west, and a quasi-stationary front near the north coast of France. This front marked the southern boundary of a broad diffuse frontal zone which lay over the southern half of England. Earlier charts had shown a weak occlusion lying across England north of the quasi-stationary front and approximately parallel to it. However, the occlusion grew too weak to be located with confidence and was omitted from the official analysis.

At 1200 GMT the only rain reported over Great Britain was the small area of light rain near Finningley, and the rain there died out soon afterwards. The chart for 1500 GMT showed two new outbreaks of rain, one near Shawbury

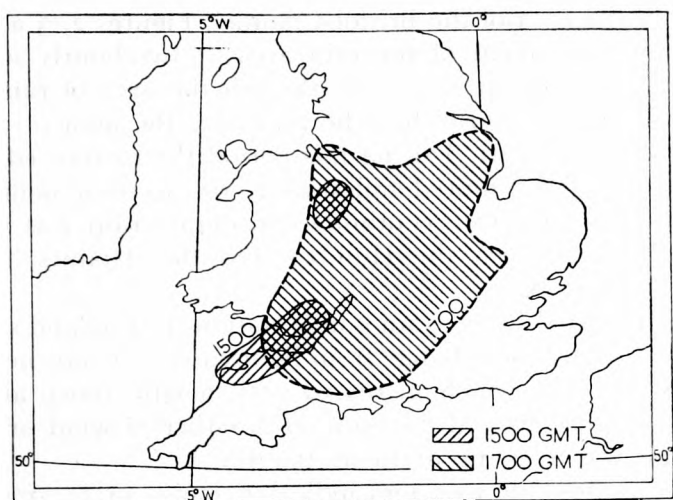


FIGURE 2—RAIN AREA FOR 1500 AND 1700 GMT, 7 APRIL 1961

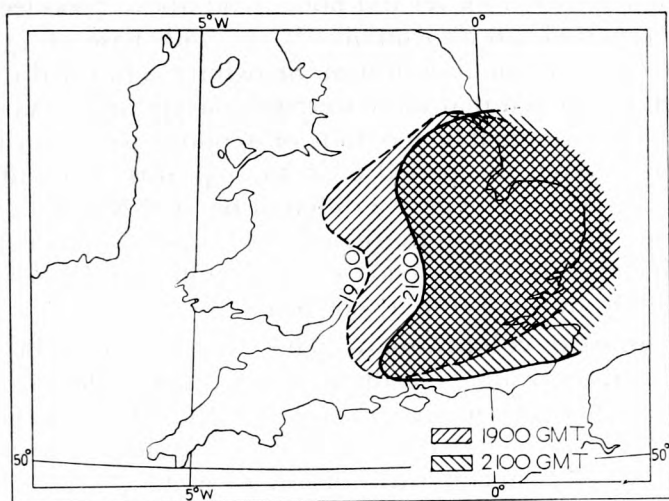


FIGURE 3—RAIN AREA FOR 1900 AND 2100 GMT, 7 APRIL 1961

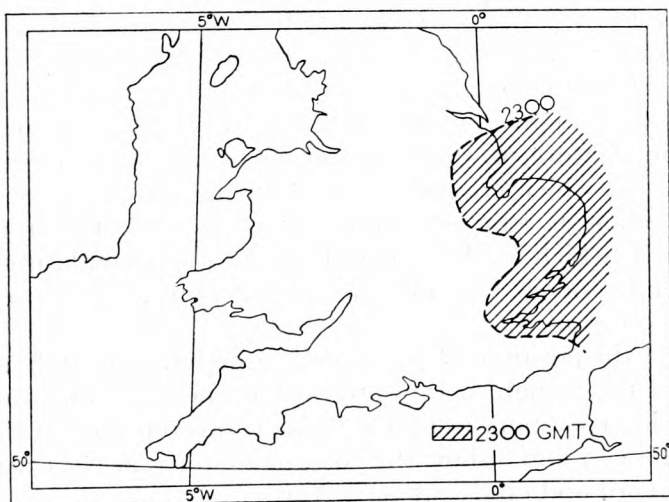


FIGURE 4—RAIN AREA FOR 2300 GMT, 7 APRIL 1961

By 0100 GMT, 8 April, rain had ceased over England.

and the other in the area of the Bristol Channel. Figures 2, 3 and 4 show the development and movement of the rain area at two-hourly intervals up to 2300 GMT on 7 April. By 0100 GMT on the 8th the area of rain was clear of eastern England. These charts show how rapidly the area of rain increased between 1500 and 1700 GMT. During this period the eastern edge of the rain area advanced about a hundred miles while the western boundary showed little movement. By 1900 GMT continuous moderate rain was reported by a number of stations between the Humber and the Thames, and from the Welsh border to Norfolk.

Upper winds reported by the radiosonde stations in England showed that at midday there was a gradual change from light easterly winds near the surface to a south-westerly flow which increased with height above about 850 mb. There were no marked frontal discontinuities either of wind or temperature. However, the air was moist up to about 350 mb.

Although the radiosonde messages indicated moist air to great heights the morning aircraft reports from Lincolnshire, East Anglia and also Ternhill showed that the main cloud layer did not extend above 7000 feet. An aircraft from Pershore reported 4/8 altocumulus layers with base at 13,000 feet and cirrus top at 26,000 feet. An aircraft from Shawbury confirmed the main cloud top at 7000 feet, but added that there were thin layers up to 35,000 feet. These higher layers were presumably too thin or tenuous to be measured. These morning reports covered the period 0845 to 1030 GMT. Aircraft observations made after the rain had begun gave a different picture. At 1800 GMT an aircraft from Honington reported that the cloud over East Anglia extended up to 27,000 feet with cirrus above. At 1930 GMT an aircraft from Cottesmore reported the cloud as solid from 500 feet to 27,000 feet.

Consideration of developments.—There had obviously been a considerable change since the morning, but the reason was not evident from the surface charts. Surface pressures continued to rise over the whole of the British Isles throughout the afternoon and evening. In the absence of a clearly defined frontal surface over England it was difficult to make use of a hodograph to establish up-slope motion, nor was there any clear sign of cold air “over-running” at high levels. In fact a comparison between the ascents from Hemsby for 1200 GMT on the 7th and 0001 GMT on the 8th showed little change in temperature or humidity in the air between 250 mb and 415 mb. From 415 mb down to the surface the temperatures were between two and three degrees Celsius colder at midnight than they had been twelve hours earlier.

The important feature on this occasion seems to have been the movement of an upper trough which crossed England during the afternoon and evening to reach eastern Norfolk soon after 0001 GMT on 8 April. The trough shows up best at 300 mb, at which level it was well marked between latitudes 49°N and 54°N. At 400 mb and at 500 mb the trough appeared at much the same position as at 300 mb.

Figure 5 shows the positions of the 300 mb trough line at six-hourly intervals. The positions of the trough at the intermediate hours of 0600 and 1800 GMT were drawn by interpolation, using the radar winds reported at these hours for guidance. Figures 6, 7 and 8 show the 300 mb contours at 0001 GMT on 7 April, 1200 GMT on 7 April and 0001 GMT on 8 April.

Comparison between the chart showing the movement of the upper trough and the charts showing the positions of the rain area demonstrates that the



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PRESENTATION OF L. G. GROVES MEMORIAL PRIZES AND AWARDS
(see p. 80)

Left to right: Mrs. K. J. Groves, Major K. J. Groves and Mr. E. Knighting.



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PRESENTATION OF L. G. GROVES MEMORIAL PRIZES AND AWARDS

(see p. 80)

Left to right: Senior Technician L. Hodgkinson, Squadron Leader J. M. Robertson, Mr. E. Knighting, Major K. J. Groves, Mrs. K. J. Groves, Air Marshal Sir Ronald Lees, Sergeant H. S. Carden and Flight Lieutenant R. J. K. Nicholas.

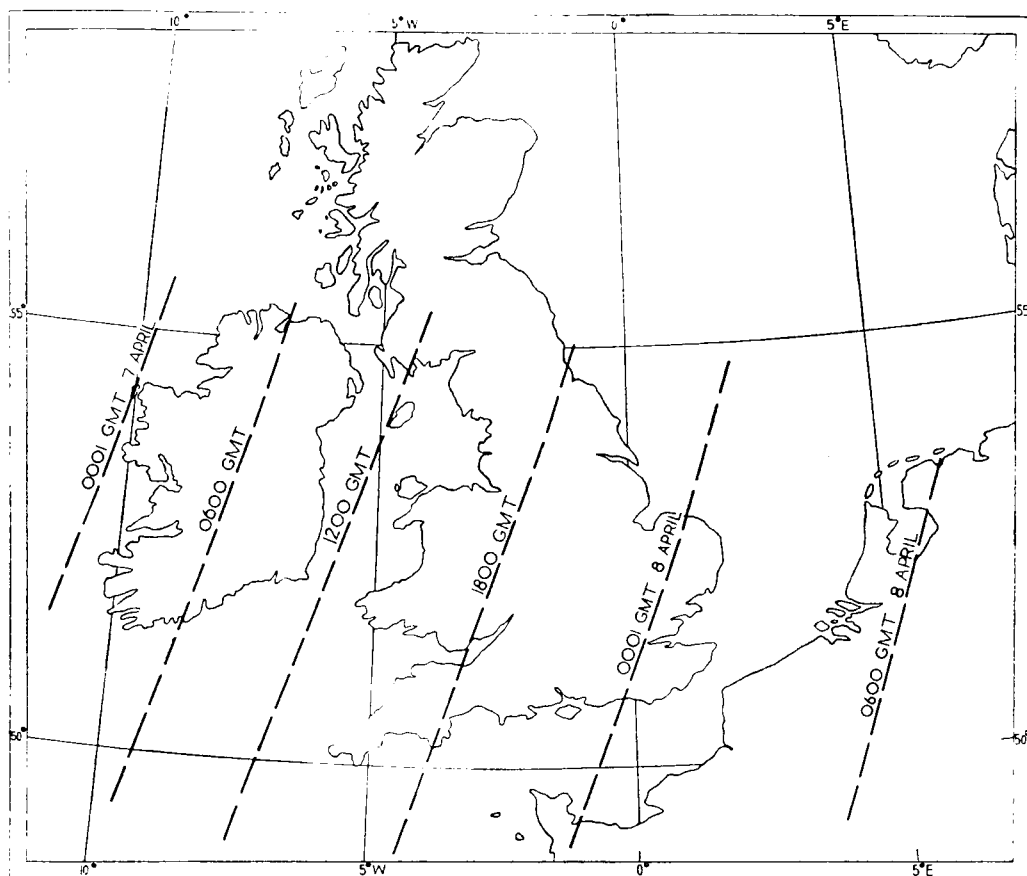


FIGURE 5—MOVEMENT OF 300 MB TROUGH LINE FROM 0001 GMT, 7 APRIL
TO 0600 GMT, 8 APRIL 1961

first outbreak of rain in the west occurred just ahead of the trough line and later extended more than a hundred miles in advance of the line. Within broad limits the rear edge of the rain was more or less coincident with the trough line.

It appears that in the region east of the trough line there was ascent of the already moist air mass. The Camborne upper air sounding for 1200 GMT on the 7th showed the air would have reached saturation at levels above about 750 mb after an ascent of 1000 to 1500 feet. West of the trough line the 1200 GMT upper air soundings from Aldergrove and Valentia both indicated regions of subsided air above the 850 mb level.

Cloud observations plotted on the 1200 GMT chart also showed a difference between the air on either side of the upper trough line. Over Ireland, then west of the trough line, there was no medium-level cloud and practically no cirrus. In contrast just east of the trough line there was an almost complete cover of medium or high cloud at Carlisle, Valley, Aberporth and St. Mawgan. The western edge of the medium and high cloud sheet was in this case nearly coincident with the line of the upper trough.

Three points suggest that the line of the upper trough was also the approximate boundary between regions of ascending and descending air in the middle troposphere.

- (i) The rain developed exclusively ahead of the trough line.
- (ii) The edge of the upper cloud observed at midday corresponded fairly

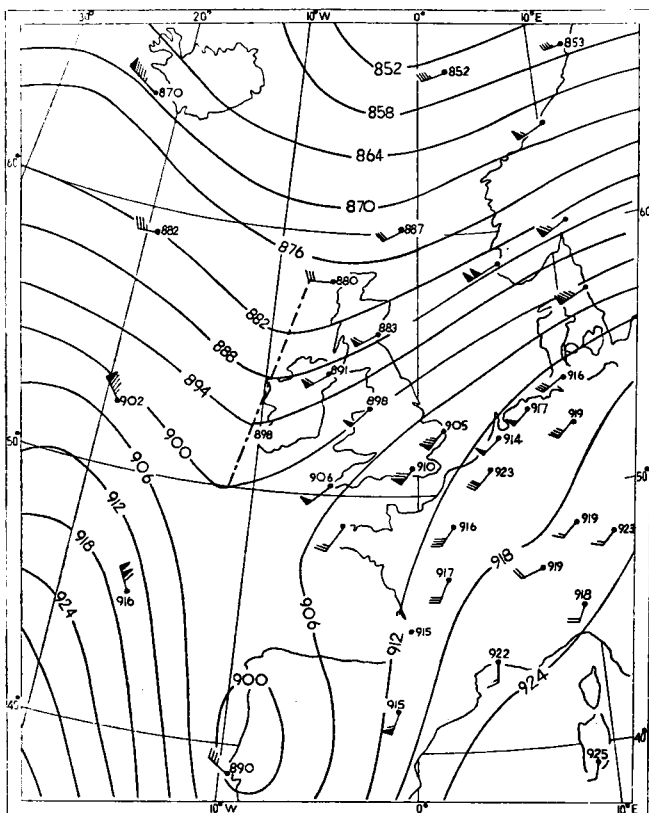


FIGURE 6—300 MB CONTOURS FOR 0001 GMT, 7 APRIL 1961

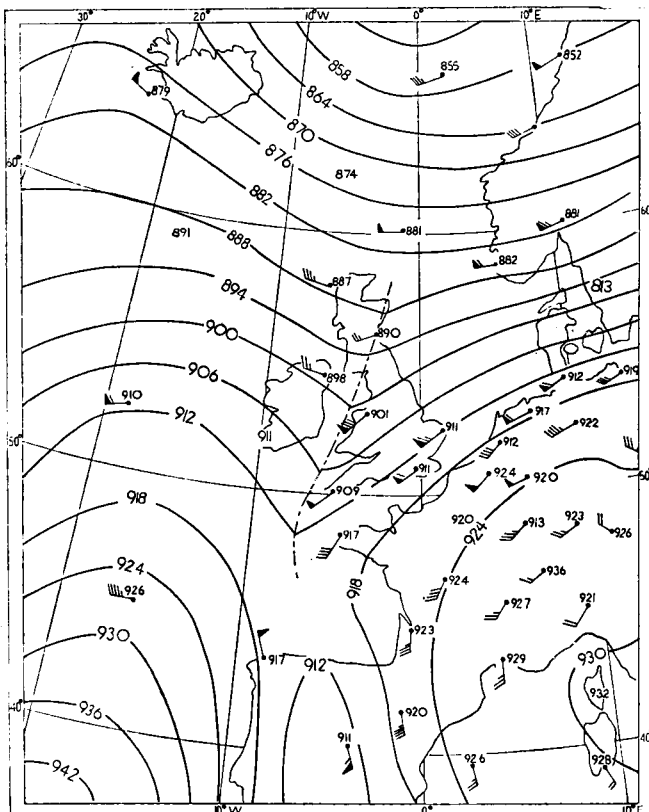


FIGURE 7—300 MB CONTOURS FOR 1200 GMT, 7 APRIL 1961

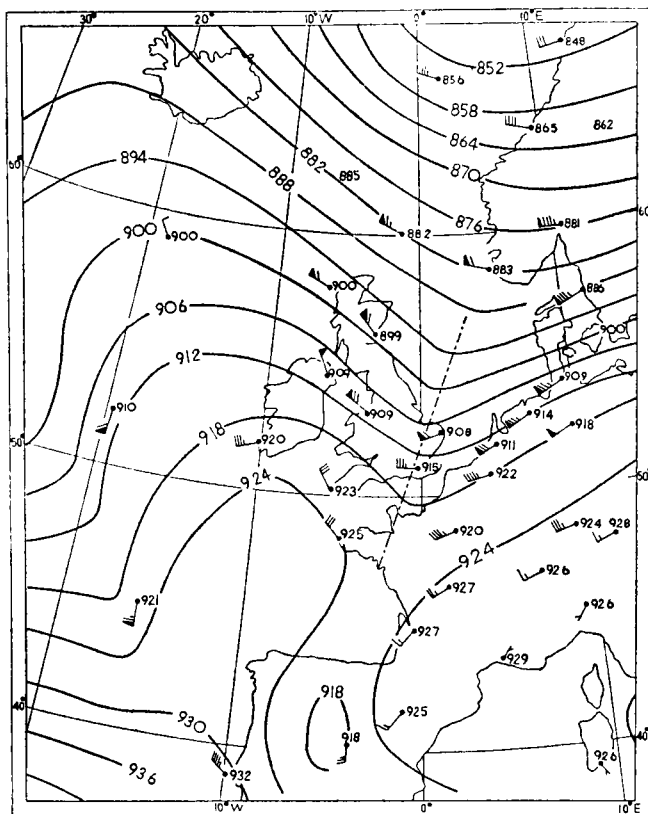


FIGURE 8—300 MB CONTOURS FOR 0001 GMT, 8 APRIL 1961

closely to the line of the upper trough, but not to the orientation of the surface frontal system.

- (iii) The midday Irish radiosonde ascents showed subsidence had taken place in the air west of the trough line.

Several writers have shown that the upper trough line may at times be a dividing line between areas of ascending and descending air in the middle troposphere. Oliver¹, describing the use of 700 mb charts, stated that elongated vee-shaped troughs have cloudiness and precipitation in the southerly current in advance of the trough with clearing at the trough line and behind it. Fleagle² produced an idealized vertical cross-section showing the trough line marking a boundary between a region of ascending air ahead of the trough and descending air behind it.

Petterssen³, dealing with the distribution of vorticity in the upper troposphere, gave examples of the advection of positive vorticity ahead of a 300 mb trough. This occurs when the upper wind is blowing through the trough, and is associated with high-level divergence ahead of the trough. Such upper troughs have been observed to travel faster than the surface frontal systems and overtake them. This overtaking by an upper trough (with positive vorticity advection in advance of it) of a frontal system in the lower troposphere is considered by Petterssen to be one of the most reliable indications of cyclonic development at sea level. It was found that as the upper trough neared the surface front the divergence at high level was compensated by convergence at low levels resulting in ascent of air through the level of non-divergence which was generally found near the 600 mb level.

This process could account for the development which took place ahead of the upper trough over England on 7 April. With an upper trough of this type ascent of air from the lower levels can occur in advance of the trough, while descent takes place to the rear of the line. It is not certain that the existence of a front is vital to the process, but undoubtedly the presence of a considerable depth of moist air over England was necessary for the rapid development of rain. Had the air been dry the upper trough would probably have passed unnoticed.

Value of the 300 mb chart.—It is considered that in general the development and movement of upper troughs can be seen more clearly from a sequence of 300 mb charts than other standard levels. Examination of the 1000–500 mb thickness lines on 7 April 1961 showed that this chart gave little indication of the sharpness of the 300 mb trough. The trough in the thickness lines was of small amplitude and very broad, and the speed could not readily be worked out by simple methods of advection or extrapolation. At 300 mb the axis of the trough was sufficiently well marked for the approximate speed to be found from a sequence of observations.

The movement of upper troughs is not always in phase with features shown on the surface chart, and on the occasion described above the upper trough was largely independent of the systems shown on the surface chart of the area near the British Isles. It is thought that a study of the development and movement of the 300 mb pattern can be of help in forecasting surface developments, particularly when the commonly used contours of the 1000–500 mb thickness fail to show any well defined features.

Summary.—The movement of upper troughs over frontal systems in the lower troposphere can result in ascent of air in the region ahead of the trough. This process is considered to have caused the rapid development of rain over England on 7 April 1961. A sequence of 300 mb charts can help in forecasting similar occasions when inactive fronts may develop a fresh rain area on account of the low-level convergence and high-level divergence ahead of the upper trough.

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2. FLEAGLE, R. G.; The fields of temperature, pressure and three-dimensional motion in selected weather situations. *J. Met., Lancaster, Pa.*, **4**, 1947, p. 165.
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551.5:028:41

LEARNING TO READ RUSSIAN METEOROLOGICAL LITERATURE

By R. F. ZOBEL, O.B.E.

A vast amount of Russian scientific and technical literature is now reaching this country and amongst it are many papers on all the various branches of meteorology, hydrology, oceanography and other sections of geophysics. Most professional meteorologists in this country are able to read the French literature, whilst a good sprinkling are also able to read German. But the

accession of Russian papers into the Meteorological Office Library is considerably greater than those in either French or German. Yet very few meteorologists are even able to read the Cyrillic alphabet. No doubt this situation is not peculiar to meteorologists, but applies to scientists in general.

The main publishers of meteorological papers in Russia are the Hydro-meteorological Service, the Academy of Sciences and the Arctic and Antarctic Institute. These are all major scientific institutions. Indeed the first-named is probably the largest meteorological service in the world and many of its published works, and those of the other institutions, are major works which the progressive meteorologist cannot afford to ignore. There are only two ways of obtaining a full knowledge of the contents of these papers. One is to rely on somebody else's translations and the other, by far the better, is to read them oneself.

Both these ways are beset with quite serious difficulties. Professional translators almost always have adequate command of the language, but their command of meteorological terminology and parlance usually leaves a great deal to be desired. So much so, indeed, that sometimes the real meaning is quite obscure. For example, a linguist would almost certainly translate ВЕРТИКАЛЬНАЯ СТРАТИФИКАЦИЯ ("vertikal'naja stratifikacija"—international system of Cyrillic transliteration) as "vertical stratification", but a meteorologist with a knowledge of Russian would translate it as "lapse rate". Another very great problem confronting the professional translator concerns the names of non-Russian authors referred to in the text. The Russian practice with such names is to write them in Cyrillic characters so as to obtain, as nearly as possible, the correct pronunciation of the name in the original language. But this leads to untold difficulties for the translator in arriving at the English spelling of the name. For example, a translator might well be forgiven for not knowing that КОШИ (Kosi) is equivalent to Cauchy. A particular pitfall lies in the fact that there is no letter H in the Russian alphabet. That symbol does in fact appear but it is equivalent to N. Therefore the Russian renders foreign words in his own language by transliterating an H by a Cyrillic Г. But this means that the names Hill and Gill, for example, would appear in a Russian text as precisely the same. Only one quite familiar with the bibliography on the subject of the paper could tell the real name of the author. The professional translation always requires correction and editing by a meteorologist, but this is in itself a tall order, as he must have a good working knowledge of Russian and also be familiar with the branch of meteorology being discussed. Another disadvantage of the professional translation is the time-lapse before it becomes available, not to mention the cost which always far exceeds the cost of the original document. For a long text the difference in cost may be several hundred pounds.

There is no doubt at all that the best, cheapest and, in the long run, the quickest way of obtaining a knowledge of Russian scientific literature is to learn to read it oneself. But here again there are difficulties and they are more obvious. Firstly, one needs the determination and the time and, secondly, one preferably needs to find a competent instructor or an institution offering part-time classes in Russian. Most of these classes are not aimed specifically at teaching one to read Russian scientific literature and they may devote considerable time to the speaking of Russian, which to the scientist who is only wanting to read is rather a waste of time.

There is however no escaping the fact that one must acquire a thorough knowledge of the whole language, though the vocabulary required may be somewhat restricted. This point is made in the first paragraph of the Introduction to *An introduction to Russian science reading* by A. Dressler*, which as the name implies is intended specifically to assist scientists to become able to read Russian scientific texts. It is, however, possible to dispense with instructors and classes and to become proficient by self-study. Indeed it can be a fascinating hobby which provides useful dividends in one's work.

Truly the learning of any language is a big undertaking and Russian is no exception. Possibly the difficulties are greater than in learning, say, French or German. First of all there is, of course, the unfamiliar alphabet of 32 letters. But the scientist will actually be familiar with quite a few of them, because some are the same as in English and others have direct Greek equivalents as used in mathematics. Others he will need to learn but it is easy to learn the letters in an hour, though the correct order of them, so necessary to know when using a dictionary, will take a little longer. Then again, rather like Latin, Russian has three genders, nouns even names (with exceptions) are declined and verbs conjugated. The Russian verb presents difficulties, apart from the conjugations (some of which are irregular), as there are only three tenses as against twelve in English. But, of course, a Russian is perfectly able to express the finer shades of meaning and times of action of a verb, though he does it in a way which is unfamiliar, focussing attention on whether the action is in progress or is an habitual action (imperfective aspect), or whether the action is to be thought of as a completed whole (perfective aspect). As with other languages the thought processes and the syntax are not the same as in English, but there need be no great fear of the difficulties of the Russian language. Of course, some flair for languages is no disadvantage.

Another prerequisite to self-study is a thoroughly sound and reasonably comprehensive textbook. As any such book must do, Dressler's makes all the main points and he puts them clearly and concisely. It is not entirely clear, however, if the author really intends the book to be used as a text for self-study by a raw beginner, who by the time he has worked through to the last page will be able to tackle Russian literature on his own subject. There is some suggestion in the Introduction that this is the case, although the alternative use of the book under a tutor's guidance is certainly envisaged and its title includes the word "introduction". As a self-study text, however, one can but feel that it is scarcely sufficiently comprehensive alone. It is a slim volume of only 158 pages, the last 43 of which are entirely devoted to translating exercises. This leaves few more than 100 rather small pages for the grammar and the acquisition of a working vocabulary before setting out to translate passages from scientific texts. Incidentally there is no key to the translations which is unhelpful to a self-taught student, though in fairness a number of hints are given, but only in relation to the easier exercises. When one considers that a well known, often recommended textbook on scientific Russian provides over 600 pages on grammar, interspersed with reading exercises only here and there, it will be realized that Mr. Dressler has resorted to considerable condensation. This is also very apparent in the index which leaves a good deal to be desired.

* *An introduction to Russian science reading*, by A. Dressler. 8 in. × 5½ in., pp. x + 161, English Universities Press Ltd., 102 Newgate Street, London, E.C.1, 1961. Price: 20s.

It is also a pity that there is no glossary of Russian words. This would avoid the student needing to refer to a dictionary in order to translate the passages in the book.

In view of the very considerable difficulties in deducing the real names of transliterated authors' names, referred to earlier, it is felt that the book should make some reference to it. One also needs to be put on one's guard against "faux amis". These are prolific in French, for example "ciment" is not "cement", and there are some too in Russian. ГРАДАЦИЈА (gradacija) is simply given in many dictionaries as meaning "gradation", but in meteorological texts it mostly means "range" as, for example, in the phrase "within the range 1000-1010 mb". The word ДИАПАЗОН (diapazon) is also used for "range" in contexts having no association with acoustics. The word КАМЕРА (kamera) does not mean camera unless qualified, but means a cell or chamber. The word БАЛЛ (ball) occurs with monotonous regularity, but it does not mean "ball", but indicates a reading, mark, or point on an arbitrary, usually ten-point, scale. A Russian regards ДЕКАДА (dekada) as a ten-day and not a ten-year period. There are other points of difficulty which might well have found greater prominence in Mr. Dressler's book. One of these, especially important in forecasting texts, relates to the manner in which the precise time of an action is expressed, for example, at, by, after, before three o'clock; three hours later; three-hourly, etc. These have been known to give real difficulty to quite experienced translators.

The book under review has however many commendable features as a supplementary text. The section on word-building is particularly well done and will be found most useful. The exercises have been chosen with care and lead naturally to the more difficult passages, which are introduced by admirable hints on how to get the most value out of dictionaries. These passages will appeal particularly to meteorologists, because although chemistry and other sciences are well represented, quite a number of them have meteorological associations. The latter indeed includes a passage on phosphorescence at sea which makes reference to a paper published in our contemporary, the *Marine Observer*.

Although the price of £1 cannot be regarded as cheap, any scientist learning Russian will be pleased to have this little book.

It is to be hoped that the knowledge that such books as Mr. Dressler's and others exist with the express aim of allowing scientists to read the information published by their Russian colleagues, will encourage many others to learn at least to read the language. The advantages in doing so, as against reading someone else's translation, are many, which is perhaps reward enough, but there is also a satisfaction in the achievement which adds pleasure to the more material rewards.

NOTES AND NEWS

Meteorological Office, Royal Air Force, Felixstowe, 1918-61

Felixstowe was a Royal Naval Air Station during the First World War (1914-1918) but early in 1918 the station was taken over by the Royal Air Force and it has been associated with the Royal Air Force up to the present day. Weather

observations were made at the Coastguard Station, Felixstowe, as early as 1914 and continued up to 1928. Routine observations at the Royal Air Force Station (about half a mile distant) began in 1918 and at this time the Felixstowe Meteorological Office was one of a total of only a dozen meteorological offices in the whole country, compared with over a hundred today. Since 1924 weather observations at Felixstowe have been made at the "synoptic" hours (which have changed over the years) almost without interruption until 1936 when the office was temporarily closed. In recent years observations have been made at every hour of the day and night without interruption.

There have been three meteorological office buildings at Felixstowe since 1918. The first was a wooden building used until 1928 and the second was a brick building adjoining the first office and this was used from 1929 to 1937 (Plate I, facing p. 70). The present office was built in 1937; it is a self-contained brick building situated on the sea-front facing west across the estuary of the Rivers Stour and Orwell (Plate II). It is approximately 30 feet from high water mark and before the erection of a 5-foot sea wall was liable to be flooded as in 1947 and 1953. In the flooding from 31 January to 2 February 1953, the anemometer hut was under 6 feet of water and the Stevenson screen was submerged. In spite of the severe damage, the office was operational again within three days.

Felixstowe during most of its history was closely connected with Coastal Command of the Royal Air Force and therefore with flying boats, seaplanes and marine craft. The Marine Aircraft Experimental Establishment was based at Felixstowe since the early years of the station although it was originally based in 1921 at Royal Air Force, Isle of Grain, Kent, where there was also a meteorological office. The association of the Marine Aircraft Experimental Establishment with Felixstowe ended in 1956 when it moved to Bedford. The seaplanes which took part in the international Schneider Trophy air races carried out their trials at Felixstowe during the 'twenties and early 'thirties. The Trophy was won outright in 1931. Another notable project in the years just preceding the Second World War was the "Mayo" catapult combination of a seaplane lying on a flying boat. Various types of flying boats were stationed at Felixstowe, for example the Stranraers and the Lerwicks, but the most well known were the Sunderlands for their anti-submarine exploits during the war. Forecasting for these aircraft was not easy because of the large sea areas they covered over periods up to 24 hours. The Search and Rescue role of Felixstowe, in peace and war, must not be forgotten; Walrus aircraft were used for this purpose during the war and in recent years (1956-61) Westland Whirlwinds of 22 Squadron performed this vital role. Other units that have been dependent on the Felixstowe meteorological office for their forecasts have been the Balloon Barrage Unit during the war, the neighbouring Naval units, including H.M.S. *Ganges*, and many civilian organizations such as sailing clubs, local flying clubs and of course the information bureau of the Felixstowe Urban District Council.

The work of the Meteorological Office, Felixstowe, was well known to the local community and it is fitting to close this article with an extract from the very warm tribute paid to the Felixstowe staff in a letter from the Chairman of the Urban District Council:

"With the closing of the Meteorological Office at the R.A.F. Station, Felixstowe, I desire on behalf of the Council to convey to you and your colleagues the appreciation and grateful thanks of the Council and the townspeople and visitors for the excellent service which you have so willingly

given over a long period of years in providing us with the daily weather records and forecasts.

“The information obtained has been most valuable to the Council and its Information Bureau from the record and publicity point of view, and at the same time it has provided the public with a most useful facility. Forty years is a long time for such a service to have operated continuously, and we are indeed extremely sorry that it was found necessary to discontinue the meteorological service here.”

J. PEPPER

AWARDS

L. G. Groves Memorial Prizes and Awards

The presentation of the L. G. Groves Memorial Prizes and Awards for 1961 was made by Major K. J. Groves in the Air Historic Room at Air Ministry, Whitehall, on 24 November 1961. The winners are given below:

The Memorial Prize for Meteorology was awarded to *Mr. E. Knighting, B.Sc.*, with the following citation:

“Mr. E. Knighting joined the Meteorological Office in 1940. He was a member of the team which developed the techniques of upper air analysis and forecasting from the network of upper air temperature and wind observations which have contributed much to upper wind forecasting and aircraft safety. He has made a notable analysis of the structure of the lowest 100 metres of the atmosphere, has studied the application of electronic computers to weather forecasting and, since 1959, has headed the British team on numerical weather prediction. In 1960–61 he published several important papers contributing to the establishment of numerical methods as a practical basis for weather forecasting and to the fundamental understanding of large-scale atmospheric motions.”

The Memorial Award for Air Meteorological Observers was awarded to *Flight Lieutenant R. J. K. Nicholas* with the following citation:

“As an aircraft captain engaged on meteorological reconnaissance duties at Royal Air Force Station, Aldergrove, Flight Lieutenant Nicholas has completed 180 reconnaissance flights of which 43, involving 388 flying hours, have been during the past twelve months. He has never been deterred from completing the task by weather conditions at his base or in the reconnaissance area. His perseverance in the course of these gruelling and demanding flights has made a valuable contribution to the weather forecasting service and he has been granted the Air Meteorological Observers' Award for 1961 in recognition of his meritorious service.”

The Memorial Prize for Aircraft Safety was jointly awarded to *Senior Technician L. Hodgkinson* and *Sergeant H. S. Carden* for devising a test set for checking the operative parts of an aircraft fire extinguisher circuit.

The Second Memorial Award was made to *Squadron Leader J. M. Robertson* for his design of a computer which provides a fighter pilot with a quick, simple and effective means of calculating the magnetic track and distance from his base, or a diversion, airfield.

REVIEW

Where no birds fly, by Philip Wills. 8 $\frac{3}{4}$ in. \times 5 $\frac{3}{4}$ in., pp. 141, *illus.*, George Newnes Ltd., Tower House, Southampton Street, London, W.C.2, 1961. Price: 21s.

Philip Wills has accrued thirty years of gliding experience over countries ranging from Scotland to New Zealand and Poland to the United States of America. He has navigated across the inhospitable mountains of Yugoslavia, searched for landing areas amidst the vast lakes and forests of Sweden, ridden the turbulent mistral over the French Alps, circled across the mesquite of Texas, soared to 30,000 feet over Mt. Cook and has won the World Gliding Championship in Spain. Luckily for book lovers, he also has the gift of describing his experiences in an entertaining and informative style. In this, his second book on gliding, he tells with humour and modesty of many of his famous flights and records incidents in the growth of the British gliding movement from its early hesitant beginnings to its present position of international pre-eminence.

Naturally the weather has its place in all the aerial adventure stories told, sometimes as almost commonplace convection, sometimes in the form of hail, lightning, giant lee waves, violent rotor flow or sea-breezes. Almost any of Mr. Wills' exploits could well be the subject of a meteorological paper or article. Tacit suggestions range from a climatological study of the Mackenzie country of New Zealand to a local investigation of what was probably a "land-breeze front" which he explored off the east coast of Kent.

The flying tales are interspersed with accounts of gliding organization and the arduous toil required by ground crews during gliding operations. To the uninitiated these accounts may appear to be overdramatized but they are nonetheless true. Indeed, although Mr. Wills' enthusiasm for gliding is obvious, he presents his observations of the air and its ways factually without premature conjectures or wild theories, and thereby makes these facts all the more impressive and intriguing for the meteorological reader.

C. E. WALLINGTON

PUBLICATION RECEIVED

Proceedings of the Iraqi Scientific Societies, Vol. 4, 1960-61. 9 $\frac{1}{2}$ in. \times 6 $\frac{3}{4}$ in., pp. 44, *illus.*, Ar-Rabita Press, Baghdad, Iraq. Subscription: £1 per annum.

OBITUARY

Mr. H. Garnett.—The news of the death of "Joe" Garnett on 27 December 1961 at the early age of 57 came as a great shock to his many friends inside and outside the Meteorological Office. His cheerful and happy nature had endeared him to all those with whom he came in contact over a varied Office career lasting more than 35 years.

"Joe" Garnett joined the Meteorological Office in 1927. From his earliest days he was known as "Joe" although this was not his real name. The origin of this title is lost in the mists of time. For about eighteen months after taking up his first appointment, Mr. Garnett was employed on forecasting duties both at Meteorological Office Headquarters in London, and for a short time at that

famous place, now alas gone from the Royal Air Force, Calshot. In those days a short time spent at Calshot was an almost inevitable part of the earlier experience of the young Junior Professional assistant gaining his first knowledge of aviation forecasting for the Royal Air Force.

However, in 1929 Mr. Garnett moved over to chemical defence research work at Porton, and for the next 17 years he was associated with this type of meteorological work both at Porton, and in India where he served two tours, one between 1934 and 1937, and another shorter tour at the end of the war and just after.

In 1946 Mr. Garnett returned again to forecasting duties and served with the Royal Air Force at H.Q. 47 Group (Transport Command); also at Dunstable and London Airport, before becoming, in 1948, Senior Meteorological Officer at H.Q. 38 Group (Upavon), again one of the Transport Command groups. In 1951, during a Transport Command reorganization, H.Q. Transport Command moved to Upavon and absorbed H.Q. 38 Group. Mr. Garnett remained at Upavon until 1960 as Chief Meteorological Officer of Transport Command. During this period he had many problems to deal with as the Command gradually became equipped with the modern and more advanced types of aircraft.

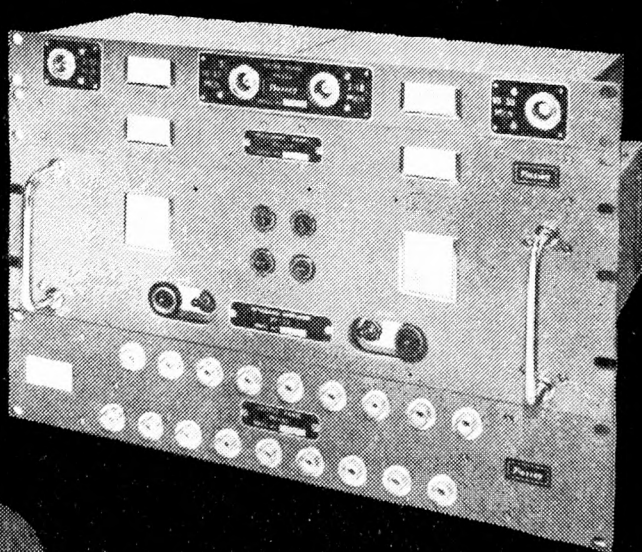
Mr. Garnett took up his last appointment in the Meteorological Office in September 1960, when he joined the Headquarters Branch specializing in the meteorological problems connected with agriculture. This Branch was then at Harrow, but Mr. Garnett moved with it to the new Meteorological Office Headquarters at Bracknell only a few months before his death.

“Joe” Garnett will be sorely missed by a wide circle of friends in the Meteorological Office, and also by many outside the Office with whom he came into contact during his varied official career. The deepest sympathy is extended to his widow and family.

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SOME EMPIRICAL RESEARCH IN SHORT-RANGE FORECASTING

By V. R. COLES

It is the hope that present and future developments in the field of dynamical research will ultimately lead to the production of forecast surface charts, upper air charts and charts depicting vertical motions in the atmosphere for periods up to 24 hours ahead, of such a standard that the practising forecaster will be able to dispense with many of his present modes of procedure. Errors in forecast surface charts, incorrect assessments of future (and present) frontal activity will then become, if not things of the past, at least much less frequent than they are now. At the present time, however, as Bushby and Whitlam¹ have indicated the standard of the forecast charts produced by METEOR is certainly not higher than that attained by the human forecaster and it appears that, although progress in the field of numerical prediction is to be expected, it will almost certainly be slow. There is still scope, therefore, at least for several years, for synoptic investigations of the many problems which still trouble the forecaster in his day-to-day duties and it is the purpose of this article to describe some aspects of current research in the Synoptic Research Branch of the Meteorological Office in the hope that the ideas put forward may prove of assistance to forecasters generally.

Three main investigations are at present under way in the section devoted to research in the short-range field. The first concerns the development and movement of depressions on the Atlantic with special reference to those depressions which deepen by 20 millibars or more in 24 hours. The second problem is that of forecasting the amount of rainfall likely from individual fronts and the third, which is associated to a certain extent with the second, is that of predicting the development of warm- and cold-front waves.

There have been many published contributions in the past on all of these topics and it might appear, at first sight, that there is little to be gained in tackling them again. However, as many practising forecasters are aware, the flow patterns at the level of strongest winds (200–300 millibars) seem often to be an important and perhaps controlling factor when unforeseen developments occur at the surface. As examples, rain often breaks out unexpectedly, or

existing rainfall becomes more intense, ahead of sharp troughs in the 300-millibar pattern and warm fronts often give a good deal of rain when the 500-millibar ridge ahead of the warm front lies well to the rear of the corresponding ridge at 300 millibars. It appeared therefore, that a study of the flow patterns above 500 millibars might provide a starting point in tackling these problems once again and that particular attention should be paid to those situations in which there is a marked difference in the direction of the 300–500-millibar thermal wind from that between 500 and 1000 millibars. In these circumstances the 500–1000-millibar thickness pattern cannot be expected to reveal the whole of the developmental picture. This aspect of the problem of development will be elaborated later.

So far as the investigation into the development and movement of depressions on the Atlantic is concerned it was decided to tackle the problem, first of all, in an almost purely statistical manner using curvilinear and graphical multiple regression techniques developed by Freeman ². Data for more than 700 depressions were extracted from the synoptic charts and numerous measurements of all possible predictors were made, including wind speeds and directions at all standard levels, vorticity advection at all levels and thermal vorticity advection for all thickness layers. The analysis has not yet been completed and it is perhaps too early to quote firm results, but it seems certain that the two most important predictors in the problem of forecasting the central pressure of a depression in 24 hours time are (i) the present central pressure of the depression and (ii) the 300-millibar wind speed over the centre of the depression. These two predictors will almost certainly yield a multiple correlation coefficient higher than 0.80 between the predicted and actual pressure in the centre of a depression in 24 hours time. Other predictors, such as the time of year, the latitude and longitude of the depression, may improve marginally on this correlation coefficient but the improvement may not be significantly large enough to warrant their inclusion in the final sets of diagrams or tables. No matter what is the outcome of this investigation, however, it has certainly pointed to the importance of the 300-millibar flow and, indeed, a cursory study of the data highlights the fact that a depression is unlikely to deepen by 20 millibars or more in 24 hours unless the direction of the 300-millibar wind over it lies between 200 and 270 degrees and the 300-millibar wind speed exceeds 70 knots. It is planned to make a synoptic study of many of the depressions which deepened by 20 millibars in 24 hours, although past experience with the problem of forecasting the visibility three and six hours ahead at London Airport² suggests that it may be very difficult to better the predictions of the general multiple regression scheme in respect of any particular class of depressions. Up to date no similar statistical analysis has been made of the movement of depressions but one suspects that the direction of the strongest 300-millibar wind in the vicinity of the centre of the depression (say within a circle of radius of 300 miles) may be the controlling factor.

So far as the problem of rainfall amounts at individual fronts is concerned, Wallington has described (in an unpublished paper) an especially interesting case of two warm fronts which were very similar in structure at all levels up to 500 millibars but which gave very different amounts of rain as they crossed the British Isles. However, Wallington did not carry his analysis of the associated fields of flow to levels above 500 millibars, and the 300–500-millibar thickness patterns showed considerable differences in the two cases. There are, of course,

several ways in which the flow patterns near the level of maximum wind speed can be included in Sutcliffe's development theory³. Thickness charts for the layer 300–1000 millibars could be constructed or use could be made of the isopleths of thickness of the 300–500-millibar layer which are drawn as routine to enable the chart depicting the contours of the 300-millibar surface to be built up from that at 500 millibars. However, the difficulty of assessing relative divergence, and therefore the vertical velocities, from either of these charts (or from the 500–1000-millibar thickness patterns) lies in the fact that, in the neighbourhood of a front, the two main terms in Sutcliffe's development formula usually contribute to the relative divergence in opposite senses. For example, using the 1000- and 300-millibar surfaces the relative divergence is expressed in the usual notation by:

$$l(\text{div } \mathbf{V}_{300} - \text{div } \mathbf{V}_{1000}) = -V' \frac{\partial}{\partial s} (2\zeta_{1000} + \zeta' + l) \quad \dots (1)$$

and whilst $-2V'\partial\zeta_{1000}/\partial s$ is normally positive over the region of a warm front, $-V'\partial\zeta'/\partial s$ is often negative. The forecaster has, therefore, to decide which term is the more important, and this is often impossible by inspection alone. However, if Sutcliffe's theory is applied to the 100–300-millibar layer the expression of the relative divergence between 100 and 300 millibars is:

$$l(\text{div } \mathbf{V}_{100} - \text{div } \mathbf{V}_{300}) = -V'' \frac{\partial}{\partial s} (2\zeta_{100} - \zeta'' + l) \quad \dots (2)$$

where V'' and ζ'' are respectively the velocity and vorticity of the 100–300-millibar thermal wind. Now Probert-Jones⁴ has shown that the 100-millibar flow is approximately non-divergent and since most contour charts of the 100-millibar surface exhibit large areas where the relative vorticity is either zero or nearly constant (see Figure 1), equation (2) above can be approximated by:

$$l \text{ div } \mathbf{V}_{300} = -V'' \frac{\partial \zeta''}{\partial s} \quad \dots (3)$$

if the change of Coriolis parameter with latitude is ignored.

Equation (3) states that the divergence at 300 millibars is represented simply by one term, namely the advection of thermal vorticity by the 100–300-millibar thermal wind, and it follows therefore that the patterns of divergence at 300 millibars are almost completely depicted by the various thermal patterns described by Sutcliffe and Forsdyke⁵ so that, for example, the left exit of a 100–300-millibar thermal jet stream is one of divergence at 300 millibars. It should be borne in mind, however, that Sumner⁶ has shown how the stability term

$$\frac{R}{l^2} \int_{p_1}^{p_0} \left\{ \nabla^2 \left(\frac{dp}{p} \right) \right\} d(\log p)$$

which was neglected by Sutcliffe³ may affect the amount of upper divergence. In the layer 100–300 millibars the quantity Γ_p is likely to be larger than in the lower troposphere, but dp/dt at these high levels is almost certainly smaller. Furthermore, if a level of zero vertical velocity at 200 millibars or thereabouts is postulated then there will be partial compensation in the 100–300-millibar layer due to the effects of opposing vertical motions above and below this level. However, the effects of the Sumner stability term with respect to the 100–300-millibar layer will need to be examined in some detail.

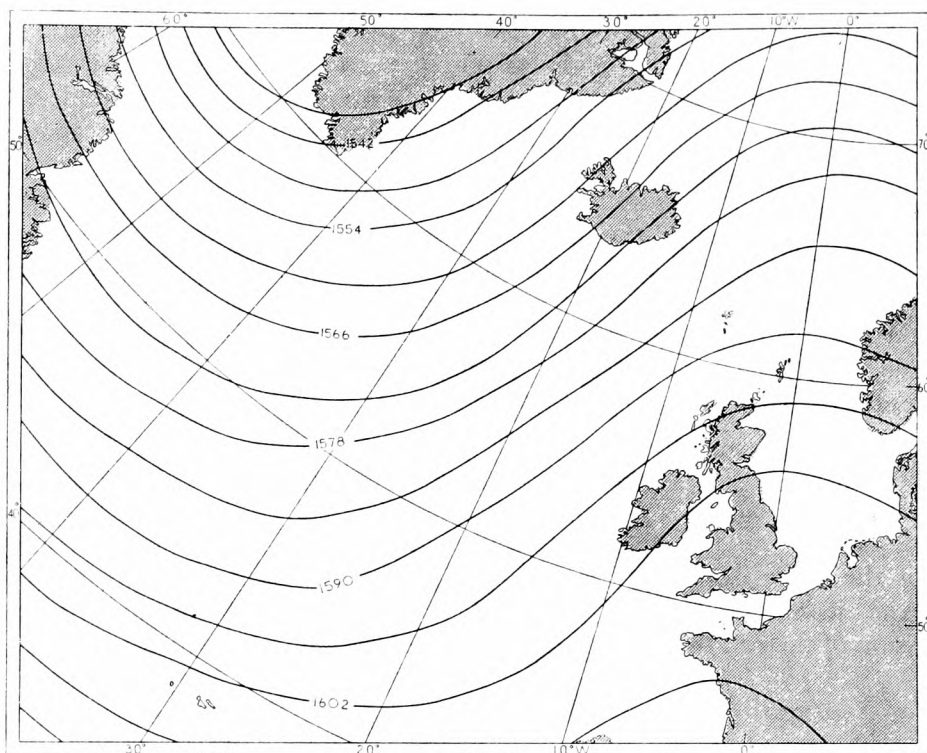
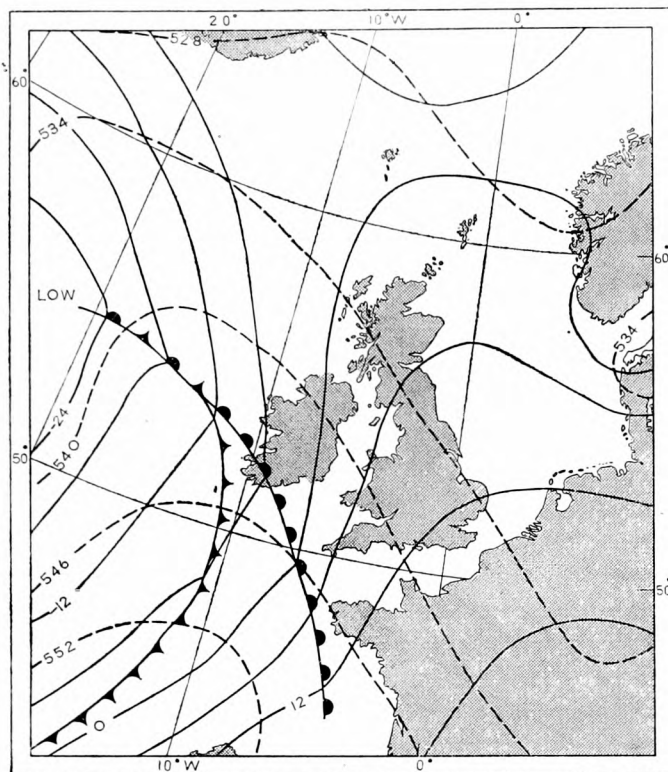


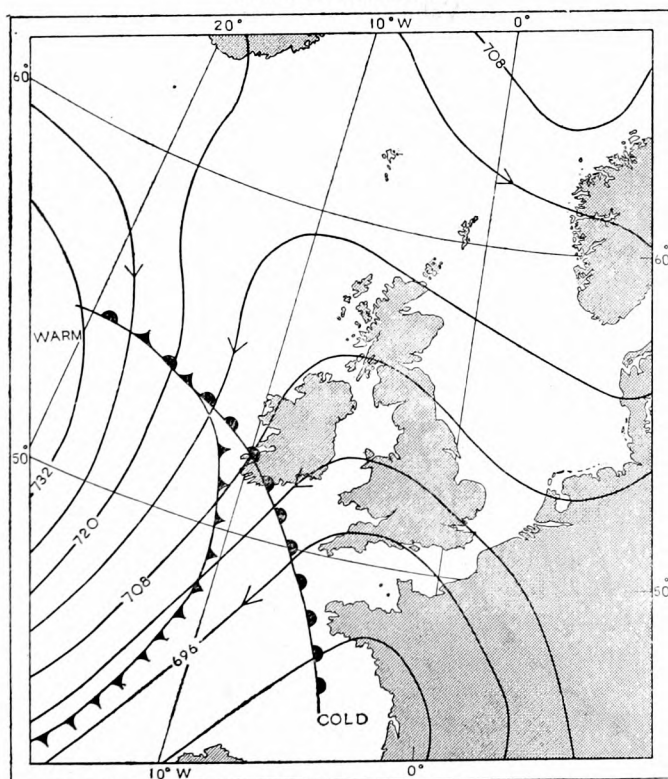
FIGURE 1—100 MB CONTOUR CHART FOR 0001 GMT, 23 FEBRUARY 1961, ILLUSTRATING CONSTANCY OF 100 MB RELATIVE VORTICITY OVER LARGE AREAS
Values in decametres

It should be possible, therefore, to obtain from the 100–300-millibar thickness pattern alone, an estimate of the divergence present at 300 millibars above individual fronts and a preliminary examination of a selection of fronts indicates that there is some hope of distinguishing between wet, moderately wet and dry fronts on the basis of the 100–300-millibar thickness patterns associated with the fronts.

Figures 2(b) and 3(b) show respectively the 100–300-millibar thermal patterns associated with a wet and with a dry warm front. It will be noted that the surface warm front in Figure 2(b) lies in a position, relative to the 100–300-millibar thickness pattern, favourable for considerable upper divergence—the forward side of a cold trough. The warm front shown in Figure 3(b), on the other hand, is situated under a region of light 100–300-millibar thermal winds indicating little, if any, upper divergence. A thorough examination is now being carried out, using METEOR, in order to establish the correlation between the estimated divergence at 300 millibars, as measured from the 100–300-millibar thickness charts, and rainfall at fronts. Such a relationship, if it exists, will mean that these thickness patterns can be used as a short-term forecasting tool (say up to 12 hours ahead). Whether they have a prognostic value over a longer period depends on our ability to forecast how the patterns change with time. The positions of the isopleths on the 100–300-millibar thickness charts are, of course, changed by advection and by adiabatic and non-adiabatic effects. Assuming a constant direction of the thermal wind between 300 and 100 millibars the thickness lines can be advected with either the wind at 300 or at 100 millibars,



**FIGURE 2(a)—1000 MB CONTOUR CHART AND 500–1000 MB THICKNESS CHART
FOR 0300 GMT, 7 FEBRUARY 1957, ASSOCIATED WITH A WET WARM FRONT**
Values in decametres



**FIGURE 2(b)— 100–300 MB THICKNESS CHART FOR 0300 GMT, 7 FEBRUARY 1957,
ASSOCIATED WITH A WET WARM FRONT**
Values in decametres

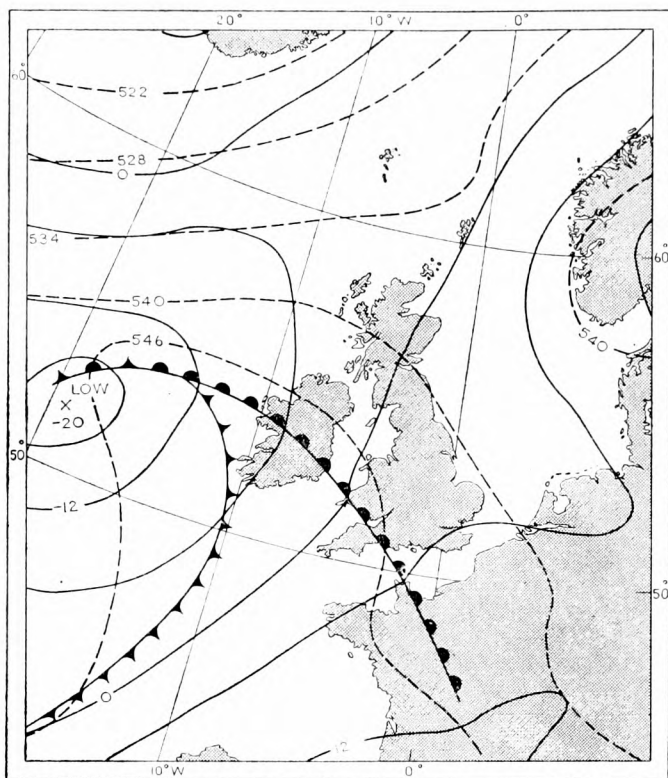


FIGURE 3(a)—1000 MB CONTOUR CHART AND 500 - 1000 MB THICKNESS CHART FOR 0300 GMT, 8 MARCH 1957, ASSOCIATED WITH A WARM FRONT WHICH GAVE LITTLE RAIN OVER MOST OF ENGLAND AND WALES
Values in decametres

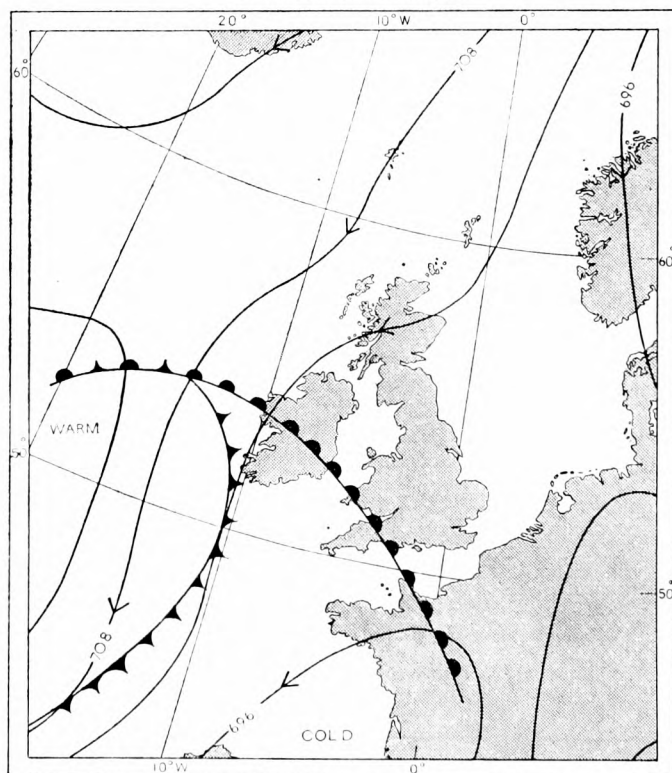


FIGURE 3(b)—100 - 300 MB THICKNESS CHART FOR 0300 GMT, 8 MARCH 1957, ASSOCIATED WITH A WARM FRONT WHICH GAVE LITTLE RAIN OVER MOST OF ENGLAND AND WALES

but since the 100-millibar flow is normally much weaker and more conservative than the flow at 300 millibars it is natural to choose this level. Non-adiabatic effects are probably very small between 300 and 100 millibars but there may be considerable modification of the 100–300-millibar thickness field by vertical motion since much of the layer is in the stratosphere. It will be necessary to determine whether changes of thickness due to vertical motion can be forecast satisfactorily before it will be possible to attempt to forecast changes of intensity of frontal rainfall over periods 12 to 24 hours ahead.

The intensification of rain on warm or cold fronts is often due to wave formation on the fronts. Some years ago Sawyer⁷ investigated such wave developments with reference to the 500–1000-millibar thickness pattern and his findings are well known. However, on many occasions waves form on warm and cold fronts and are not accompanied by the patterns Sawyer illustrated. This again lends support to the idea that surface developments cannot always be forecast satisfactorily without consideration being given to events above the 500-millibar level. Figure 4 illustrates a synoptic situation where a wave formed on a warm front and moved east-south-eastwards across the southern half of the British Isles. The appropriate 100–300-millibar thickness chart (Figure 4(d)) indicates that the pattern was suitable for upper divergence near the area of formation of the wave. The 500–1000-millibar thickness pattern, on the other hand, does not appear to be favourable for wave development. However, a large number of warm- and cold-front waves will have to be examined in order to determine how often the 100–300-millibar thickness pattern is a useful indicator of wave formation and to establish the time lapse between the appearance of the appropriate thickness patterns and the formation of the waves.

It appears, therefore, that it may become necessary to introduce into the routine the preparation of yet another upper air chart. However, if developments in the lower layers of the troposphere are controlled, even on a minority of occasions, by events at high levels then there is obviously no hope of predicting correctly such developments without some consideration being given to levels above 500 millibars. Since

$$-(\zeta_{300} + l) \operatorname{div} \mathbf{V}_{300} = \frac{\delta \zeta_{300}}{\delta t} + \mathbf{V}_{300} \cdot \frac{\delta}{\delta s} (\zeta_{300} + l) \quad \dots (4)$$

and since the speed of movement of the ridge–trough patterns at 300 millibars is usually much less than the speed of the general 300-millibar flow, it is certain that in many cases the dominant factor in determining the divergence at 300 millibars is the advection of vorticity at 300 millibars. Thus it may be possible to estimate the divergence at this level using the 300-millibar pattern alone without the need for constructing the 100–300-millibar thickness chart. However, tests of the relationship between rainfall patterns and vorticity advection at 300 millibars were made several years ago by Riehl, Norquest and Sugg⁸ and Teweles⁹ with somewhat inconclusive results and it seems that the local change of vorticity at 300 millibars, which they neglected, may be important. The effects of this term are taken into account by considering the advection of 100–300-millibar thermal vorticity by the 100–300-millibar thermal wind and it appears, therefore, that in order to obtain a more realistic estimate of the divergence at 300 millibars, it will be necessary to use a field of relative topography rather than the contour patterns of the 300-millibar surface. Indeed the 100–200-millibar thickness chart is already being drawn at London Airport¹⁰ and its use as an aid in constructing forecast charts for the 200-millibar level is now being tested.

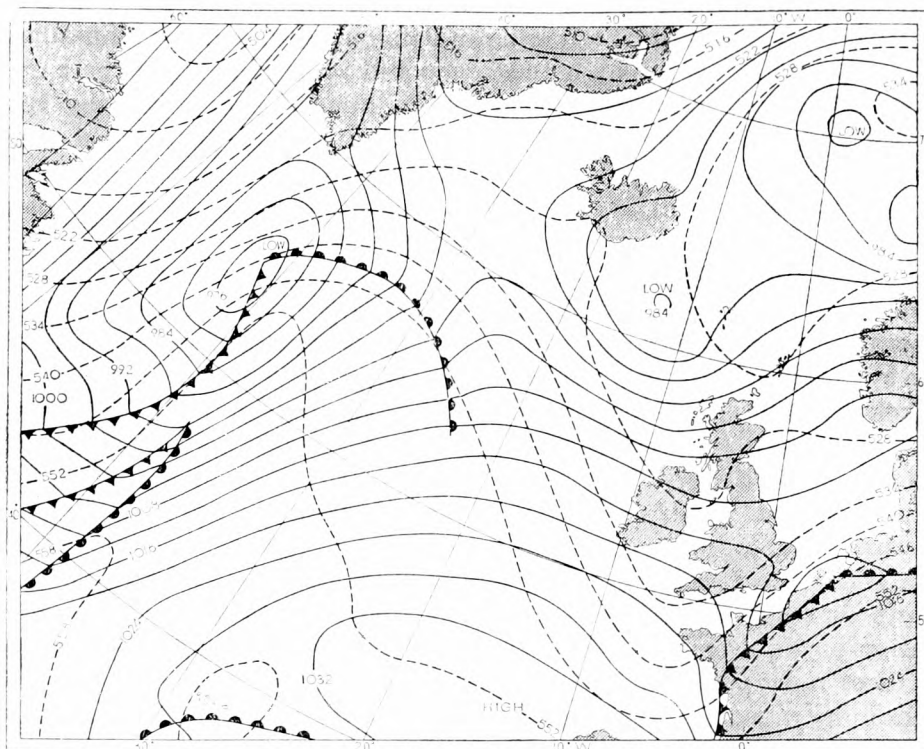


FIGURE 4(a)—SURFACE CHART AND 500-1000 MB THICKNESS CHART FOR
0001 GMT 28 FEBRUARY 1961

Broken lines are thicknesses in decametres

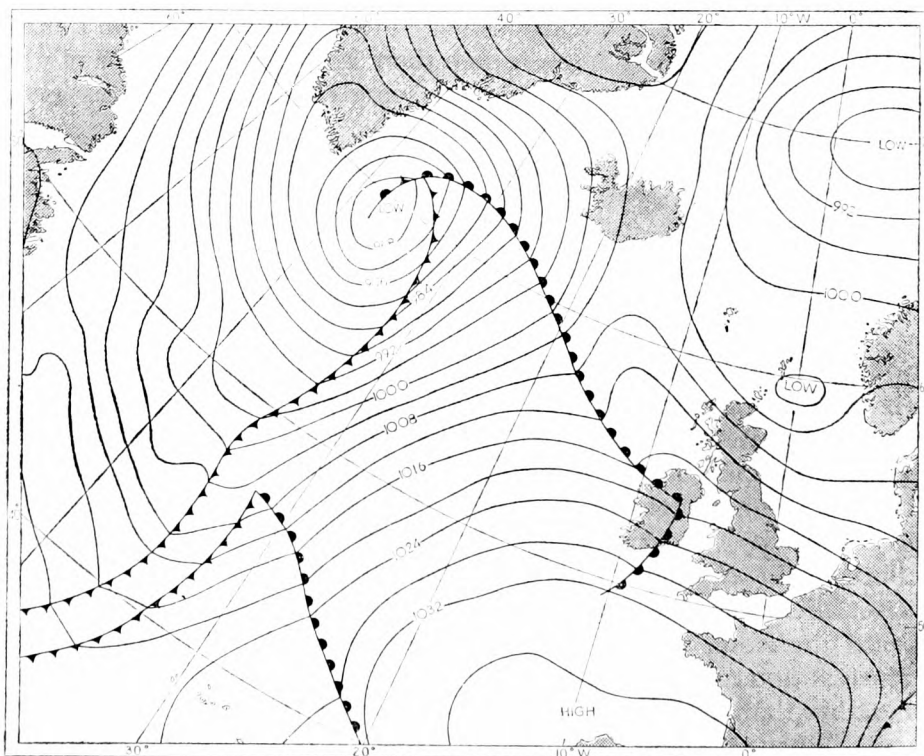


FIGURE 4(b)—SURFACE CHART FOR 1200 GMT, 28 FEBRUARY 1961

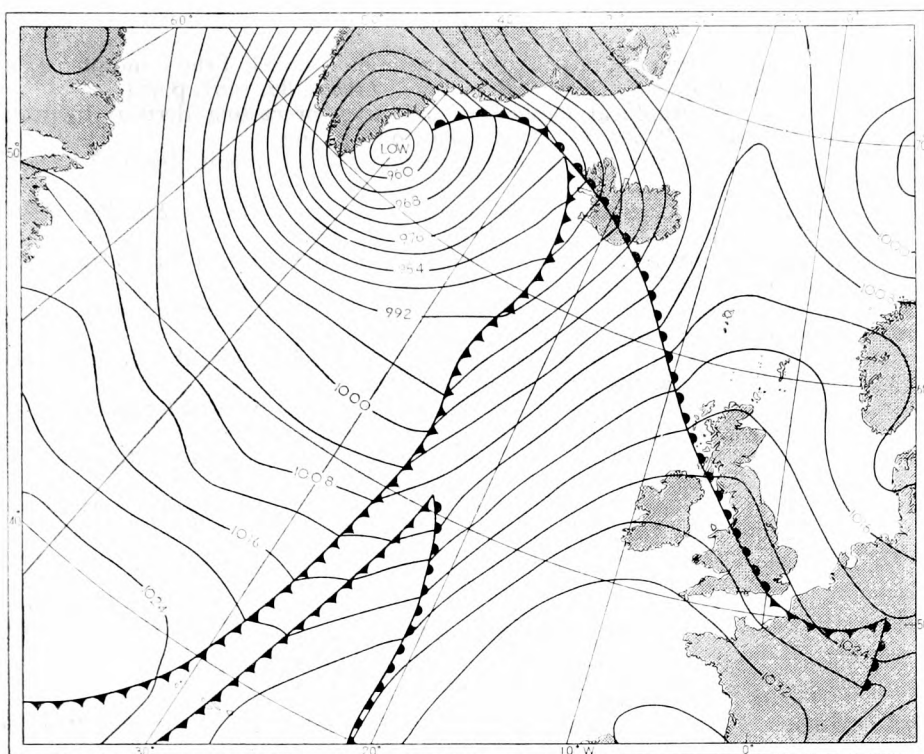


FIGURE 4(c)—SURFACE CHART FOR 0001 GMT, 1 MARCH 1961

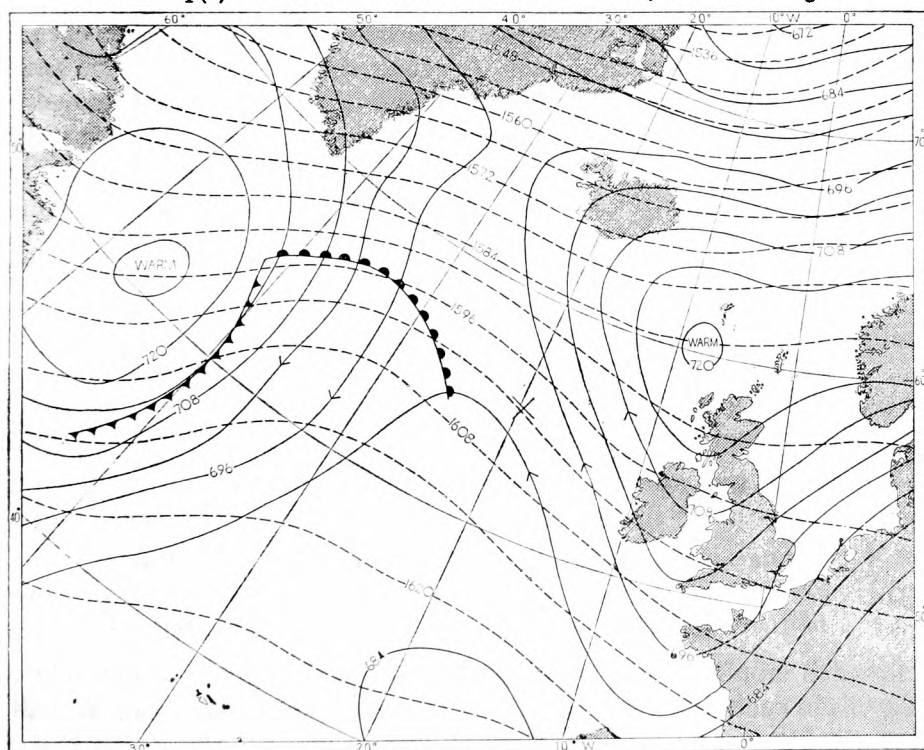


FIGURE 4(d)—100-300 MB THICKNESS CHART (FULL LINES) AND 100 MB CONTOUR CHART (BROKEN LINES) FOR 0001 GMT, 28 FEBRUARY 1961, ILLUSTRATING AT X DIFFLUENT PATTERN PROBABLY ASSOCIATED WITH WAVE FORMATION ON WARM

FRONT
Values in decametres

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551.577.37:551.589.1

WET SPELLS AT LONDON

By C. A. S. LOWNDES

Introduction.—This work was undertaken to provide a background to the problem of forecasting wet spells at London. For the purpose of this investigation a wet spell was defined as a period of five days with (i) at least 15 millimetres of precipitation and no day with less than one millimetre or (ii) at least 20 millimetres with one such day or (iii) at least 25 millimetres with two such days. A period of five days was chosen because it seemed to be the longest spell which could be related to a single weather type, e.g. the average length of the German “Grosswetterlagen” is four to five days. The histograms of daily rainfall at Kew published in the Monthly Summary of the *Daily Weather Report* were used to extract the dates of the wet spell periods. If a wet spell continued for more than five days, the first five days which fulfilled the criteria were taken and the search for the next wet spell was not begun until a day with less than one millimetre of precipitation had occurred. The spells were extracted for the 25-year period 1935 to 1959, for all months of the year. The spells occurring in each month were listed separately. Where a spell extended from one month to another, it was included in the month which contained the greater part of it.

Frequency of wet spells.—There were 225 spells during the whole period, giving an average of 0.7 spells per month. Table I shows the average number of

TABLE I—AVERAGE NUMBER OF SPELLS FOR EACH MONTH

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1.1	0.6	0.6	0.4	0.8	0.6	0.6	0.9	0.5	1.0	1.3	0.7

spells for each month, ranging from 0.4 in April to 1.3 in November. The number of spells in each individual year ranged from four in 1955 to 14 in 1958; the average number was nine, of which about five occurred in the winter half of the year and about four in the summer half.

The frequency of spells according to the amount of precipitation associated with them is shown in Figure 1. The modal value of the distribution occurs at 25 to 29 millimetres of precipitation, representing 25 per cent of the spells.

Some 92 per cent of the spells had a total precipitation of between 15 and 44 millimetres, whilst the wettest spell totalled 86 millimetres. The arithmetic mean value was 30 millimetres. The 225 spells accounted for 45 per cent of the total precipitation at Kew over the 25 years.

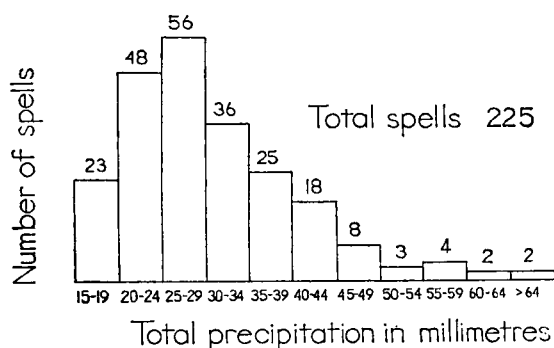


FIGURE 1—FREQUENCY OF SPELLS WITH RESPECT TO TOTAL PRECIPITATION

Synoptic types associated with wet spells at London.—A short description of the synoptic type in the region of the British Isles was written for each of the 92 spells which occurred during the 10 years 1950 to 1959. This involved a description of the position or movement of the depressions, waves, troughs or fronts with which the wet spell was associated. The types were then classified according to the region from which these features moved towards the British Isles or in which they were situated if stationary. The regions are shown in Figure 2. For example, depressions, waves, troughs or fronts moving from the west were classed as Type VI; depressions as VID, waves as VIW, troughs as VIT and fronts as VIF. Depressions or troughs which were stationary over the

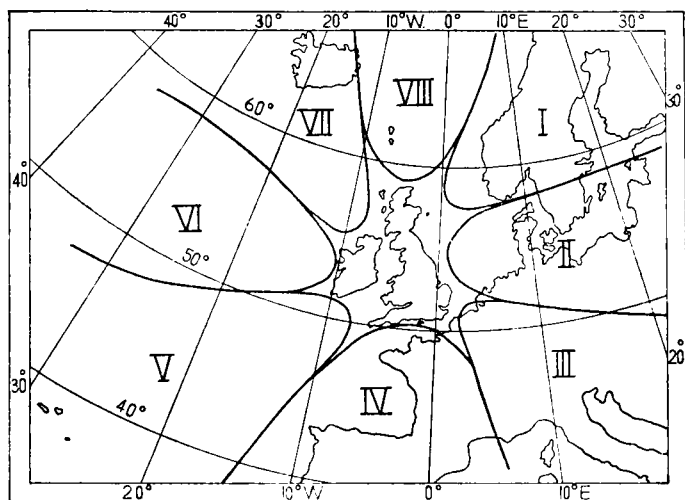
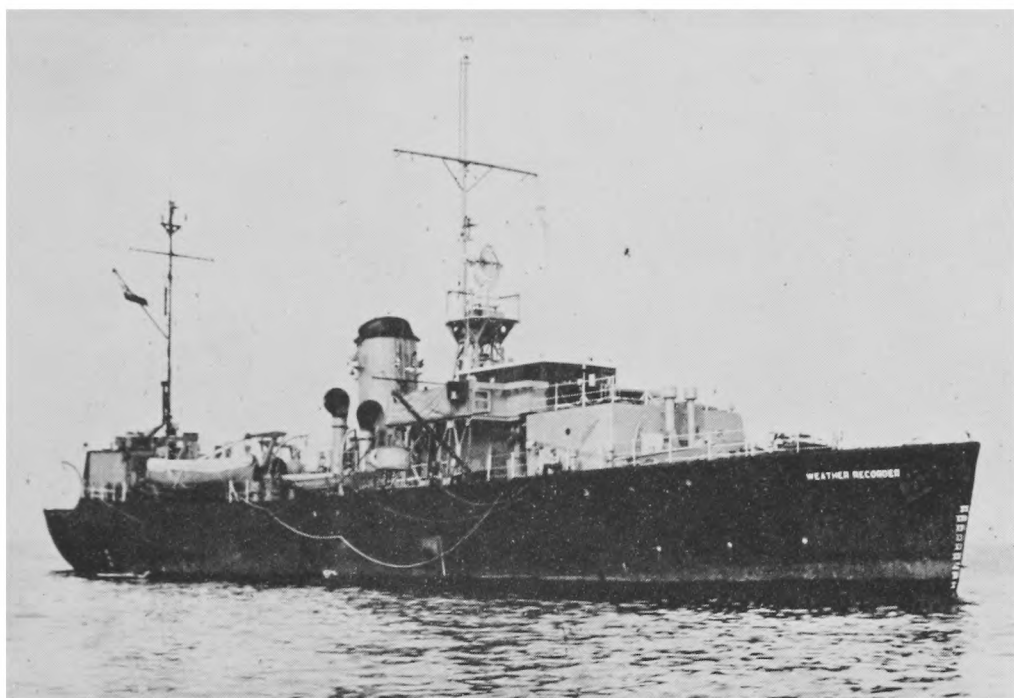


FIGURE 2—REGIONS USED IN THE CLASSIFICATION OF SYNOPTIC TYPES

British Isles were classed as Type IX. The types were sub-classified by a suffixed figure according to the track taken by the depression or wave across the region of the British Isles and by a suffixed letter according to the type of front or frontal system. In the main each spell was associated with from two to five sub-types. In some cases all the sub-types were different, but in others the same one

TABLE II—CLASSIFICATION OF SYNOPTIC TYPES (TOTAL OCCURRENCES 260)

Synoptic type	Class	Number of occurrences
Depression over southern North Sea	IID	1
Cold front from east moved westward across British Isles	IIF _c	1
Depression over Holland	IIID	1
Wave from France moved to North Sea	IIIW	1
Depression from Biscay or France moved northward across British Isles	IVD ₁	2
Depression from west of Spain or Biscay moved along Channel region	IVD ₂	2
Depression from France moved to North Sea or North Germany	IVD ₃	4
Shallow depression slow moving over France	IVD ₄	4
Wave from Spain, Biscay or France moved northward across British Isles	IVW ₁	9
Wave from Biscay moved across England to North Sea	IVW ₂	2
Wave from Spain or Biscay moved along Channel region	IVW ₃	7
Wave from France moved to North Sea	IVW ₄	1
Warm front from south moved northward across England or to Channel region	IVF _w	3
Cold front from south moved northward across England	IVF _c	2
Occlusion from south moved northward across England	IVF _o	3
Depression from south-west moved { northward across British Isles across England to North Sea along Channel region to France	VD ₁ VD ₂ VD ₃ VD ₄	10 14 18 1
Wave from south-west moved { northward across British Isles across England to North Sea along Channel region	VW ₁ VW ₂ VW ₃	2 10 18
Warm front from south-west moved north-eastward across England	VF _w	4
Cold front from south-west moved north-eastward across England	VF _c	6
Occlusion from south-west moved north-eastward across England	VF _o	5
Partly occluded frontal system from south-west moved eastward or north-eastward across British Isles	VF _s	15
Depression from west moved { across Scotland to North Sea across England to North Sea across England to Channel along Channel region	VID ₁ VID ₂ VID ₃ VID ₄	1 10 4 5
Wave from west moved { across England to North Sea along Channel region	VIW ₁ VIW ₂	10 3
Warm front from west moved eastward across England	VIF _w	9
Cold front from west moved eastward across England	VIF _c	8
Occlusion from west moved eastward across England	VIF _o	3
Partly occluded frontal system from west moved eastward across British Isles	VIF _s	32
Trough from west moved eastward across British Isles or England	VIT	6
Depression from north-west moved { east of British Isles to Continent across British Isles to Continent	VIID ₁ VIID ₂	1 2
Cold front from north-west moved south-eastward across British Isles	VIIIF _c	3
Occlusion from north-west moved south-eastward across British Isles	VIIIF _o	1
Depression from north moved east of British Isles to southern North Sea	VIIID	2
Wave from north moved southward across British Isles	VIIIW	1
Cold front from north moved southward across England	VIIIF	3
Occlusion from north moved southward across England	VIIIF _o	1
Depression stationary over British Isles	IXD	5
Trough stationary over British Isles	IXT	4



Photograph by O. M. Ashford

“WEATHER RECORDER”
(see p. 107)



Photograph by S. Soulsby.

“WEATHER MONITOR”
(see p. 107)



335°

350°

NORTH

Crown copyright

CUMULUS CLOUD GENERATED BY A RUBBER PLANTATION FIRE IN SOUTH MALAYA

(see p. 104)



Photograph by G. Nicholson

FULWELL STATION AT 8 P.M. ON 24 AUGUST 1961
(see p. 111)

To face p. 101



Photograph by J. J. H. Pennells



Photograph by J. J. H. Pennells

SNÓWFALL OF 31 DECEMBER 1961
(see p. 110)

occurred more than once. The amount of precipitation at Kew associated with each sub-type was noted. Sub-types which were associated with only one or two millimetres of precipitation were not included. The complete classification is shown in Table II, together with the number of occurrences of each type.

The most frequently occurring types during the wet spells were Types V and VI. Type V occurred in 73 per cent of the spells and Type VI in 64 per cent. Type IV occurred during the course of 33 per cent of the spells. At least one of these three types occurred during each of the 92 spells.

Amount of precipitation associated with the various synoptic types.—Of the total precipitation, 91 per cent was associated with Types IV, V and VI; 41 per cent with Type V, 32 per cent with Type VI and 18 per cent with Type IV. Of the total, 63 per cent was associated with depressions or waves, 18 per cent with single fronts and 14 per cent with partly occluded frontal systems.

TABLE III—AMOUNT OF PRECIPITATION ASSOCIATED WITH SYNOPTIC TYPES IV, V AND VI

	Type IV			Type V			Type VI			
	<i>D</i>	<i>W</i>	<i>F</i>	<i>D</i>	<i>W</i>	<i>F</i>	<i>D</i>	<i>W</i>	<i>F</i>	<i>T</i>
Percentage of total precipitation	7	7	4	21	11	9	9	5	16	2
Average precipitation (mm)	15	9	13	13	9	8	11	10	8	8

Table III shows the amount of precipitation associated with Types IV, V and VI in more detail. Of the total precipitation, 21 per cent was caused by depressions from the south-west and 16 per cent by fronts from the west. The highest average precipitation of 15 millimetres was associated with depressions from the south. Fronts from the south and depressions from the south-west produced an average of 13 millimetres. The lowest average of eight millimetres was associated with fronts from the south-west and west and with troughs from the west.

About 50 per cent of the total precipitation was associated with eight of the 47 synoptic types listed in Table II. These eight types are shown in Table IV, together with the percentage of the total precipitation and the average precipitation associated with each.

TABLE IV—SYNOPTIC TYPES ASSOCIATED WITH MOST PRECIPITATION DURING WET SPELLS

Synoptic type	Precipitation	
	Per cent	Average <i>mm</i>
Depression from south-west moved along Channel region (VD_3)	10	14
Depression from south-west moved northward across British Isles (VD_1)	5	13
Depression from south-west moved across England to North Sea (VD_2)	6	11
Wave from west moved across England to North Sea (VIW_1)	4	11
Wave from south-west moved across England to North Sea (VW_2)	4	11
Partly occluded frontal system from west moved across British Isles (VIF_5)	10	8
Wave from south-west moved along Channel region (VW_3)	6	8
Partly occluded frontal system from south-west moved across British Isles (VF_5)	4	7

Some 10 per cent of the total precipitation was produced by depressions from the south-west which moved along the Channel region and a further 10 per

cent by partly occluded frontal systems from the west which moved across the British Isles. The highest average precipitation of 14 millimetres was also associated with depressions from the south-west which moved along the Channel region. Depressions from the south-west which moved northward across the British Isles produced an average of 13 millimetres. The lowest averages of seven or eight millimetres were associated with partly occluded frontal systems from the west or south-west and with waves from the south-west which moved along the Channel region. Six of the synoptic types were associated with depressions, waves or partly occluded frontal systems which moved from the south-west (Type V) and two with waves or partly occluded frontal systems which moved from the west (Type VI).

From an examination of rainfall data associated with depressions which moved eastward across the British Isles over the period 1941-50, Sawyer¹ found that the average amount of precipitation at stations near the depression track was about 15 millimetres. Depressions which passed between Scotland and the Faeroes gave an average of about two millimetres at London and depressions which crossed Scotland about three millimetres. Depressions which crossed England gave about eight millimetres at London and depressions which moved east near the English Channel some 11 millimetres. The present investigation shows that depressions which moved eastward across England gave an average of 10 millimetres at London and depressions which moved along the Channel region gave 14 millimetres. These amounts are a little higher than the comparable values obtained by Sawyer, but may be biased by the inclusion only of occurrences within wet spells.

There were 47 cases of partly occluded frontal systems of which 32 moved from the west and 15 from the south-west. Those from the west produced an average precipitation of eight millimetres and those from the south-west an average of seven millimetres.

In 23 cases the point of occlusion crossed England with an average precipitation of seven millimetres and in 18 cases crossed southern England or the Channel region with an average of nine millimetres. In four cases the point of occlusion crossed Scotland and in two crossed well to the south of the British Isles.

Thunderstorms and thundery rain.—Of the 92 wet spells which occurred during the 10 years from 1950 to 1959, 58 were associated with reports of thunderstorms in southern England. Heavy rain was reported during a further 32 spells.

TABLE V—FREQUENCY OF WET SPELLS ASSOCIATED WITH THUNDERSTORMS

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
3/6	3/9	2/7	3/3	4/5	5/6	7/8	10/10	8/8	4/9	5/13	4/8

Table V shows the number of spells associated with reports of thunderstorms in southern England for each month of the year, expressed as a fraction of the total number of spells for each month. Nearly all the spells which occurred during the months April to September were associated with reports of thunderstorms but only about one-third to a half of the spells which occurred during the winter half of the year were similarly associated.

From data for Kew, Cheshire and Plymouth for the months May to August, over the period 1941 to 1945, Douglas and Moorhead² showed the importance

of rains of thundery origin, generally moving from some southerly point. They concluded that over a large area of England extending from the south-east coast to the Mersey, more than half the summer rain was of a thundery type.

Northerly outbreaks which preceded wet spells.—The beginning of a wet spell was usually associated with a depression near the British Isles or a complex area of low pressure to the west. In many cases there was a strong northerly flow on the western flank of the depression or low-pressure area. By tracing it back from chart to chart, the date of the first appearance of the northerly ("outbreak") over the Atlantic was obtained. This was taken to be the date on which the northerly, of comparable intensity and latitudinal extent, first appeared.

Of the 92 wet spells, 61 were preceded by such an outbreak of northerly surface winds over the Atlantic. The following details of the outbreaks were noted: (i) longitude, (ii) width in degrees of longitude, (iii) the lapse of time in

TABLE VI—LONGITUDE OF NORTHERLY OUTBREAKS

	Longitude ($^{\circ}$ W)					
	0° – 9°	10° – 19°	20° – 29°	30° – 39°	40° – 49°	50° – 59°
	<i>number of wet spells</i>					
Six summer months	2	2	7	5	8	2
Six winter months	0	0	5	6	11	13
Year	2	2	12	11	19	15

hours between the outbreak and the beginning of the wet spell at London. The longitude of the northerly outbreaks are shown in Table VI. Over the whole year, 93 per cent occurred between 20° W and 60° W. The most striking difference between the summer and winter months was concerned with the number of cases between 50° W and 60° W. During the summer months there were only 8 per cent of cases but in the winter months there were 37 per cent. In the winter months there were no cases east of 20° W.

TABLE VII—WIDTH OF NORTHERLY OUTBREAKS

	Width ($^{\circ}$ longitude)				
	5°	10°	15°	20°	25°
	<i>number of wet spells</i>				
Six summer months	1	15	4	5	1
Six winter months	0	6	19	7	3
Year	1	21	23	12	4

Table VII shows the width of the northerly outbreaks estimated to the nearest five degrees of longitude. Over the whole year, 92 per cent were from 10° to 20° of longitude in width. During the summer months the most frequent width was 10° but in the winter months was 15° .

TABLE VIII—TIME LAPSE BETWEEN NORTHERLY OUTBREAK AND BEGINNING OF WET SPELL

Lapse in hours	6–12	13–24	25–36	37–48	49–60	61–72	73–84
Number of cases	6	18	8	12	12	2	3

Table VIII shows the time lapse which occurred between the onset of the surface northerly and the beginning of the wet spell at London. In 82 per cent of cases the time lapse was between 12 and 60 hours. There was no significant difference between the distributions for the summer and winter months. No clear-cut relationship could be found between the time lapse and the longitude

of the northerly. However, on average, the time lapse tended to become longer the farther west the northerly outbreak occurred.

Position of persistent anticyclones.—Of the 92 wet spells, 33 were associated with blocked situations in the region of the British Isles. In 17 cases a blocking anticyclone was situated to the east over Russia, in six cases to the north-east over Scandinavia and in 10 cases to the north of the British Isles.

Blocking was associated with five of the six wet spells during which the precipitation was produced entirely by fronts. In two cases the anticyclone was situated to the east and in three to the north-east. In all these cases the fronts became slow moving or quasi-stationary, orientated north-south or north-west-south-east parallel to the surface isobars to the east or north-east of the front. A further 22 spells were associated with high pressure over Greenland. In all these cases there was no blocking in the region of the British Isles.

Conclusions.—In the period 1935 to 1959, the wet spells, as defined in this paper, averaged nine per year and accounted for 45 per cent of the total precipitation at Kew.

In the period 1950 to 1959, the spells had an average total precipitation of 30 millimetres and were associated in 90 per cent of cases with depressions, waves, fronts, or troughs which in general moved from the south, south-west or west across the British Isles. Of the total precipitation, 63 per cent was associated with depressions or waves and 32 per cent with fronts. Depressions from the south and south-west and fronts from the south provided the highest average precipitation. The point of occlusion of partly occluded frontal systems crossed England or the Channel region in 87 per cent of cases.

Nearly all the wet spells during the summer months were associated with thunderstorms in southern England. In the winter months about one-third to a half were similarly associated.

In many cases, the wet spells at London were preceded by an outbreak of surface northerlies over the Atlantic and associated trough development in the surface isobars to the west of the British Isles. This type of development is to be studied more closely in an attempt to formulate rules for the forecasting of wet spells at London.

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2. DOUGLAS, C. K. M. and MOORHEAD J. K.; The relation between wind direction in the middle troposphere and the incidence of thundery conditions and rainfall in England in summer. *Quart. J. R. met. Soc., London*, 72, 1946, p.207.

551.509.68 : 551.576.11

CUMULUS CLOUD GENERATED BY A RUBBER PLANTATION FIRE IN SOUTH MALAYA

By P. F. McALLEN

The photograph between pp. 100-101 was taken at 1415 local time on 27 June 1961, looking due north from Royal Air Force, Changi, Singapore, and shows cumulus development resulting from an extensive fire on a rubber plantation in south Johore, Malaya. The deliberate burning of rubber estates is a common

practice in Malaya as a means of clearing the rubber trees that have outlived their useful productive life. Rubber trees are very resinous and when burning liberate considerable heat, and cumulus development over such fires has often been observed, but not to the magnitude of that shown in the photograph. One of the most impressive aspects of this cloud was its very rapid development and bubbling turbulence which presented a spectacle surpassed only in the writer's experience by the convection generated by an atomic explosion on Christmas Island.

The fire occurred during a relatively dry spell, and after an early morning shower on 27 June there were only very small amounts of fair weather cumulus with about half cover of medium and high cloud, the surface wind being light southerly. The exact time at which the fire started is not known, but dense smoke and rapid cumulus development were observed at about 1330 local time, when the top of the cloud was already approximately 20,000 feet. By the time the photograph was taken at 1415 local time the top of the cloud had reached its maximum height of about 32,000 feet, as measured by clinometer using a base-line of $8\frac{1}{2}$ miles. The remains of a well marked pileus cap which had formed at about 30,000 feet can still just be seen to the right of the highest peak in the photograph. It is of interest to note that at the height of 32,000 feet where the temperature was -36°C there was no evidence of glaciation. The only other low clouds in the sky were small amounts of cumulus with bases about 3000 feet and with tops up to 7000 feet, some of which can be seen in the left foreground.

The cumulus development resulting from the fire produced a well defined precipitation echo on the storm warning radar at Royal Air Force, Changi, which showed the cloud to be $8\frac{1}{2}$ miles from the point where the photograph was taken. Rain can in fact be seen falling from the cloud in the photograph and this rain continued until 1430 local time.

The winds at low levels were light south-westerly becoming westerly 15–20 knots from 7000 feet to 20,000 feet. At 20,000 feet the winds became light and variable, and above this height they were 080° 40 knots at 32,000 feet increasing to 57 knots at approximately 40,000 feet. This wind shear can be clearly seen in the photograph, with the cloud being very discoloured by smoke up to the level at which the wind régime changed and the increase in wind speed above 20,000 feet causing a more rapid dispersal of the smoke.

A pennant cloud was observed to stream from the cumulus between 20,000 feet and 30,000 feet giving evidence of the relatively strong easterly winds at these levels, but this pennant cloud dispersed within a few minutes, indicating that the cloud consisted of water droplets and not ice particles. Shortly after the pennant cloud was observed the cumulonimbus attained its maximum vertical development and then rapidly dispersed.

In Figure 1 the Paya Lebar radiosonde ascent on this day is compared with that of 19 June 1961, an occasion discussed by Frost¹, when cumulonimbus development extended almost to the tropopause and a false cirrus canopy which formed at about 32,000 feet streamed out over Singapore. A small difference which may have been a limiting factor to the height of the top of the cumulus development over the fire, is the slightly warmer air between 335 mb and 200 mb. It will be noted that although the normal cloud development was very different on these two days, and in fact on the second had it not

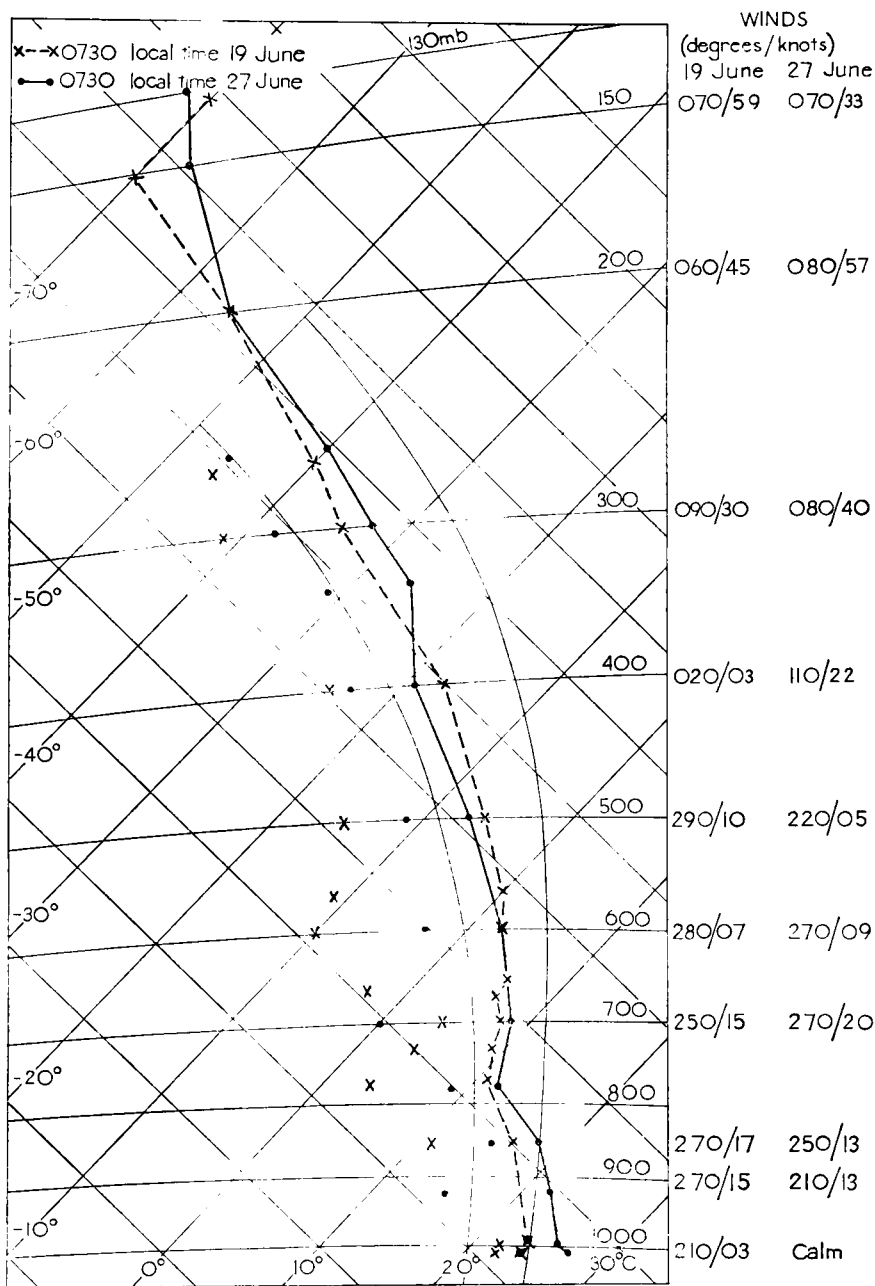


FIGURE I—UPPER AIR ASCENTS FOR PAYA LEBAR, SINGAPORE,
0730 LOCAL TIME, 19 AND 27 JUNE 1961

been for the fire, development would have ceased at 7000 feet, the wind régimes were broadly similar and the temperature differences at all levels were so slight as to be almost within the range of instrumental error. This perhaps serves to illustrate the difficulty often experienced by a forecaster in the tropics in interpreting upper air soundings and how fine is the critical margin between the fair weather sky and cumulonimbus development giving showery weather.

REFERENCE

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“WEATHER MONITOR” TAKES THE PLACE OF “WEATHER RECORDER”

By C. E. N. FRANKCOM, O.B.E.

At 12.30 p.m. on 30 May 1961 *Weather Recorder* arrived in Greenock, and thus completed her 106th and last voyage as an ocean weather ship in the North Atlantic. On 15 June *Weather Monitor*, the third of the “Castle” class vessels to be converted to an ocean weather ship, sailed from Greenock for Ocean Station “Juliatt”, thus taking the place of *Weather Recorder*.

Weather Monitor, formerly the “Castle” class frigate H.M.S. *Pevensey Castle*, was officially given her new name on 12 May at a little ceremony in Blyth (Northumberland) by Mrs. A. C. Best, wife of the Director of Services of the Meteorological Office. The renaming took place in the dockyard of the Blyth Dry Dock and Ship Building Co. Ltd., which had done the extensive job of converting the ship to make her suitable for her new duties. The ceremony, which was pleasantly informal, was attended by the Mayor and Mayoress of Blyth and representatives of the Meteorological Office, Ministry of Aviation and Admiralty. The ship was “dressed” with the national flags of the countries which operate ocean weather ships in the North Atlantic and, as the weather was appropriately kind for this meteorological occasion, she looked quite gay. Members of the ship’s company who had already joined the ship were assembled on the quay and each of them was introduced to Mrs. Best and her husband. A number of the Blyth Dry Dock Company’s men who had done the conversion work were also present.

Mrs. Best boarded the ship, accompanied by Captain A. A. Robinson, the temporary Master, and having cut a tape which released a canvas cover to disclose the ship’s name, said “I rename this ship *Weather Monitor*. May God bless her and all those who sail in her.”

After a tour of inspection of the ship, the visitors were entertained to luncheon by Mr. Mitcheson, the General Manager of the shipyard. In a brief informal speech, Dr. Best said how impressed he had been with the good job that the shipyard had made of this conversion, and mentioned in particular the high quality of the woodwork and general layout of the accommodation. He emphasized the useful work that weather ships have done and are doing in the somewhat inclement waters of the North Atlantic: without the meteorological information provided by these ships, supplemented by that provided voluntarily by merchant ships, the job of the meteorologists in Europe would be made very much more difficult. Also, the ships provide very useful navigational aids and communication services for transatlantic aircraft. The North Atlantic weather ship scheme provided an outstanding example of effective international co-operation for peaceful purposes, from which a large number of countries and individuals benefited. Mr. Mitcheson, in reply, said how pleased he was that his shipyard had had the opportunity of converting three of these ships (*Amberley Castle*, *Pevensey Castle* and, still in the process of conversion, *Rushen Castle*).

The general layout of *Weather Monitor* is almost exactly the same as that of *Weather Adviser* which sailed on her maiden voyage as an ocean weather ship

in September 1960. *Weather Monitor* is fitted with all the equipment necessary to perform her duty as an ocean weather ship and the general standard of her accommodation is as good as will be found in any other ship of a similar size.

Weather Recorder was formerly the "Flower" class corvette *Genista*; launched in 1941, she served as an escort trawler during the last war, mostly in the South Atlantic and Indian Ocean areas. Converted to an ocean weather ship in Devonport dockyard, she sailed on her first patrol at an ocean station in October 1947. During her fourteen years' service as an ocean weather ship in the North Atlantic she carried out her various duties very efficiently. The following extracts from the Master's voyage reports of *Weather Recorder* during her last five voyages will perhaps serve as an epitaph.

Voyage 102 to Station Juliett, October 1960

"For the first two weeks on station the weather was varied, ranging from good spells to rather uncomfortable ones. During the final week a severe storm developed; it became so bad that it was necessary, in the interests of safety, to turn ship and run before the wind which, blowing hard for many hours in one direction, built up a tremendous sea. Ship was driven . . . to the S.S.E., i.e., more than 100 miles off the Grid. When the weather finally eased sufficiently so that ship could be turned into wind and sea, there was insufficient fuel, and time remaining to get back again before being relieved. The appropriate Authorities were advised and ship remained in this approximate area until the *Weather Adviser* reached the corresponding longitude . . ."

Voyage 103 to Station Juliett, December 1960

"A Methop exercise in which two aircraft from St. Mawgan took part occurred on the 22nd. December. One aircraft carried out the exercise while the other photographed the proceedings. It was with great surprise and pleasure that we were told by the pilot of one of the aircraft that Air Vice-Marshal Bower, Air Officer Commanding, No. 19 Group, Royal Air Force, was present. At the end of the exercise, after the mail had been recovered, our distinguished visitor passed a Christmas Message to the Ship's Company. A further mail-drop, this time by an aircraft from Kinloss, took place on the 24th of December. The mail delivered on these two occasions was very much appreciated by all—the cakes and Christmas tree suffered no harm from their undignified drop into the North Atlantic."

Voyage 105 to Station Kilo, March 1961

"A surprise visit was made to the ship on Thursday, 23rd. March, by a French Air Force aircraft; he seemed to be rather surprised to find a British ship on station instead of a French one. This is borne out by the fact that he came armed with a large quantity of current French newspapers and magazines which he offered to drop if we wanted them. This offer was accepted and proved to be a windfall for the erudite few but a disappointment to the less well endowed majority."

Voyage 106 to Station India, May 1961

"The weather encountered throughout the period on station was, like that on Station Kilo last voyage, very good indeed. It would appear that whosoever controls the weather had decided to cast a benign eye on this, the *Weather*

Recorder's last voyage as a weather ship Members of the crew also indulged in swimming using rubber dinghies.

"One sad occurrence marred the voyage and that was the receipt of the news of the death of the Chief Engineer's wife It was fortunate that, just at that time, the *Weather Watcher* was homeward bound from Station Alfa and her Chief Engineer agreed to change places with my Chief Engineer, so that he could get home much sooner than otherwise would have been the case. The exchange took place on the 23rd. of May despite the temporary deterioration in the weather which made the operation not without a certain degree of hazard to the Chief Engineers and the boat's crew.

"On the 26th. May the German Navy Training Barque *Gorch Fock* closed the ship and sent over two officers—one, a meteorologist and the other an executive officer—to see a weather ship in action; they were most interested and left two cases of German beer, while we in turn gave them a case of English lager and a case of Guinness along with a bottle of whisky for the Commander of the German ship, Captain Erhardt. A photograph of the *Gorch Fock* was also given to us."

NOTES AND NEWS

British Glaciological Society 25th Anniversary Celebrations and Symposium, Cambridge 6–7 January 1962

The twenty-fifth anniversary of the formation of the British Glaciological Society was celebrated with a banquet in St. John's College and by a two-day symposium on the "Problems of mass balance studies". Though closely related to climatic and meteorological factors it was surprising that so few meteorologists were present to learn of the work and problems in a neighbouring field of study. Delegates from a dozen nations attended including some from across the Atlantic. All in all a good proportion of the world's active glaciologists were there and it served to show the international esteem for the British Glaciological Society and its Journal.

The first session, under the Chairmanship of Dr. G. de Q. Robin (Director, Scott Polar Research Institute) sought to bring unanimity to the terminologies that have been applied to the budget terms of a glacier (Dr. Meier, United States of America) and to explore the implications of mass balance studies (Dr. J. F. Nye, Great Britain). Dr. Nye defined climatic change as, denoted by the function $a_1(t)$, the changing accumulation and/or ablation budget, that is, the net effect of all climatic changes of the region concerned. He was able to show analytically that $a_1(t)$ is some function of the total thickness of the glacier $h_1(t)$, and can be represented by the polynomial $a_1 = \lambda_0 h_1 + \lambda_1 dh_1/dt + \lambda_2 d^2h_1/dt^2 + \dots$. Changes in the value of h_1 are directly proportional to advance or retreat of a glacial snout, which is easily determined. With additional knowledge of the flow rate of a glacier, the width and slope, the coefficients λ_n may be determined. This has been done for one glacier in North America, but glaciers that are well documented for velocities and snout positions dating back to the last century are scarce. Even so this offers the climatologist and hydrologist a tool for estimating precipitation and glacial extent at some time other than the present.

Professor Hoinkes (Austria), and Dr. V. Schytt (Sweden) described actual work on glaciers in their respective countries. These are by no means academic studies; the shrinkage of European glaciers is a serious problem and must be studied fully to be understood. Dr. Schytt was well aware that his impressive large-scale experiment needed the services of a meteorologist to study synoptically the weather related to his annual budget problem.

The second session, with Dr. Fristrup (Denmark) as Chairman, covered the "Seasonal velocity changes of temperate glaciers" (G. R. Elliston, Great Britain), "The assessment of glacier mass budgets from air photographs" (Dr. E. R. LaChapelle, United States of America), "Mass balance of the Ellesmere Ice Shelf" (Dr. H. Lister, Great Britain), and some "Hydrological investigations into the mass balance of a Greenland glacier" (Dr. F. Nusser, Germany).

W. O. Field of Canada was the Chairman of the last session, which after an account of work in the Canadian Arctic (Dr. Müller) turned to the Antarctic. In an excellent discourse J. T. Hollin stated the problems of the Antarctic mass budget. With a continent of the size of the Antarctic and a time lag in change of the ice cap probably of the order of some 4000 years behind the climate, it was difficult to find any evidence of change in mass. Most accumulation data are obtained in the less windy regions, the other regions are too uncomfortable to inhabit and make accumulation measurements. It is in these regions that there is probably a net loss of snow cover, thus reducing the net annual accumulation for the whole continent. Neither was there sufficient data on the calving rate, or under-water melting of the ice shelves. He concluded that he would regard the Antarctic ice cap as being in equilibrium until there was proof to the contrary.

Further problems arose when C. R. Bentley (United States of America) produced results of seismic and gravity traverses in west Antarctica. Surface features showed little relation to the rock profile at the bottom of the ice, and the basal shear stresses were less than two bars, which Dr. Nye pointed out was the minimum necessary to produce movement of a cold ice sheet. Was this static ice, despite the apparently significant surface slope? And, if so, is the mass of the continent increasing?

Discussion was lively and to the point throughout the symposium and much valuable knowledge and "knowhow" was exchanged. Obviously the scope of this type of work will increase, limited only by finance and man-power.

D. W. S. LIMBERT

Snowfall of 31 December 1961

The two photographs facing p.101 show an unusually heavy accumulation of snow on a thin wire. They were taken by Mr. J. J. H. Pennells, Meteorological Office cartographic draughtsman at his home in Reading between 9 and 10 a.m. on 31 December 1961. He states that rain commenced between 2.30 a.m. and 3 a.m. turning to snow about 3.30 a.m. The rain caused glazed frost on which the snow subsequently accumulated to a total diameter of $1\frac{1}{2}$ to 2 inches.

Fulwell Station on 24 August 1961

The photograph between pp. 100-101 shows an unusual production of condensed water vapour in the atmosphere. It was taken by Mr. G. Nicholson at 8 p.m. on 24 August 1961 at Fulwell Station. British Railways (Southern Region) state that the efficiency of the insulators had been greatly reduced by being partially submerged. The current passing over the insulators therefore produced local heating and consequent steaming.

OFFICIAL PUBLICATION

The following publication has recently been issued:

SCIENTIFIC PAPER NO. 11—*Some calculations of terms in the energy balance for monthly periods at the ocean weather stations I and J in the North Atlantic*, by H. C. Shellard, B.Sc.

Meteorological data from the North Atlantic ocean weather stations I and J for the period 1948-56 are used to compute monthly values of terms in the energy balance. The annual and year-to-year variations in the various terms are discussed and comparison is made between the mean seasonal and annual values of evaporation, sensible heat exchanged between sea and atmosphere, total energy exchanged between sea and atmosphere and of the Bowen ratio, and the corresponding values found by W. C. Jacobs for the same areas. It is suggested that in general Jacob's values are too low. Estimates are also made of the average annual amounts of heat advected into the two areas by ocean currents, and bathythermograph observations during six months in 1956 are used to show that this advection term may vary considerably from one month to the next.

METEOROLOGICAL OFFICE NEWS

Sports activities

We learn from the Senior Meteorological Officer, Royal Air Force, Khormaksar that in the Station Sports, held on 29 January and 2 February 1962, Mr. R. M. Blackall, Meteorological Office, finished first in the 3 miles, the 1 mile, the 3000 metres steeplechase and the 880 yards. In the Middle East Command Trials on 13 February, he was first in the 3 mile and 1 mile events, and second in the 880 yards. And in the Middle East Command Cross-Country Championship on 20 February, over a 4 mile course, Mr. Blackall finished first among 50 competitors.

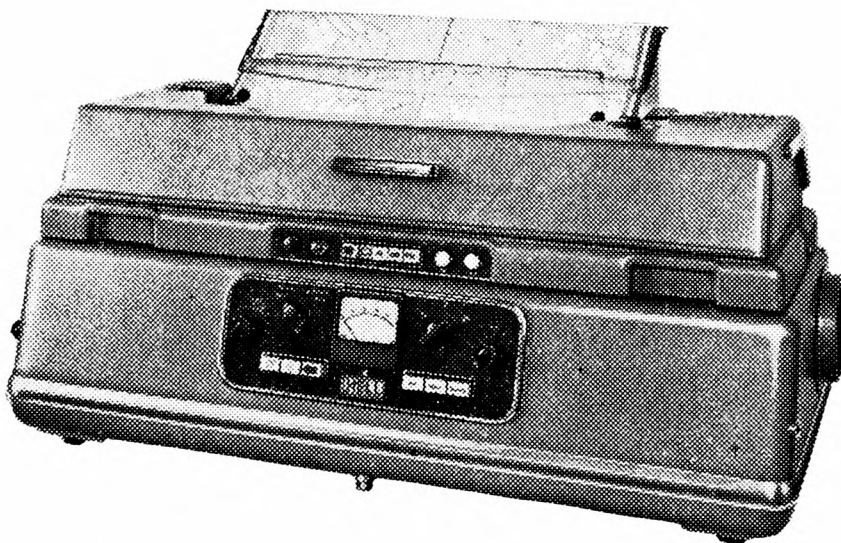
CORRIGENDUM

Distribution of total solar radiation on a horizontal surface over the British Isles and adjacent areas.

In Table 1 on page 272 of the October 1961 *Meteorological Magazine* the body responsible for Valentia Observatory should, of course, be the Irish Meteorological Service.

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APPLICATION OF AN INSTABILITY INDEX TO REGIONAL FORECASTING

By P. G. RACKLIFF, Dip. Geog.

Introduction—Showalter¹ and Galway², working in the United States of America, introduced the "stability index" and the "lifted index," both relatively simple parameters to be used as aids in predicting local storms. The Showalter stability index is a static measure of latent instability, computed by lifting a parcel or bubble of air adiabatically from 850 millibars to 500 millibars. The theoretical temperature of the lifted parcel is then subtracted algebraically from the environment temperature at 500 millibars. Positive numbers indicate stability and negative numbers, instability. The lifted index is computed by similar but less objective methods, making use of the forecast maximum temperature. Using a similar technique, the author has attempted to produce a simple parameter to be called the instability index, for use in the production of regional forecasts when conditions are favourable for the development of air-mass type thunderstorms. The intention has been to provide an index which can be rapidly computed from the 2300 GMT temperature soundings and plotted on a small-scale chart. Isopleths may then be inserted to delineate areas of maximum latent instability and the chart can be used in compiling forecasts which have to be prepared early in the day, often before 0600 hours. Although some values of the index are as liable to precede showers as not, it is felt that the use of the method set out below will assist forecasters to delineate the most probable areas of thunderstorm occurrence and will also prevent failure to forecast thunderstorms on some occasions, as illustrated by the examples.

Computation of the instability index.—A network of thirteen radiosonde stations was used, nine in the British Isles and four adjacent continental stations, namely De Bilt, Uccle, Trappes and Brest. It was impracticable to make a rapid assessment of the theoretical maximum temperatures for all thirteen locations, extending as they do over a relatively large area, with varying degrees of exposure to maritime influences, and it was therefore decided to use an entirely objective method, in order to produce a working chart as quickly as possible. With this aim in view, the author used the 900-millibar wet-bulb potential temperature, since this measurement, whilst being representative of the air at low levels, would not be affected to any degree at

night by outgoing terrestrial radiation. At pressures higher than 900 millibars, temperature and humidity fluctuations arising from nocturnal radiation, stratification and condensation on nuclei or the earth's surface, will be reflected in the lowest readings of the midnight soundings. Normal convention was followed in taking the 500-millibar dry-bulb temperature as the second reading to be used in the calculation, since this reading is indicative of the thermal structure in the middle troposphere and usually reflects the warm or cold tongues of the thickness chart. The 500-millibar dry-bulb temperature was subtracted algebraically from the 900-millibar wet-bulb potential temperature (both measured in degrees Celsius), the result being the instability index. Expressed as a simple formula,

$$\Delta T = \theta_{w900} - T_{500}$$

where, ΔT is the instability index

θ_{w900} is the 900-millibar wet-bulb potential temperature
 T_{500} is the 500-millibar dry-bulb temperature.

The instability index for each upper air sounding can be calculated in a few seconds from the tephigram. Since dew-point is reported and not wet-bulb temperature, the intersection of the dry-adiabatic and mixing-ratio lines, appropriate to the 900-millibar dry-bulb and dew-point readings, respectively, can be used to fix the saturated adiabatic curve and the 900-millibar wet-bulb temperature. The wet-bulb potential temperature can be read directly from the saturated adiabatic curve, since each curve is clearly labelled on the current British tephigram. Thus, a 900-millibar wet-bulb potential temperature of 12°C and a 500-millibar dry-bulb temperature of -18°C will give an instability index of 30.

The indices are plotted on a small-scale chart, of say 1 in 10 million, and isopleths are then inserted at one- or two-degree intervals. Index values calculated during the period May–August 1959 ranged from 21 to 35 (Table I). The high values indicated a marked degree of instability and the low values indicated stable conditions.

Evaluation.—This was carried out in two steps. The first step was an attempt to fix the threshold value of the instability index to be associated with the occurrence of significant showers or thunderstorms. Degrees of shower or thunderstorm activity in south-east England were tabulated, together with the value of the instability index calculated from the 2300 GMT temperature sounding at Crawley, Sussex. Reports from 29 meteorological stations within a 75-mile radius of Crawley were studied in order to assess shower or thunder activity for each day during the period May–August 1959. These observations were supplemented by press and radio reports which normally provided confirmation of heavy storms and resultant flooding. Occasions when the activity was directly associated with a frontal discontinuity were excluded, thus eliminating the rather large fluctuations in the value of the indices associated with frontal passage, so making it possible to determine representative values for air-mass instability.

The degree of shower activity was tabulated on a four-point scale. Occasions with showers were divided into two groups, one for showers accompanied by thunderstorms, and the other unaccompanied. There was a further subdivision for days with thunder, in order to categorize occasions with thunderstorms

which could be rated as heavy. Similarly, showery days without thunder were split into two categories, by extracting and grouping those days when the showers could only be regarded as very slight and isolated.

The tabulation is produced as Table I. There is a significant shift towards the high indices in the thunderstorm categories, as would be expected. The lowest index value associated with any showers was 25 and on this occasion the precipitation was very slight. The highest value of 35 was associated with heavy thunderstorms, and showers or thunderstorms occurred on all occasions with an instability index of 32 or more, with the probability of 2 to 1 on thunderstorms. It is noteworthy that on the five days with heavy thunderstorms the instability index ranged from 31 to 35, suggesting a threshold value of about 30. The fourteen days when the index stood at 30 are evenly divided, seven with shower activity and seven with none. Nevertheless, thunderstorms occurred on five of the seven showery days.

TABLE I—DEGREES OF SHOWER ACTIVITY AND THE ASSOCIATED INSTABILITY INDEX FOR SOUTH-EAST ENGLAND, MAY–AUGUST 1959

		Instability index (from 2300 GMT Crawley sounding)																		
		21	22	23	24	25	26	27	28	29	30	31	32	33	34	35				
		<i>number of days</i>																		
No showers	..	1	1	0	6	9	5	6	7	9	7	4								
Very slight and isolated showers					1	1	1	3	0	1	1							
Slight-moderate showers									1	1	1	1	3	1				
Showers accompanied by thunderstorms	..										1	5	2	0	2	3				
Heavy thunderstorms													2	0	1	1	1			

The assessment covered 89 days. Occasions with frontal activity were excluded.

The second stage of evaluation was carried out using plots of thunderstorm reports and fixes on sources of atmospherics (Sferics). The accuracy of Sferic reports in fixing lightning discharges was adequate for this investigation and has been discussed elsewhere by Horner³. A number of maps were produced for days when thunderstorms and Sferic plots were in evidence on the synoptic charts. Once again, occasions with frontal activity were excluded. Instability indices computed from the thirteen soundings made at 2300 GMT were plotted on a small-scale chart and isopleths inserted, together with symbols denoting thunderstorm reports or Sferic fixes extracted from the three-hourly synoptic charts, commencing with the chart for 0001 GMT and terminating with the 2100 GMT chart.

The synoptic chart for 0001 GMT, 12 May 1959, is produced as Figure 1. The Atlantic depression was drifting slowly north-westwards and pressure was intensifying over the British Isles, under the influence of the Scandinavian anticyclone and an intensifying ridge west of Biscay. Figure 2 depicts the instability index chart for 2300 GMT, 11 May 1959. The isopleths delineate an elongated zone of maximum latent instability with the major axis orientated approximately north-south, extending from Normandy to northern Scotland. The zone with high indices thus embraces most of Britain and from the thunderstorm reports and Sferic fixes received on 12 May it is apparent that thundery showers or storms affected large areas of Britain and Normandy.

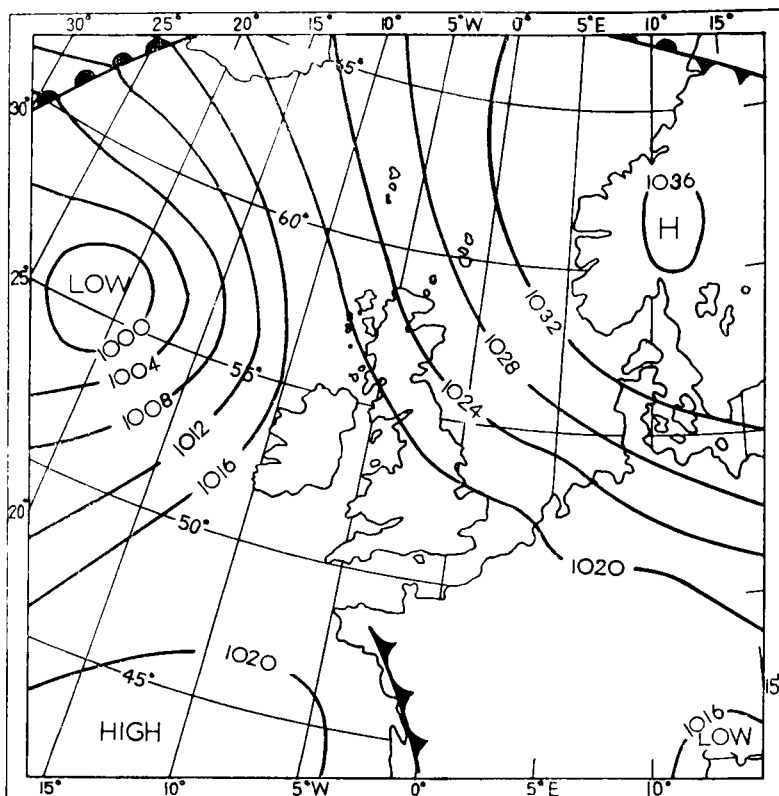


FIGURE 1—SURFACE CHART FOR 0001 GMT, 12 MAY 1959

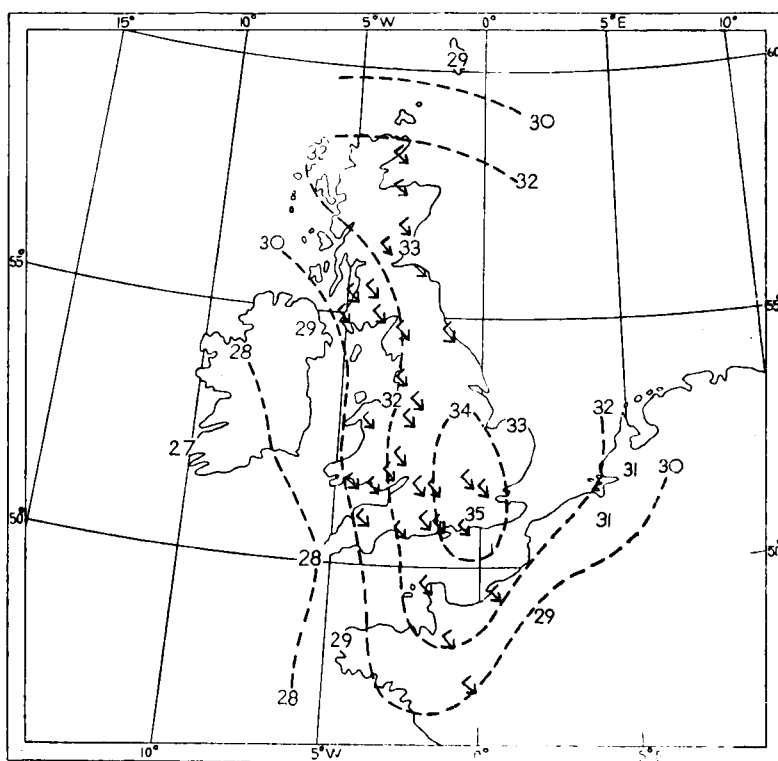


FIGURE 2—INSTABILITY INDEX CHART FOR 2300 GMT, 11 MAY 1959

The broken lines are isopleths of the index, obtained from tephigrams. The symbols denote thunderstorm reports or Sferic fixes for 12 May 1959.

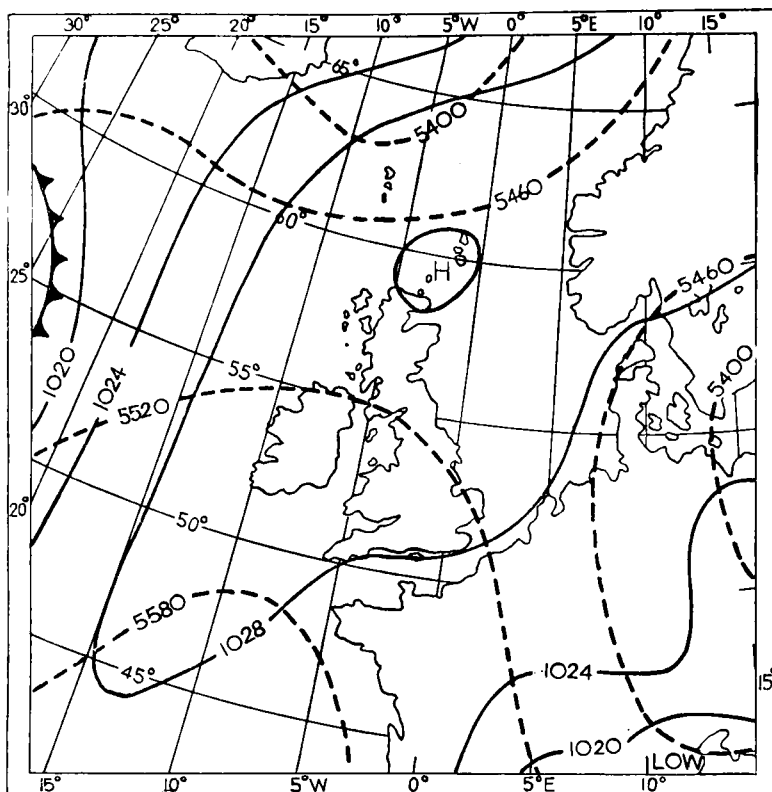


FIGURE 3—SURFACE CHART FOR 0001 GMT, 14 MAY 1959
The broken lines are isopleths of thickness (geopotential metres) for the 1000-500 mb layer.

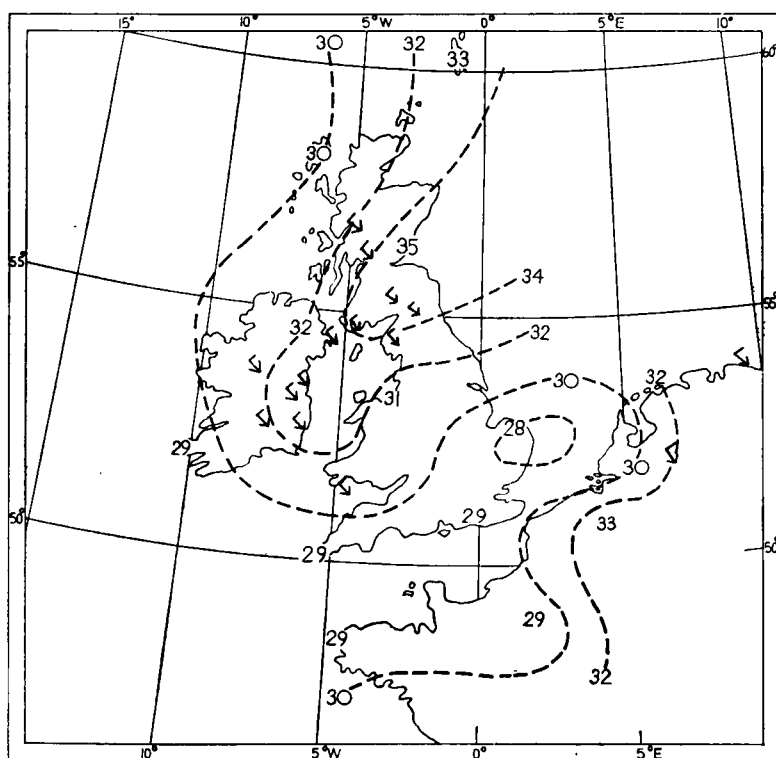


FIGURE 4—INSTABILITY INDEX CHART FOR 2300 GMT, 13 MAY 1959
The broken lines are isopleths of the index, obtained from tephigrams. The symbols denote thunderstorm reports or Steric fixes for 14 May 1959.

The 24-hour forecast from noon, issued with the *Daily Weather Report* for 12 May 1959 contained the statement, "thunderstorms will occur in places". This is rather vague in the regional sense, but using the instability index as a guide the forecaster could have indicated that thunderstorms would be widespread, but were unlikely to occur in extreme south-west England and Ireland, i.e. in those areas where the index fell below 30 (Figure 2).

On 14 May 1959 an anticyclone centred near Orkney covered the British Isles. The 1000–500-millibar thickness pattern has been superimposed on the synoptic chart (Figure 3); a warm ridge extended across Biscay to the British Isles, with no evidence of cold troughing and associated instability over the region. Nevertheless, the instability index chart for 2300 GMT, 13 May 1959 indicated a zone of instability in the form of a tongue or wedge, with its axis extending from the North Sea, through Berwick and Galloway to south-east Eire, and a more stable region to the south-east, extending from East Anglia to the Dutch coast (Figure 4). Subsequent thunderstorms and Sferic fixes reported during the day were plotted over north-west England, west and south-west Scotland and east and central Eire. There were also reports from the fringe area of the map, in north-west Germany. Aircraft reports also indicated significant cumulonimbus development during the day. An aircraft over the Isle of Man at 0800 GMT reported an isolated cumulonimbus top at 17,000 feet but by 1315 GMT cumulonimbus tops ranging from 30,000 to 35,000 feet were reported in a position about 25 miles north of Silloth, Cumberland. Figure 4 indicates good agreement between the fixes and the isopleth pattern and an inspection of this chart, and the previous chart for 11 May 1959, suggests a critical or threshold value of about 30, for the instability index, in agreement with the inference drawn from Table I.

The 2300 GMT soundings for Camborne, Aughton (Liverpool) and Aldergrove of 13 May 1959, indicated rather moist air aloft, and the forecast issued with the *Daily Weather Report* for 14 May 1959 included the statement, "scattered thunderstorms may break out in western areas later this afternoon". The forecaster inspecting the instability index chart and noting the prominent tongue or wedge pattern, might have been prompted to state that thunderstorms were most likely to occur in northern England, southern Scotland and eastern Ireland. This would have been preferable to the rather vague reference to "western areas". The degree of confidence or probability could also have been raised, assuming a threshold index value of about 30 and noting that the plotted indices ranged as high as 34 to 35.

Figure 6 depicts the instability index chart for 2300 GMT, 27 July 1959, and the isopleths indicate a high degree of instability over southern and eastern regions of the British Isles. The assumption of thundery activity, with indices well above the 30 mark, was borne out by the numerous Sferic fixes and thunderstorm reports plotted during the succeeding day; these extended from the Low Countries and North Sea across England to eastern Ireland. The synoptic chart for 0001 GMT, 28 July 1959 (Figure 5) indicated a slow-moving depression centred near the Solway Firth and an associated cold front extending from the North Sea, through the German Bight to south-west France.

The 24-hour forecast from noon, issued with the *Daily Weather Report* for 28 July 1959, merely stated that "thunderstorms are likely in places". On the

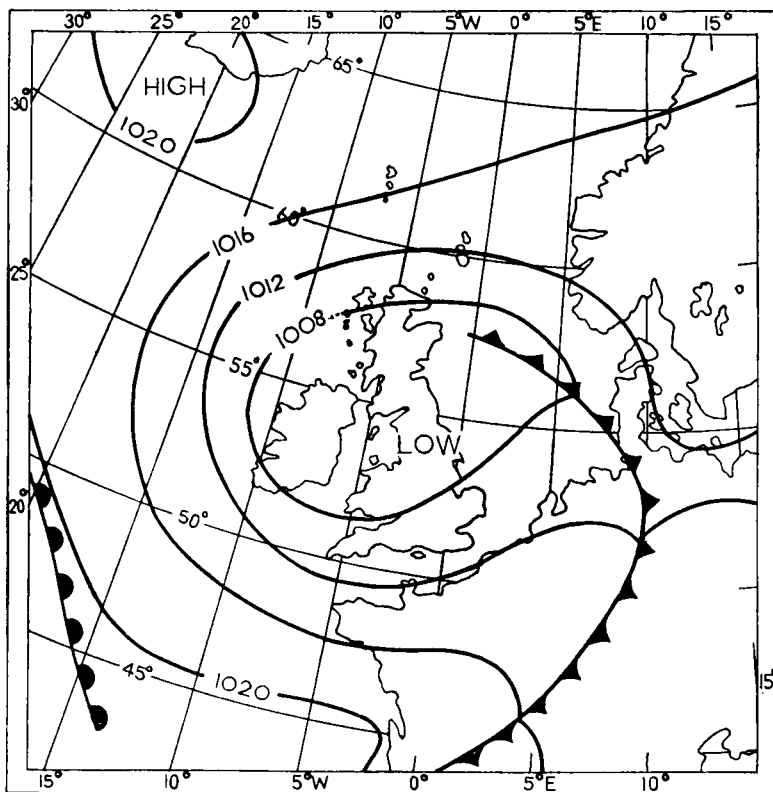


FIGURE 5—SURFACE CHART FOR 0001 GMT, 28 JULY 1959

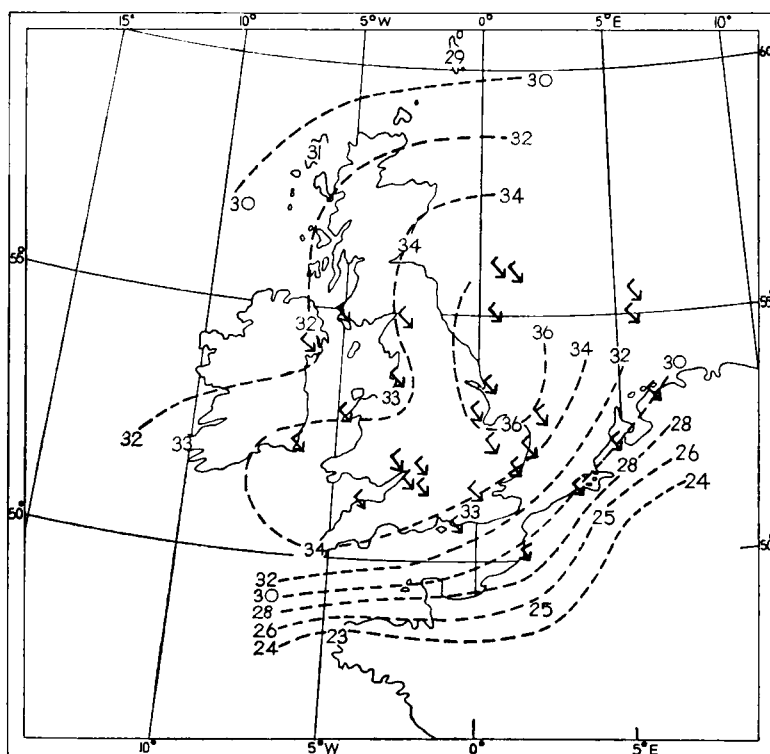


FIGURE 6—INSTABILITY INDEX CHART FOR 2300 GMT, 27 JULY 1959
The broken lines are isopleths of the index, obtained from tephigrams. The symbols denote thunderstorm reports or Sferic fixes for 28 July 1959.

following day there was little change in the synoptic situation and the instability index over most of Britain exceeded 32, indicating a strong probability of further widespread thunderstorm activity. Nevertheless, the forecast issued with the *Daily Weather Report* for 29 July 1959 did not mention thunderstorms although, in fact, widespread thunderstorms did occur. The forecaster, using the instability index chart as an additional aid, could have confidently predicted widespread thunderstorms, or at least indicated a strong probability of widespread storms occurring on both 28 and 29 July 1959.

Conclusions.—It is suggested that a chart based on the instability index would assist the regional forecaster, particularly during the summer thunderstorm régime. The simple computations and objective method mean that charts can be prepared very rapidly from the 2300 GMT radiosonde data; thus the deduced information is available for the early forecast bulletins.

In non-frontal situations, an index value exceeding 30 should alert the forecaster to the prospect of significant showers accompanied by thunderstorms.

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551.509.311: 551.509.317: 551.509.323.7

SYNOPTIC FACTORS ASSOCIATED WITH RELAXING THERMAL TROUGHS AND THEIR PREDICTION VALUE

By M. K. MILES and G. A. WATT

Summary.—All troughs in the 1000–500-millibar thickness lines which underwent a certain minimum amount of relaxation between the east coast of America and about 15°E in the years 1953–59 (inclusive) form the basis of the study. It is found that, despite the strong contribution of convective warming over the west and central Atlantic, the process is essentially a dynamical one. The two main agents in this appear to be:

- (i) an upwind trough coming, or forming, within 35°–40° longitude and
- (ii) an anticyclone (usually centred north of 40° N) within 35°–40° longitude downwind.

They are usually both present when relaxation starts. A forecasting rule based on the sum of these two spacings was tested on data for 15 months 1960–61, and 82 per cent of the forecasts made were correct.

Relaxation has the following synoptic consequences:

- (i) a rise in surface pressure on the associated cold front, together with a reduction in rainfall intensity and suppression of wave formation;
- (ii) an increase in static stability within the thermal trough.

Introduction.—Since charts of thickness (1000–500 millibars) became a working tool just after the end of World War II, the warming (and weakening) of cold areas (represented by troughs in the thickness lines and usually known as thermal troughs) has been recognized as an important occurrence. The process, involving northward movement of the thickness lines in the trough, early came to be described as relaxation: the term is now so securely built into the synoptic meteorologist's vocabulary that it seems expedient to continue to use it.

Figures 1 to 4 illustrate a case in which four thickness lines of a trough in the east Atlantic relaxed although the warmest line did not. It is not uncommon for

this to happen and in such cases there is either a surface low or a cut-off cold pool associated with the southern part of the trough.

This study was designed to discover, more precisely than is known at present, the synoptic factors which favour and accompany the process of relaxation.

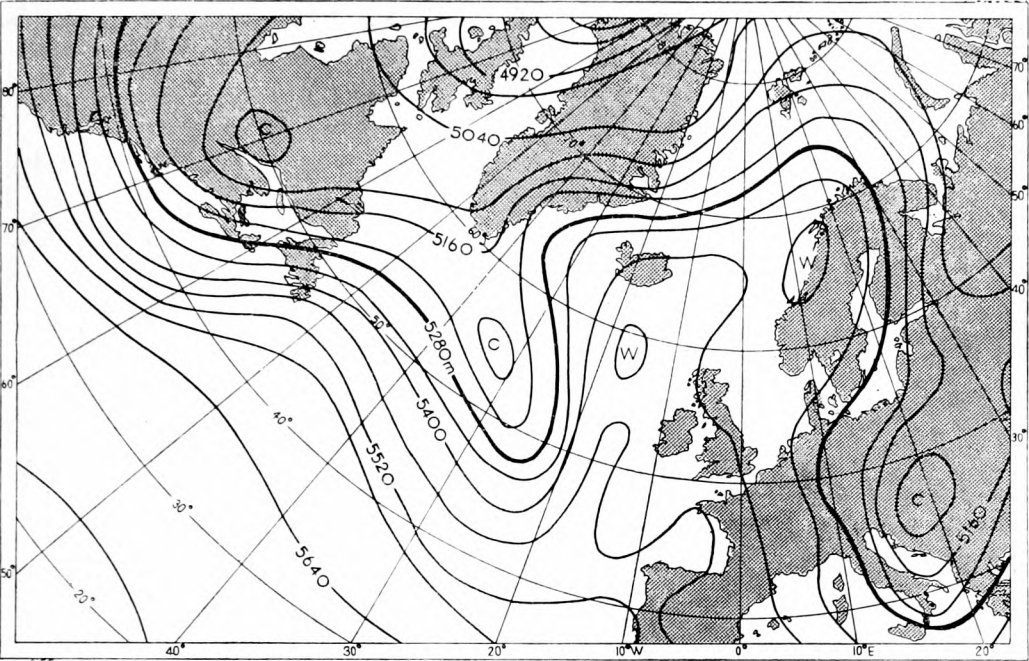


FIGURE 1—1000-500 MB THICKNESS CHART FOR 1500 GMT, 9 MARCH 1956

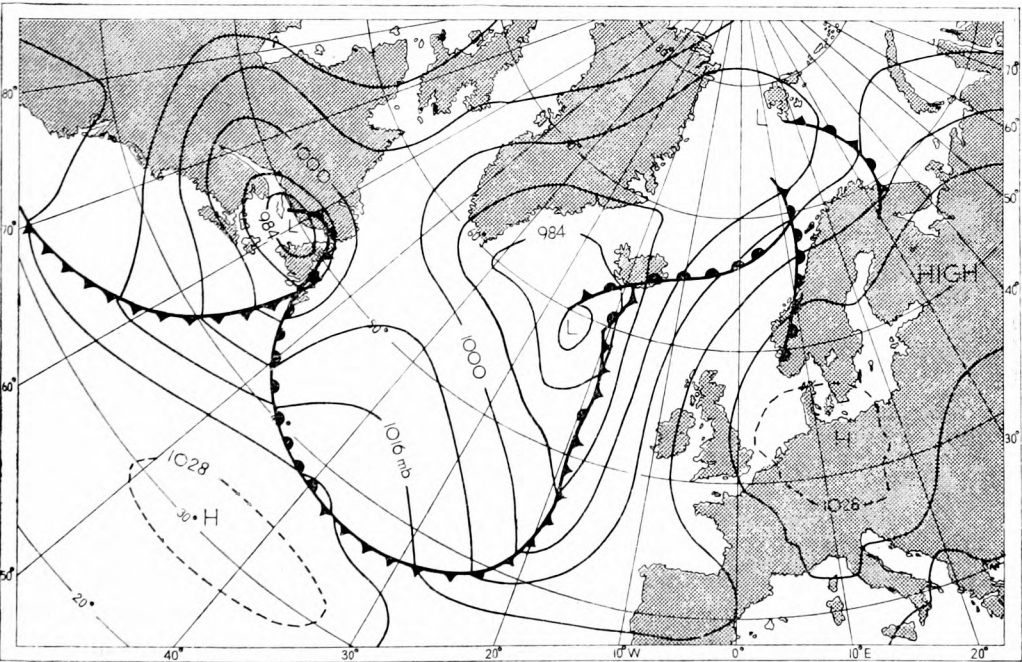


FIGURE 2—SURFACE CHART FOR 1500 GMT, 9 MARCH 1956

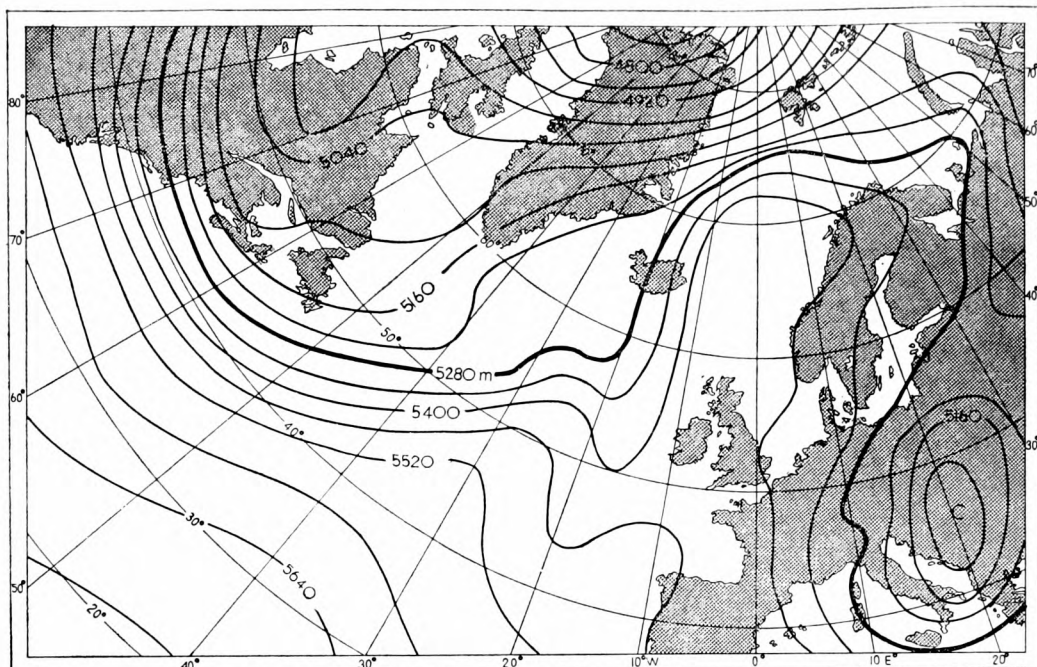


FIGURE 3—1000-500 MB THICKNESS CHART FOR 1500 GMT, 10 MARCH 1956

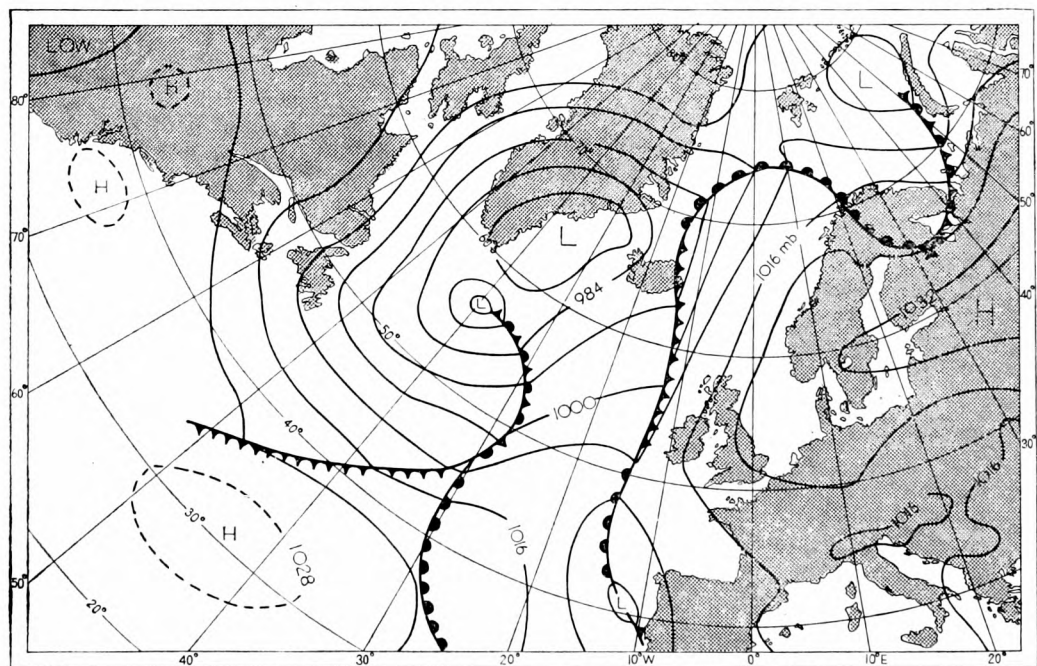


FIGURE 4—SURFACE CHART FOR 1500 GMT, 10 MARCH 1956

Observational material.—For the purpose of this study a thermal trough was taken to have relaxed if several thickness lines moved north and one of these at least 5° latitude in a 24-hour period. Relaxation is said to have started at the beginning of this period. This line was usually other than the coldest line of the trough, and will henceforth be referred to as the *defining thickness line* of the trough.

All thermal troughs which relaxed between the American coast and 15°E were noted for the seven years 1953 to 1959. Calling the time when relaxation starts t , the following data were extracted for $t-24$ hours, t and $t+24$ hours for each case:

- (i) the latitude and longitude of the most southerly point of the defining thickness line of the trough;
- (ii) the latitude and longitude of the most southerly point of this defining thickness line in the next upstream thermal trough;
- (iii) the latitudes and longitudes of the most northerly point of this defining thickness line in the adjoining thermal ridges;
- (iv) the latitude, longitude and central pressure of the nearest downwind anticyclone, provided there was not another thermal trough in between;
- (v) the latitude and longitude and central pressure of the nearest upwind anticyclone, provided this was situated east of the upwind thermal ridge.

Synoptic statistics associated with relaxation

Characteristics of the relaxing trough.—During the first 24 hours of relaxation the average speed of the 277 relaxing troughs was 13° longitude per day (standard deviation 6.3) and the average northward movement of the defining thickness line was 7° latitude. Of these, 162 could be identified at $t+48$ and the average speed was 14° longitude per day from $t+24$ to $t+48$ and the average relaxation was 6° latitude. The average movement over the 24 hours preceding relaxation was 12° longitude and the average meridional movement of the defining thickness line was 0° latitude.

The latitude and average value of the defining thickness line is shown in Table I for each month of the year. It appears that relaxation tends to occur most frequently in a fairly restricted latitude band between the subtropical

TABLE I—LATITUDE AND AVERAGE VALUE OF DEFINING THICKNESS LINE

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Average latitude ($^{\circ}\text{N}$)	40	40	41	41	43	45	48	46	47	43	43	42
Standard deviation	4.1	4.3	3.1	4.3	4.9	3.7	6.8	3.2	4.2	4.6	4.9	5.1
Average value of defining thickness line (decametres)	536	535	534	536	545	548	554	553	545	545	539	535
No. of cases	26	37	25	25	37	17	15	18	19	17	23	19

high-pressure belt (30° – 35°N) and the mean pressure trough at about 60°N . The seasonal movement is of the same order as the seasonal shift of these mean circulation features.

Relaxation had begun on the majority of occasions by the time the trough reached 30°W . This is especially so in winter (November to March inclusive) when the proportion is 85 per cent. In the months June to August (inclusive) the percentage of troughs relaxing east of 30°W rises to 58 per cent. The greater non-adiabatic warming of cold continental air moving into the west Atlantic in winter is clearly reflected in these figures.

The mean thickness gradient was measured over a distance of 400 nautical miles at a representative position ahead of and behind the trough at t . This allowed a diffuence ratio (gradient behind to gradient ahead) to be worked out for each trough. If ratios equal to or greater than 1.5 are taken to represent markedly diffuent troughs, then less than 4 per cent of the total were of this kind at the start of relaxation. About 40 per cent were confluent if this is defined by values of the ratio equal to or less than 0.7. The remaining 56 per cent cannot be described as markedly confluent or diffuent. Thus it may be concluded that though confluence is commonly associated with relaxation it is by no means a necessary condition for it.

Relation to upwind features

(a) Upwind thermal trough.—It has been the common experience of synoptic meteorologists that the formation of a new thickness trough upwind was, under some circumstances, associated with the relaxation of its downwind neighbour. This study has shown that one of the circumstances is the spacing between the two. Table II shows the mean spacing at $t - 24$, t and $t + 24$, and the standard deviation of these quantities. The value is significantly shorter than the more usual spacing of about 60° longitude* between troughs in the westerlies, even before relaxation begins and it gets less as the process goes on. Although there

TABLE II—MEAN SPACING FROM UPWIND THERMAL TROUGH BEFORE AND DURING RELAXATION OF A THERMAL TROUGH

	$t - 24$	t	$t + 24$
Spacing ($^\circ$ longitude)	42	38	34
Standard deviation	9.2	8.5	10.3
No. of cases	184	263	270

is a certain amount of scatter in the spacing distribution, 77 per cent of the relaxations began when the upwind trough was between 30° and 49° longitude away.

The upwind thermal trough underwent some meridional extension between $t - 24$ and t in just over half of the cases. On some occasions it first appeared as a recognizable feature in this interval, and was frequently only a small-amplitude trough at time t . Its average movement was 14° longitude from $t - 24$ to t , and 16° longitude in the next 24 hours.

(b) Upwind thermal ridge.—Table III shows the relation of this feature to the relaxing and upwind thermal troughs at three times during the process. It

TABLE III—SPACING OF UPWIND THERMAL RIDGE FROM RELAXING AND UPWIND THERMAL TROUGHS

	$t - 24$	t	$t + 24$
Spacing from relaxing trough ($^\circ$ longitude)	25	21	15
Standard deviation	6.8	5.6	5.4
Spacing from upwind trough ($^\circ$ longitude)	17	17	18
Standard deviation	6.7	6.1	7.9

is evident that while the short spacing between the upwind thermal trough and the ridge remains sensibly constant, the thermal ridge is steadily approaching the relaxing thermal trough. This finding confirms the result given by Miles¹

*The mean value for 26 trough pairs used in a test of the Rossby formula at the Central Forecasting Office was 58° longitude.

based on a study of one year's troughs, though it indicates that the relaxation actually begins when the thermal ridge is rather farther away than the figure of 15° longitude that he found.

The average movement of the thermal ridge was 16° longitude between $t - 24$ and t and 14° longitude in the next 24 hours, i.e. very nearly the same as the upwind thermal trough. These two features represent a fairly mobile perturbation of small to moderate amplitude. The surface depression associated with this thermal pattern deepened by an average of 11 millibars between $t - 24$ and $t + 24$ and moved at an average speed of 16° longitude per day over the same interval. It very rarely moved round the crest of the upwind thermal ridge.

(c) Upwind surface anticyclone.—As Table IV shows this anticyclone is rather close to the relaxing trough.

TABLE IV—SPACING BETWEEN UPWIND ANTICYCLONE AND RELAXING TROUGH

	$t - 24$	t	$t + 24$
Spacing ($^\circ$ longitude)	13	12	9
Standard deviation	5.9	5.2	4.9

By way of comparison it was found that the mean spacing of 98 thermal troughs from the nearest upwind surface anticyclone after 24 hours of meridional extension was 22° longitude.

Relation to downwind features

(a) Downwind thermal ridge.—The data in Table V indicate that the downwind thermal ridge is already a fairly large-amplitude feature 24 hours before

TABLE V—SPACING AND AMPLITUDE DATA FOR RELAXING TROUGH AND DOWNWIND THERMAL RIDGE

	$t - 24$	t	$t + 24$
Amplitude * ($^\circ$ latitude)	15	20	16
Standard deviation	7.2	5.9	5.9
Spacing ($^\circ$ longitude)	21	21	20
Standard deviation	8.8	10.7	10.4

*defined as latitudinal difference of defining thickness line in relaxing trough and downwind ridge

relaxation begins and grows on average a further 5° latitude in this interval. It moves east at the same speed as the relaxing trough. It is noteworthy that although the amplitude decreases between t and $t + 24$, the defining thickness line on the crest moves north by an average amount of 3° latitude.

(b) Downwind anticyclone.—There was a downwind anticyclone associated with about 90 per cent of the relaxing troughs. Before and during the relaxation, as the figures in Table VI show, the relaxing trough was getting nearer to the centre of this anticyclone. Relaxation began at a rather wide variety of distances from the anticyclone. The modal value lay between 30° and 35° longitude but

TABLE VI—AVERAGE SPACING BETWEEN RELAXING TROUGH AND DOWNWIND ANTICYCLONE

	$t - 24$	t	$t + 24$
Spacing ($^\circ$ longitude)	43	37	29
Standard deviation	13.4	11.3	11.9
No. of cases	243	251	246

there were a substantial number of cases when the value was more than 45° longitude, especially when the anticyclone was over north-west Europe.

However, it was very rare for it to exceed 45° longitude when the defining thickness line of the trough was less than 5° latitude south of the centre of the anticyclone. The centre of the anticyclone was on average 9° latitude north of the defining thickness line in the trough at the start of relaxation: this was reduced to 2° latitude at $t + 24$.

TABLE VII—AVERAGE LATITUDE OF DOWNWIND ANTICYCLONE AT START OF TROUGH RELAXATION

Average latitude (°N)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	47	47	50	49	53	64	57	53	52	51	49	49

The average latitude of all the downwind anticyclones at time t was 51°N (standard deviation 8.7° latitude), indicating that a large preponderance of them were well north of the subtropical high-pressure belt. In fact 90 per cent of them were north of 40°N . From Table VII it is evident that many of the relaxations in June and July and to a lesser extent in May are associated with fairly high-latitude blocking anticyclones.

There is some evidence that the latitude of the downwind anticyclone determines whether the trough accelerates or decelerates during relaxation. If acceleration is defined as a change of 5° longitude or more in successive 24-hourly movements centred around the start of relaxation (t), then 78 troughs accelerated and 69 retarded. The mean latitude of the downwind anticyclone for each of these two classes was 48°N and 54°N respectively and the standard deviations of these two means were 0.9 and 1.2. This indicates that the difference of 6° in the two means is probably significant, and that acceleration is more likely to accompany relaxation when the downwind anticyclone is south of 50°N .

Spacing of the anticyclones adjacent to the relaxing trough.—At t the mean spacing between the upwind and downwind anticyclones was 48° longitude. When the downwind anticyclone was centred west of 10°E (over 75 per cent of the cases) 70 per cent of the spacings lay between 35° and 55° longitude (inclusive). For the remaining cases, spacings greater than 60° longitude were about as frequent as those less than 60° longitude. In this connexion it is interesting to note that Miles and Leaf² found evidence that a trough does not readily extend between two anticyclones less than 60° longitude apart. It is also significant that the spacing of the upwind and downwind anticyclones decreased at an average rate of 9° longitude per day from $t - 24$ to $t + 24$.

Some synoptic occurrences associated with relaxation

Behaviour of associated surface depressions.—The latitude of the surface depressions associated with the relaxing trough was found to increase on average 5° latitude per day from $t - 24$ to $t + 24$. The average eastward movement was only a little over half that of the relaxing trough. By contrast the surface depression associated with the upwind ridge-trough pattern moved much faster and the two systems were coming together at an average rate of 8° – 9° longitude per day.

Surface pressure changes.—There was usually a rise of surface pressure over the central region of the relaxing trough. Although the statistics given earlier show that the centre of the anticyclone behind the relaxing trough did not move

north during relaxation, it was not unusual for a ridge from it to extend north-eastwards with the relaxing trough.

There was nearly always a rise of surface pressure on that part of the associated cold front between the latitude of the defining thickness line of the trough at t and $t + 24$. For 17 cold fronts associated with relaxing troughs which were east of 20° W at $t + 24$, the average rise was 6 millibars for points at the same latitude on the front.

Changes in frontal activity.—The behaviour of the rain belt with 38 cold fronts crossing the British Isles and north-west Europe was examined for the period t to $t + 24$. For 32 of them the amount of rain was small or, if it was moderate at t , had become slight or ceased by $t + 24$.

Wave formation on the associated cold front.—A sample of 77 cold fronts associated with relaxing troughs which were east of 20° W at $t + 24$, was examined for new wave formation in the period t to $t + 24$. On only two* of them was there wave formation after t . At time t the average length of the baroclinic zone ahead of the trough was about 1200 nautical miles and it decreased during relaxation. Since there was almost always sufficient thermal gradient ahead of the trough, this result supports the conclusion reached by Sawyer³ that spacing is the dominant factor in determining wave formation on cold fronts.

The mechanism of trough relaxation.—A detailed study of several individual cases showed that the relaxation was partly due to non-adiabatic warming of the layer from the surface to about 700 millibars and partly to dynamically produced effects most apparent above this level. For example, there was usually evidence of subsided cold air between 700 and about 550 millibars and sometimes of warmer moister air above this. Trajectories at 500 millibars indicated that this was air carried into the trough from the upwind thermal ridge. The contribution of non-adiabatic warming becomes less in the east Atlantic; in this region in summer, the effect is almost entirely due to adiabatic warming.

This dynamical effect appears to be mainly due to:

- (i) the short spacing between the relaxing trough and the upwind trough and
- (ii) the approach to an anticyclone strong enough to have a moderate-to-large-amplitude thermal ridge 15° to 20° longitude to the west of it on average.

The increasing nearness of the upwind thermal ridge as relaxation proceeds e.g. 25° , 21° and 15° longitude at $t - 24$, t and $t + 24$ respectively, appears to be an important upwind factor. A few cases of relaxation were encountered in which the upwind thermal ridge was within 20° longitude but there was no downwind anticyclone and the distance to the upwind trough was more than two standard deviations greater than the mean value associated with relaxation. This corresponds to an asymmetric pattern with a long belt of south-westerly flow between the upwind trough and the ridge: it is usually associated with a wide, open warm sector i.e. minimum width 25° longitude. Asymmetry in the other direction, however, i.e. upwind thermal ridge 35° from the trough and 15° from the upwind trough appears not to be associated with relaxation. Indeed relaxation only occurred when the thermal ridge was between 30° and 35° away if its amplitude was less than 15° latitude.

*One of these was with an unusually large and intense trough (1000–500 -millibar thickness anomaly at 51° N 45° W at t was -36 decametres) on 28 January 1957.

However, most cases of relaxation occurred when both conditions were satisfied, i.e. the closer than usual upwind trough and the presence some 30° – 50° longitude downwind of a well developed anticyclone. The intensity of these anticyclones is indicated by the size of the thermal ridge associated with them, and their central pressures which averaged 1032 millibars between October and January and 1028 millibars from February to September. Only two of them had central pressures less than 1020 millibars.

A possible prediction parameter.—It appears that the two principal factors determining relaxation may be represented by requiring that the distance between the downwind anticyclone and the upwind thermal trough should fall below some particular value. The individual distances are shown as the ordinate of the scatter diagram in Figure 5 with the longitude of the downwind anticyclone as the abscissa. There appears to be a fairly well defined upper

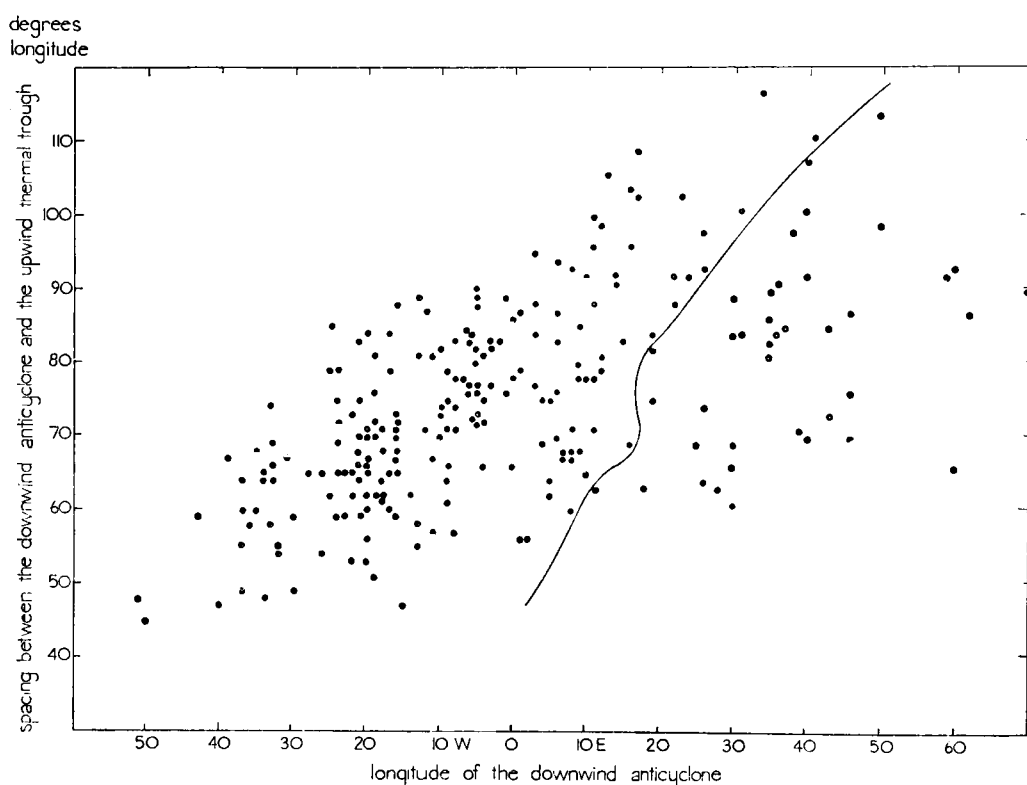


FIGURE 5—RELATION BETWEEN SPACING AND LONGITUDE OF DOWNWIND ANTICYCLONE AT START OF RELAXATION

All cases to the right of the line occurred in the months March–September.

limit which increases the farther east the relaxation occurs. As there is also an effect due to the latitude of the downwind anticyclone it was necessary to examine the values geographically. The result is shown in Figure 6 in which areas are delineated with a representative mean value. A value is also shown, above which 25 per cent or less of the relaxations occurred.

A preliminary test on independent data showed that the use of this value eliminated obvious over-forecasting of relaxation. It may also be expected to



Photograph by G. A. Tunnell.

**“WEATHER REPORTER” (IN FOREGROUND) AND “WEATHER ADVISER” IN THE
JAMES WATT DOCK AT GREENOCK**



Photograph by R. S. Scorer

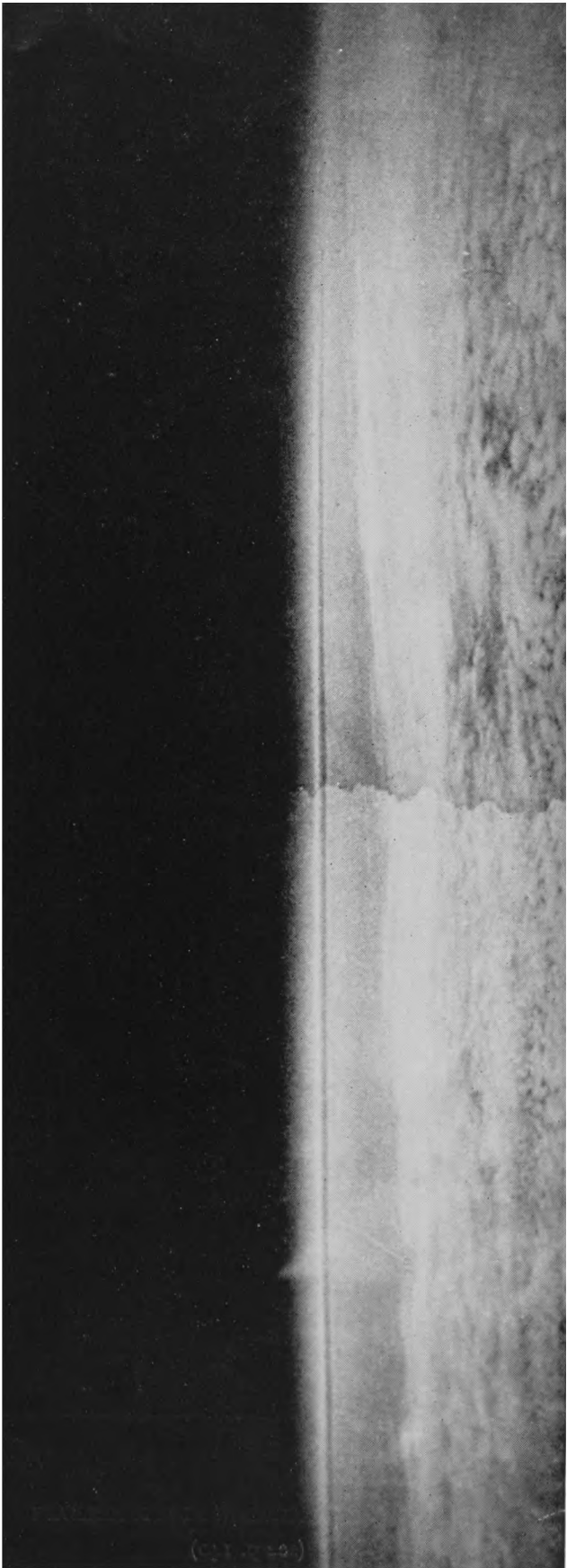
RADIOSONDE BALLOON BEFORE RELEASE
(see p. 140)



Photograph by R. S. Scorer

RADIOSONDE BALLOON AFTER RELEASE

(see p. 140)



Photograph by CSIRO.

DUST LAYER ABOVE TROPOPAUSE PHOTOGRAPHED FROM A HEIGHT OF 66,000 FEET
(see p. 139)

lead to failure to forecast at least 25 per cent of relaxations and a further small percentage which occur either without an upwind thermal trough or a downwind anticyclone.

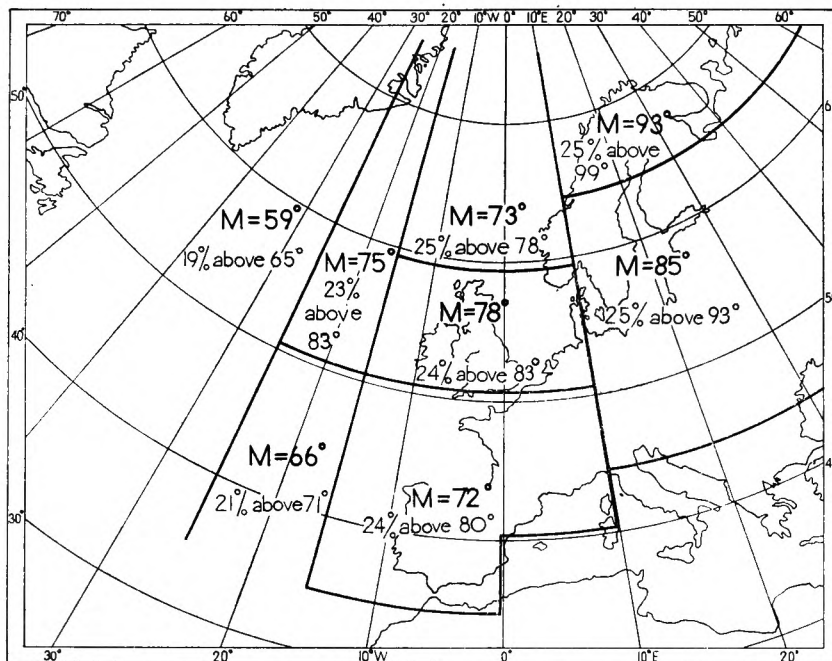


FIGURE 6—MEAN VALUE (M) OF THE SPACING BETWEEN DOWNWIND ANTICYCLONE AND UPWIND THERMAL TROUGH IN RELATION TO THE AREA IN WHICH THE ANTICYCLONE IS CENTRED

A proposed forecasting rule and its test.—Whenever there is both an upwind thermal trough and a downwind anticyclone and the spacing between them does not exceed the value appropriate to the region in which the anticyclone is centred (see Figure 7), relaxation of the trough by more than 5° latitude in 24 hours should be expected provided the following further conditions are all satisfied:

- (i) the amplitude of the downwind thermal ridge is greater than 5° latitude, but if less than 15° latitude it shall have increased by at least 2° latitude in the preceding 24 hours,
- (ii) the central pressure of the downwind anticyclone is at least 1020 millibars for the months February to September (inclusive) and at least 1024 millibars for the months October to January,
- (iii) the upwind thermal ridge is not more than 35° longitude away from the trough, and, if it is between 30° and 35° longitude away, the amplitude is less than 15° latitude.

It should be borne in mind that the upwind thermal trough is not necessarily the next large-amplitude trough upwind. A quite small-amplitude feature (even less than 5° latitude) should be used especially if it is in a region of northerly surface flow.

The test of this rule was carried out on all well defined troughs between the American coast and 10°E occurring in the period January 1960 to March 1961

inclusive. A forecast was made on every day with a suitable trough, provided relaxation had not already begun. A forecast of relaxation was considered to be correct if at least one thickness line of the trough (other than the coldest) moved north 5° latitude or more in a 24-hour period starting either at the time of forecast or 12 hours later. 201 forecasts were made and Table VIII is a contingency table showing the four combinations of forecast and outcome.

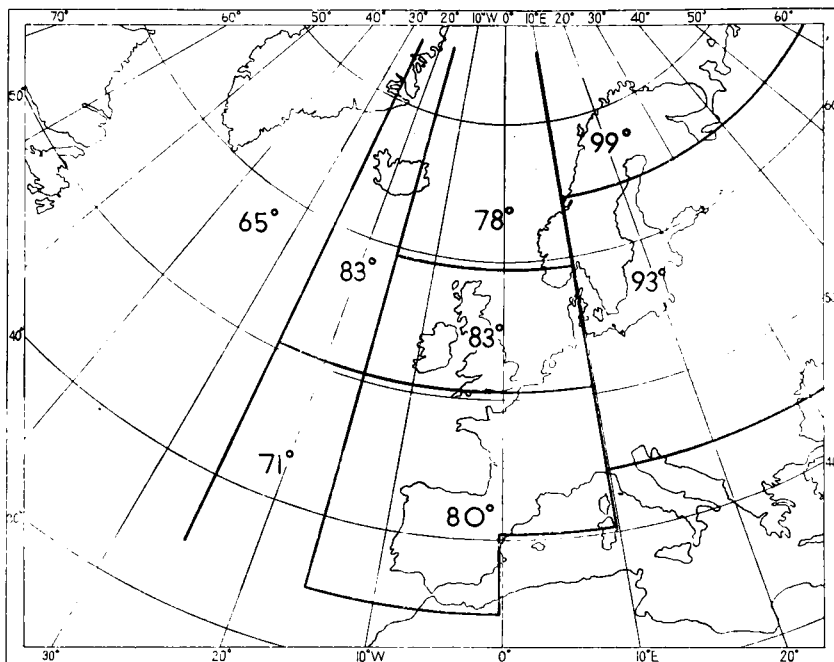


FIGURE 7—MAXIMUM VALUE BETWEEN DOWNWIND ANTICYCLONE AND UPWIND THERMAL TROUGH FOR EXPECTATION OF RELAXATION

TABLE VIII—TABLE OF RELAXATION FORECASTS AND OUTCOMES

		Forecast	
Outcome	{	Relaxation	No relaxation
		32	19
		18	132

This shows that the rule as it stands does not seriously over-forecast relaxation and that when no relaxation is indicated a considerable degree of skill is obtained. The fact that 37 per cent of cases of relaxation were not forecast is not surprising. The fact that 36 per cent of the forecasts of relaxation were not borne out calls for some comment. A few of these were cases when less than 5° of relaxation occurred and there was one at least in which the upwind depression had filled, in the 12 hours before the forecast was made. The other situations in which expected relaxation did not occur may be summarized under two headings:

- (i) very meridional situations when short spacings and large amplitudes are typical,
- (ii) troughs occurring in very close association with large slow-moving surface depressions.

Conclusions.—Relaxation of thermal troughs is a fairly common occurrence in the west and central Atlantic in the winter half of the year. It is much less common in the east Atlantic and the north-west European seaboard, though in the months June to August (inclusive) occurrences east of 20°W slightly exceed those west of this longitude.

Over the west and central Atlantic convective warming from the sea plays an important part, though dynamical warming also occurs and is mainly apparent above the 700-millibar level. Over the east Atlantic and the British Isles dynamical warming is the main factor, and in summer probably the only factor. This dynamical process appears to be mainly attributable to a combination of the following two conditions:

- (i) a thermal trough approaching (or forming) within 35° – 40° longitude upwind of the relaxing one,
- (ii) the relaxing trough approaching within 35° – 40° longitude of a well developed anticyclone centred north of the subtropical high-pressure belt (average latitude 51° N).

Some important consequences of trough relaxation over the east Atlantic and the British Isles are:

- (a) a rise of pressure along the associated cold front,
- (b) a reduction in the intensity of rain associated with the cold front,
- (c) almost complete suppression of wave formation on the cold front, and
- (d) an increase in the static stability of the air in the thermal trough.

There is usually a surface anticyclone situated rather close behind the axis of a relaxing trough. The average separation of 12° longitude is significantly less than the average 22° longitude for a sample of extending troughs.

The spacing between the upwind thermal trough and the downwind anticyclone has been used as the basis for a rule for predicting relaxation. In a test on 15 months' data in 1960–61 a successful forecast of relaxation or no relaxation was obtained on 82 per cent of occasions.

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3. London, Meteorological Office; Meteorological Office discussion. *Met. Mag., London*, **79**, 1950, p. 146.

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A NOTE ON SEVERE TURBULENCE AT RENFREW (GLASGOW) BETWEEN 500 AND 1000 FEET ON 26 JANUARY 1961

By R. WILSON

Synoptic situation.—At 1800 GMT, 26 January 1961 (see Figure 1), an intense depression about 150 miles south of Iceland was moving slowly north-north-west and the associated fronts were affecting western and northern areas of the British Isles. Pressure was high over Europe. The main cold front curved south-westwards to an active wave depression some 550 miles west-south-west of Valentia, the wave deepening and moving very rapidly north-eastwards.

A warm occlusion, which lay from Cape Wrath to Rothesay to Bangor thence southwards, was moving steadily eastwards and passed Renfrew around 2100 GMT. A warm front lying north-west to south-east over the western half of Northern Ireland was moving steadily eastwards; by midnight it was lying

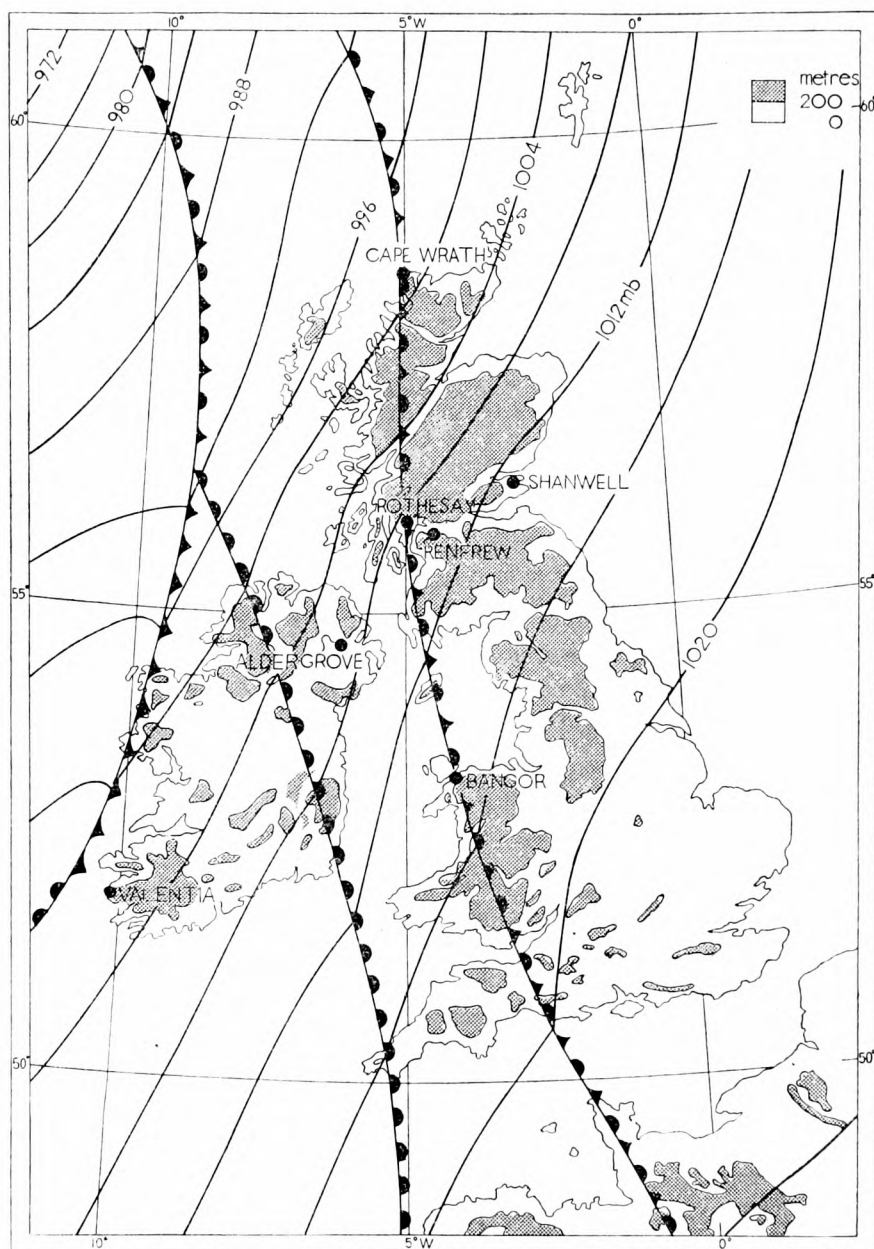


FIGURE 1—SURFACE CHART FOR 1800 GMT, 26 JANUARY 1961

north to south to the immediate west of Renfrew and passed through the station soon afterwards.

Local features.—The wind at 2000 feet estimated from the 1800 GMT chart was 200 degrees, 60 knots. The estimate from the 0001 GMT chart was 200 degrees, 45 knots. Table I shows the behaviour of the surface wind and outside air temperature.

Report of severe turbulence.—Aircraft landing during the evening experienced very considerable drift on the approach to runway 08 and all reported at least moderate turbulence between 500 and 1000 feet. Severe turbulence was reported by the pilot of the Viscount which landed at 2130 GMT. On his first approach, the pilot missed the runway altogether and gave his

TABLE 1—SURFACE WIND AND TEMPERATURE AT RENFREW, 26–27 JANUARY 1961

Time	Wind	Temperature
GMT	degrees knots	°C
1820	130 11	0.4
1850	120 15	0.4
1950	090 06	1.2
2050	150 07	1.7
2120	150 08	2.2
2150	160 06	2.3
2350	090 02	3.8
0020	190 19 Gust 30	3.4
0050	180 20 Gust 32	3.9

estimate of the wind at 1000 feet as 190 degrees, 45 knots, with degree of turbulence moderate. On his second approach, he “had great difficulty in controlling the aircraft in the circuit” and encountered “severe turbulence between 600 feet and 800 feet” at which heights the wind was estimated as 190 degrees, 40–45 knots. Below 500 feet, conditions became smooth, with little or no drift, and the aircraft landed on runway 26.

“With gradients of 160 degrees–210 degrees, winds above 40 knots will give normal surface directions and speeds.” (Extract from “Notes on local weather at Renfrew”). In this case, however, the day started with surface temperatures at, or a little below, freezing-point, there was no sunshine and the maximum temperature between 0900 GMT and 2100 GMT was only 1.7°C. Thus, during the evening, a “cold pool” was established in the basin in which Renfrew lies; this

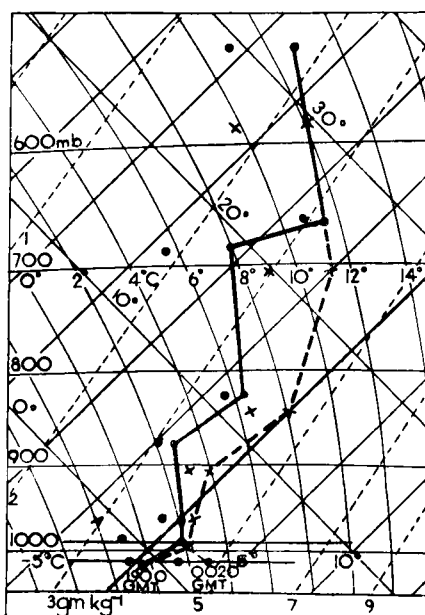


FIGURE 2—TEMPERATURE DISTRIBUTION WITH HEIGHT ON EVENING OF 26 JANUARY 1961

— Aldergrove, 1200 GMT, 26 January 1961

x - - - x Shanwell, 0001 GMT, 27 January 1961

Renfrew 1900 GMT surface temperatures have been substituted for the Aldergrove and Shanwell values, and the Renfrew 0020 GMT temperatures added.

pool remained undisturbed by the very strong gradient aloft. By substituting Renfrew 1900 GMT temperatures on an otherwise unaltered (and representative) Aldergrove 1200 GMT tephigram, this undisturbed region shows up as a slight inversion between the surface and 700 feet. The Shanwell sounding for mid-night, unaltered except for the substitution of the same Renfrew surface temperatures, is of a pattern similar to that of the midday Aldergrove sounding, the layer between the surface and 700 feet being almost identical (see Figure 2).

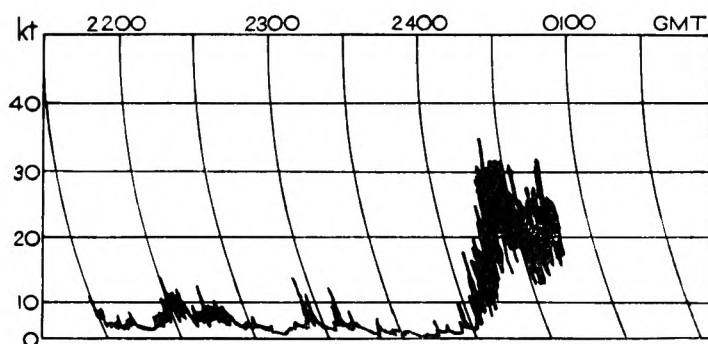


FIGURE 3—SURFACE WIND SPEED AT RENFREW, 26–27 JANUARY 1961

As warmer air progressed steadily eastwards, this inversion gradually broke down, finally allowing the strong winds to penetrate to the surface at 0020 GMT (see Figure 3). The 0020 GMT temperature is also shown in Figure 2.

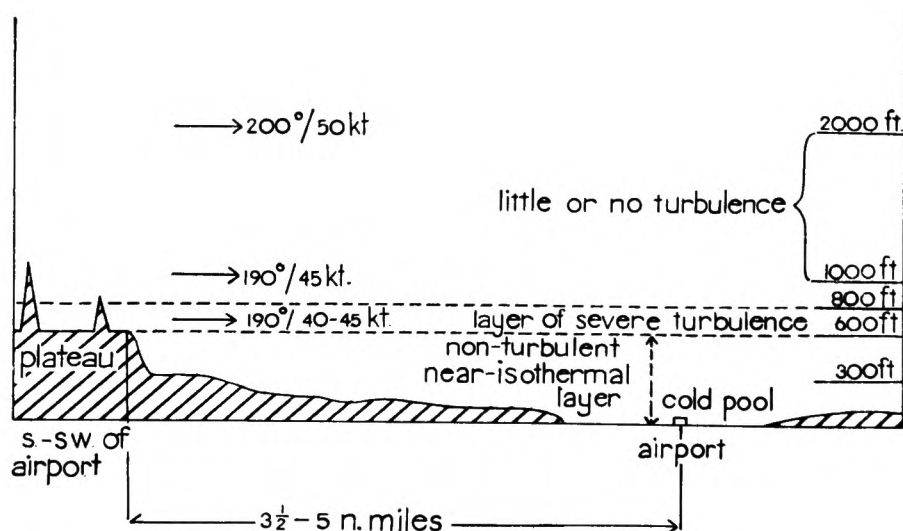


FIGURE 4—CROSS-SECTION SHOWING WIND DISTRIBUTION WITH HEIGHT AT RENFREW AT 2130 GMT, 26 JANUARY 1961

Figure 4 represents a cross-section of the air above the airport and surrounding district as the Viscount was preparing to land. The severe turbulence experienced was most likely due mainly to the abrupt wind shear immediately above the inversion, but frictional turbulence caused by the hills to the south and south-west of the airport may have been a contributory factor.

ATMOSPHERIC DIFFUSION

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Given an amount of foreign substance (gaseous or particulate) released into the atmosphere in a known way, and given the condition of the atmosphere, how will that material become dispersed as a function of time? This is a subject of which a reasonably full and separate account now appears for the first time.* Those at all familiar with the complexity of the atmosphere will not expect any facet of the problem to be easy, and so it proves: the book is not for the lay reader. But it is a fascinating subject for the professional man, be he physicist, mathematician, or engineer; and there will be many outside meteorology who will require this book as a background for its applications in pollution and public health, in military and defence questions, and in the agricultural and botanical fields. Here is a book for which there is a real need, among so many for which the author's ego or pocket appears the main excuse.

A long review must both comment on the subject and describe the book, but Dr. Pasquill's arrangement is so logical that the two are best done together. To one who was introduced to atmospheric diffusion in 1939, towards the end of an era described by Dr. Pasquill as "the early days", the subject appeared already highly elaborated. But it has since acquired a radically new look, in the conception and development of which Dr. Pasquill and his colleagues at Porton have played leading roles. This has been an achievement which belongs by and large to the 1950 decade, so that the appearance of a connected narrative is both quick and timely.

In a short opening chapter we are introduced to the formal statistics which are used in general analysis of turbulence structure, most notably the autocorrelation and spectrum functions. We learn to look at these through a *window*, the slowest fluctuations being removed by sampling over a limited period τ , and the fastest by averaging over a period s . When the mean square value σ^2 of one of the components of turbulence is obtained in this way, it can be seen that $\sigma_{\tau,s}^2$ should be able to serve as an index of the dispersion of a cloud of material diffusing for a time s , from a source which emits for a time τ . That σ^2 goes on increasing, more or less indefinitely, with τ is the feature which distinguishes atmospheric from other forms of turbulence, and makes it the harder. The direct measurement of these window-framed functions, and the basing of diffusion estimates upon them, may be said to epitomize the new approach.

The next chapter summarizes the results of measurement of the spectrum and correlation functions in the atmosphere. Pause might be taken here to view the ultimate operational objective. Presumably at special places such as Windscale and Porton the need for window-spectrum information will be catered for by continuous monitoring and *ad hoc* analysis. But for general purposes one envisages the need for a climatology of these statistics, matching the comprehensive studies of vertical gradients, etc., in the early days by Johnson, Best, Flower and others. The task has been well started by Panofsky and his colleagues in the

**Atmospheric Diffusion*, by F. Pasquill. 9½ x 6 in., pp. xii + 297, *illus.*, D. Van Nostrand Company Ltd., 358 Kensington High Street, London, W.14, 1961. Price: 60s.

United States of America, but much more remains to be done, both in the detail of the effects of thermal stratification, and in the atmosphere above the boundary layer. It is a formidable prospect in view of the doubly-infinite character of each element $\sigma_{\tau,s}^2$, and one can only hope that theory will come to the rescue and shorten the task by providing functional forms. Some attempts to this end are described, but few would regard them as definitive: even of the high-frequency properties, which appear the most amenable, Dr. Pasquill is compelled to write "the only simple rule yet to emerge even tentatively is that near the ground in neutral or unstable conditions the isotropic limit occurs at a wavelength roughly the same as the height above ground."

Chapter 3 sets out the main theory: not a theory of turbulence, but the formal development of the links between the chosen indices of the flow field which we can measure, and the dispersion which this flow field effects. Here we first veer away from purely statistical concepts and hark back to the eddy diffusivity K , to the profile of wind with height, to the differential equations akin to those of classical diffusion theory and their explicit solutions for the concentration in terms of x, y, z and t . This was a main theme of the early days, with Sutton as the outstanding exponent. Its essential limitation, long recognized, is the inability to handle all the spectrum attributes of the problem, in that a cloud will respond to different ranges of eddies as its own size continuously grows. Caught up in the enthusiasm for the new, more direct type of measurement, it may be too easy to overlook the major part that the old formulation, in terms of K and mean gradients, has played; and, extended by some flash of inspiration, may yet play again in development and understanding. Here only, for instance, does one find the physical reasons why the crosswind and vertical distributions of concentration are commonly sought as exponential functions. Again the ability to incorporate K as any function of position, and of height in particular, gives an inherent advantage in dealing with nature's reality, and we may look forward to further exploitation of this merit. Let us remember for example that a neutral or slightly unstable layer capped by an inversion is one of the most significant situations for pollution; and let us remember that the statistical theories are basically theories of a homogeneous field of turbulence.

The larger part of the chapter deals with the formal development of the statistical approach, from the foundations laid by G. I. Taylor and L. F. Richardson to the present day. This is the hardest part of the book, though master it one must if traps are to be avoided. Here too are fundamental obstacles yet to be surmounted. Whereas the particle responds to the fluctuations in velocity which it experiences as it moves along, i.e. in a Lagrangian framework, these are generally impracticable to measure and the bulk of data relates to fluctuations at a fixed point (the Eulerian system). It is intuitively clear that the time scale of the former should be the larger, and in practice the assumption of similarity of spectral form on a fourfold time scale has led in many instances to conformity with dispersion observations. But there is no evidence or argument to suppose that this represents a general truth.

And this is only the beginning of the trouble. The problem of the spread of a cluster involves essentially more than time variations for one point or one particle; new covariance spectra are required which relate the fluctuations of two particles both simultaneously and at different times. To obtain the instantaneous rate of growth we must look through yet another window—here

called a band-pass filter—to cut out eddies which are either too large or too small to have expansionist tendencies: and the limits of the band must be allowed to change with time to match the changing size of the cluster. While the principles have been clarified the blue sky of practice has become very dark, and the data requirement is by now multiply infinite. The aim of theory will be to reduce this mass to a manageable number of parameters. But whilst we may admire the way such reductions have been achieved in the special case of isotropic turbulence, we dare not copy too closely because this is a simplification to which by and large, as every meteorologist knows, the atmosphere refuses to conform.

Chapter 4 pieces together the information coming from experiments aimed at answering salient questions such as:—What is the precise form of crosswind and vertical distribution? What index in the power law (with distance or elapsed time as the argument) best represents the variation of concentration or of dispersion for clouds of the idealized types (point source, line source, etc.). This is very thoroughly done and will be appreciated for reference purposes, though those concerned mainly with the flow of ideas may find the chapter somewhat tedious and may be excused for skipping. But it is necessary glue for coating the framework which has gone before so that practical prediction techniques may now be stuck on, however thin the glue may appear to be when it comes to other than near-neutral conditions. A valuable recapitulation concludes this, the more fundamental, part of the book.

As a preliminary to the problem of estimation we are next introduced to the main modes of behaviour of chimney and other plumes (looping, coning, fanning, lofting, fumigation) and the conditions in which each occurs. Illustrations of typical Dines traces would have been helpful in driving the lessons home, and it is to be regretted that the classification has not yet been taken beyond the descriptive stage. There follows a wholly admirable synthesis of the formula-techniques for estimating diffusion from each basic type of source, culminating in a general system of the author's own devising. This appears by judicious compromise to steer its way round many of the theoretical difficulties previously commented on. Having been led carefully through the details of the operation, in which he will need to keep his wits about him, the reader emerges equipped to give the answers if he knows the weather. How accurate the results will be, however, is left to his own judgment and experience and he may feel that the experts, by giving theirs, could have been more helpful on this point.

In the final chapter Dr. Pasquill turns from the necessarily idealized framework to consider some of the added complexities which arise in real situations. The first is the rise of a buoyant plume. Here theories are in existence and are reasonably adaptable but are still waiting for some good data, covering a range of the important atmospheric variables and measurements thereof. The account is accordingly scrappy, in contrast with the valuable synthesis of data on the spreading of chimney plumes which follows a little later. The intervening treatment of deposition deals with the concurrent processes of spreading and settling, with boundary condition subject to the concept of *deposition velocity*, or rate of deposition per unit area divided by the concentration. It is not clear that this concept, interpreted as it has been here in terms of the concentration at some distance from the surface, achieves anything more than the substitution of one phenomenon by another equally abstruse. The deposition velocity for

instance is not equal to the terminal velocity but is dependent on the turbulent flow (including the nature of the boundary), an idea which is described as relatively novel but which should at once have been obvious from the kinship of the problem to that of natural evaporation. Technical blemishes in this section include the use of the same symbol, D , for two quite different quantities and a printing error and omission of units on the same line of page 235.

Finally there are brief summaries of the work on such varied applications as the surveys of distributions from single stacks, including the climatic distribution, the effects of gross surface irregularities, the Leicester survey, smog, the Wind-scale accident, bomb explosions, and the dispersal of spores and sprays and other minutiae of agricultural interest, including locusts. This, one might suspect, is the chapter which will most quickly call for amplification, if not for revision. Indeed there may well be an early need for a practical manual, dealing with the *ad hoc* problems in much greater detail than is possible here, and so forming a companion volume to the more basic considerations with which Dr. Pasquill has been mainly occupied. If we have to erect a stack in a given locality, where exactly shall we put it?

No reference whatever is made to the problems of evaporation from the Earth's surface which, energy consideration apart, are dominated by atmospheric diffusion and are probably the most important geophysical example thereof. In this process, unlike the applications treated by Dr. Pasquill, the properties of the source cannot be specified *a priori* since they are diffusion-dependent. As hinted earlier, this and other boundary complexities (the sometime presence of a laminar sublayer and the control of transpiration by stomata) intrude in much the same way as in the problem of deposition, and more contact between these fields might be stimulating to both.

And now what of the book, as distinct from its chapters? In assembling so much material for the first time Dr. Pasquill has had no easy task, and he has earned our admiration and our thanks for his clear connected account of the subject. This may be expected to take its place for some years as the standard work of reference. The style is mainly narrative and the author is punctiliously fair, at times even charitable, to the many who have worked along the way. At some points indeed, to obtain more critical and sharper focus, the general reader might have preferred a single composite re-analysis or re-synthesis of all the material by Dr. Pasquill himself. Where this has been done, as in Chapter 5, it is conspicuously successful. My only criticism of the arrangement is that the treatments of the two extraneous processes, fall-out and buoyant motion, are both unnecessarily split into two different parts of the book. The printing, diagrams, index and references are uniformly impressive.

And what in summary of the subject, as distinct from the book? Even in the early days it was recognized not only that knowledge of eddy intensity, or gustiness, was inherent for the prediction of diffusion but also that the relevant gustiness must be a function both of sampling time and, for a given cloud, of elapsed time. Nevertheless the hope was there that the main problem of that era, diffusion in the boundary layer, could be made determinate in terms of the bulk parameters alone (height, vertical wind and temperature gradient, roughness length). This is a justifiable scientific aspiration, and there still appears no reason why it should be abandoned. The march of events has, however, caused it to be set aside, because the interest in diffusion at higher

levels has focussed the demand for a new look, while developments in computing and recording techniques have been timely in making this practicable. There have followed considerable gains in precision and, with the practical logic of bringing the predictor index closer to the predictee variable, presumably also a gain in accuracy when the data are available. This represents primarily an engineering rather than a fundamental advance. The clothes are now designed so that one can work most effectively with the tools of the day, but the body inside the clothes has changed but little. To mix the metaphor, in real understanding we still have to bridge the Lagrange-Euler ditch, which is deep though narrow, and the much wider river of non-isotropic intensity spectra and the influence of thermal stratification, etc. upon them. In the geophysical applications of atmospheric turbulence, where the concern is still with mean gradients and with flux rather than intensity spectra, rather more fundamental progress is evident. That this is because the problems are somewhat easier may provide the explanation but little solace, for there is danger that without the understanding the burst of progress which has followed the new approach to diffusion may now rather soon lose its momentum.

Moreover, conscious of the atmosphere's infinite variety, we must always be on guard lest any approach enjoying current success becomes too stereotyped. The global distribution of radioactivity from H-bombs, for example, depends on small but significant mean meridional motions, leakages through the break between troposphere and stratosphere, and other composite but not, in the usual sense, turbulent motions. And it is not only when one extends the *scale* that one meets a *type* of dispersing motion to which the normal formulations can never apply. We are reminded of some of these, though not all, at the opening to Chapter 5, where it is pointed out that the methods as they stand cannot be expected to give reliable estimates (a) in calm conditions, (b) when there are local disturbances, for example in the immediate vicinity of obstacles and (c) when the airflow is channelled or contains circulations or drainage set up by heating or hilly terrain. And how long is a piece of string? There are some questions, which were asked at Porton in the "early days" and are apparently still being asked, whose very nature permits no quantitative answer. Possibly these were in Dr. Pasquill's mind when he chose the enigmatic illustration on the dust-jacket of his book.

NOTES AND NEWS

High-level layer of dust

The photograph facing page 129 has been received from Dr. Bowen of the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia. Dr. Bowen's theories in relation to dust of meteoric origin are well known. His notes on the photograph are as follows:

This photograph was taken at 9.30 a.m. local time on 31 October 1961 by Major R. Anderson of the U.S.A.F. flying at an altitude of 66,000 feet at 46°S, 147°E, facing SE, and shows a marked dark band near the horizon. This band could be seen to the SE, S and SW, and persisted at least as far as 60°S. It was not visible from a height of 50,000 feet and optical considerations indicate that the layer must have been at a height close to that of the aircraft. On this occasion there was broken altostratus cloud to 20,000 feet and cirrus at 34,000 feet just below the tropopause.

This observation formed part of a programme of sampling of high-altitude aerosols on behalf of the Radiophysics Laboratory, CSIRO, Sydney. No such layers were observed visually on seven subsequent flights to similar heights.

LETTER TO THE EDITOR

Photographs of a radiosonde balloon

The accompanying photographs [between pp. 128–129] show the shape assumed by a radiosonde balloon before and after release. They show that the shape usually ascribed to balloons is no longer assumed when the balloon is in motion and at a sufficiently low altitude for it still to be very flabby. Ordinary pilot balloons are well stretched and are therefore not easily distorted. These photographs were taken at the Col des Aravis between Annecy and Mont Blanc in July 1960 where a team of French meteorologists, led by D. G. Barbé, was studying the small details of the air flow over the Alps by releasing balloons every hour for several days.

A patch of stratus can be seen in the ravine on the hill side.

Department of Mathematics, Imperial College, London, S.W.7.

R. S. SCORER

REVIEW

Elements of dynamic meteorology, by A. H. Gordon, M.Sc. 8½ in. x 6½ in., pp. xxi + 217, *illus.*, The English Universities Press Ltd., 102 Newgate Street, London, E.C.1., 1962. Price: 25s.

In this book the author has attempted the very difficult task of providing a successor to Sir David Brunt's "Physical and dynamical meteorology". It has some good features but fails seriously.

Its first defect is the large amount of space devoted to utter trivialities. It may be possible to justify deriving the Clausius–Clapeyron equations, which is done with considerable care, but it is not reasonable, for example, to write the (two) equations for the geostrophic wind a second time merely with a term transposed to the other side. This is typical and the book abounds with examples.

Its major defect is in the poverty and occasional inaccuracy of its explanations of the physical significance of the treatment. One instance is that though the hydrostatic equation is derived (*sic*) and elaborated considerably, the essential consequence of its assumption, namely the removal of sound waves from the equations, is not mentioned. Another which may be quoted is in the discussion of the isallobaric wind. The isallobaric term becomes important when $\partial \mathbf{V} / \partial t$ is the major term in the expansion of the acceleration

$$\frac{d\mathbf{V}}{dt} = \frac{\partial \mathbf{V}}{\partial t} + \mathbf{V} \cdot \nabla \mathbf{V}.$$

This does not mean "... that the (pressure) pattern is not moving in space ...". It means either that \mathbf{V} is small or the gradient of \mathbf{V} is small, or both. Such is the nature of the atmosphere that this usually means that \mathbf{V} must be small. Judging by remarks later in the particular section of the book, this seems to be in accordance with Mr. Gordon's experience. These are examples picked at random from abundant material.

The usefulness of the book to many readers will be that quite a lot of the basic algebra of meteorology is duly derived. Mostly it is accurate, though the equation for the variation of wind with height looked deficient to the reviewer. But

please can we recognize that the modern student is weaned on to vectors almost immediately after leaving school. If we use them they save a great deal of time and paper. In 1962 they should not be relegated to an appendix.

A. W. BREWER

OBITUARY

Mr. George Munn Gray Lightbody.—It is with deep regret that we learn of the death on 9 February 1962 of Mr. G. M. G. Lightbody, Senior Experimental Officer. George Lightbody joined the Office in January 1939 in the grade of Assistant III and was first appointed to Abbotsinch in the vicinity of his native Glasgow. On the outbreak of war he was transferred to Hornchurch, where he served during some of the worst days of the “blitz”. On the brighter side, it was here also that he met his future wife.

After a period of training in forecasting duties at Gloucester he was promoted Acting Assistant II in 1942. Several postings to stations in East Anglia followed, and no doubt it was during this period that George acquired the facility of limpid clarity in briefing which was so characteristic of him. Further moves to Dunsfold and Netheravon followed, and eventually he was posted to India in December 1944. His promotion to Acting Assistant I was promulgated while he was still en route to the east.

Returning to England in 1946, he was established in the grade of Experimental Officer in 1947 and served for several years at Northolt before going abroad again to Cyprus in 1951. A serious illness in Cyprus marred, but did not destroy, his enjoyment of the then peaceful and delightful island, nor did it deter him from plunging whole-heartedly into the activities of the *ad hoc* committee formed there to draw up the first foreign service allowance price returns, to which committee he was appointed as Air Ministry representative.

Home again in 1954, he went to Leeming, where he remained until November 1960, when he was promoted Senior Experimental Officer and posted to Uxbridge, where he remained until his untimely death.

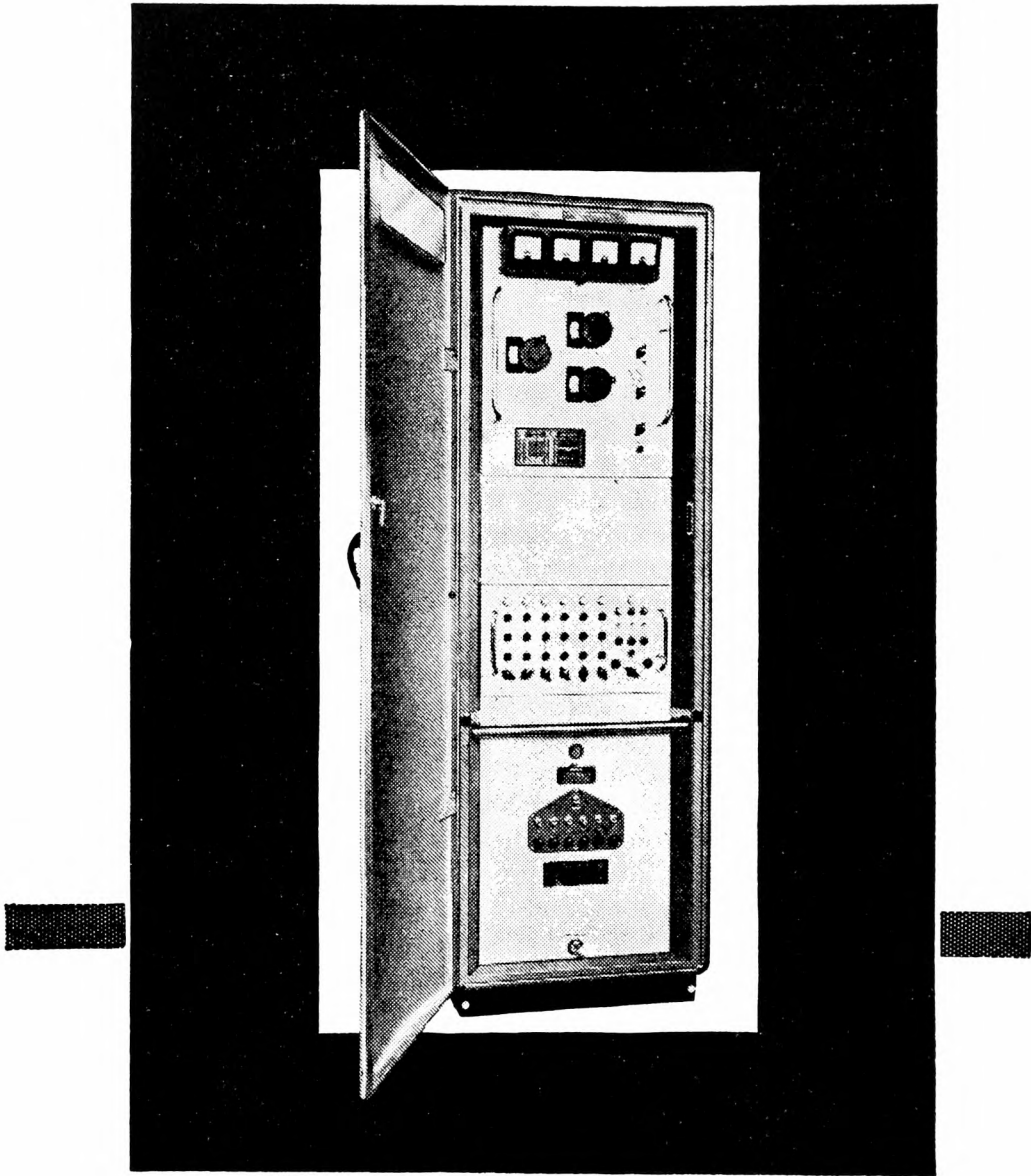
George was always a genial and gregarious person and a good friend. His many longstanding friendships amongst his colleagues and also in the Royal Air Force bear witness to his personal sincerity and charm, and no less to the esteem which his high professional standards inspired. His zest was infectious, and there will be few who knew him who will not most readily remember some of his good companionship or perhaps some characteristic act of understanding and generosity. All his colleagues and friends will wish to extend their heartfelt sympathy to his widow and two children.

L.J.A.

METEOROLOGICAL OFFICE NEWS

Report on the first season of the Meteorological Office, Bracknell, Table Tennis Club

The Table Tennis Club was formed at the beginning of this season and entered a team in the Third Division and another in the Fourth Division of the local league. Much to the surprise of the original members both teams went through the season undefeated and emerged as winners of their respective leagues, collecting handsome trophies. Next season it is hoped to run three, or perhaps four, teams and we hope to maintain our run of success after promotion to higher divisions.



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THE METEOROLOGICAL MAGAZINE

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Mr. J. S. SAWYER, FELLOW OF THE ROYAL SOCIETY

By R. C. SUTCLIFFE, C.B., O.B.E., F.R.S.

Some four years ago it was my pleasant task to write for the *Meteorological Magazine* an appreciative note recording the promotion of Mr. J. S. Sawyer, by special merit, to Deputy Chief Scientific Officer and now, with his election as Fellow of the Royal Society on 21 March 1962, I gladly take the opportunity to express once more our gratification, shared by all meteorologists who have worked with him or have followed his output of original work over the past fifteen years.

Mr. Sawyer joined the Office just prior to the outbreak of World War II as a first appointment after taking the Cambridge Mathematical Tripos and served during the war years with various Royal Air Force units in England and abroad. Although there was little opportunity for research during those vital years there was a great concentration of experience in the ways of the atmosphere and Mr. Sawyer's latent abilities emerged as soon as the opportunity came, first while working under the late C. S. Durst on Special Investigations and, from 1948, in the newly-formed forecasting research group at Dunstable. Mr. Sawyer was appointed Principal Scientific Officer in charge of short-range forecasting research and maintained a steady stream of research papers which had, in 1958, already exceeded 50 in number and which has since gained some notable additions as exemplified by the following papers in the *Quarterly Journal of the Royal Meteorological Society*: in 1959, "The introduction of the effects of topography into methods of numerical forecasting"; in 1960, "Numerical calculation of the displacements of a stratified airstream crossing a ridge of small height"; in 1961, "Quasi-periodic wind variations with height in the lower stratosphere". We may be sure that this is not the end.

In his present post as Deputy Director for Dynamical Research Mr. Sawyer has responsibilities for forecasting research, including long-range forecasting, climatological research and general circulation studies, as well as for that field of dynamical and synoptic meteorology with which his own name is especially associated. There are eminent meteorologists distinguished by their skill and insight as synoptic analysts and others with enviable mathematical prowess, but few indeed who combine these talents as successfully and fruitfully as does Mr. Sawyer, and the Meteorological Office may count itself fortunate in his services. Election to the Royal Society is a most fitting recognition.

DIURNAL, SEASONAL AND ANNUAL CHANGES IN THE INTENSITY OF LONDON'S HEAT-ISLAND

By T. J. CHANDLER
University College, London

An urban climate is a function of three variables: the general climate of the region, the modifying influences of local morphology, and the "self-induced" modifications following the congregation of houses, factories, power stations and surfaced roads into the complex of the city. Each house, factory, wall and road creates its own microthermal conditions and these combine to produce a fairly distinct climatic entity—the urban climate. The city modifies almost all aspects of the regional climate, including local thermal conditions.

London, in common with other towns, is usually (though not invariably) characterized by temperatures above those prevailing in the surrounding country districts. The warm air, or heat-island, which lies within and above the city is the product of a number of factors including the high thermal capacity of the city fabric: back radiation from the pollution haze and from tall buildings; heat released in the combustion of fuel in factories, offices, homes and vehicles; and the cellular structure of the city which reduces heat diffusion. The efficiency of these factors is controlled by a number of meteorological elements, including cloud amount, preceding and present regional temperatures, humidity, wind velocity and direction and the extent and morphology of the urban area.

Being the sum of so many varied influences, the degree of warming of the city's air is very variable. The intensity of the heat-island, its extent and form change in sympathy with variations in the above mentioned factors but in spite of the ever-changing form of the mass of warm air, there are discernible variations of a periodic nature. These cover time scales ranging from hours to years.

The temperature difference between a city and the surrounding rural districts is generally strongest by night as Figure 1 shows. Bayfordbury, in the

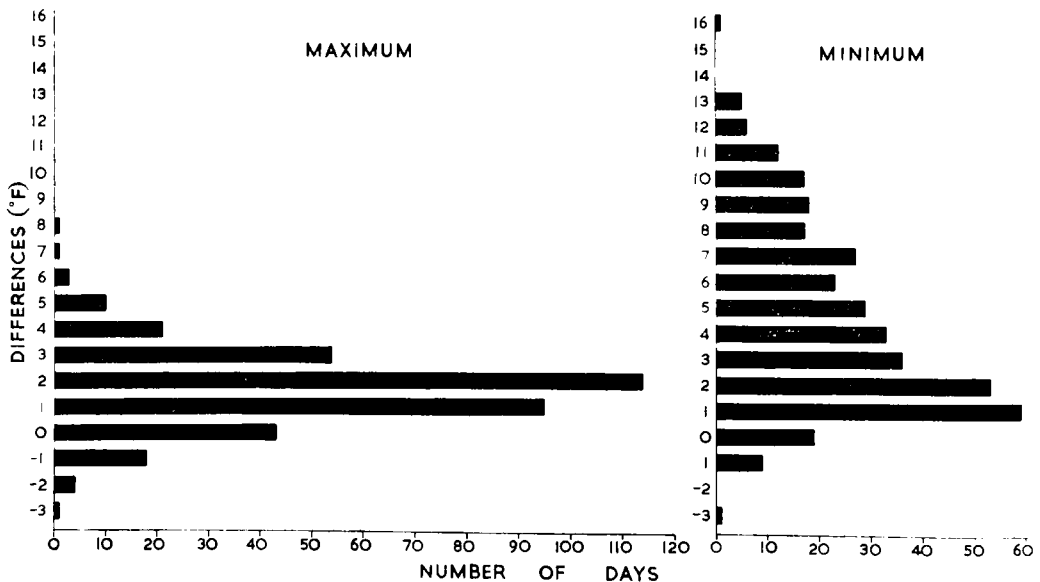


FIGURE 1—DIFFERENCES IN MAXIMUM AND MINIMUM TEMPERATURES, KENSINGTON-BAYFORDBURY, 1959

(Reproduced by courtesy of the Hon. Editor of *Geography*)

green belt north of London, is 140 feet higher than Kensington in the centre and under normal lapse rate conditions we should expect a difference owing to altitude of about 0.5°F . The generally higher differences in minimum temperatures than in maximum temperatures is immediately obvious. During 1959 there were 76 occasions with a difference in minimum temperatures of 8°F or more, although the median value was 4°F and the mode 1°F . Extreme differences in minimum temperatures were -3°F and 16°F . By contrast, the median difference in maximum daily temperatures at the two stations was much less, namely 2°F , varying between -3°F and 8°F . It will be noted that on a number of occasions both during the day and night, Bayfordbury, a rural station, was warmer than Kensington in central London. Many such instances can be explained in terms of the locations of fronts or local differences in cloud amounts (perhaps for very short periods on a generally cloudy day) or through pollution and fog density contrasts. Others are more difficult to understand and not all of the explanations given for similar features in other cities are applicable.¹

But although the margins of the heat-island normally parallel those of the built-up area, the mass of warm air is rarely symmetrical and Kensington only infrequently lies in its peak area. This seems to be in the Stoke Newington, Islington, Shoreditch, Hackney and Bethnal Green districts of the north-east. This is owing both to the intensity of urban development in these areas and the frequent displacement of peak intensities by the prevailing south-westerly winds. Two distributions will serve to show the primary characteristics of daytime and night-time temperatures in London. The maps (Figures 2 and 3) are based upon readings from 17 official climatological stations sending returns to the Meteorological Office, and from a close network of 32 newly established stations in the lower Lea valley district of the north-east. These formed part of the Lea Valley Climatological Survey which operated between January 1959 and December 1960. In January 1961 the Survey was enlarged to cover the whole London district and re-named the London Climatological Survey.² Broken lines are used where the station network was open and some uncertainty existed in the precise location of isotherms.

Figure 2 shows the pattern of maximum temperatures on Saturday, 27 June 1959. One cannot be certain that this distribution is instantaneous, although thermograph traces at several stations within and beyond the city margin indicate negligible differences in the timing of maximum temperatures.

At mid-day on 27 June 1959 a small depression centred over Ireland was moving east. A northward-moving warm front lay across northern England and in the London region, winds of 10 to 15 knots blew from between south-south-west and south-west. There was a seven-eighths cover of cumulus and stratocumulus cloud. The associated heat-island was intense by daytime standards with an extreme anomaly of 8°F (though temperatures at Kensington and Bayfordbury differed by only 5°F) but the complicated, cellular temperature pattern is typical of daytime conditions. Pockets of warm and cold air, reflecting closely built-up and open urban areas as well as an irregular and constantly changing pattern of thermals, no doubt existed on all scales from several square miles to a few square yards. Only in the north-east was the station network close enough to record even the largest of these. Extensive cloud and moderate turbulence no doubt limited the heat-island's intensity.

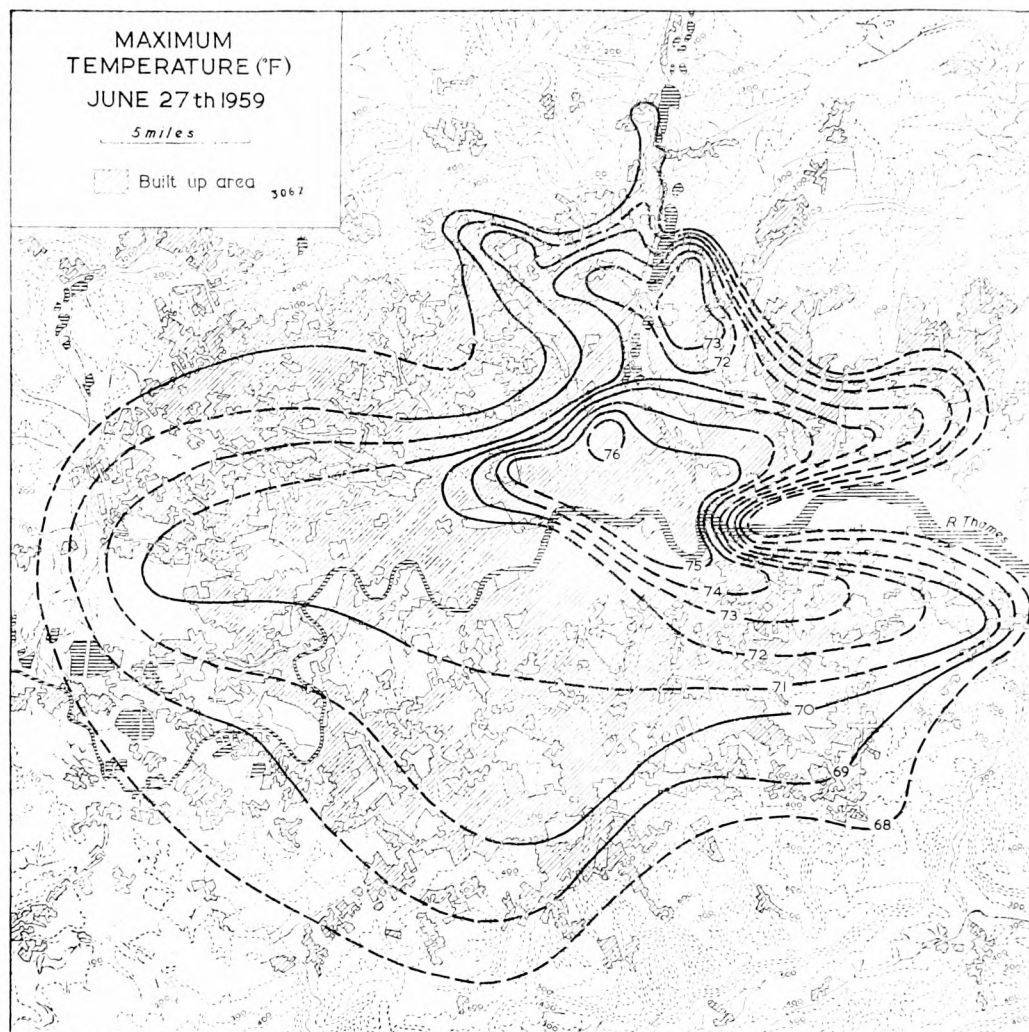


FIGURE 2—MAXIMUM TEMPERATURE ($^{\circ}\text{F}$) ON 27 JUNE 1959

Wind controls are very obvious. In south-west London, winds of 10 to 15 knots were associated with strong vertical heat diffusion which led to weak thermal gradients in these areas, although the complicated interlacing of houses and open spaces so characteristic of the south-west suburbs no doubt intensified the effect. In the north-east, leeward part of the city, near-surface wind-speeds were less and local urban development is characterized by closely spaced nineteenth century and early twentieth century terrace houses with few open spaces and possessing a high thermal capacity. Winds were warmed as they moved north-east to the inner suburbs of the lower Lea valley where temperatures were further increased owing to the above mentioned atmospheric and geographical conditions. The result was a displaced heat-island centre with the highest temperatures in Islington and Shoreditch and steep thermal gradients along the north-east city limits. It seems likely that local reverse, thermally induced winds occasionally pulse along these margins, moving toward the centre of the heat-island but soon halted by friction with the serrated surface of the city^{3,4}. These winds may have sharpened temperature gradients between

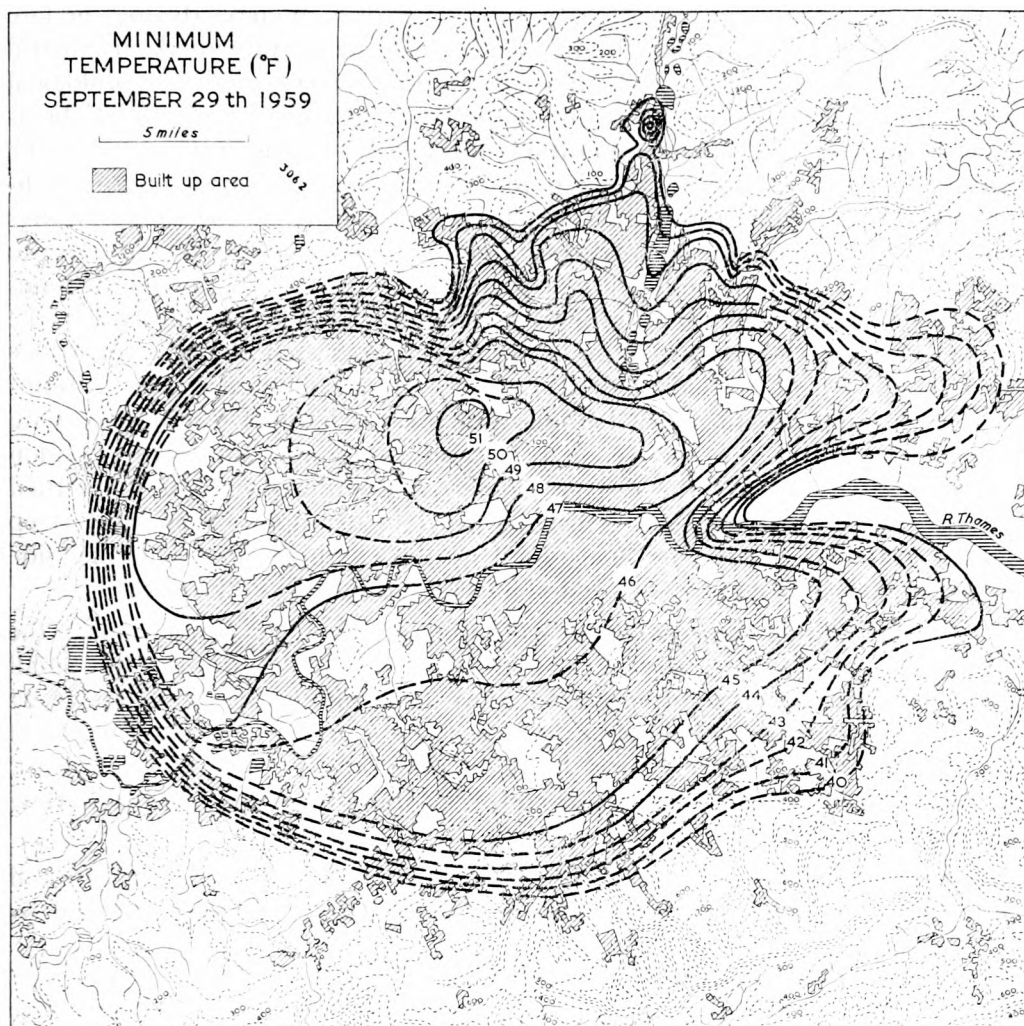


FIGURE 3—MINIMUM TEMPERATURE ($^{\circ}\text{F}$) ON 29 SEPTEMBER 1959

the closely settled districts of West Ham, Greenwich and Woolwich and the open marshlands of lower Thames-side, for there is some evidence that near-surface currents, similar in genesis to sea-breezes, frequently blow westward along the Thames towards the peak of the heat-island. Together with reduced frictional drag, these may account for the light easterly breezes one experiences near the river below Westminster on days when there is hardly any air movement in central districts. Owing to the reduction of wind speeds on the leeward side of the city, such local winds are more frequent there than along windward margins.

Night-time heat-islands tend to be stronger and simpler in form, the latter mainly because turbulence is generally weaker than during the day and local variations in cloud cover are less regionally differentiating. Figure 3 shows a situation typical of the more intense night-time heat-islands. During the night of 28–29 September 1959, Great Britain lay on the western fringes of an anti-cyclone centred over Poland and covering most of Europe. In the London region, winds of about five knots backed from south-east to north-east during

the night; the only cloud was a two-eighths cover of high cirrus during the late evening and early morning. Light winds (near-calm prevailed in central London) and almost clear skies allowed the full interplay of meteorological factors contributing to urban-rural temperature contrasts and a 11°F heat-island developed with peak temperatures displaced towards Hampstead in the north-west. North-west suburbs were about three degrees warmer than south-east districts at comparable distances from the centre. Lower temperatures above the Lea floodplain in north-east London were probably owing more to its open nature than to the downflow of chilled air, for although cool air tends to move down from open high ground such as the flanks of Epping Ridge, the air ponds against the margins of low-lying urban areas such as Waltham Abbey where its movement is almost halted. Extensive frost-hollows are rarer in built-up areas owing both to urban heating and the mechanical interference with airflow^{5,6}, but open areas such as the parks and commons of south-west London are frequently two or three degrees cooler at their centre than the settled districts around their margins. As in the previous example, remarkably steep thermal gradients border the heat-island on the north-western, leeward, side of London, and above the open areas of lower Thames-side in the east.

In less favourable meteorological conditions than on 27 June 1959 or the night of 28–29 September 1959, heat-islands are weakly developed. Only small anomalies accompany wind speeds of more than about 14 knots (above 22 knots London temperatures usually equal those outside), extensive banks of thick cloud (a factor more critical by night than day for in summer, at least, the reduction of net radiation is greater), high humidities, and cool preceding or present weather.

Seasonal changes.—An analysis of the differences in daily maximum and minimum temperatures at Kensington and Bayfordbury during 1959 and by

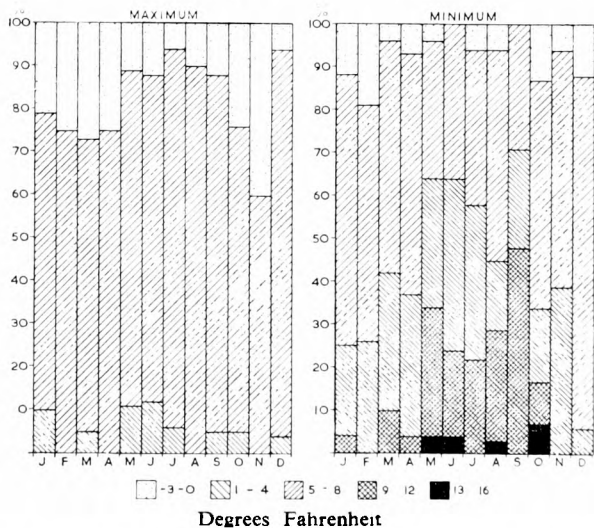


FIGURE 4—DIFFERENCES IN MAXIMUM AND MINIMUM TEMPERATURES, KENSINGTON-BAYFORDBURY, 1959

months reveals seasonal variations in the intensity of London's heat-island (Figure 4). Contrasts of daily maximum temperatures show a weak tendency to a summer and early autumn maximum and spring minimum but, as already

noted, differences in maximum temperatures at Kensington and Bayfordbury were generally small throughout the year.

Differences in daily minimum temperatures were not only greater but showed a pronounced and more regular seasonal variation with a summer and autumn maximum and a winter and early spring minimum. The substantial differences of January 1959 were probably owing to an unusually sunny month. This pattern is typical of most years although differences were sometimes small.

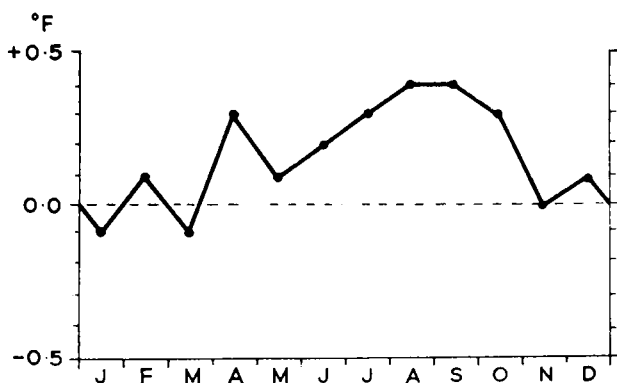


FIGURE 5—DIFFERENCE IN MAXIMUM TEMPERATURES, KENSINGTON-WISLEY, 1921-50

Mean monthly maxima and minima differences at Kensington and Wisley for the period 1921-50 show the same general pattern of change as during 1959 (Figures 5 and 6). Bayfordbury's records begin in 1953 and cannot be used in such long-period analyses.

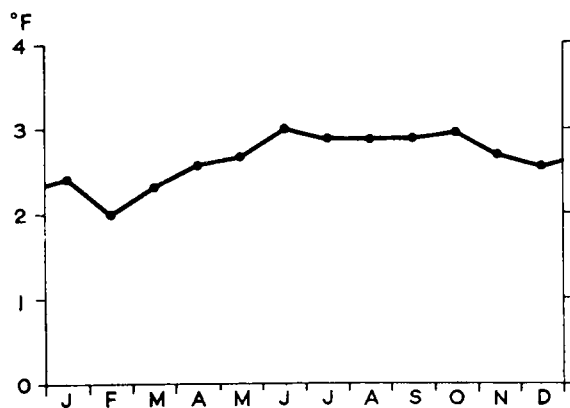


FIGURE 6—DIFFERENCE IN MINIMUM TEMPERATURES, KENSINGTON-WISLEY, 1921-50

Annual changes.—Lengthening the time scale once more, the differences in mean annual maxima and in mean annual minima at Kensington and Wisley between 1921 and 1960 are shown in Figures 7 and 8. Differences in mean annual maxima at the two stations were small in all years, varying between -0.6°F (in 1944) and 1.0°F (in 1959). The difference in mean annual minimum temperatures at Kensington and Wisley between 1921 and 1960 varied between 1.9°F (in 1924) and 3.2°F (in 1929 and 1933).

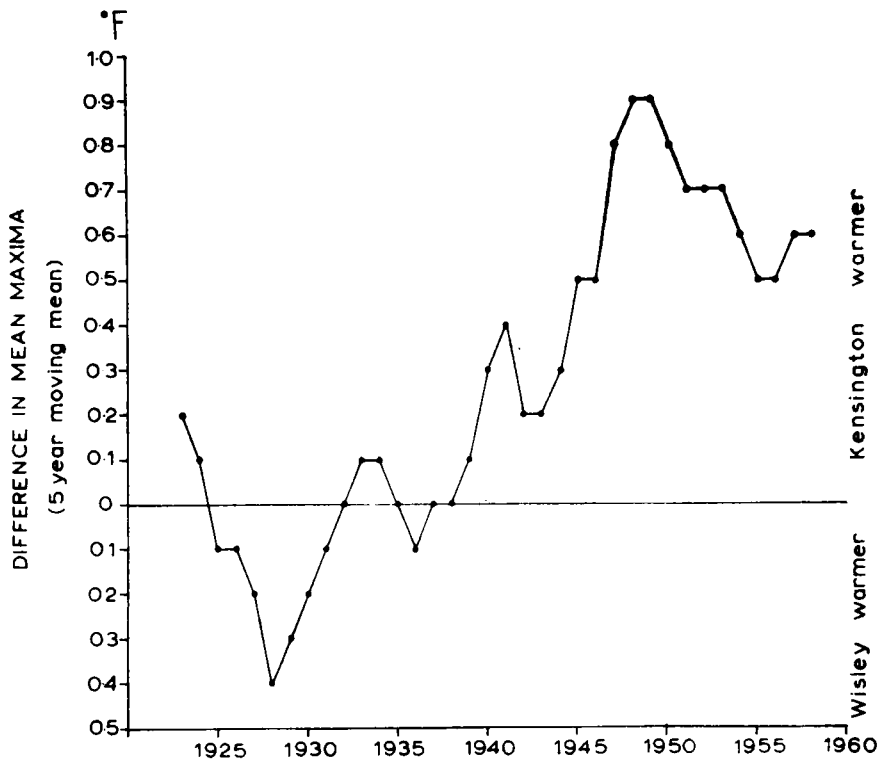


FIGURE 7—DIFFERENCE IN MAXIMUM TEMPERATURES, KENSINGTON-WISLEY, 1921-60

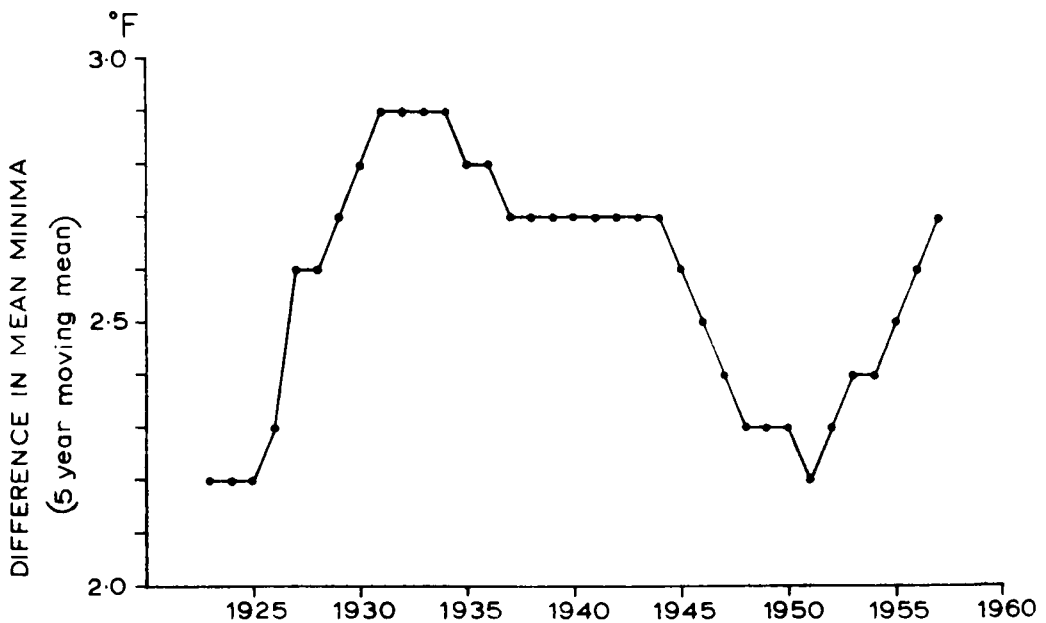


FIGURE 8—DIFFERENCE IN MINIMUM TEMPERATURES, KENSINGTON-WISLEY, 1921-60

Conclusions.—The intensity of London's heat-island shows significant variations over diurnal, seasonal and annual time scales, and recognizable periodic trends occur in spite of perturbations imposed by irregular changes in weather. Amongst these trends are the marked contrast between daytime and night-time intensities and, only a little less pronounced, the differences between

seasons: changes from year to year are smaller and less regular. The form of these variations throws some light on the relative importance of the several factors leading to urban-rural temperature contrasts.

At dawn, air temperatures within and above London will usually be several degrees higher than in its rural envelope (the anomaly is usually greatest shortly before dawn) but the city air fails to warm as quickly as that above the fields and woods of the green belt. This is partly owing to differences in heat capacity and conductivity between the city-fabric and the vegetation-covered soils; partly to the effect of a haze hood above London intercepting radiation from the sun; and partly to the strong mechanical turbulence of air in contact with city buildings mixing the warmer air near the ground with the cooler air above. For these and other less important reasons temperatures around London soon reach values very near those in the centre and maximum temperatures are little different. By night, however, these same factors cause a more rapid fall of temperature in rural areas than in the city and of very great significance is the heat retained by the buildings and surfaced roads. This warms the air within and immediately above the city, and being part back-radiated from the walls of tall buildings, serves to diminish the net rate of cooling. The supreme importance of thermal capacity contrasts between urban and country districts also explains the summer and early autumn peak of London's heat-island intensity—a time of the year when the pollution haze is weakest and when the combustion within the city is least. It is almost certain that London's heat-island is mainly owing to heat retained by the fabric of the city to be released later, thus giving the typical night-time and summer and autumn maxima.

Annual changes reflect yearly changes in those aspects of the general climate bearing upon heat exchange processes. This is most clearly seen in the case of the larger minimum temperature contrasts. The cool, unsettled and generally cloudy years from 1922 to 1924 were no doubt mainly responsible for the low values of the night-time urban anomaly in those years, while the wet, somewhat stormy years from 1946 to 1948 and in 1950 and 1951 probably account for the weak heat-islands at these times. The years 1933 and 1934 were milder and calmer than the preceding years and drier than those which immediately followed. These features influence the degree to which the several factors producing the urban-rural anomaly are effective, and are no doubt the main determinants of annual changes in the intensity of London's heat-island.

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A NEW PRECISION ANEROID BAROMETER

By C. HINKEL, B.Sc.

Abstract.—A new type of precision aneroid barometer is briefly described. Test results both for outstation and headquarters trials are given.

Description of the instrument.—A two-stage aneroid capsule (A) (see Figure 1) made of beryllium-copper alloy is rigidly fixed at one side. The other side is free to move with changes of air pressure and deflects a pivoted bar (B) which is maintained in contact with the free side of the capsule by the hairspring (C). The bar pivot is mounted in jewelled bearings and the hairspring causes the bar to exert, on the capsule, a pressure which is only a very small fraction of that imposed by a conventional system of gears and levers. The displacement of the

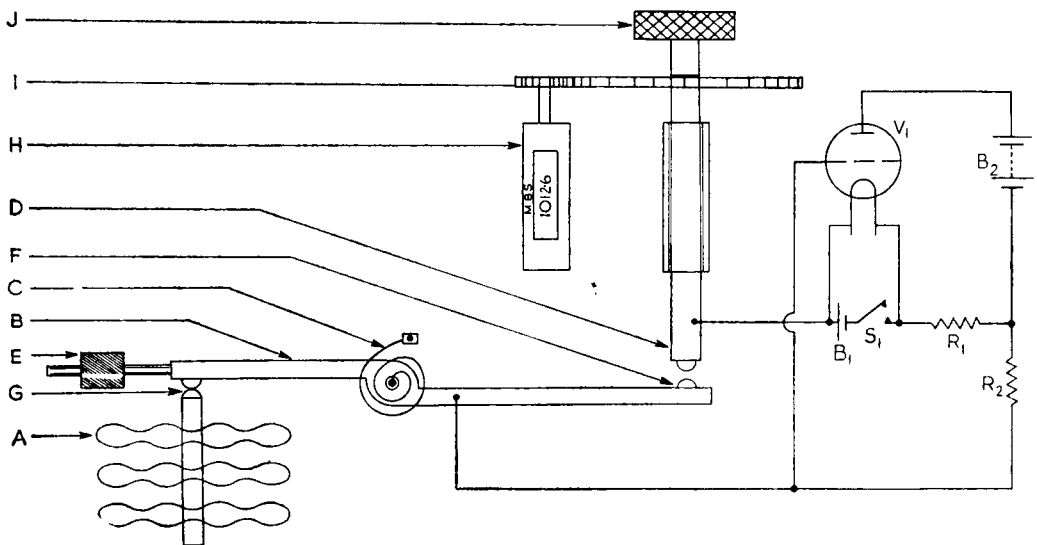


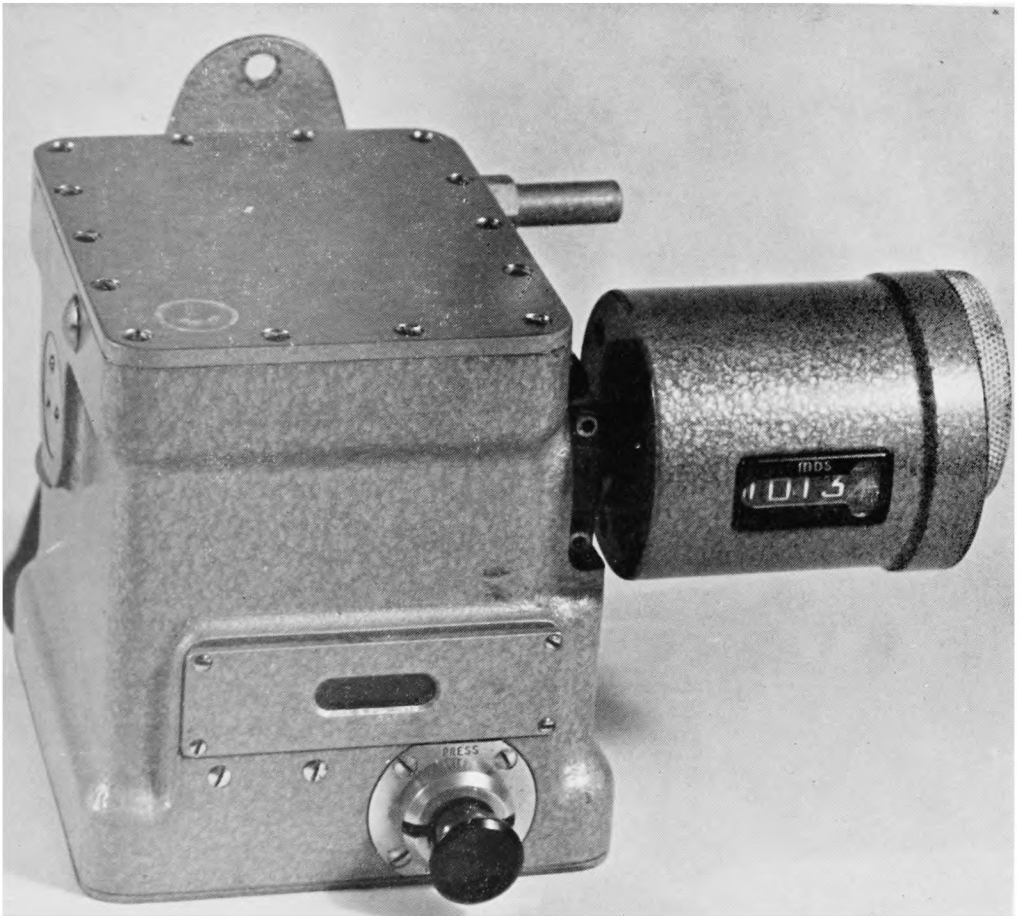
FIGURE 1—SCHEMATIC DIAGRAM AND CIRCUIT OF PRECISION ANEROID BAROMETER

- | | | | |
|---|---------------------------------|----------------|---------------------------------|
| A | aneroid capsule assembly | I | gearing |
| B | pivoted arm | J | operating knob |
| C | hairspring | V ₁ | "magic-eye" indicator type DM70 |
| D | micrometer-type spindle and nut | S ₁ | switch |
| E | counterbalance | B ₁ | battery, 1.5V |
| F | sliding electrical contacts | B ₂ | battery, 60V |
| G | mechanical contacts | R ₁ | resistance |
| H | digital display | R ₂ | resistance |

other end of the bar, caused by movement of the capsule, is measured by the micrometer screw (D) graduated directly in millibars and tenths. Contact between the bar and the micrometer is sensed electrically and displayed by means of a cathode-ray indicator tube. The assembly is enclosed in a metal case which can be completely sealed from the ambient air if required. The micrometer drum is situated on the outside of the case. The instrument covers the pressure range from 930 mb to 1055 mb.

The initial tests were carried out at headquarters using the manufacturers' prototype, but all subsequent tests were performed on production models embodying a number of improvements. One of these was the replacement of the micrometer by a counter giving a digital presentation of the pressure in whole millibars and tenths.

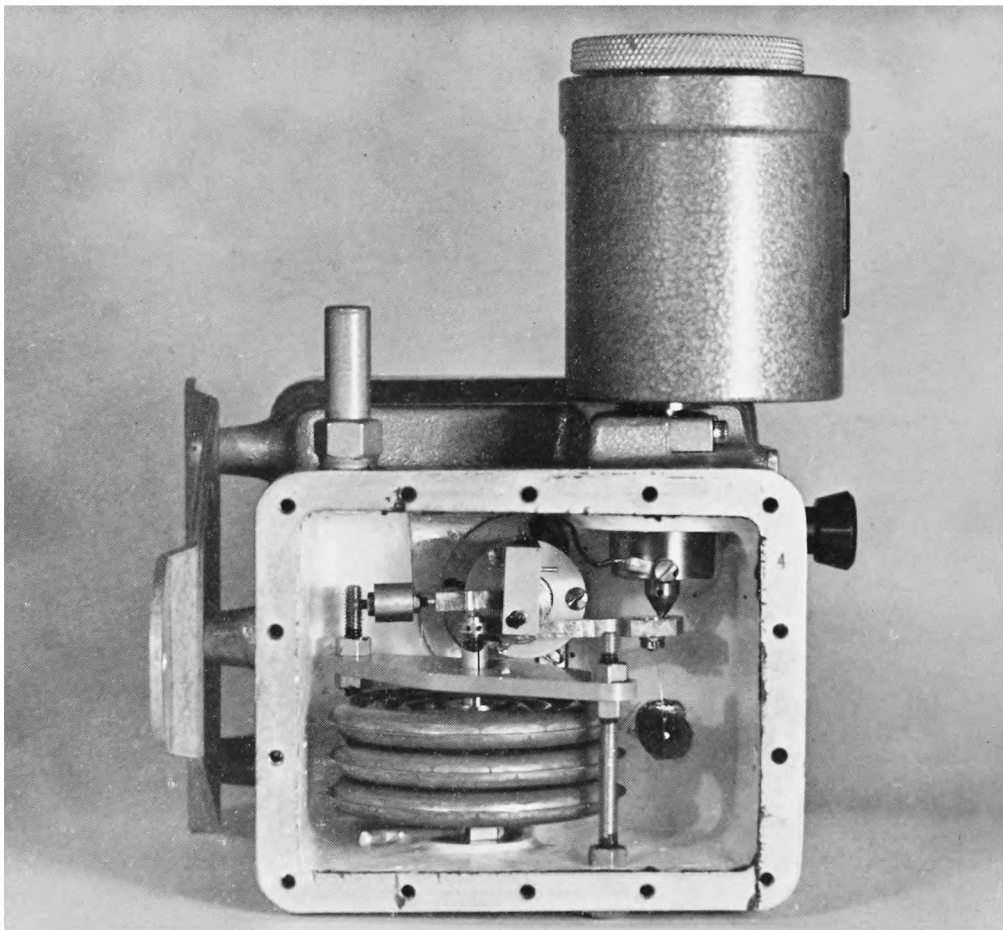
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PLATE I—GENERAL VIEW OF NEW PRECISION ANEROID BAROMETER

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PLATE II—VIEW OF INTERIOR OF NEW PRECISION ANEROID BAROMETER

General views of the instrument are shown in Plates I and II between pp. 154-155.

Trial procedure.—Each of the aneroid barometers used in the trials was tested at atmosphere pressure by comparison with a mercury barometer, simultaneous readings of each instrument being taken once or twice daily. The trials fall naturally into three parts:

- (i) The manufacturers' prototype was tested over a period of about three months. It was then sent by road to the Ocean Weather Ship Base at Greenock and back. No special packing precautions were taken. The instrument in its box was placed on the seat beside the driver and left there for the whole journey. Unusually bad road conditions existed on the northern half of the route and the aneroid received extremely harsh treatment. On return it was allowed a week to settle down and then a further set of readings was taken.
- (ii) A production instrument was sent to each of four outstations for three months' comparison with the station mercury barometer, simultaneous readings of both being taken twice daily. At the end of the period the instruments were returned to headquarters, the micrometers were replaced by a counter and the instruments sent back to their respective outstations for a further three months' trial.
- (iii) Ancillary tests were undertaken to clarify the results obtained from the outstations. In addition the aneroids were all read simultaneously before despatch to and on return from the outstations. Only the aneroid tested at outstation "C" showed a mean difference greater than 0.1 mb between these two sets of readings.

As part of the trial procedure under (ii) above the aneroids were transported, packed in their transit cases, by road, rail, air and even through the ordinary parcel post. No ill-effects or changes in calibration resulted from this treatment although they underwent similar rough treatment to that experienced by the prototype.

Results and discussion.—Mean differences of the readings of the mercury barometers minus those of the corresponding aneroids were computed together with the standard deviations of the differences. These results are set out in Table I.

The initial comparison shows that the prototype underwent a change of calibration of about 0.6 mb after its rough handling during transport. The difference was found to be purely a shift of zero. As a result of this experience the makers introduced modifications in the production instruments to prevent similar shifts and so far none has occurred.

The results from the outstation trials, using production instruments fitted with micrometers, require little comment. The somewhat large mean difference at station "A" is now known to be due to the mercury barometer being in error. The large standard deviation at station "D" is somewhat disappointing, but otherwise the standard deviations compare very favourably with that for two mercury barometers which is given in the "Handbook of meteorological instruments"¹ as 0.18 mb.

The trial using production instruments fitted with counters was of interest in that it allowed the pressure to be read directly as a unique set of figures. Station "D" again shows an unexpectedly large standard deviation. This was so large that the instrument was given a separate test on its return to headquarters.

TABLE I—COMPARISON OF ANEROID AND MERCURY BAROMETERS

Aneroid fitted with micrometer			
	Mean difference (mercury-aneroid) mb	Standard deviation mb	No. of observations
<i>Initial Comparison in HQ Instruments Branch</i> (makers prototype)			
Before road journey	0.09	0.15	137
After road journey	0.73	0.10	125
<i>Comparison at four outstations</i> (production models)			
"A"	0.51	0.20	169
"B"	0.06	0.15	184
"C" before 7 February 1961	0.08	0.19	184
"C" after 7 February 1961	—	—	—
"D"	0.13	0.29	156
All occasions		0.21	693
Aneroid fitted with counter			
	Mean difference (mercury-aneroid) mb	Standard deviation mb	No. of observations
<i>Comparison at four outstations</i> (production models)			
"A"	0.47	0.15	171
"B"	0.13	0.09	194
"C" before 7 February 1961	0.56	0.15	133
"C" after 7 February 1961	0.25	0.10	44
"D"	0.40	0.42	163
All occasions		0.23	705
<i>Miscellaneous tests</i> (production models)			
Aneroid at "D" in HQ test room	0.13	0.05	62
Aneroid at "C" in HQ test room	0.53	0.09	45

The results, summarized in the last section of Table I, point to causes other than the aneroid, such as large temperature variations in the attached thermometer of the mercury barometer and difficulty in reading either barometer. The other instruments all showed an improved standard deviation and the unanimous opinion of all four stations was that they preferred the instrument fitted with the counter to that with the micrometer.

At outstation "C" an unaccountable shift on zero occurred between 6 and 7 February 1961. Zero shifts of this type have been known to occur with aneroid barometers before. The magnitude of the shift was 0.31 mb and is the only one of its kind to occur with this particular type of aneroid over a period of nearly two years. The instrument was tested on return and it was confirmed that a zero shift had taken place. The altered zero has been retained and has subsequently shown no sign of returning to the original value. The causes of shifts of this type are not yet fully understood, but are thought to be due to the relief of strains in the capsule material introduced during manufacture and which have not been completely eliminated by artificial ageing.

A comparison of two aneroids was also undertaken. Instruments (fitted with counters) returned from outstations were used for this purpose. This showed that the two instruments were mutually very consistent, the mean difference of 67 pairs of readings being 0.16 mb with a standard deviation of 0.03 mb.

Conclusions.—The aneroid barometers tested at headquarters have shown that they are at least as accurate as a standard mercury Kew pattern barometer. They are considerably easier to read and outstation opinion confirms this view. The results from station "D" are not consistent with those from the other three but, if they are ignored for the reasons given above, the instrument fitted with the counter shows a slightly improved performance over the micrometer version. The instruments are able to stand up to a considerable amount of rough treatment and the problem of transporting them is much simpler than for a mercury barometer. The zero shift of the instrument used at station "C" shows that a check against a standard at regular intervals is desirable in order to detect any shifts of this nature. It is, however, easier to carry out this check with the aneroids than with mercury barometers.

Acknowledgements.—Acknowledgements are gratefully made to Miss M. K. Hinds and Mr. P. B. Sarson for their assistance with the computer programme and to the members of both the headquarters and outstation staff who carried out the barometer trials.

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MEAN WINDS OVER SINGAPORE, WITH SPECIAL REFERENCE TO THE 40,000 AND 50,000 FOOT LEVELS

By P. F. McALLEN

Introduction.—In the first part of this paper an attempt is made to show, as clearly as possible, the seasonal changes in the tropospheric wind régime over Singapore using monthly mean winds between the surface and 50,000 feet obtained from radar-wind observations and pilot-balloon ascents. In the second part the ten-year mean winds at 40,000 and 50,000 feet over Singapore are discussed in detail.

Vertical cross-section.—The vertical cross-section Figure 1 depicts the mean winds over Singapore classified into quadrants. In the construction of this diagram the mean winds at the surface and 1500 feet were taken from pilot-balloon observations made between 0630 and 0830 local time at Kallang Airport by the Malayan Meteorological Service for the period 1934-41. Although it had originally been expected that wind observations made between these hours might be biased slightly by a land-breeze effect, these wind observations are in close agreement with the mean surface observations made over a five-year period at the Royal Air Force Station, Changi at 1030 local time when the wind is unlikely to be affected by either land- or sea-breezes, and it is considered therefore that these winds can be accepted as representative means. The mean winds at levels above 1500 feet are also based on observations made by the Malayan Meteorological Service. The mean winds at standard pressure

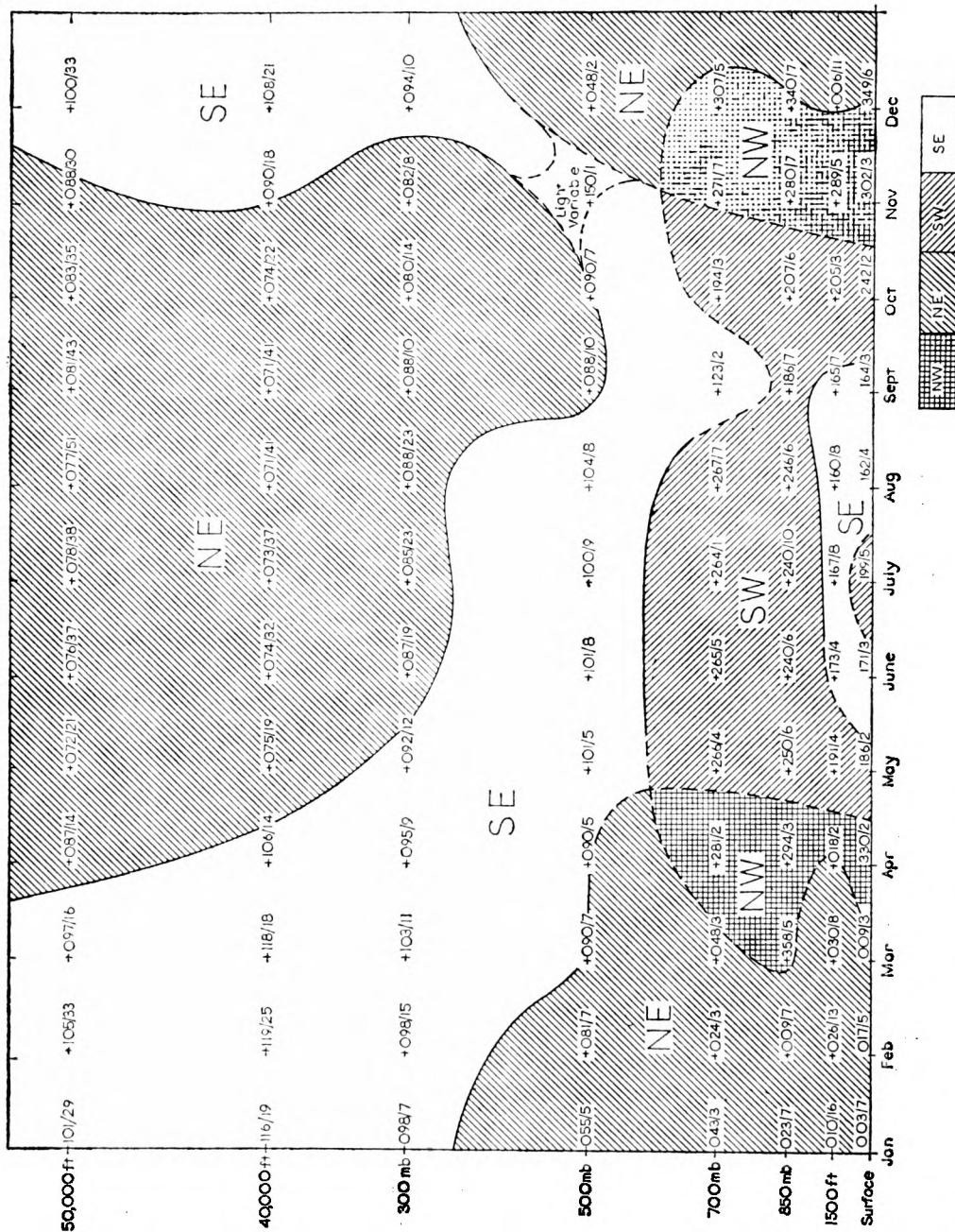


FIGURE 1—VERTICAL CROSS-SECTION OF VECTOR MEAN WINDS, DIVIDED INTO QUADRANTS, OVER SINGAPORE
Broken lines divide quadrants where velocity is less than 5 knots.

levels shewn in Figure 1 refer to the period February 1955 to December 1959, while the mean winds at 40,000 and 50,000 feet are for the ten-year period from January 1951 to December 1960.

It is of interest to see that the popular conception of two inter-monsoon periods over Singapore, centred about April and November and associated with light and variable winds, is not strictly true, for the winds, though light, are during these periods consistently westerly or north-westerly from the surface to between 700 and 500 millibars.

During the south-west monsoon there is a suggestion of south-easterly winds both at the surface and 1500 feet in June, August and September. This is most probably due to the incursion of the south-east trades across the equator, although it may also be due, but to a lesser degree, to the diversion of the south-westerly flow at low levels by the land mass of Sumatra. As far as Singapore is concerned this monsoon could be more accurately described as the south or south-east monsoon.

In view of these observations it may be more reasonable to say that the low-level winds over Singapore fall into four main divisions, namely north-easterly winds between January and March, light north-westerlies in April, southerlies between May and October and north-westerlies in November and December.

The increase in the wind at low levels normally associated with the north-east monsoon is masked at the surface by the sheltering effect of south-east Malaya, but is well marked in December, January and February at 1500 feet. It is also apparent that these north-easterly winds, which extend from the surface to about 20,000 feet during the winter months, are very light above 5000 feet.

Mean winds at 40,000 and 50,000 feet.—In a previous paper Clarkson¹ presented an analysis of winds at 40,000 feet and 50,000 feet over Singapore, based on all available radar-wind observations between January 1951 and April 1955. Clarkson's statistics are shown in Tables I and II at *A*. The statistics of monthly mean winds at 40,000 feet and 50,000 feet over a period of ten years, January 1951–December 1960 are also shown in Tables I and II at *B*. The vector mean wind \mathbf{V}_R was obtained for each month from the mean components V_N and V_E , and the standard deviations σ were computed when combining the individual years by the method prescribed by Brooks and Carruthers.²

Since at both 40,000 feet and 50,000 feet the shorter- and longer-period means are for the most part in very close agreement, it is proposed to concentrate mainly on those results which show a marked difference.

Constancy.—One means of expressing the steadiness of the wind, which is shown in Tables I and II, is by the constancy q which is defined as the percentage ratio of the vector mean speed to the scalar mean speed V_S . With this definition, if the wind over a period of a month remained always in the same direction and only the speed varied, then the constancy would be 100 per cent. However, if the wind came with equal frequency and strength from opposing directions, then the constancy would be zero.

Palmer³ has stated that a constancy of 90 per cent may be obtained in the most steady trade winds, whilst a constancy of 97 per cent is obtained in some months in the Krakatoa easterlies at a height of 30 kilometres between 15°N and 15°S, and in the Von Berson westerlies, a narrow band at approximately 20

TABLE I—MONTHLY MEAN WINDS AT 40,000 FT OVER SINGAPORE

		No. of obs.	V_S kt	V_N kt	V_E kt	V_R deg.	kt	σ kt	q %
Jan.	A	65	23.3	-7.2	20.2	110	21	13.1	92
	B	355	23.0	-8.3	16.8	116	19	17.4	81
Feb.	A	78	28.0	-10.7	23.3	110	26	17.2	92
	B	347	27.8	-12.2	21.6	119	25	15.4	90
Mar.	A	85	20.8	-6.4	15.1	110	17	16.2	79
	B	384	21.7	-8.6	15.9	118	18	15.2	83
Apr.	A	79	19.4	-2.0	16.3	100	16	14.1	85
	B	368	17.7	-3.7	13.1	106	14	14.4	79
May	A	50	22.4	3.4	17.9	80	18	15.7	81
	B	381	22.3	4.9	18.6	75	19	16.7	85
June	A	52	34.5	9.9	31.1	70	33	15.9	95
	B	375	34.3	8.8	30.8	74	32	17.9	93
July	A	53	39.2	14.1	34.6	70	37	15.6	96
	B	395	39.0	11.0	35.8	73	37	16.7	95
Aug.	A	46	44.2	14.4	39.9	70	42	17.6	96
	B	393	42.4	13.4	38.5	71	41	17.3	97
Sept.	A	44	41.4	14.1	37.2	70	40	17.5	96
	B	316	36.9	11.2	33.4	71	35	15.9	95
Oct.	A	51	25.9	3.8	23.9	80	24	15.1	93
	B	368	25.3	6.3	21.7	74	22	16.9	87
Nov.	A	67	25.0	-4.0	23.0	100	23	13.0	93
	B	407	21.5	0.2	18.3	90	18	16.2	84
Dec.	A	47	22.3	-5.6	18.6	110	19	15.3	87
	B	393	24.2	-6.5	20.3	108	21	15.0	87

A. Clarkson's means for observations at 0300 GMT between January 1951 and April 1955.

B. 10-year means, January 1951 to December 1960 i.e. Clarkson's means A plus means for observations at 0300 and 1500 GMT from May 1955 to March 1957 and at 0001 and 1200 GMT from April 1957 to December 1960.

TABLE II—MONTHLY MEAN WINDS AT 50,000 FT OVER SINGAPORE

		No. of obs.	V_S kt	V_N kt	V_E kt	V_R deg.	kt	σ kt	q %
Jan.	A	64	39.7	-6.0	36.3	100	37	22.1	93
	B	330	34.9	-5.2	28.0	101	29	29.5	83
Feb.	A	75	38.6	7.7	28.7	100	30	33.9	77
	B	329	39.8	8.5	31.3	105	33	30.0	83
Mar.	A	85	23.9	3.7	9.4	70	10	26.0	42
	B	380	25.1	2.1	16.1	97	16	24.3	63
Apr.	A	78	23.9	2.9	19.5	80	20	19.6	82
	B	356	20.6	0.8	13.9	87	14	18.9	68
May	A	48	30.2	9.8	25.2	70	27	18.0	90
	B	366	25.9	6.8	20.3	72	21	20.3	81
June	A	46	36.1	7.9	31.4	80	32	25.3	90
	B	344	39.9	9.1	35.9	76	37	24.0	93
July	A	45	41.6	6.7	37.8	80	39	23.9	93
	B	354	40.6	8.1	37.2	78	38	23.2	94
Aug.	A	35	53.0	12.4	49.6	80	51	25.0	97
	B	355	52.6	11.2	49.7	77	51	24.3	97
Sept.	A	41	52.1	9.6	49.1	80	50	28.2	96
	B	291	46.5	6.7	42.9	81	43	23.2	93
Oct.	A	48	38.4	6.6	35.8	80	36	20.9	95
	B	342	36.3	4.1	34.4	83	35	19.2	95
Nov.	A	68	42.4	-0.3	41.7	90	42	20.7	98
	B	393	34.9	0.9	30.2	88	30	23.8	86
Dec.	A	39	32.5	-2.6	29.6	100	30	22.3	91
	B	361	31.2	3.8	22.4	100	23	28.0	74

kilometres centred about 2°N . By these standards, therefore, it can be seen in Tables I and II that the winds at 40,000 feet and 50,000 feet over Singapore show a surprisingly high constancy, especially in August at the height of the south-west monsoon, when the steadiness of the wind at both these levels equals that of the Krakatoa easterlies and Von Berson westerlies.

The lower constancy figures of 63 per cent and 68 per cent respectively at 50,000 feet reflects the incursion of stratospheric westerly winds into the high tropospheric easterly flow in March and April. In March 1960 westerly winds were observed at 50,000 feet on 16 days; in March 1956 westerly winds were observed on 13 days at 50,000 feet and on 6 days at 40,000 feet. Similar incursions have been observed at 50,000 feet in the winter months, the most outstanding case being a period of 17 consecutive days of westerly winds between 29 November and 15 December 1958.

It is obvious from this that means with incomplete observations taken over a short period could give misleading results, and Clarkson was perhaps fortunate in the period he was obliged to select. Had he used a similar set of observations covering the period 1956 to 1960 he would have obtained results, especially for November and December, which would have borne a less close relationship to the longer-period means.

Zonal component (V_E)—Clarkson's¹ means for the shorter period suggest that the easterly zonal component is least in the month of March at both 40,000 feet and 50,000 feet. The ten-year means, however, show that this component, due mainly to the incursion of the westerlies discussed above, is a minimum at both levels in April. The longer-period means are therefore consistent with Figure 1 which shows that April and not March is the transitional month.

There is close agreement between the long- and short-period means, both of which give August maxima of approximately 40 knots and 50 knots at 40,000 and 50,000 feet respectively at the peak of the south-west monsoon period. However, the suggestion of a secondary maximum in January in the shorter period appears over the longer period to occur in February at both levels. Both this secondary maximum in February and the minimum zonal component in April are also found at the 300-millibar level (see Figure 1).

Meridional component (V_N).—In Figure 2 the mean meridional components at 40,000 feet and 50,000 feet for the ten-year period are shown for each month, and for interest the mean meridional components at standard pressure levels for the period February 1955 to December 1959 have also been incorporated. It can be seen from this diagram that the seasonal reversal in the meridional flow occurs three to six weeks after the equinoxes, and it is interesting to note that the reversal in the meridional flow in April first sets in at 50,000 feet.

The maximum high-level meridional flow in August and February, during the south-west monsoon and north-east monsoon respectively is consistent with the picture of the meridional vertical cross-section presented by Goldie.⁴

Summary of the general wind régime.—The wind régime over Singapore up to about the 600–500-millibar levels shows clearly the dominating influence of the two well known monsoons, namely the north-east monsoon from late November or early December to mid or late March, and the south-west monsoon from late April or early May to the end of October. As far as Singapore is concerned, however, the northern hemisphere summer monsoon

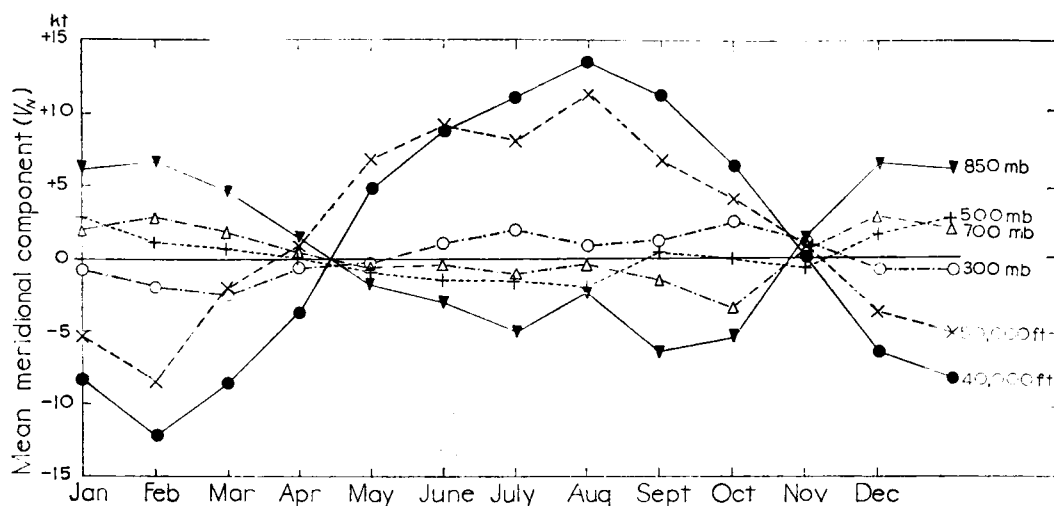


FIGURE 2—MEAN MERIDIONAL COMPONENTS (V_N) AT 40,000 AND 50,000 FT AND STANDARD PRESSURE LEVELS OVER SINGAPORE

could be more accurately described as the south or south-east monsoon. These monsoons are separated by two short transitional periods centred about April and November respectively, when the winds from the surface to at least 700 millibars are light north-westerlies.

Above the 600–500-millibar level the winds are predominantly easterly. At 40,000 and 50,000 feet they show a high constancy between June and October, especially in August. However, incursions of stratospheric westerly winds chiefly at 50,000 feet occur in March and April and occasionally during the winter months, the most outstanding case noted in recent years being in November–December 1958.

The maximum zonal component at both 40,000 feet and 50,000 feet occurs in August with a secondary maximum at both levels in February. The maximum meridional components also occur in the same months. The seasonal reversal in the meridional flow occurs three to six weeks after the equinoxes at 40,000 feet and 50,000 feet and the reversal in April appears to set in first at 50,000 feet. This latter effect is not however apparent in the other reversal in October–November.

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FOG AT LIVERPOOL AIRPORT

By G. J. BINDON

Introduction.—The diurnal and annual variation of fog and thick fog at Liverpool Airport has been studied and compared with the results of similar investigations for other stations.

Liverpool Airport is situated 80 feet above mean sea level on the north bank of the river Mersey, six miles upstream from the centres of Liverpool and Birkenhead. Within a very close semicircle round the north side of the airport are many sources of both domestic and industrial smoke; over three miles across the river, on the Wirral Peninsula, are further concentrations of industry. Smoke from industrial east Lancashire, and to some extent from the Midlands also, affects visibility at Liverpool.

Analysis.—Two diagrams have been prepared based upon a statistical analysis of occasions when the visibility was less than 1100 yards (Figure 1), and less than 220 yards (Figure 2) at each hour of the day over a period of 15 years, from September 1945 to August 1960. Each month was subdivided into

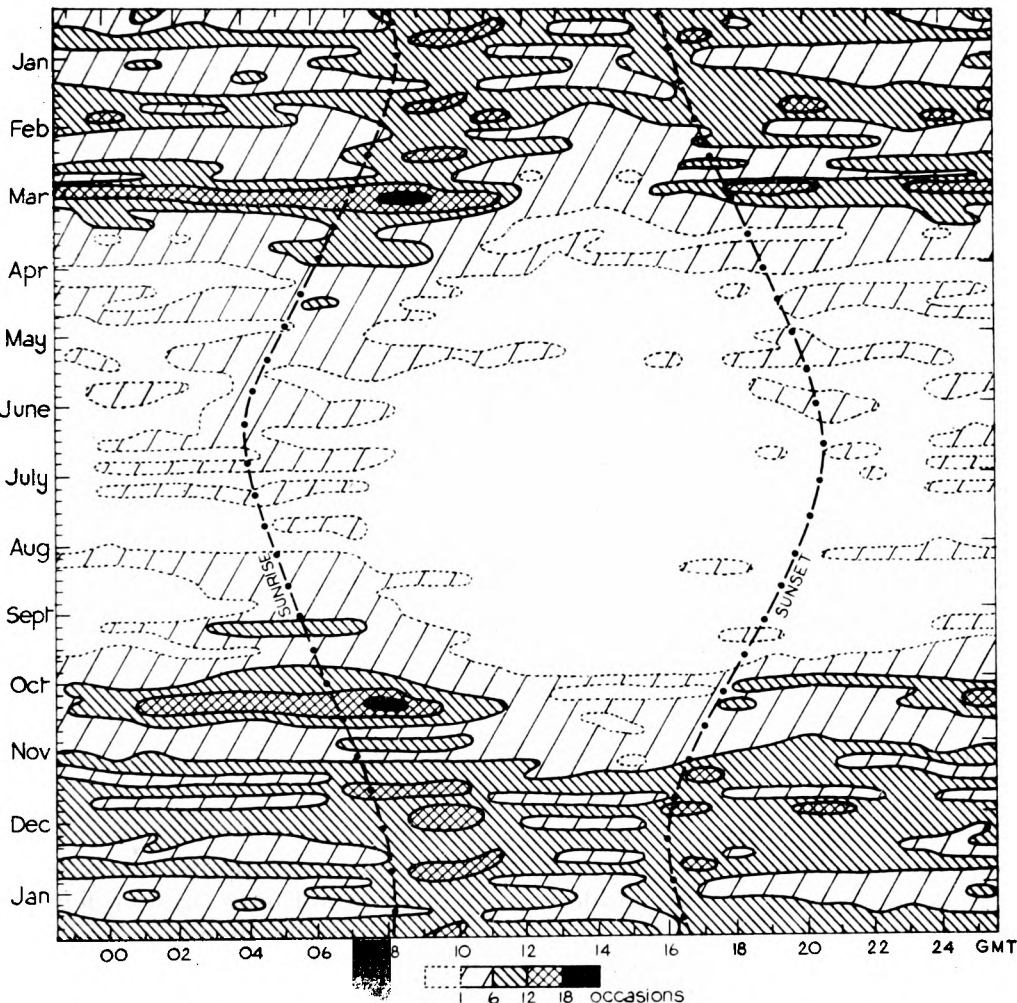


FIGURE 1—DIURNAL AND ANNUAL VARIATION OF FOG (< 1100 YD.) AT LIVERPOOL AIRPORT

six 5-day periods, 1st–5th, 6th–10th and so on; a proportional reduction of totals was necessary in the last period of the 31-day months and also a proportional weighting at the end of February. The isopleths in Figures 1 and 2 show the number of occasions on which visibilities within the specified ranges

occurred at each hour in 15 years, i.e. out of 75 possible occasions in any 5-day period. Tables I and II reproduce the hourly figures as monthly and annual totals.

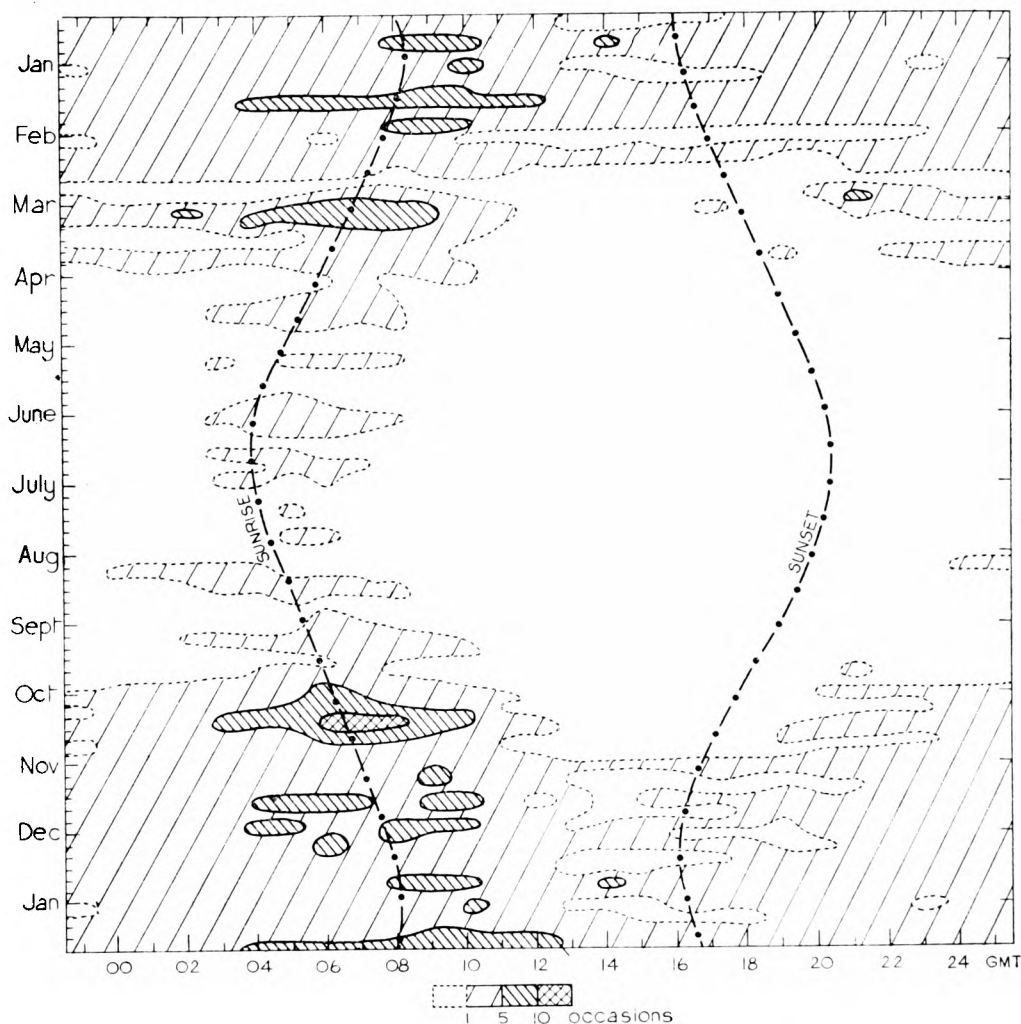


FIGURE 2—DIURNAL AND ANNUAL VARIATION OF THICK FOG (< 220 YD)
AT LIVERPOOL AIRPORT

Precipitation occurred during about 13 per cent of all occasions of fog. These were studied individually, and those occasions omitted (approximately 6 per cent of total) where it was considered that there would have been no fog had there been no precipitation. Mostly, those cases where fog already existed prior to the onset of precipitation were included. Precipitation was rarely considered a factor in reducing visibility to thick fog.

The outstanding features of fog at Liverpool Airport appear to be:

- (i) Two peak periods of fog frequency.
 - (a) From late February to early March from about sunset to 1100 GMT with maximum at 0800–0900 GMT.
 - (b) From early to mid-October, chiefly between midnight and 1000 GMT with maximum at 0800 GMT.

TABLE I—FREQUENCY OF OCCASIONS WITH VISIBILITY BELOW 220 YARDS AT
LIVERPOOL AIRPORT, SEPTEMBER 1945–AUGUST 1960

Time GMT	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
frequency of occasions													
0000	19	8	7	..	..	..	..	1	1	12	13	12	73
0100	22	8	10	..	..	..	..	1	1	13	18	12	85
0200	20	8	10	..	..	..	..	2	4	15	17	17	93
0300	19	7	11	1	1	3	..	3	6	21	17	17	106
0400	22	7	14	1	1	5	..	3	7	26	21	16	123
0500	21	5	15	4	4	6	2	3	9	27	18	17	131
0600	19	7	17	5	4	6	1	3	10	34	17	24	147
0700	19	9	21	4	2	4	..	2	12	36	18	20	147
0800	24	7	18	4	1	1	..	1	7	34	24	24	145
0900	27	9	16	1	..	..	..	..	4	25	25	23	130
1000	31	4	9	1	..	..	..	..	1	15	23	19	103
1100	22	4	2	..	..	..	..	..	..	8	14	16	66
1200	22	3	..	..	..	..	..	..	..	5	8	10	48
1300	12	1	..	..	..	..	..	..	..	..	5	10	28
1400	10	1	..	..	..	..	..	..	..	..	3	11	25
1500	9	2	..	..	..	..	..	..	..	..	5	8	24
1600	11	1	..	..	..	..	..	..	..	..	5	10	27
1700	14	2	1	..	..	..	..	..	..	..	7	8	32
1800	12	2	..	..	..	..	..	..	..	..	7	11	32
1900	13	1	1	..	..	..	..	..	..	1	8	9	33
2000	15	3	..	..	..	..	..	..	..	4	9	8	39
2100	15	8	2	..	..	..	..	..	1	5	10	9	50
2200	15	8	4	..	..	..	..	..	..	6	11	10	54
2300	16	8	6	..	..	..	..	..	..	9	9	12	60
Total	429	123	164	21	13	25	3	19	63	296	312	333	1801
hours per month													
Mean	28.6	8.2	10.9	1.4	0.9	1.7	0.2	1.3	4.2	19.7	20.8	22.2	
Average number of hours per annum: 120													

TABLE II—FREQUENCY OF OCCASIONS WITH VISIBILITY BELOW 1100 YARDS AT
LIVERPOOL AIRPORT, SEPTEMBER 1945–AUGUST 1960

Time GMT	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
frequency of occasions													
0000	45	31	29	2	3	2	1	2	8	36	38	39	236
0100	41	29	31	2	2	3	1	1	10	44	36	39	239
0200	35	28	28	3	4	2	1	4	12	51	35	38	241
0300	35	28	30	6	3	7	1	5	16	50	32	38	251
0400	39	22	30	8	9	10	1	9	19	48	37	30	262
0500	34	24	32	10	12	12	4	17	23	46	38	29	281
0600	32	23	48	22	11	13	3	16	28	56	35	33	320
0700	35	35	55	14	8	6	4	14	29	60	50	35	345
0800	48	46	58	10	6	3	..	3	19	64	55	46	358
0900	55	58	46	5	2	..	..	1	13	50	59	63	352
1000	57	43	36	2	1	..	..	1	7	36	56	63	302
1100	54	28	22	1	1	..	..	..	3	20	42	53	224
1200	50	21	10	2	1	..	..	..	..	16	34	39	173
1300	40	17	6	..	1	..	..	..	..	7	28	34	133
1400	29	16	5	..	..	..	..	..	..	4	26	40	120
1500	35	13	4	..	..	..	..	..	..	5	26	41	124
1600	39	16	9	..	1	..	..	..	..	8	36	55	164
1700	52	27	14	1	..	..	..	1	..	18	56	61	230
1800	51	40	28	1	1	..	..	1	1	26	39	43	231
1900	49	31	32	2	5	1	..	..	4	28	42	45	239
2000	47	27	25	5	6	1	..	..	1	27	46	47	232
2100	47	29	24	5	2	3	..	1	3	23	48	44	229
2200	44	31	24	4	1	2	1	1	4	22	45	41	220
2300	41	31	24	3	1	..	..	1	6	29	40	40	216
Total	1034	694	650	108	81	65	17	78	206	774	979	1036	5722
hours per month													
Mean	68.9	46.3	43.3	7.2	5.4	4.3	1.1	5.2	13.7	51.6	65.3	69.1	
Average number of hours per annum: 381													

- (ii) The diurnal maximum frequency occurs about one and a half hours after sunrise. There is also a smaller evening peak about half to one hour after sunset.
- (iii) The high frequency of thick fog in January is followed by the relatively low frequency in February.
- (iv) The low fog frequency from early April to mid-September has a minimum frequency in July. The few thick fogs during these months are mostly confined to the hours 0300–0900 GMT.

The use of 5-day periods rather than 15-day or monthly periods has resulted in more precise diagrams. It may be therefore that some small differences noticed, when comparing individual weeks on other diagrams, could be accounted for by the differing methods used.

Considering the normal causes of fog formation relative to the length of night, it is not surprising to find a marked similarity between the results for Liverpool and those published for London Airport^{1,2}, Northolt³ and Leeuwarden⁴ (the Netherlands). There are however some differences worthy of note:

- (i) Leeuwarden, being in a rural situation, has the diurnal maximum fog frequency at sunrise or a little earlier. London, Northolt and Liverpool airports, all greatly affected by smoke pollution, have their maximum frequency between one and three hours after sunrise.
- (ii) During winter evenings at the London stations there is normally a gradual increase in fog frequency from about dusk, reaching a secondary peak around midnight. At Liverpool this secondary peak is usually just after sunset, followed frequently by an improvement in visibility an hour or two later. The reason for this earlier peak at Liverpool may possibly lie in the closer proximity of local smoke sources to the airport.
- (iii) From a closer study of 1058 occasions of visibility below 1100 yards it was discovered that in 45 per cent of fogs in the range 220–1100 yards and in $7\frac{1}{2}$ per cent of thick fogs (below 220 yards) the relative humidity was less than 95 per cent. Fogs with relative humidity 65–75 per cent were not uncommon. On rare occasions, with relative humidity as low as 60 per cent, visibility fell to around 400 yards. This contrasts with Buma's⁴ statement that in almost all cases of fog at Leeuwarden the relative humidity was more than 95 per cent.
- (iv) The annual mean number of hours of fog at Liverpool and Leeuwarden are very similar, being 40 per cent fewer than at London or Northolt.
- (v) The ratio of "all occasions of fog" to "thick fog occasions" at Liverpool, London and Northolt is about 3 : 1. Compared to fog frequencies for some stations in south-east England estimated by Shellard⁵, this appears to be about normal. Even at Leeuwarden this ratio appears to be maintained, so far as can be deduced from figures available, in spite of the generally high humidities mentioned earlier.

The individual yearly total hours of fog at Liverpool showed no pattern or trend towards an increase or decrease over the 15 years; the totals varied between 264 and 636 hours per annum. It may be interesting in future years to note the trend when smokeless zones become more widespread on Merseyside.

To face p. 166



Photograph by R. M. Brass.

O.W.S. "WEATHER REPORTER" IN A HEAVY SEA

To face p. 167



Photograph by R. M. Brass.

WINCH HOUSE ON THE FO'C'SLE DECK OF O.W.S. "WEATHER REPORTER"

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TECHNIQUES FOR HIGH-LEVEL ANALYSIS AND FORECASTING OF WIND AND TEMPERATURE FIELDS

By C. L. HAWSON

The subject of upper air analysis and the forecasting of wind and temperature fields is fundamental to many modern techniques for forecasting the weather itself. It is also directly important to the aviation forecaster. Thus it is a subject which concerns nearly all forecasters, whether they are employed on a national or local scale, or forecasting for civil or military flights.

The publication under review * is therefore of great potential interest to meteorologists in many fields. This book is both interesting and informative, packed with ideas and opinions, and written by an international collection of authors which only the World Meteorological Organization (WMO) could command. It comprises 187 pages and consists of an assembly of reports contributed by twelve Members, describing the techniques they have developed for the analysis and forecasting of wind and temperature fields from 1000 millibars up to pressure levels ranging from 300 to 100 millibars. Also included is a subject index, in the form of a table, which facilitates ready reference to the way any particular facet of the subject is dealt with by any of the contributing Members. It is a worthy member of the series of WMO "Technical Notes". However, we must accept the fact that there is as yet no universally adopted method; perhaps a complete exposition of every country's methods would prove not only too voluminous and monumental to be enclosed in a single cover, but also distinctly tedious to absorb.

It may be disappointing that at this stage individualism is still rampant and that different methods are championed by different countries, but this is not really surprising. The subject is complex, touching many aspects of meteorology and although the aim for all seems the same, this would be so only if perfect and complete precision in analysis and in forecasting were possible. Such perfection is not possible at present. In consequence each particular service tends to concentrate its efforts on those issues most useful to its own customers. In service offices it is better thus, rather than reduce this effort to encompass detail of less immediate practical value to the users. To illustrate the point, a forecaster at London Airport, faced with an Atlantic westbound flight in a situation involving a headwind jet stream, is less concerned with the detailed, level-to-level structure of the jet stream than with the detailed vertical and

* *Techniques for high-level analysis and forecasting of wind and temperature fields*, WMO Technical Note No. 35. 11 in. x 8½ in., pp. xvi + 187, illus., World Meteorological Organization, Geneva, Switzerland, 1961. Price: Sw. fr. 8.—.

horizontal fields well away from the jet core. He concentrates rightly on the space and time through which his particular customers will choose to fly. He is of course deeply concerned with the location and evolution of the jet stream because these vitally affect his problem. Nevertheless he is much less interested in the detail around the jet core than an American forecaster faced with the same weather situation, but with an eastbound flight for which the same jet stream is a tailwind. Even forecasters on the same side of the Atlantic, dealing with transatlantic aircraft, but at different stations, face different problems because of circumstances such as available manpower or the heights and periods of the forecasts. The common requirement is a safe, efficient and economic service. The different viewpoints of the Members influence their contributions.

Volumes of individual papers are often marred by errors, inconsistencies and repetitions. This book has its share and the items vary widely in their quality and length. The U.S.S.R. contributes three pages of concentrated information which give the bare bones of their methods and provide six references to enable those interested to pursue their study and clothe the skeleton. The U.S.A. contributes an informative eight-page survey, plus a 24-page appendix discussing the tropopause-vertical wind shear chart at length without recourse to further references. Every meteorologist will not accept all the U.S.A.'s basic assumptions, but their chapter makes stimulating reading. It is encouraging to learn that they find the most useful tool in analysis is the use of the numerically prepared 12-hour barotropic prognosis from the preceding set of charts. Introduction of this prognosis ensures a rigorous and consistent time continuity.

The Canadian contribution is the longest. It begins with seven pages, with references in the text, devoted to the broad aspects of their particular problems, including a section on the organization of forecast offices. It follows with five appendixes, dealing with different aspects of the subject, running to another 39 pages. This is perhaps the most enjoyable section to read. It is written in a forthright manner from a practical viewpoint, contains the fruits of much experience and sets down pithy advice to guide the reader. It is not implied that the reviewer agrees with all their statements or that the contribution is beyond criticism, but here is stimulating material which can hardly fail to challenge meteorologists who are ever ready for the chance to examine expert opinion critically in the light of their own experiences.

The German service contributes an excellent twenty pages of lucid information and references. It includes assessments of the accuracy of forecasts and a table for deriving the level and speed of the maximum wind from the winds at 300 and 200 millibars. It is evident that the Germans are actively engaged in research in this field, a point they underline by giving the date of their contribution, July 1959.

The contribution of the United Kingdom and Northern Ireland is a commentary on the organization of work and the methods used at London Airport. Again the date of the contribution, October 1960, is given, and it is clear that, although the present methods provide a reasonably satisfactory means of meeting the operators' requirements at the moment, an open mind is maintained for the future and efforts to improve on present standards are being made. One would like to have seen some mention here of their efforts to build down to the 200-millibar level from the more conservative level of 100 millibars. Perhaps it is too

early for this to be reported but, in summer at least, the idea has considerable attraction and nowhere in the book is such a possibility suggested.

The book is further enriched by contributions from British East African Territories, France, French Equatorial Africa, Israel, the Netherlands, Norway and the Sudan. These all contain something of interest, extend the regions covered to include equatorial areas and outline a method of numerical analysis suitable for use on an electronic computer. It is difficult however to understand how the Sudanese technique, arising from a suggestion by Grimes involving dynamic pressure, is actually applied in practice. It is also difficult to accept the Sudanese suggestion that upper winds tend to increase their speeds by approximately 50 per cent at night.

Despite the multiplicity of the methods described some factors stand out: (a) the pre-eminence of the mean sea level surface pressure chart, because this is the level for which the observations are most numerous, most rapidly available and least subject to error; (b) the linking of the topographies of the standard levels by the relative topographies or thickness patterns, to form a clear idea of the three-dimensional thermal structure and to build up the higher-level analyses; (c) the necessity for critical, scientifically guided assessment of the errors inherent in the measurements of the various upper air parameters; (d) the prime importance of continuity, both in time and vertically from level to level; (e) not least the need for progressive revision. These are the major factors which raise the quality of analysis and forecasting.

To sum up, the note is a useful assembly of articles to stimulate experienced workers and guide newcomers in the upper air fields. It tells of the days when contour and thickness lines manipulated by human forecasters are the main tools and of the days when mathematicians and physicists are harnessing electronic computers to challenge human forecasters, but have not completely encompassed the problems of atmospheric motion within the confinement of a practical mathematical discipline. It will be some years yet before scientific trials weed out the weaker methods.

METEOROLOGICAL OFFICE DISCUSSIONS

Turbulence and diffusion

Opening the Monday discussion on 15 January 1962, Dr. F. Pasquill gave a brief survey of the history and present position of the work on turbulence and diffusion in the atmosphere. Reference was made to three important branches of the work, namely the measurement and systematic description of the turbulence, the experimental study of diffusion, and the relation between diffusion and turbulence. Emphasis was laid on the fundamental importance and practical utility of developments in the statistical approach to turbulence and diffusion, though it was pointed out that in some aspects of the problem progress still relied on the use of diffusion coefficients.

This introduction was followed by three more detailed and specific presentations. Mr. M. J. Blackwell of the Meteorological Office Research Unit, Cambridge, talked about the vertical diffusion of water vapour near the ground, especially in the light of previous and current work at Cambridge. Attention was focused largely on the aerodynamic method of determining evaporation

from the vertical profiles of wind speed and humidity, and especially on the difficulties and limitations which arise from thermal stratification of the atmosphere and lack of homogeneity in the relevant properties of natural surfaces. Dr. J. K. Angell of the United States Weather Bureau followed with a description of the use of constant-level balloons in studying turbulence on a much larger scale. Examples were shown of results from "transosonde" flights at the 300-millibar level over the North Pacific, and of "tetron" flights in the lower troposphere over Nevada. These techniques provide information on the Lagrangian (following the motion) aspects of airflow and in this sense are particularly relevant to the consideration of diffusion on medium or large scale. Finally Mr. N. Thompson, of the Meteorology Research Division, Chemical Defence Experimental Establishment, Porton, described recent experience with the fluorescent particle tracer method of examining medium-range diffusion. This brought out the difficulties which can arise in using a tracer material in an absolute sense when long times of travel are concerned and unexpected decay of the tracer material occurs. However such a decay does not preclude the use of the tracer in a relative sense (i.e. for defining the lateral and vertical spread of material) and results therefrom can be used to calculate the concentrations of material of negligible or specified time-decay.

The discussion, opened by the Director-General, reflected the rather specialized and complex nature of the problems. Some of the outstanding fundamental and practical issues were immediately brought to the fore in opening questions by Professor Sheppard. It was clear, to quote the Director-General, that "the work in this field had not been sterile or static, and it was characteristic that the results had thrown up more problems all the time, showing a vigorous development of the science".

F. P.

Climatic variation

The second Meteorological Office discussion of the winter season was held at the Royal Society of Arts on 18 December 1961. The subject was "Climatic variation".

Mr. A. I. Johnson opened the discussion with a brief survey of some of the more important factors (astronomical, solar, etc.) which constituted possible causes of climatic variation. Subsequently he described some recent studies in which mean circulation patterns have been constructed for each January and July of the past 200 years, making use of records of atmospheric pressure from all parts of the world. These patterns have revealed an increase in vigour of the zonal circulation, apparently over the whole world and in both January and July from early in the nineteenth century to some time in recent decades.

The second opening speaker, Mr. H. H. Lamb, emphasized that apart from their intrinsic interest investigations of climatic change were of real practical value. He pointed out that they had contributed to our knowledge of the general circulation and also that meteorologists had a responsibility to establish the historical facts of climate for workers in allied fields such as archaeology and botany. Furthermore, some understanding of climatic change would be essential before any large-scale attempt to modify climate. It was even essential for interpreting the most relevant climatic trends or other statistics for advice to such concerns as the builders of long-term irrigation projects, etc. Mr. Lamb

concluded with an account of a survey of documentary evidence of the character of summers and winters in different European longitudes from A.D. 1100 to the present day.

In the ensuing discussion Professor Manley suggested further investigation of the effect of changing Atlantic sea temperatures on British climate. Mr. Veryard doubted the usefulness of these studies in forecasting future climatic trends; he preferred a dynamical approach. Various speakers referred to difficulties encountered when standard statistical methods were applied in climatology. Closing the meeting, the Director-General commented on the way in which climatological and synoptic research appeared to be drawing closer together: the work which had been described was very relevant to many forecasting problems.

H. H. L., A. I. J.

NOTES AND NEWS

Seminars on high-level forecasting

Seminars on high-level forecasting for turbine-powered aircraft operations over Africa and the Middle East were held in Cairo from 30 October to 17 November 1961, and in Nicosia from 21 November to 9 December 1961, under joint WMO and ICAO auspices. The purpose of the seminars was to enable forecasters to pool their knowledge and experience and so help their services to meet the growing demands for forecasts over long routes at high levels, and the exacting requirements of terminal forecasting for jet aircraft operations.

Experienced forecasters from many countries took part in programmes of practical work and attended lectures given by invited experts, under the direction in Cairo, of Professor W. Bleeker and in Nicosia, of Professor R. Scherhag. Each seminar was divided into two parts: one part dealt with the area comprising North Africa, the Mediterranean, and the Middle East as far as Pakistan; and the other part was concerned with the problems met by forecasters working at airports in tropical Africa.

The practical work included the analysis of three selected situations, each extending over several days. Participants worked in pairs to analyse surface charts, and upper air charts for standard levels from 850 millibars to 200 millibars for each day. Lively discussions followed when analyses were compared with each other and with master analyses prepared by chief analysts T. H. Kirk, Chief Meteorological Officer, Malta, and D. H. Johnson, Climatological Research Branch, Meteorological Office, Bracknell. There were two sessions for the preparation of flight forecasts over selected routes using recommended forms of flight documentation which required the preparation of prontours. In Nicosia, Professor Scherhag discovered with some delight that for one route, the mean of the high-level winds predicted independently by 15 pairs of forecasters verified precisely with the actual.

Lectures were given by Professor H. Flohn; D. V. Rao, Senior Meteorological Officer, Calcutta Airport; the chief analysts; and, in Cairo, by A. I. El-Tantawy and S. S. abd El-Hady. A wide range of topics of interest in aviation forecasting was discussed including: analysis techniques; synoptic models; thickness

patterns; cold pools; jet streams; high-altitude turbulence; high-level clouds; tropopause, maximum wind and shear charts; discontinuities; aerodrome forecasting; and climatological and objective aids.

The work of the seminars revealed old truths and fresh outlooks. The need in forecasting for painstaking, but not over-elaborate, analysis was amply demonstrated, and it was clear that the parochial approach in aviation forecasting is giving way even in its last stronghold, the tropics, as relations between middle- and low-latitude developments become better understood, and demands are met for forecasting and briefing for high-level flight stages direct from equatorial countries to Europe. The value of bringing together meteorologists fresh from the forecasting bench, to discuss techniques and problems during a working programme, hardly needs stressing. From the number of international airports represented in the list of addresses of the participants—Amman, Munich, Tel-Aviv, Abidjan, Athens, Damascus, Accra, Paris, Cairo, Tunis, Ankara, Khartoum, Belgrade, Geneva, Calcutta, Rome, Nicosia, Warsaw, Addis Ababa, Copenhagen, Beirut, Fort Lamy, Budapest, Tananarive, Malta, Lagos, Zurich, Bombay, Jedda, and Tehran—the extent of the dissemination of experience and knowledge can be gauged.

In Cairo, participants appreciated the excellent working facilities made available at the Meteorological Training Centre by the Director-General of the Meteorological Department, United Arab Republic. The seminar in Nicosia had the distinction of being the first international meeting to be held in the New Republic of Cyprus, local arrangements being made by the Chief Civil Aviation Officer. Foundations well laid by representatives of WMO and ICAO ensured full and interesting programmes both during and outside the working hours of the seminars.

Participants from the Meteorological Office were: in Cairo, R. O. Roberts (Meteorological Office Training School); and in Nicosia, P. K. D'Allenger (Akrotiri), D. Gibbons (El Adem) and R. C. Sivill (Nicosia).

Arrangements are being made for the publication of the cases studied and lectures given during the seminars. Seminars in other regions are being planned.

D. H. J.

OBITUARY

Mr. Ernest Harry Clarke.—It is with deep regret that we learn of the death on 27 April 1962 of Mr. E. H. Clarke, Experimental Officer, at the age of 57. Mr. Clarke entered the Meteorological Office in 1935 as an Observer at Lympne and remained there until 1939. He was promoted to Assistant III in 1941 and to Assistant II in 1944, becoming a very keen forecaster on RAF stations. He was commissioned in the RAF in 1943 and after service in the United Kingdom was posted to 83 Group in 2nd TAF. Since his return to the Office in a civilian capacity as an Assistant Experimental Officer in 1946, and since 1949 as an Experimental Officer, he spent almost his whole career on the more remote stations, including two years at Stornoway, about six years at Lerwick, where he was in charge of the magnetic section, and seven years at Eskmeals.

He had many valuable qualities, and a real enthusiasm for his work. He took a fatherly interest in the welfare of the assistants working under him and was well liked by all who worked with him.

We offer our deepest sympathy to his widow and family.

METEOROLOGICAL OFFICE NEWS

Retirements.— The Director-General records his appreciation of the services of:

Dr. D. N. Harrison, O.B.E. who retired from the Meteorological Office on 28 February 1962, after 35 years of service. Arriving from Balliol College, Oxford on 1 October 1926, he brought with him a knowledge of work with Professor Dobson on the early development of the ozone spectrophotometer, and a valued trophy in the form of an oar, signed by the Balliol College "Eight" of which Dr. Harrison had been a member.

After a very short period in M.O.2 in Kingsway, a branch even then responsible for public forecasts as at present, Dr. Harrison took up the more specialized aspects of observational meteorology which were to form his main interest for the remainder of his career. He spent six months at Kew Observatory, after which time he arrived at Edinburgh where he remained for the next seven years, later going to Lerwick Observatory. In 1937 he was transferred to M.O.4, then in South Kensington, until the outbreak of war and subsequently took part in the war dispersal move to Stroud. At this time M.O.4 was responsible not only for the Meteorological Office stores but also for the design of instruments, and Dr. Harrison was closely connected with the early development of the radio direction-finding system for upper wind measurement. Continuing in this line, he was posted to Larkhill in 1940, returned to M.O.4, then at Harrow, in 1947 and joined the Instrument Development section on its formation in 1948, where he remained until retirement. From 1948 until the reorganization of 1957 he served as Head of M.O.17, the upper air development branch, until its absorption into the existing M.O.16.

From the introduction of routine upper air measurements, Dr. Harrison played a considerable part in the development of the equipment, including the use of radar for upper wind measurements and the assessment of the accuracy of radiosonde and radarwind measurements. He produced several papers on the matter of upper air accuracies, the last, a massive study of a prolonged trial under routine operating conditions, being in course of publication.

For the past few years Dr. Harrison has been engaged on a complete re-development of the British radiosonde. Although manufactured versions of this will not be available for some while, the basic system and much of the detailed design have been completed under his guidance.

Dr. Harrison attended as principal United Kingdom delegate the first and second sessions of the World Meteorological Organization Commission for Instruments and Methods of Observation (CIMO), at Toronto, in 1953 and at Paris, in 1957 respectively. He also served as an active member of the working group set up at CIMO-I, and continued by CIMO-II, to arrange for the international comparison of radiosondes. Dr. Harrison took part in the two international field trials held in this connexion at Payerne, Switzerland.

In private life, Dr. Harrison has a variety of interests. His skill as a carpenter and model maker was demonstrated by an excellent model yacht. As an amateur photographer he won first prize at the Meteorological Office, Harrow photographic exhibition and he is currently undertaking a series of photographs of landscapes and buildings on behalf of the National Trust. Throughout his career Dr. Harrison used a carefully maintained motor-cycle as his normal means of reaching his office and achieved remarkable regularity and punctuality in battling against the most adverse conditions which could be achieved

either over Salisbury Plain or in the traffic chaos of the northern London suburbs.

Gardening and the enjoyment of classical music, both at "live" concerts and by the use of high fidelity reproductions, have formed other aspects of his interests. With such a wide and varied choice we can confidently wish Dr. Harrison the greatest possible happiness in his retirement. A. L. M.

Mr. J. D. Ashton, Experimental Officer, who retired on 20 February 1962, after 42 years' service. Mr. Ashton joined the Office in January 1920 as a Technical Assistant at Hounslow. He served on many aviation stations including Heliopolis and Ismailia and was mobilized as a Flight Lieutenant from 1943 until 1946. Since 1946 he has been concerned almost exclusively with Civil Aviation including postings to London (Heathrow), Eastleigh, Croydon and London (Gatwick) Airports.

Mr. J. L. Marshall, Experimental Officer, who retired on 28 February 1962, after 33 years' service. Although Jack Marshall did not join the Meteorological Office until 1929 he managed to become involved with meteorology during his Royal Air Force career prior to that date and joined the R.A.F. Reserve as a meteorologist in November 1927 serving at Calshot until he took up his civilian appointment. He served at many aviation stations during his career, including the period 1943-46, when he was commissioned in the Royal Air Force. He was transferred to the Instruments Provisioning Branch (M.O.4) in 1955 and remained there until he retired.

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

General Certificate of Education—"A" Level

Pure Mathematics: D. H. Clark, E. Hall, K. M. Jones, J. P. Kimber,
D. A. MacIntyre and R. E. W. Pettifer.

Applied Mathematics: J. P. Kimber.

Physics: Miss J. A. Davies and R. Ward.

REVIEW

Bibliography of agricultural meteorology, edited and compiled by Jen Yu Wang and Gerald L. Barger. 10½ in. x 6½ in., pp. xi × 673, University of Wisconsin Press, 430 Sterling Court, Madison 6, Wisconsin, 1962. Price: \$6.75.

One of the first requirements of any research worker is an adequate and up-to-date bibliography in his subject. Such a reference book is especially essential in a field such as agricultural meteorology which covers two disciplines. To be reliable, the publication must be comprehensive, accurate and up-to-date.

The editors of this book, and their numerous collaborators both in the United States and elsewhere, have gone a very long way to meet this requirement. Over 10,000 references are included, covering work in 27 different languages, and a great deal of care has been taken to try and make them as accurate as possible, at times an almost impossible task.

There are two indexes, an author index and a subject index; the references are arranged by subjects with the authors in alphabetical order. If any criticism of this method of presentation had to be made, it would be that it would have

been additionally helpful to have the references under each subject heading arranged in chronological order. This not only leads the user to the latest work in the easiest manner, but also eases the manner of compilation of a future edition, which, it is greatly hoped, will eventually appear. This type of book is far too important to be confined to a once-for-all exercise, and those who have been concerned in it deserve the thanks of all workers in the subject. Every library that makes any claim to be a source of references will find this publication invaluable.

L. P. SMITH

OFFICIAL PUBLICATION

The following publication has recently been issued:

A course in elementary meteorology, London, HMSO, 1962. Price: 17s 6d.

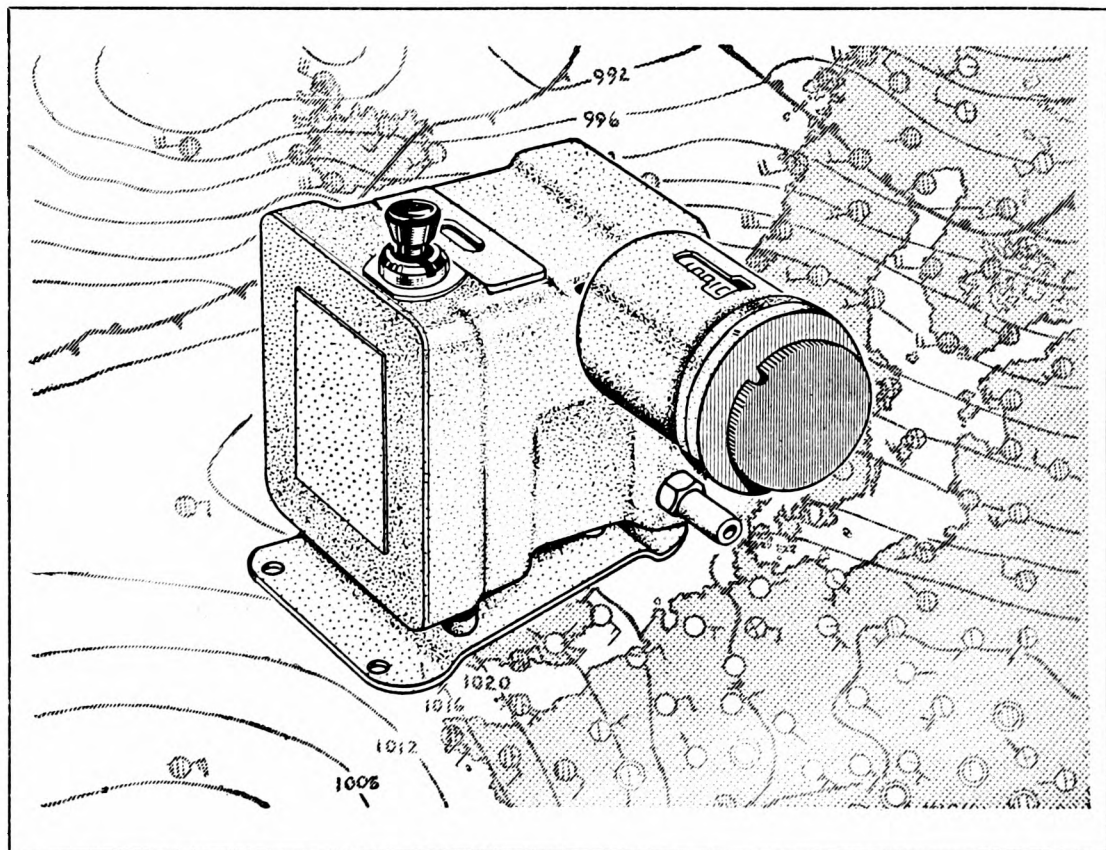
The late W. H. Pick wrote the first edition of *A short course in elementary meteorology* some forty years ago. It was revised at intervals until the fifth edition was issued in 1938, and is now out of print. Since that time great advances have been made in meteorological knowledge, largely owing to the accumulation of observations at high levels in the atmosphere by means of aircraft and radio-sondes. The inter-relation of surface and upper air effects is so close that revision of W. H. Pick's text to bring it up to date was impracticable, so an entirely new book, *A course in elementary meteorology*, was written by D. E. Pedgley, B.Sc. while he was an instructor at the Meteorological Office Training School.

The book is intended for the reader whose knowledge of physics is roughly equivalent to that of upper science forms in schools, though there are a few sections, given in smaller print, of a rather higher standard. These are included for the benefit of those who may wish to delve into the subject a little more deeply. The new book is no longer called a short course, and is about half as long again as W. H. Pick's book; a great deal of information is concentrated into the 183 pages in a clear concise style.

Part I is concerned with physical meteorology. Chapters 1 to 3 deal with temperature, pressure and wind, and water in the atmosphere, and comprise the first third of the book. The emphasis here is on the basic physical principles. The remaining five chapters of the first part are more descriptive and are concerned with "weather" as it is observed; the topics are visibility, clouds, precipitation, thunderstorms and optical phenomena. The cloud section includes 18 plates. The last third of the book is taken up with Part II, which is entitled synoptic meteorology. Chapters on air masses and fronts, depressions, and anticyclones describe how the elements dealt with in Part I, temperature, clouds etc., are related in space and time and these sections lead on to a final short chapter on forecasting.

Each chapter concludes with a full bibliography, giving the interested reader a ready means of extending his knowledge further; most of the articles quoted are easily readable, and many are from the *Meteorological Magazine* or *Weather*. *A course in elementary meteorology* forms an admirable textbook for observers, sixth-form scholars or others who require an authoritative yet simple account of the basic facts of present-day meteorology.

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THE METEOROLOGICAL MAGAZINE

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AN INDEX OF DRIVING RAIN

551.556.6:551.577.6:r69

By R. E. LACY, B.Sc. (Building Research Station, Garston) and H. C. SHELLARD, B.Sc.

Summary.—Two maps are presented, one showing the variation of an index of driving rain over the British Isles, the other showing how the index varies with direction. The method of preparing the maps from data of rainfall and wind speed is described.

Introduction.—When rain is carried along at an angle to the vertical by wind, so that it impinges on vertical surfaces, some of it will be absorbed if the surface is porous, or driven into cracks between units which are impervious. Damage to buildings, to their decorations and even to their contents from rainwater which is driven onto a wall in this manner is of common occurrence. Not only does the rainwater absorbed by the structure cause direct damage, but also by increasing the thermal conductivity of the materials it tends to lower the temperature at the inner face and so increase the risk of condensation there. Greater heat-losses because of the higher thermal conductivity either reduce the comfort of the occupants or increase costs because the losses must be made good by burning more fuel.

Such wind-driven rain is called “driving rain” and it is useful to have some measure of its severity. It is common knowledge that the problem of penetration of buildings by rain is more acute in some parts of the country than in others; in some parts special precautions may need to be taken, precautions which would be unnecessary in other places. It may therefore be possible to save money in areas which are not liable to have severe driving rain by using simpler methods of construction than those needed elsewhere, or by using materials which would not be suitable in more exposed regions. Clearly then, there is a need for a map of the country showing how the severity of driving rain varies from place to place.

In 1956–57 measurements were made on buildings in Glasgow, using specially developed raingauges for measuring the amount of rainwater driven onto a vertical surface¹. Comparison of the catch in one of these gauges was made with the rainfall and wind at Renfrew, about three miles to the north-west of the building. For this purpose, each hourly amount of rain on the horizontal (i.e. the normal rainfall on the ground) was multiplied by the corresponding component of the wind speed resolved normal to the surface of the wall in which the gauge was set. In this particular case the wall faced 220° true. The daily sums of these products were compared with the corresponding catches of the gauge in the wall, and were found to be proportional to these catches.

It seemed clear as a first approximation that we could use the product of the rainfall on the ground and the mean wind speed while rain was falling, as an index of driving rain. Thus an average map showing the distribution of driving rain over the country might be constructed by combining a map of average rainfall with one showing the average wind speed during rain. Unfortunately a map of average wind speed during rain does not exist and such information is available for only a few places. Table I gives values for three widely separated stations, based on hourly observations over the ten years 1946-55, and suggests that the ratio of mean wind speed during rain to that for all hours does not vary greatly. It seems reasonable therefore to assume that

TABLE I—MEAN WIND SPEED DURING RAIN (TEN-YEAR MEANS, 1946-55) FROM HOURLY DATA

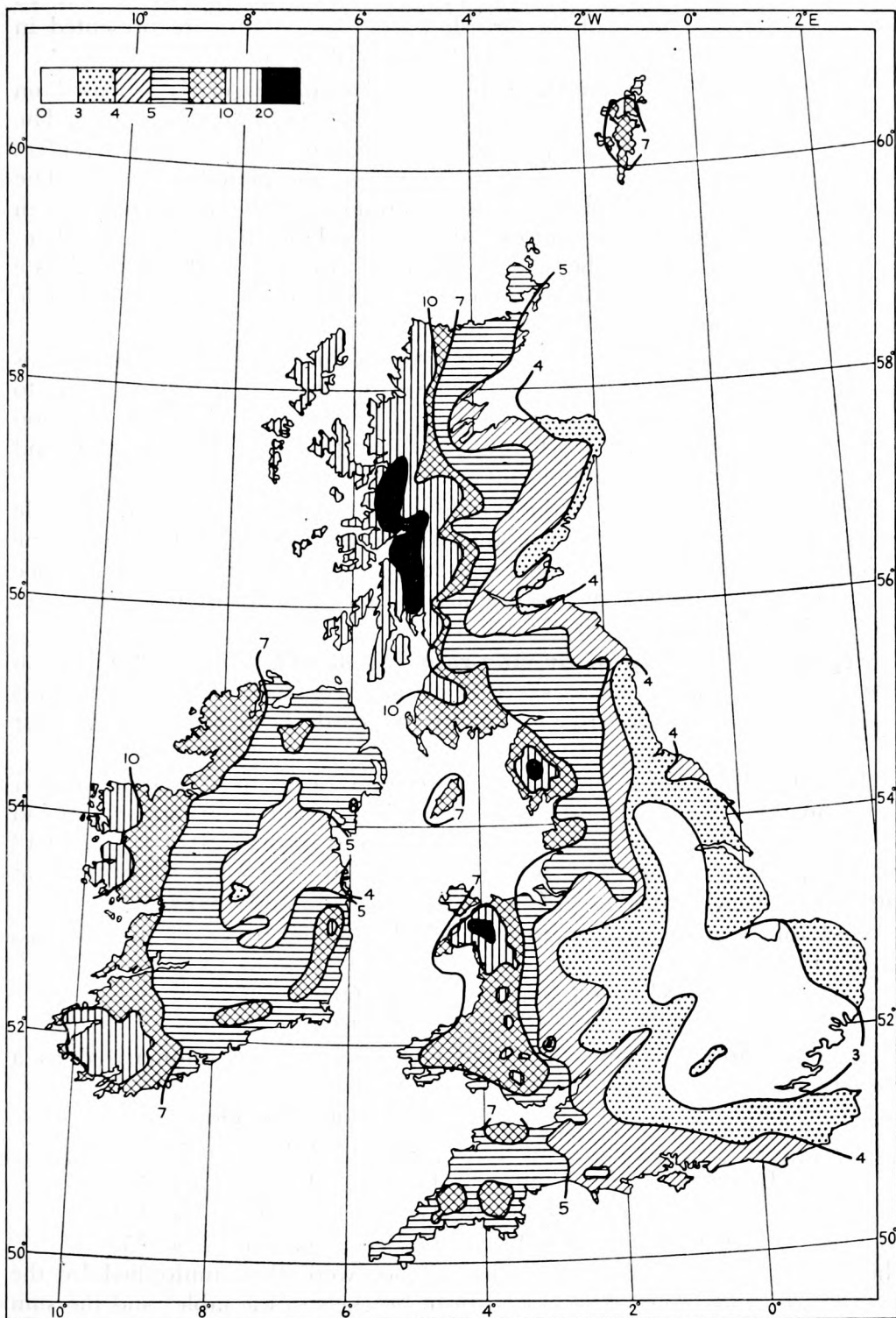
Station	Wind speed during rain	Wind speed at all hours	Ratio
	<i>mph</i>	<i>mph</i>	
Croydon	11.5	8.9	1.29
Holyhead (Valley)	16.9	14.1	1.20
Renfrew	12.2	8.7	1.40

All speeds are reduced to the standard height of 33 ft.

this ratio is more or less constant and to construct a driving-rain map using maps of average annual rainfall and of average annual wind speed. Such a map is shown in Figure 1 and it is considered unlikely that the picture it presents is significantly distorted by the assumption that mean wind speed during rain bears a constant ratio to overall mean wind speed. The method of construction of the map is described below.

A map of driving rain for Norway has been constructed by Hoppestad², using daily observations of rainfall and the corresponding wind speeds, but in view of the fact that many of the wind data he used were subjective estimates, it is unlikely that the final result is any more accurate than that presented here.

Figure 1 gives in effect a driving-rain index for a vertical surface which is always facing the wind. For our purpose it is also necessary to know if the index is always highest for the direction facing the prevailing wind, or whether severe driving rain can occur with other directions of wind. The data readily available for this purpose were limited. Once again the only detailed data available were hourly instrumental observations of rainfall and wind at Croydon, Holyhead and Renfrew, during 1946-55, which had been analysed as part of a preliminary investigation of the driving-rain problem a few years ago. The full results of this analysis cannot be presented in the limited space available here, because they involve three variables—rainfall amount, wind speed and wind direction, but some of them are presented in Tables II, III and IV on an annual basis. The bottom line in each table gives the percentage of the total driving-rain index (sum of products of frequency, times mean wind speed, times mean rainfall amount) from eight ranges of wind direction. These figures indicate that the direction of maximum index is not necessarily that of the prevailing wind. At both Croydon and Holyhead, for example, the maximum index occurs with south winds while the prevailing winds are from south-west; at Renfrew the maximum index occurs with south-west winds and the prevailing wind is westerly. In order to obtain a better picture of the variations of driving-rain index with wind direction over the country a further



(Units $\text{m}^2 \text{sec}^{-1} \text{yr}^{-1}$)

FIGURE 1—ANNUAL DRIVING-RAIN INDEX FOR THE BRITISH ISLES

analysis was undertaken to obtain approximate "driving-rain roses" for 20 stations in different parts of the British Isles. The results are presented in Figure 2, the preparation of which will be described later.

Preparation of the driving-rain index map.—Figure 1 is based on the two maps on pp. 20 and 72 of the *Climatological atlas of the British Isles*³. The first of these shows isopleths of average wind speed in miles per hour at 33 feet (10 metres) above ground in open situations, for the period 1926–40. The second map shows isohyets of average annual rainfall for the period 1901–30, in inches. No maps for more recent periods were available, nor was it possible to use a common period for the two sets of data. In view of the approximate nature of the subsequent computations, it is unlikely that any appreciable extra error was introduced thereby.

The first step was to prepare annual mean wind speed and total rainfall maps to a common scale, at the same time converting the readings respectively to metres per second and millimetres. These were then traced onto a common map, on tracing paper, it being found convenient to draw the isopleths of wind speed in black ink, and the isohyets in coloured inks.

The driving-rain index was then computed for as many readily identifiable points as possible, the resulting products being plotted onto a further outline map on tracing paper, to the same scale as the other maps. For convenience the products were divided by 1000. Finally isopleths of the annual index were drawn, the units being $\text{m}^2 \text{sec}^{-1} \text{yr}^{-1}$.

Preparation of map of driving-rain roses.—The roses of driving-rain index shown in Figure 2 are based on an analysis of data for the ten years October 1929–September 1939, punched on cards from the *Daily Weather Report*.

The data used were information on precipitation in the "present weather code" (in the categories slight, moderate or heavy) and information on wind direction and force. They referred to observations made at 01, 07, 13 and 18 GMT at 14 of the 20 stations, and to observations at 07, 13 and 18 GMT only at Tiree, Aberdeen, Eskdalemuir, Chester, Birmingham and Cranwell.

Wind direction frequencies were reduced to eight points of the compass (from 32) thus:

$$\begin{aligned}\text{NE} &= 03 + 04 + 05 + \frac{1}{2}(02 + 06) \\ \text{E} &= 07 + 08 + 09 + \frac{1}{2}(06 + 10), \text{ etc.}\end{aligned}$$

The observations from each of the eight points were summarized as a frequency table, as follows:

		Wind force (Beaufort)		
		1–2	3–4	5
Intensity of precipitation	Slight	f_1 (1)	f_2 (3)	f_3 (5)
	Moderate	f_4 (3)	f_5 (9)	f_6 (15)
	Heavy	f_7 (5)	f_8 (15)	f_9 (25)

The frequencies f_1, f_2 , etc. in each category were then multiplied by the corresponding weighting factors (shown in brackets in the table) and the sum of the products was considered to represent an approximate index of driving rain, the weighting factors being very roughly proportional to the product of mean rate of rainfall and the mean wind speed for the group concerned.

In each rose the length of each vector indicates the percentage of the total index for the station from that direction.

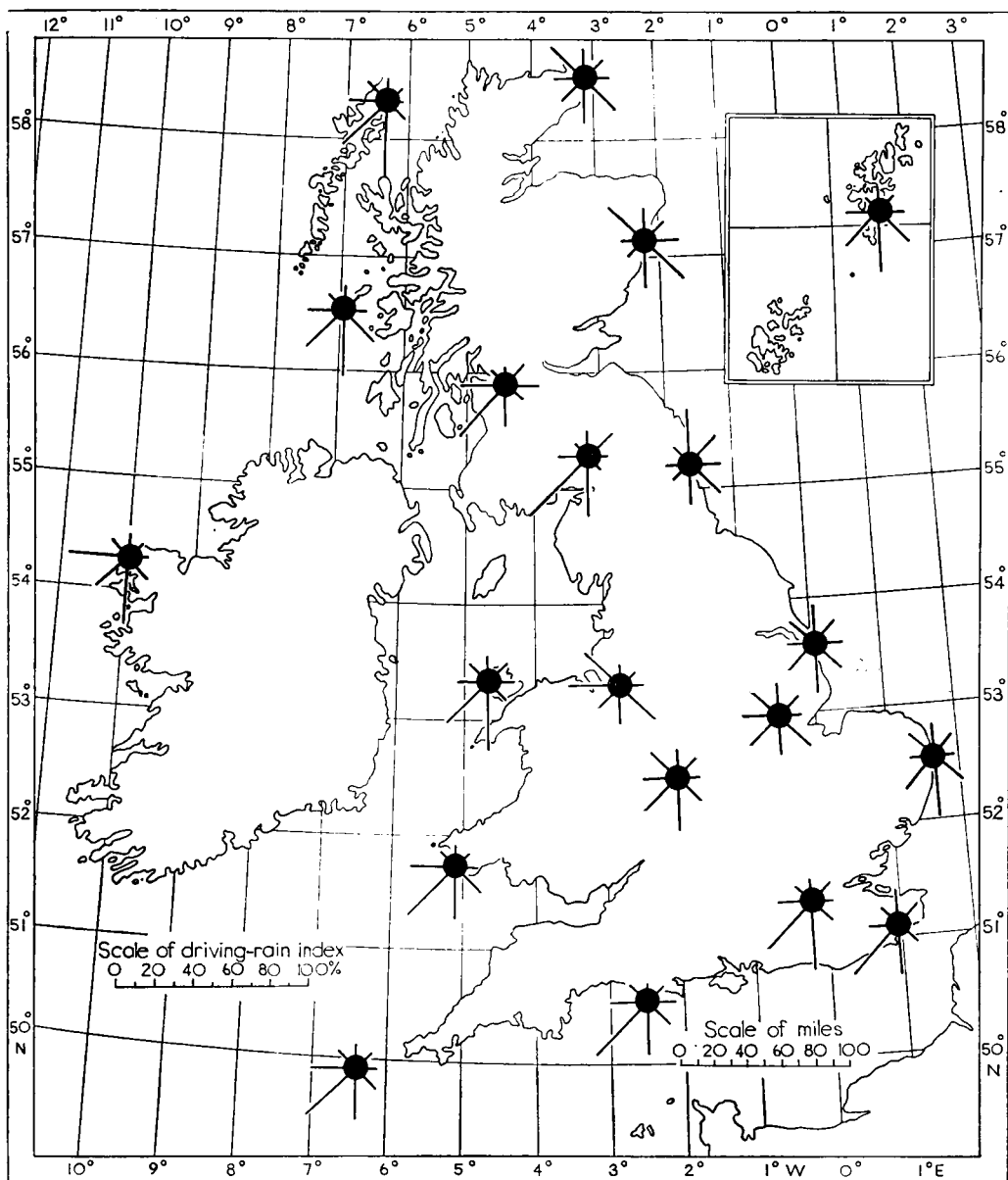


FIGURE 2—ANNUAL RELATIVE DRIVING-RAIN INDEX FROM EACH OF EIGHT WIND DIRECTIONS FOR 20 STATIONS

The length of each vector shows the percentage of total index for the station from that direction.

Discussion.—The “driving-rain index” presented in Figure 1 above is a figure proportional to the total amount of rain which would be driven on a vertical surface always facing the wind. The assumption is made that the mean wind speed while rain is falling is the same as, or some constant proportion of, the annual mean wind speed. Further, it is assumed, in effect, that for a given wind speed the spectrum of raindrop sizes is always the same, so that the mean angle of incidence of the raindrops is constant. In fact, the spectrum varies considerably from rainstorm to rainstorm and so does the angle of incidence of the drops. However, as has already been remarked, it is probably sufficient

for our purpose to assume that the product of total rainfall amount and overall mean wind speed can be used as a driving-rain index. This index should give a measure of the relative severity of the driving-rain problem in different parts of the country.

There are obvious limitations to this simple index. Firstly, it gives no information on the effect of direction of the wind. This can only be obtained by an analysis of the wind speed and direction at times when rain is falling. Secondly, the map is based on averages, while it is likely that the most serious rain penetration occurs on a few occasions of strong winds with prolonged rainfall. It is thought, however, that the relative severities under worst conditions in the different parts of the country would be much the same as under mean conditions. Finally, it must be emphasized that a small-scale map such as this cannot show the local variations of exposure which must be very significant. The map of mean wind speed used in the preparation of the index refers to winds in open situations—but not, for example, on isolated hills, on cliff tops or in mountainous areas. The rainfall map takes account of variations due to the large-scale topography, but not of the effects of local features. In open country, quite a small hill experiences appreciably stronger winds and greater rainfall than the level country around it, with a corresponding increase in the driving-rain index. These local variations, especially of mean wind speed, must be taken into account when using the map.

It has been suggested that the increase in severity of exposure experienced by high buildings, as compared with low ones at the same place, is greater than the change in severity between different parts of the country. The map shows a range of index of about 10:1. It is unlikely that the range between say 300 feet and 30 feet on a building in an open situation much exceeds 2:1, except perhaps at the corners and at copings.

TABLE II—FREQUENCY SUMMARIES OF HOURLY WIND SPEED AND HOURLY RAINFALL AMOUNTS AT CROYDON IN TEN YEARS (1946-55)

Rainfall <i>mm</i>	Speed in miles per hour										Total
	Calm	1-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	
	<i>frequencies</i>										
0.1- 0.9	173	545	1607	1637	1235	813	250	85	14		6359
1.0- 1.9	13	93	283	328	266	178	68	31	7	2	1269
2.0- 2.9	6	29	90	84	114	80	24	11	2		440
3.0- 3.9	2	23	42	38	35	19	17	7	2		185
4.0- 4.9	1	7	14	11	25	14	2	5	2		81
5.0- 5.9	1	6	11	8	11	5	5	2	1		50
6.0- 6.9		3	4	1	1	3			1		13
7.0- 7.9	1	2	3	3	1	2	1				13
8.0- 8.9			2	1	1	2					6
9.0- 9.9			1	1		1					3
10.0-10.9				1							1
11.0-11.9											
12.0-12.9		1									1
23.0-23.9			1		1						2
26.0-26.9						1					1
Total	197	709	2058	2113	1690	1118	367	141	29	2	8424
	NE		E	SE		S	SW	W	NW		N
Percentage of total driving-rain index	6		6	8		31	30	11	4		4
Total driving-rain index=4.7m ² sec ⁻¹ yr ⁻¹											

TABLE III—FREQUENCY SUMMARIES OF HOURLY WIND SPEED AND HOURLY RAINFALL AMOUNTS AT HOLYHEAD IN TEN YEARS (1946-55)

Rainfall <i>mm</i>	Calm	Speed in miles per hour													Total		
		1-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64			
0.0-0.9	141	394	944	1399	1762	1631	819	380	179	45	15	6		1	7716		
1.0-1.9	21	69	211	323	376	423	185	95	50	8	4	1			1766		
2.0-2.9	7	24	71	143	119	123	71	37	27	3					625		
3.0-3.9	4	8	24	50	48	56	26	17	7	3					243		
4.0-4.9	1	7	16	14	32	21	6	7	1						105		
5.0-5.9	4	5	6	3	12	10	3	6	1						50		
6.0-6.9			3	5	8	4	1			1					23		
7.0-7.9		1	2	1	5	4	2								15		
8.0-8.9				1											1		
9.0-9.9					1	1									2		
Total	178	508	1277	1939	2363	2273	1113	543	265	60	19	7		1	10,546		
		NE			E		SE		S		SW		W		NW		N
Percentage of total driving-rain index		5			6		8		33		25		11		7		5
Total driving-rain index = 7.7 m ² sec ⁻¹ yr ⁻¹																	

TABLE IV—FREQUENCY SUMMARIES OF HOURLY WIND SPEED AND HOURLY RAINFALL AMOUNTS AT RENFREW IN TEN YEARS (1946-55)

[illegible]

Tables II, III and IV give detailed frequencies of occurrence of hourly rainfall amounts associated with various ranges of wind speed at Croydon, Holyhead and Renfrew in the ten-year period 1946-55. The corresponding average annual driving-rain indices for each station have been computed and are 4.7, 7.7 and 6.3 $\text{m}^2\text{sec}^{-1}\text{yr}^{-1}$ respectively. These values are in reasonably good agreement with the values interpolated from Figure 1 and this provides welcome supporting evidence of the validity of Figure 1. The agreement is a little better if the computed values are "corrected" by dividing by the appropriate ratios of mean wind speed during rain to that for all hours, when they become 3.6, 6.5 and 4.5 respectively.

It was hoped that the total indices obtained when calculating the driving-rain roses in Figure 2 would provide comparative data on driving-rain intensity at the various stations, but the ratios of the indices of Croydon, Holyhead and Renfrew derived by this approximate method were not in very good agreement with those derived independently from hourly instrumental observations of rainfall and wind at these three stations over the years 1946-55 inclusive.

Also the total index for some stations was clearly affected by the subjective nature of the observations on which it was based, both precipitation intensity and (at some stations in 1929–38) wind force being estimated. Thus the ratios of the total indices at Renfrew and Holyhead to that at Croydon were 1.35 and 1.33, whereas using the much more accurate hourly instrumental data for 1946–55 they were 1.36 and 1.60. Also the ratios of Gorleston, Portland Bill and Scilly to Croydon came out as 0.85, 1.82 and 1.36. It was reasonable to expect that Portland Bill would have an overall index somewhat lower than that for Scilly, which in turn would certainly be no greater than that for Holyhead, while there was no obvious reason why Gorleston on the east coast should have a lower index than Croydon (see also Figure 1). The figures obtained thus suggest overestimation at Portland Bill and underestimation at Scilly and Gorleston.

It was concluded that the 1929–38 data could not be trusted to give a fair comparison between stations, but that for any one station they would give useful information on the relative intensity of driving rain from different wind directions over a long period. This was confirmed by comparing the direction distributions obtained for Croydon, Holyhead and Renfrew with those obtained from hourly instrumental observations for these three stations, see Tables II, III and IV. The agreement is reasonably good. It is for this reason that the data in Figure 2 are presented only in the form of relative indices for each station. However, the driving-rain roses show clearly that on east coasts we may expect severe driving rain from directions between north through east to south, the worst direction at any particular place depending on the topography. Indeed, at no east coast station is the south-west side of a building the worst for driving rain—on a coast facing north-east a wall facing north may have the worst exposure, although inland or in the west this is the most sheltered direction.

Acknowledgements.—The work described here has been a co-operative effort, most of the work towards the preparation of the driving-rain map having been carried out by the Building Research Station as part of the programme of the Building Research Board. That involved in the preparation of Tables I to IV and the map of driving-rain roses has been done in the Meteorological Office.

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3. London, Meteorological Office; Climatological atlas of the British Isles. London, HMSO, 1952.

551.510.52:551.511.3:551.521.3

TROPOSPHERIC HEATING OVER THE NORTH ATLANTIC

By G. B. TUCKER, Ph.D.

Introduction.—Atmospheric systems on the meteorological scale are thermally driven. Therefore if dynamical and quantitative studies are to include the driving mechanism, an accurate specification of the areas of non-adiabatic heating and cooling is necessary on both the synoptic and climatological time scales. Clapp¹ in a synthesis of some published studies of the normal heat budget of

the lower troposphere shows that the approach to heat sources and sinks can be made via the "thermodynamic energy equation" method or via the "heat-balance" method.

The heat-balance method is represented by the equation

$$\frac{d\bar{q}}{dt} = \frac{1}{m} [\bar{L}r + \bar{R} + \bar{H}] \quad \dots (1)$$

where q is the amount of heat per unit mass, m the mass of the column of air of unit cross-section, L the latent heat of condensation, r the rate of precipitation, R the net heating in the column due to radiation, and H the rate of gain of sensible heat by exchange from the earth's surface. All three terms within the brackets present individual problems, and it is with this approach that the remainder of the paper will be concerned.

Recently four publications have appeared which enable an assessment to be made of $d\bar{q}/dt$ via equation (1) on a mean monthly basis over the North Atlantic. First, a new version of a marine atlas² enables a recomputation of \bar{H} , and these values can then be compared with individual monthly estimates made by Shellard³ at ocean weather stations "I" and "J". The third paper⁴ provides a new method of calculating rainfall over the North Atlantic Ocean; this suggests that previous estimates were too high and provides revised figures for North Atlantic weather ships. Finally Möller⁵ has shown that although net radiative cooling cannot be associated in any simple way with synoptic parameters, climatological values of the net radiative cooling throughout the troposphere (up to 300 mb) vary little from place to place. His figures suggest that a reasonable annual variation can apply to the whole of the Atlantic Ocean north of the tropics.

The information contained in these papers has been combined to obtain the mean monthly heating rate in the troposphere over the North Atlantic weather ships.

Sensible heat transfer between ocean and atmosphere.—It is considered permissible in climatology (e.g. Jacobs⁶) to represent the upward flux of sensible heat between ocean and atmosphere (\bar{H}) as

$$\bar{H} = B.E.L_w$$

$$B = 0.49 \frac{(T_w - T_a)}{(e_w - e_a)}$$

where the "Bowen ratio"

e being vapour pressure, L the latent heat of vaporization, T temperature ($^{\circ}\text{C}$), and the subscripts w and a refer to the surface layers of water and air. The difficulty lies in estimating the evaporation, E . The method usually adopted is given by the relation

$$E = k(e_w - e_a) V_a$$

where V_a is the wind speed and k is a constant obtained by using an oceanographic energy balance method (e.g. Privett⁷). No other climatological method has been established and therefore this one is used in the present analysis. Shellard's³ adaption of this has been used; it is

$$H = 0.0019 L_w V_a (T_w - T_a)$$

where V is measured in knots, temperatures are now in $^{\circ}\text{F}$,

$$L_w = 605 - 0.29 T_w.$$

The mean monthly surface air temperature, T_a , and the mean scalar wind speed, V_a , have been obtained from the "Climatological and oceanographic

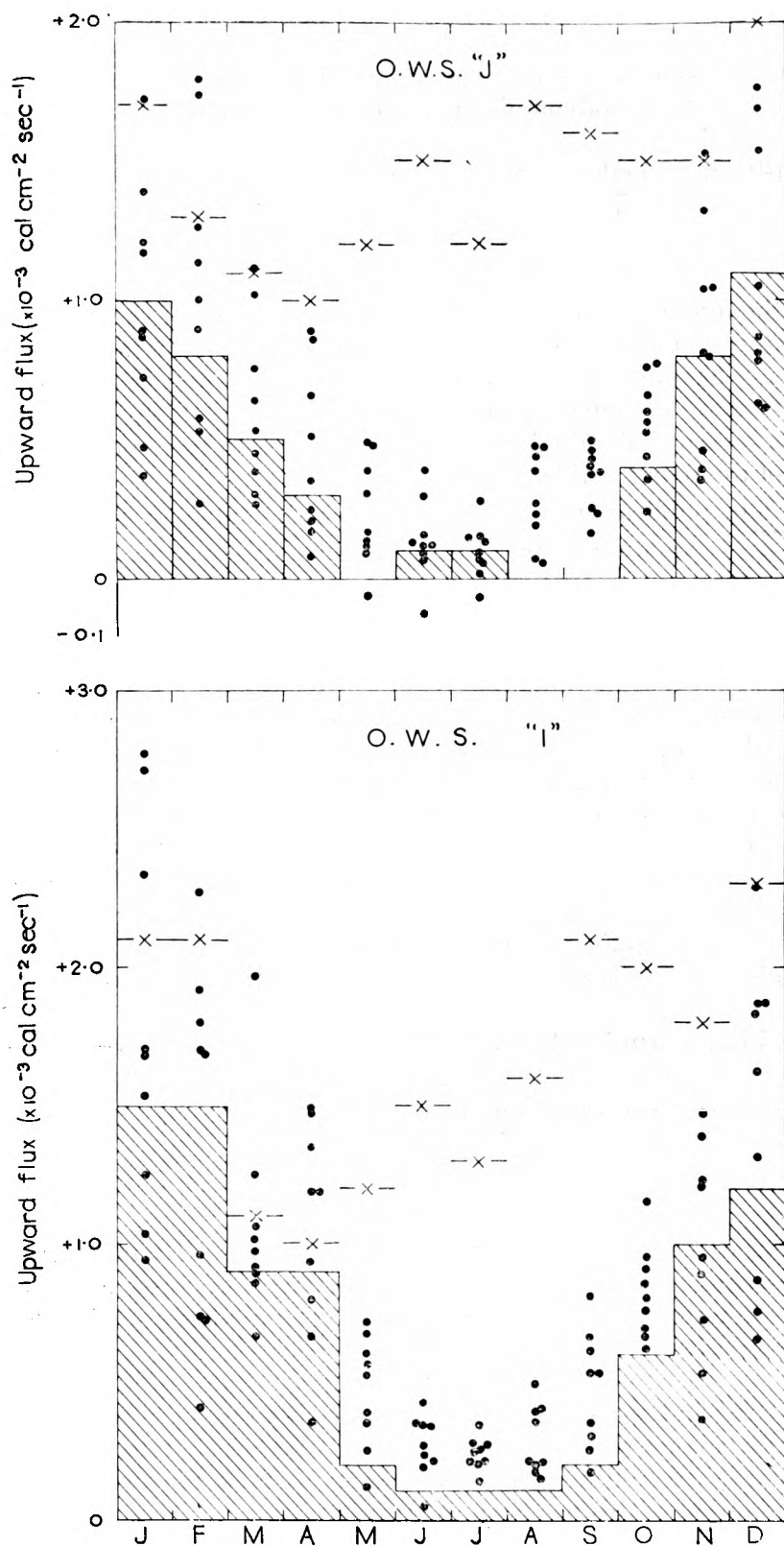


FIGURE 1—UPWARD FLUX OF SENSIBLE HEAT AT THE SURFACE FOR O.W.S. "J"
AND O.W.S. "I"

Shellard's^a monthly values from 1948-56
 -x- normal of latent heat liberated by condensation (precipitation)
 normal values using marine chart data^a are given in histogram form

atlas for mariners"², V_a being computed from the wind-rose statistics given in this publication. Unfortunately sea surface temperatures are given only for every other month, and therefore a different source of data had to be used for these statistics⁸. However, a comparison of sea surface temperature charts for the six months in which they appear in both publications shows them to be very similar, and the errors involved in using a different set of charts must be very small. All values were extracted for the standard ocean weather ship positions.

In order to check the values of H obtained from these climatological charts, the results for stations "I" and "J" are compared with monthly values obtained by Shellard³. Shellard used the ocean weather station surface data from 1948 to 1956 to obtain monthly values of H ; all his values are plotted in Figure 1. The climatological values of H as now computed are plotted on the same diagrams in the form of a histogram and it can be seen that for most months they fall well within the scatter of the individual monthly values. There appears to be sufficient similarity for the climatological values to be accepted.

Latent heat released by condensation.—Condensation above the weather ships was assumed to be represented by precipitation. Mean monthly precipitation values for the five years 1952–57⁴ were used to compute \overline{Lr} in equation (1). L at condensation level is taken as 593 cal gm⁻¹. Values for "I" and "J" are plotted for comparison with \overline{H} in Figure 1.

Net radiative heating.—Möller⁵ has shown that variations in cloudiness and humidity in the upper troposphere are mainly responsible for variations in the radiation balance; surface parameters appear unimportant. He has

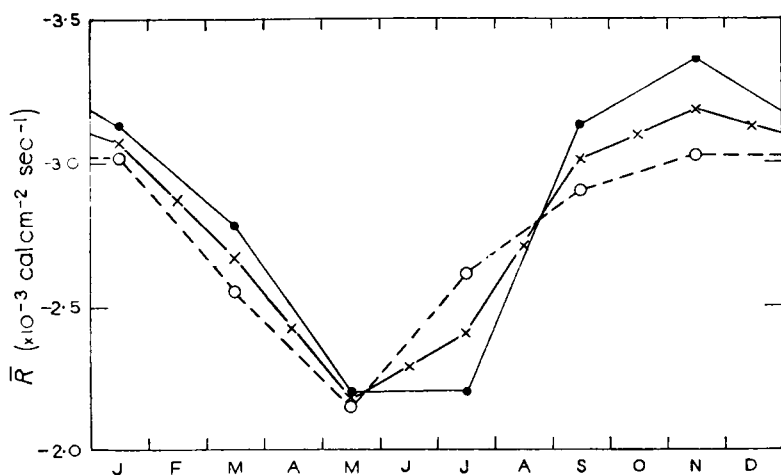


FIGURE 2—NET RADIATIVE HEATING (\overline{R}) IN THE NORTH ATLANTIC TROPOSPHERE (after Möller⁵)

- north of 50° N
- south of 50° N
- × average monthly values inferred from these data

computed mean monthly values for alternate months of the net radiative heating of the troposphere up to 300 mb at several locations. The overall figures for the northern and southern parts of the North Atlantic Ocean are reproduced in Figure 2. The values for the two parts of the Ocean were not considered sufficiently different to be used independently; accordingly, average

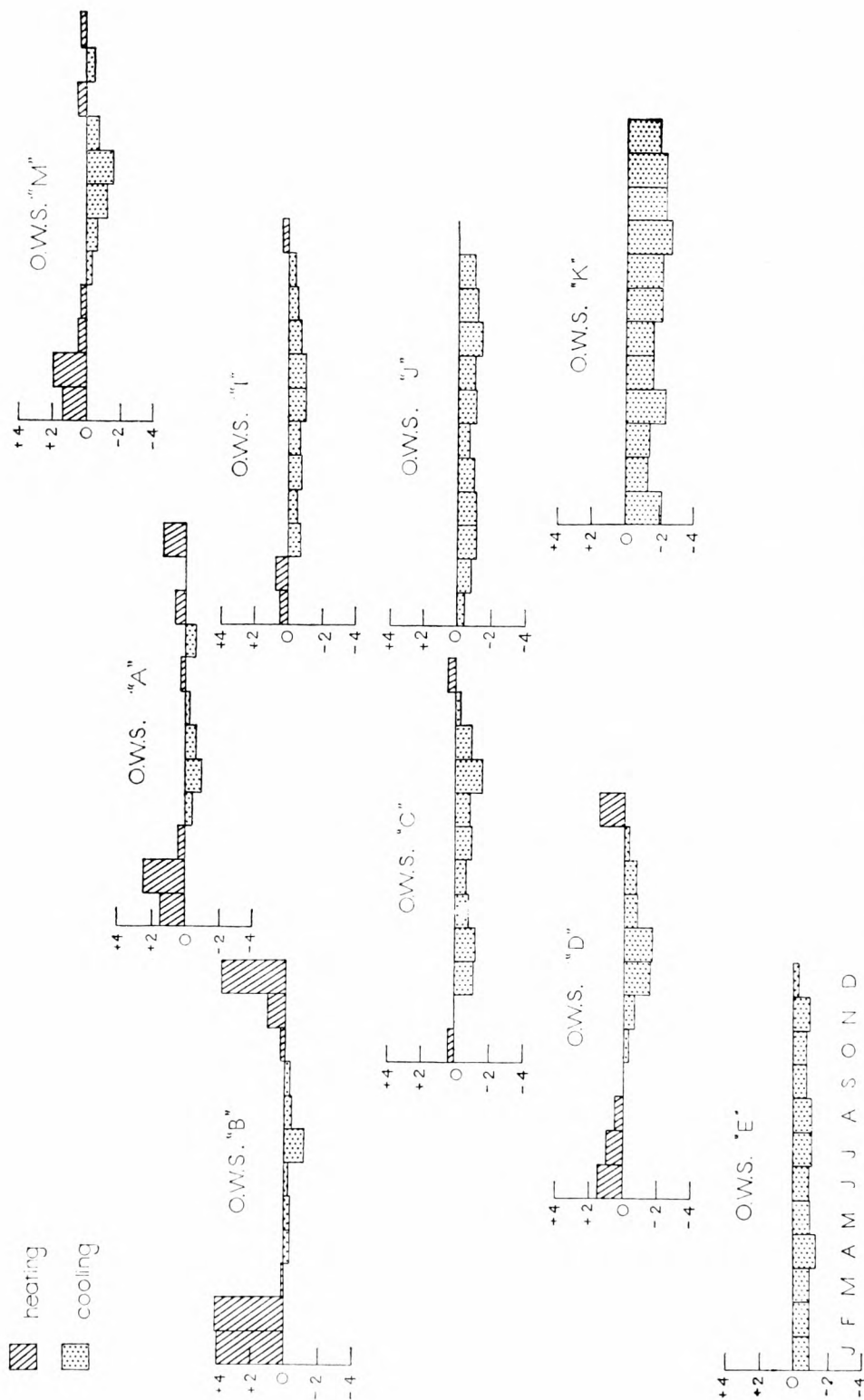


FIGURE 3—MEAN MONTHLY RATE OF HEATING IN THE TROPOSPHERE OVER THE NORTH ATLANTIC

Units: 10^{-3} cal cm^{-2} sec^{-1}

values with linear interpolation for the missing months were used in this analysis. The same value of \bar{R} was therefore applied to all weather ships in any one month.

Results.—The resulting mean monthly values of tropospheric heating over the North Atlantic weather ships are presented in diagrammatic form in Figure 3. The approximations involved in their derivation preclude any inferences from the details of the curves. The most obvious results are however:

- (i) Net heating occurs only over the northern and western parts of the North Atlantic, and only in the winter half-year.
- (ii) Heating and cooling are of the same order of magnitude everywhere, $\sim 1 \times 10^{-3} \text{ cal cm}^{-2} \text{ sec}^{-1}$.
- (iii) when plotted on a chart, a feature of every month is that the isopleths tend to be oriented in a south-west to north-east direction with the areas of greatest heating (or lowest cooling) being in the north and west. This is in general agreement with Clapp's¹ synthesis of the heat-balance results of other workers but there are two important differences. These differences are shown in Figure 4 which is a reproduction (using the units of this study) of the North Atlantic portion of Clapp's chart of normal winter heating derived via the heat-balance method.

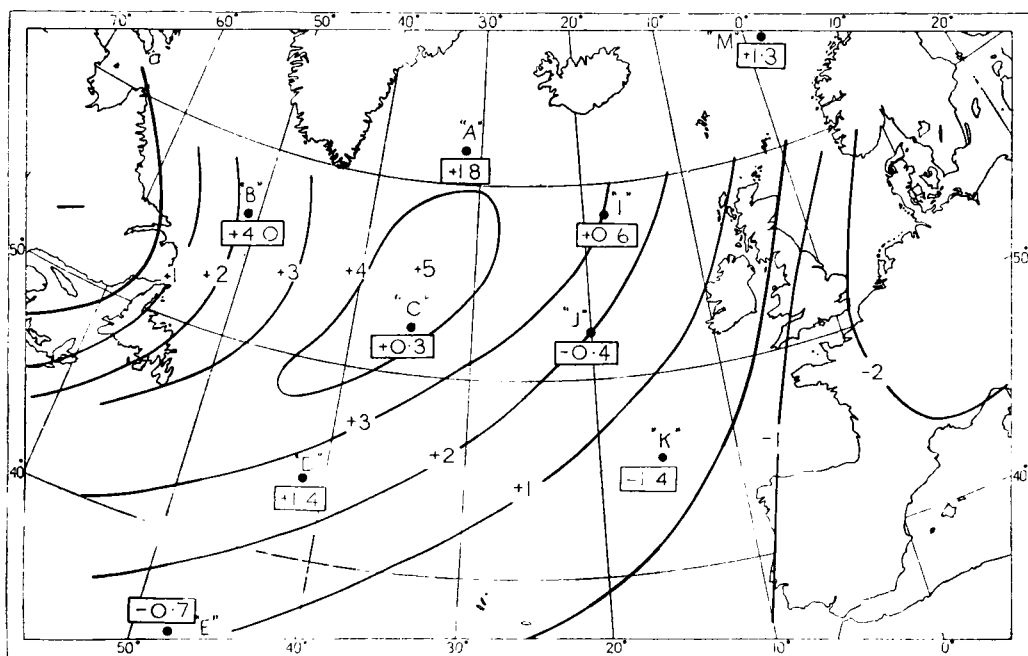


FIGURE 4—CLAPP'S SYNTHESIS OF HEAT-BALANCE METHOD CHARTS FOR NORMAL WINTER HEATING

Units: $10^{-3} \text{ cal cm}^{-2} \text{ sec}^{-1}$. Values in boxes are those obtained in this investigation.

The mean of the December, January and February values calculated here have been superimposed upon this chart; they show much less heating over the central Ocean, and a shift of the maximum heating to the vicinity of station "B". Both these results reflect the findings of the precipitation analysis⁴ which showed less rainfall than previously

supposed and a maximum over "B". However, the general conformity between the results reported here, and those described by Clapp for winter give some measure of confidence to the annual variations illustrated in Figure 3.

- (iv) A further result suggested by this analysis concerns the relative importance of the three terms in the year-to-year variation of $\overline{dq/dt}$.

Values of the coefficient of variation $\left(\frac{\text{standard deviation}}{\text{mean}} \times 100 \right)$ of

monthly rainfall have recently been produced for about 100 British Isles rainfall stations by the Meteorological Office Climatological Services Branch. These figures show that the coefficient is roughly 50 per cent for both highland and lowland stations, and does not depend on rainfall amount. This suggests that the figure of 50 per cent may also apply over the North Atlantic. Applying this value to the figures for latent heat released by condensation given in Figure 1, we obtain values of the standard deviation of monthly latent heat liberated at ocean weather stations "I" and "J" of between 0.5×10^3 and 1.2×10^3 cal $\text{cm}^{-2} \text{sec}^{-1}$, the lowest values being in the spring. Compared with the standard deviation of upward flux of heat from the surface which can be inferred from the scatter of Shellard's points on Figure 1, the latent heat variations are slightly larger in winter and spring but much larger in summer and autumn. Möller's work on the net radiative cooling suggests that the year-to-year variation of this quantity is very small. We are left with the conclusion that year-to-year variations in the value of $\overline{dq/dt}$ are likely to be associated primarily with variations in rainfall—the variations in the other terms being generally smaller, and much smaller in summer and autumn.

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SURFACE WINDS OVER IRELAND ON SATURDAY, 16 SEPTEMBER 1961

By K. WOODLEY

Introduction.—During Saturday, 16 September 1961 a small and vigorous depression passed north-north-east close to the western seaboard of Ireland, bringing severe gales. Historically the depression could be traced back to the hurricane “Debbie”, and at the time it was incorrectly so called in some press reports and elsewhere. Figure 1 gives the surface synoptic situation at 1200 GMT, 16 September 1961. The isobars are drawn at four-millibar intervals. The positions of the centre of the depression at six-hourly intervals between 0001 GMT, 16 September and 0001 GMT, 17 September are also shown.

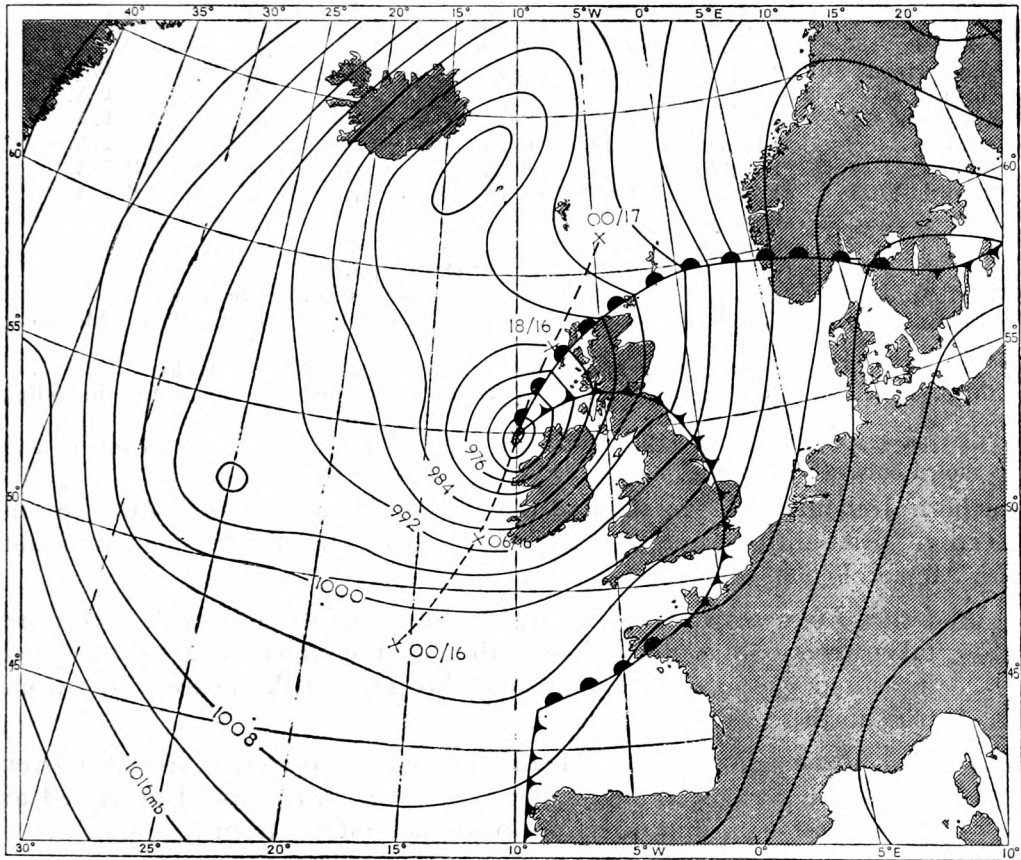


FIGURE 1—SURFACE SYNOPTIC SITUATION FOR 1200 GMT, 16 SEPTEMBER 1961

Wind data recorded.—Details of wind direction and speed were recorded on anemographs at 18 locations in Ireland and, in addition, observations at each hour of wind speed and direction from a cup-generator anemometer were available for most of the day from an auxiliary station. Details of the anemographs and their respective sites are given in Table I.

Hourly wind data.—Table II gives the hour-by-hour direction and speed of the wind during the day at stations in and adjacent to the six counties of

TABLE I—ANEMOGRAPH SITE DETAILS

Station	Irish Grid*	Lat.	Long.	Site a.s.l.	Height Head a.g.	Effective height ft	Type of instrument
Northern Ireland							
Aldergrove	IJ.145801	54°39′	6°13′	216	65	55	P.T.A.
Ballykelly	IC.624235	55°04′	7°01′	2	50	35	P.T.A.
Belfast Harbour	IJ.362769	54°37′	5°53′	10	47	—	N. & Z. An. (P.T.)
Coolkeeragh	IC.483223	55°02′	7°15′	0	42	—	Munro C.G.
Nutts Corner	IJ.196776	54°38′	6°09′	314	31	31	MO.elect.(C.G.)
Kilkeel	IJ.315140	54°04′	5°57′	60	40	—	C.G. (not an anemograph)
Republic of Ireland							
Belmullet	IF.6932	54°14′	10°00′	29	40	30	P.T.A.
Birr	IN.0706	53°06′	7°54′	232	40	30	P.T.A.
Claremorris	IM.3574	53°42′	8°59′	225	40	28	P.T.A.
Clones	IH.5026	54°11′	7°14′	289	40	28	P.T.A.
Dublin Airport	IO.2744	53°26′	6°15′	213	40	32	P.T.A.
Glenamoy	IF.8833	54°14′	9°43′	73	40	32	P.T.A.
Kilkenny	IS.4957	52°40′	7°16′	207	40	30	P.T.A.
Malin Head	IC.4158	55°22′	7°20′	80	40	30	P.T.A.
Mullingar	IN.4353	53°31′	7°21′	357	40	28	P.T.A.
Roche's Point	IW.8361	51°48′	8°15′	133	40	30	P.T.A.
Rosslare	IT.1312	52°15′	6°20′	78	40	28	P.T.A.
Shannon Airport	IR.3861	52°41′	8°55′	25	40	32	P.T.A.
Valentia Obsy.	IV.4378	51°56′	10°15′	55	41	33	P.T.A.

a.s.l. = above sea level

a.g. = above ground

P.T.A. = Pressure-tube anemograph ("Dines" pattern)

N. & Z. An. (P.T.) = Negretti & Zambra anemobiograph (pressure-tube system)

Munro C.G. = Cup-generator anemograph (speed only), by Messrs. R. W. Munro & Co. Ltd.

C.G. = Cup-generator anemometer (not anemograph)—at Kilkeel.

MO.elect.C.G. = Meteorological Office pattern, cup-generator, electrical, including direction.

* The Irish Grid reference of stations in the Republic of Ireland is very approximate, and is shown only to the two figures "easting" and "northing".

Northern Ireland. The method of determining "mean speed" and "mean direction" from anemograph records differs between the United Kingdom and Irish Meteorological Services:

- United Kingdom Meteorological Office.* Means of speed and direction are taken over 60-minute periods ending at the exact hour (GMT), speed measured to the nearest 1 kt, and direction to the nearest 10° (from true north);
- Irish Meteorological Service.* Means of speed and direction are taken over 10-minute periods ending at the exact hour (GMT), speed measured to the nearest 1 kt, and direction to the nearest 5° (from true north).

In addition to the standard tabulations of mean wind speed and direction, Table II also shows:

- the maximum gust (to the nearest 1 kt) in each of the 60-minute periods ending at the exact hour,
- the highest mean wind speed recorded over *any* 10 minutes during the day,
- the highest mean wind speed over *any* 60 minutes during the day.

The maximum gust can be obtained from the hour-by-hour entries.

General assessment.—In an attempt to present an overall picture for Ireland, isotachs of maximum gust and of maximum mean wind speed over any



By courtesy of City Surveyor, Londonderry

PLATE I—DAMAGE TO A LONDONDERRY SCHOOL ON 16 SEPTEMBER 1961

(see p. 191)



PLATE II—WIND DAMAGE TO SITKA SPRUCE (30 YEARS OLD) IN BARONSCOURT FOREST, CO. TYRONE,
AFTER GALE OF 16 SEPTEMBER 1961
(see p. 191)

Photograph by W. H. Jack



Photograph by W. H. Jack

PLATE III—CLOSE-UP OF DAMAGE TO SITKA SPRUCE (34 YEARS OLD) IN BARONS-
COURT FOREST, CO. TYRONE, AFTER GALE OF 16 SEPTEMBER 1961
(see p. 191)



TABLE II—HOURLY WIND DATA, 16 SEPTEMBER 1961

	Aldergrove		Ballykelly		Belfast Harbour		Coolkeeragh		Nuts Corner		Kilkeel		Clones		Malin Head	
	\bar{d}_{60}	V_G	\bar{d}_{60}	v_{60}	\bar{d}_{60}	v_{60}	\bar{d}_{60}	v_{60}	\bar{d}_{60}	v_{60}	d	v	\bar{d}_{10}	v_{10}	\bar{d}_{10}	v_{10}
0100	110°	10	18	040°	1	5	—	—	150°	13	18	160°	22	—	14	130°
0200	140°	15	25	030°	5	9	190°	3	160°	15	24	180°	25	—	24	090°
0300	150°	19	30	020°	2	9	180°	14	170°	17	29	—	—	—	33	065°
0400	150°	20	32	—	0	2	180°	16	170°	17	28	—	—	—	14	075°
0500	150°	19	35	140°	7	21	180°	14	170°	17	29	—	—	—	28	090°
0600	140°	19	31	130°	12	25	180°	18	160°	18	27	—	—	—	33	110°
0700	130°	19	37	140°	18	42	160°	12	150°	21	37	160°	26	—	14	130°
0800	140°	25	42	130°	18	29	150°	17	160°	23	39	160°	24	—	27	130°
0900	140°	25	39	140°	22	40	170°	22	160°	23	35	160°	30	—	41	130°
1000	150°	33	52	140°	26	45	170°	26	170°	32	49	180°	32	—	50	140°
1100	160°	37	60	160°	29	53	180°	28	180°	32	47	180°	38	—	77	165°
1200	170°	42	63	170°	35	75	190°	30	190°	35	61	200°	40	62	79	180°
1300	170°	44	69	180°	44	89	200°	33	200°	39	66	200°	44	65	87	185°
1400	180°	49	75	190°	51	82	200°	37	200°	39	69	200°	48	65	84	200°
1500	190°	49	73	190°	50	86	220°	40	210°	38	63	200°	50	70	77	200°
1600	190°	43	67	200°	46	92	220°	37	220°	37	52	230°	50	70	72	205°
1700	200°	43	61	220°	40	68	220°	32	230°	26	43	230°	45	—	57	230°
1800	210°	34	55	220°	31	56	230°	30	230°	24	48	230°	40	—	47	245°
1900	200°	28	47	220°	26	49	240°	26	230°	20	40	230°	28	—	38	240°
2000	200°	22	42	210°	19	34	230°	20	220°	17	30	250°	25	—	32	230°
2100	200°	23	36	210°	21	36	230°	16	220°	14	25	230°	22	—	31	225°
2200	190°	20	32	210°	18	37	220°	14	220°	14	24	200°	24	—	14	230°
2300	190°	17	29	210°	19	31	220°	12	210°	12	19	—	—	—	17	225°
2400																
VV ₆₀	49			51		42		45	40°			—	47		64	
VV ₁₀	51			52		47		49	44			—	50		66	
\bar{d}_{60}	mean direction over 60 minutes (degrees from true north)															
\bar{d}_{10}	mean direction over 10 minutes (degrees from true north)															
d	direction observed over a few minutes (degrees from true north)															
v	speed observed over a few minutes (knots)															
V_G	maximum gust in 60-minute period (knots)															
	mean speed over 60 minutes (knots)															
	mean speed over 10 minutes (knots)															
	maximum mean speed over any 60 minutes (knots)															
	maximum mean speed over any 10 minutes (knots)															

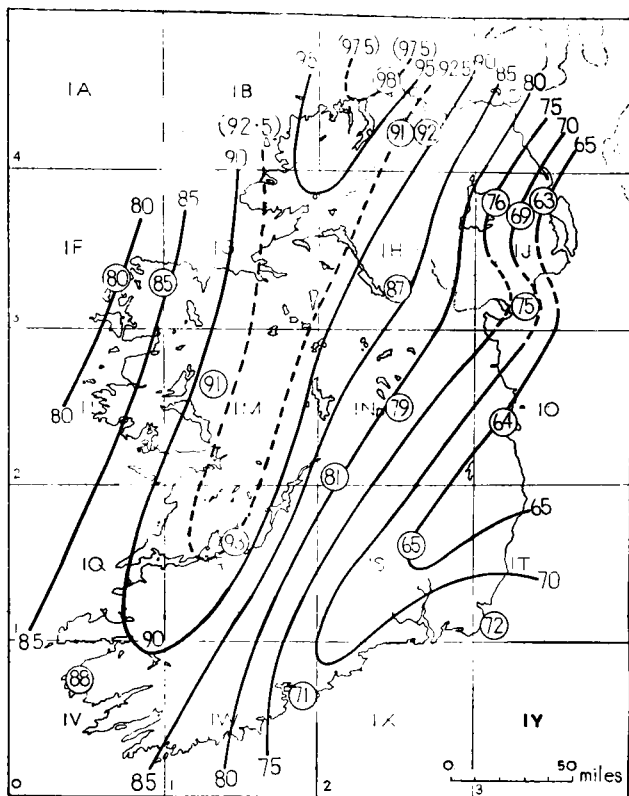


FIGURE 2—ACTUAL MAXIMUM GUST (IN KNOTS) RECORDED BY ANEMOGRAPHS,
16 SEPTEMBER 1961

The value for Kilkeel [75] was from eye observations of a cup generator anemometer indicating wind speed on a dial: no chart record is available.

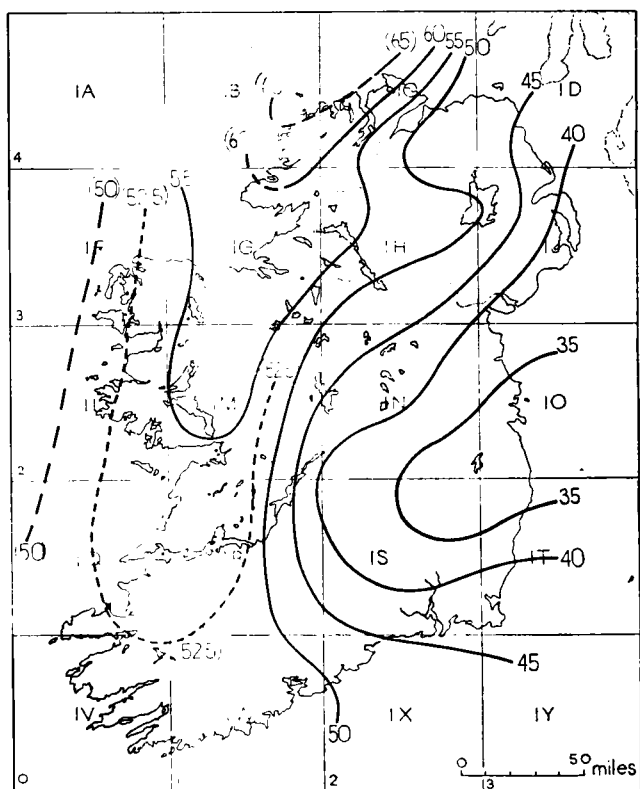


FIGURE 3—MAXIMUM MEAN WIND SPEED OVER ANY 60-MINUTE PERIOD,
16 SEPTEMBER 1961

60 minutes have been drawn: Figure 2 shows the isotachs of the maximum gust as recorded by the anemographs at each of the 19 stations—the speed of the gust (in knots) being plotted within a circle representing the station, and Figure 3 shows the isotachs of maximum mean wind speed over a period of any 60 minutes.

It will be seen that the highest wind speeds were recorded in a band, running south-south-west to north-north-east between Valentia and Malin Head, with the strongest winds at the northern end. (Lighter winds, as indicated by the data from Belmullet and Glenmoy on the coast of Co. Mayo, were experienced very near to the centre of the depression). The isotachs are dotted over southern Co. Down because the eye observations of the dials at Kilkeel cannot be treated in the same manner as data recorded on charts.

On the reliability of Figure 2 it is considered that the amount of basic data shown and their mutual consistency are such that Figure 2 can be taken to give a reasonable approximation to the true picture. Its interpretation for any given locality is subject to the remarks given below.

In the conditions prevailing at the time, the possibility of the maximum gust being close to the maximum gradient wind was considered to be worthy of examination. The isobaric charts at three-hourly intervals, drawn using some pressure data not available at the time due to communications breakdown, were examined at nine suitably chosen points over Ireland and the maximum geostrophic wind noted. The probable maximum gradient wind speed was computed and plotted for the nine points, and from these values isotachs were drawn (Figure 4). It will be seen that over much of Ireland the

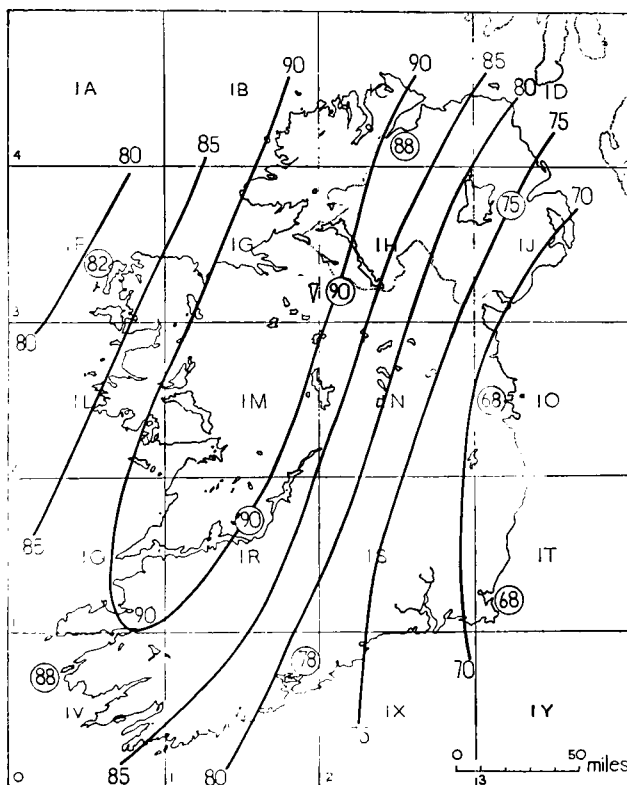


FIGURE 4—COMPUTED MAXIMUM GRADIENT WIND SPEED (IN KNOTS),
16 SEPTEMBER 1961

relationship between Figure 4 and Figure 2 is very close. This comparison between Figures 2 and 4 is interesting and suggests that estimates of the maximum gust likely to be experienced in such conditions at sites not subject to the limitations below could possibly be made from synoptic charts, if anemograph data are not available.

Limitations.—In utilizing the data in this paper, particularly if interpolation from the maps (Figures 2 or 3) is carried out, it should be appreciated that local topography could appreciably affect maximum wind speeds. None of the anemographs are at a very high altitude above sea level, so that the isotachs must be considered as being applicable only to relatively low-level areas. In addition, hills, particularly marked ranges of hills at right angles to the wind direction, would reduce wind speed for a distance on their leeward side. Conversely, valleys running parallel with the wind direction could be subject to “funnelling” effects, producing increased speeds. In built-up areas the general turbulence and eddies around buildings would affect the flow of wind, and the values given in this report cannot be considered as being representative. Generally speaking, however, mean wind speeds in built-up areas would have been appreciably lower than those indicated in Figure 3 whilst maximum gust speeds may not have fallen far short of those indicated in Figure 2 (i.e. the gustiness factor in built-up areas would be greater). It should be noted that the anemographs whose data were used for this paper were exposed to the wind under as near standard conditions as practicable (see site details, Table I).

In drawing Figure 3, the values as recorded at Coolkeeragh and Nutts Corner have largely been ignored because they are too low to fit the general pattern. This apparent anomaly is being investigated further.

Damage.—Press reports, etc., of the damage done by the winds on this occasion were numerous. The disruption of electricity and telephone services and the blocking of roads by fallen trees was widespread. The seas around Ireland were extremely rough and shipping was confined to harbour along the north and west coasts. The Spanish trawler *Andreas* ran aground in Bantry Bay and the coaster *Ulster Sportsman* in the Foyle Estuary. Serious domestic damage was reported in towns in the centre and west of Northern Ireland.

In Londonderry, in the north, a relatively new school was severely damaged, blocks being blown down (see Plate I, facing p. 192). In the Lagan Valley, near Moira, a new building was demolished. Cereal crops, which had only in part been harvested, were severely damaged, and it was reported that some 10,000 acres lost about two-thirds of the grain, another 10,000 acres lost about half, and about 20,000 acres lost about one-third. This was estimated to represent about £1,000,000 loss on the cereal crop.

Damage to forests was widespread in the areas of greatest wind speed. A survey carried out by the Department of Geography, Queen's University of Belfast¹, of all forests in Ireland, revealed the extent of the damage. Figure 5 shows the extent of wind damage in forestry plantations on this date. A certain amount of care needs to be taken in interpreting this map as, for example, the extent of the damage at any particular forest must be dependent upon the state of growth. For example, extremely young trees escaped serious damage. In this diagram the crosses represent slight or no damage and include forests comprising young plantations. The size of the other black dots is related to the

percentage area of the total forest which was damaged and these figures must also be considered as giving only a general indication, for the total forest area may include young, unaffected trees. The worst hit forest was at Baronscourt (near Newtownstewart, Co. Tyrone) where almost one-quarter of the trees

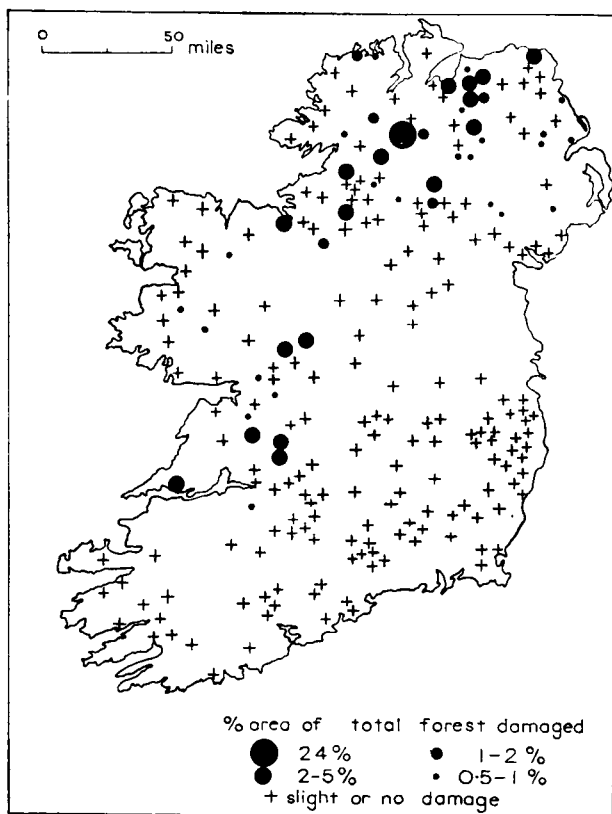


FIGURE 5—WIND DAMAGE IN FORESTRY PLANTATIONS, 16 SEPTEMBER 1961

were either uprooted or were broken off some feet above ground level (see Plates II and III between pp. 192-193). Generally speaking, trees of heights between 20 and 50 feet were damaged, conifers in the 30-40-foot height range being particularly hard hit.

Acknowledgements.—I would like to acknowledge the assistance given by:

- (a) The Director of the Meteorological Service of the Republic of Ireland, in making available specially tabulated data and copies of certain anemograms which have been used in this paper,
- (b) Messrs. Carbide Industries Ltd., for the use of their Coolkeeragh record,
- (c) The General Manager, Belfast Harbour Commission, for the use of the Belfast Harbour anemograph record, and
- (d) Mr. N. Stephens of Queen's University, for permission to reproduce Figure 5.

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THIRD SESSION OF THE WORLD METEOROLOGICAL ORGANIZATION COMMISSION FOR INSTRUMENTS AND METHODS OF OBSERVATION

By C. H. HINKEL, B.Sc.

At the invitation of the Government of India, the Commission for Instruments and Methods of Observation (CIMO) of the World Meteorological Organization (WMO) held its third session in the Vigyan Bhawan, New Delhi, from 29 January to 16 February 1962. The session was attended by delegates from 31 countries, and a number of international organizations also sent observers.

The opening ceremony was preceded by the presentation of the International Meteorological Organization Prize to Dr. K. S. Ramanathan (India) for his outstanding work in the field of solar radiation. This prize, which was presented by the Secretary-General of WMO, Mr. D. A. Davies, is awarded every two years for the most noteworthy contribution to international meteorology.

In his address Mr. Davies welcomed the delegations of new member states and said that it was most encouraging to see that the new countries were willing to play their full part as members of the WMO.

The session was opened by Mr. Ahmed Mohiuddin, Deputy Minister for Civil Aviation in the Ministry of Transport and Communication, Government of India, who spoke of the role played by the Commission in the field of meteorological instrumentation. He hoped that the third session would provide further stimulation to developmental work in this field.

In his presidential address M. A. Perlat (France) outlined the main objectives of the Commission and drew attention to the large agenda to be covered by the session. He also referred to the large gaps in the present network of observing stations some of which he hoped would be filled by automatic weather stations and he further hoped that in the future these deficiencies might be remedied by the use of artificial satellite observations. M. Perlat concluded by thanking the Government of India for making it possible for the Commission to hold its third session at New Delhi.

With these formalities completed the Commission settled down to work by setting up the necessary Committees. Two working Committees were established which met every day to discuss the various agenda items and reported their findings back to the plenary sessions of which six were held. One Committee under the Chairmanship of Mr. V. D. Rockney (U.S.A.) dealt mainly with technical matters and the other under Mr. A. L. Maidens (U.K.) considered items of an organizational and administrative nature. Both chairmen kept their respective Committees hard at work and to such good effect that, in spite of the large agenda, the final plenary session was able to be held a day ahead of schedule. In addition there was the usual co-ordination Committee, a nominations Committee for the election of new officers, and a Committee for the nomination of members of working groups.

A detailed description of the full agenda discussed during the session and the outcome of these discussions would require too much space and only a few of the more important items will be mentioned. More complete information will be available in the "Abridged Final Report of the Third Session of the Commission for Instruments and Methods of Observation", to be published by WMO.

The item which occupied most time was the "WMO Guide to International Meteorological Instrument and Observing Practice". This is one of a series of handbooks issued by WMO to provide advice and guidance to Members, especially those with newly-formed services in developing countries. The form and presentation of the subject matter of the various chapters was considered and it was agreed that a standard format to which all chapters would conform should be developed. Draft material for the complete revision of the chapters on radiation and meteorological instruments and observations on aerodromes, submitted by the respective working groups, was approved. Material for a third chapter on hydrometeorological instruments was, after considerable discussion, referred back with amendments to the Commission for Hydrometeorology for their consideration. A number of alterations and revisions were approved and Members were recommended to submit proposed changes and suggestions direct to the Secretary-General who could act as co-ordinator and take the necessary action without delay.

Examination of the WMO Technical Regulations was also carried out and a number of recommendations made, among them a proposal by the United Kingdom delegation that the regulations relating to pressure measurements on land were too restrictive and by allowing only the use of a mercury barometer for this purpose stifled development. An amendment to the appropriate regulation to include the use of other types of instrument of equal accuracy (such as an aneroid barometer) but retaining the mercury barometer as the comparison standard, was included in the recommendations on this item.

Upper air measurements formed another large agenda item and the comparison of radiosondes gave rise to lengthy discussion. The Commission finally decided that Members should be encouraged to develop a reference sonde to assist in this work, and that they should also continue to carry out comparison bilaterally and multilaterally although a number of delegates felt that in view of the failure of the previous trials no useful purpose would be served by holding more. To stimulate research in this field the Executive Committee should be asked when awarding the IMO Prize to take account of major developments in meteorological instruments. The current world-wide shortage of adequate frequency bands for users of all types of radio equipment means that the meteorologist finds himself being gradually squeezed out of his existing frequency allocations. The Commission recommended that any reduction in facilities should be strongly resisted and that vigorous efforts to maintain the present *status quo*, at least, should be pressed at both national and international levels.

Satellite and rocket meteorology provided some discussion and Members were encouraged to collaborate in satellite projects and urged to put forward suggestions for the type of observations required as well as the instruments to be used. It was the general opinion, however, that developments in these fields were taking place so rapidly that it was too early for any attempt at standardization or to set up any working groups.

The future of the Commission itself was also debated. Previous sessions had been divided concerning its usefulness but the Executive Committee of WMO had ruled that CIMO must be maintained with limited terms of reference. After much discussion it was considered that CIMO should be responsible for those aspects of instruments and methods of observation which are the concern

of more than one technical commission. Responsibility for a particular requirement by a single commission should rest with that commission which could, however, request CIMO's assistance. CIMO should also study developments in instrumental fields for possible meteorological application and promote interchange of information between members. A recommendation was drawn up on these lines.

At the end of the session the election of new officers took place. Dr. L. S. Mathur (India) was elected president to succeed M. Perlat who has held that office for the last eight years, and Mr. A. Hauer (Netherlands) was elected vice-president.

Three periods during the session were set aside for scientific discussions. Fourteen papers were read covering a wide variety of instrumental problems, such as evaporation, the uses of radar, automatic weather stations, upper air measurements, to name only a few. Social activities included a reception and a dinner given by Ministers of the Government of India, and a visit to the Indian Meteorological Department's Headquarters where the delegates were able to see the Department's fine workshops and equipment. In addition two most enjoyable and interesting tours were organized by the Indian Meteorological Department; one of them to places of historic interest in and around Delhi, while the other was a visit to Agra, over 120 miles away, where the delegates were able to see the famous Taj Mahal.

The success of the meeting was due not only to the fine co-operation of all the delegates, but also to the excellent work of the WMO Secretariat represented by Messrs. O. M. Ashford and K. T. McLeod. The Executive Secretary Mr. P. K. Das and all his staff also deserve mention for the way in which they kept the documentation right up to date. The interpretation throughout the session was extremely good. The Indian Government are to be congratulated upon the excellence of all the facilities provided. Thanks on behalf of all the delegates must be offered to them and to Mr. Krishna Rao and his staff in the Indian Meteorological Department for their helpfulness and generosity as hosts during the stay in New Delhi.

NOTES AND NEWS

Kew Observatory—a new feature

In July 1954, Mr. G. A. Whipple unveiled in the Superintendent's room at Kew Observatory, the main tablet, presented by his father, the late Mr. R. S. Whipple, giving the list of King's Observers and Superintendents from the time the Observatory was founded by George III in 1769 up to 1939, as well as the second tablet in memory of Robert Beckley. An account of the ceremony is given in the *Meteorological Magazine*¹.

Recently a collection of photographs has been assembled and placed opposite the stone tablets. There exists at Kew Observatory a small framed silhouette of the first King's Observer, Dr. Stephen Charles Triboudet Demainbray, which was presented by his great grandson Major-General G. Rigaud in 1881, as is recorded on the back in the latter's writing. No pictorial record has, however, so far as is known, survived of his son, Stephen George Francis Triboudet Demainbray who was King's Observer at Kew for 58 years, but as he did not die until 1854, at the age of 95, it is possible that a photograph may exist.

At the time of the present search photographs of six of the nine Superintendents, listed on the tablet, were available; the missing three were those of Sir Francis Ronalds, Samuel Jeffery and Dr. J. M. Stagg. The book "Catalogue of books and papers relating to electricity, magnetism, the electric telegraph etc., including the Ronalds Library" edited by A. J. Frost, 1880, stated that Sir Francis Ronalds had left his library to the Society of Telegraph Engineers and a telephone call to the Librarian to the successor to this Society—the Institute of Electrical Engineers—revealed that not only was an oil painting of Sir Francis Ronalds available, but a photograph had been taken of this by the Post Office in 1938; the Post Office readily supplied a copy of this photograph.

A search amongst old documents in the basement at Kew was rewarding in that a staff photograph marked "about 1870" showed an obvious grouping about a central figure; next to him was the unmistakable figure of a young G. M. Whipple who was then chief assistant and was later (in 1876) to become Superintendent. This central figure has been taken to be Samuel Jeffery and the photographic reproduction branch of the Air Ministry skilfully produced a suitable photograph eliminating the heavy watch chains on the waistcoats at the back of the group. Dr. Stagg could trace no photograph of himself taken in the relevant period, but kindly provided a copy of that taken in 1961 at the end of his term as President of the Royal Meteorological Society.

The group of photographs as thus assembled is shown in the photograph facing p. 193. Six of the nine photographs show Superintendents as they were during their term of office, the other three (Sir Francis Ronalds, Balfour Stewart and James Martin Stagg) show them later in life.

The silhouette of Dr. Demainbray and a small photograph of Robert Beckley are also kept in the Superintendent's room at Kew Observatory. There is also an interesting photograph of John Welsh showing him ready for a balloon ascent in July 1852; this photograph was taken from a group which included J. Gassiot and Sir Edward Sabine².

L. J.

REFERENCES

1. London, Meteorological Office; Memorial tablets at Kew Observatory. *Met. Mag., London*, **83**, 1954, p. 321.
2. SHAW, SIR NAPIER; An episode in the history of Kew Observatory. *Met. Mag., London*, **61**, 1926, p.125.

British Council course on meteorology, 1-13 April 1962

As part of its effort to encourage an appreciation of Britain abroad, the British Council organizes each year a number of courses on scientific subjects for overseas workers in the subjects, the object being to present a survey of recent developments and current practice with particular reference to British contributions and methods. It was as the result of a suggestion by Sir Cyril Hinshelwood, while he was President of the Royal Society, that the Council decided to include a course in meteorology in its 1962 programme. It will be recalled that Sir Cyril laid the foundation stone of the new Meteorological Office Headquarters building in Bracknell on 28 October 1959. The Director-General of the Meteorological Office was approached by the Council for help and advice as a result of which a suitable programme was prepared.

The course was designed for meteorologists of some standing; in the words of the advertising brochure produced by the British Council it was intended "primarily for senior members of the staff of meteorological services, but applications from senior research workers in a university or equivalent academic institution will also be considered." The total number of members was kept small to form a group in which communication would be easy and discussion free. In the event, the course attracted meteorologists from Austria, Finland, Germany, Greece, Hong Kong, Hungary, Iceland, Sweden, Switzerland and the United States of America, all of whom had long experience and proved ability in their profession. The standard of discussion aroused by the lectures was always high. It is perhaps surprising that such a large proportion of the course members came from European countries where meteorological services are already well established rather than from the developing countries but possibly the length of the course (two weeks) was too short to justify travel from distant places.

The course aimed to present a coherent picture of the present state of meteorology in this country. It was hoped that the programme achieved a balance between 'research' and 'services' topics which would assure the continuous interest of course members, bearing in mind their different backgrounds. It was inevitable that the bulk of the lectures and visits would concern the activities of the Meteorological Office. Indeed, most of the course was held within the Headquarters Building at Bracknell. However, the participation of members of the staff of Imperial College and of Rothamsted Experimental Station was most important in achieving a full account of meteorological work in this country, and contributed greatly to the ultimate success of the course.

The opening address was given by Sir Graham Sutton, the Director-General on Monday, 2 April. Sir Graham sketched the philosophy behind present developments within the Meteorological Office. He particularly emphasized three trends: first, the gradual replacement of the individual experience of forecasters by dynamical methods as the basis of weather forecasting in this country; second, the extension upwards into the high stratosphere of the region being examined synoptically by meteorologists; and third, the planned growth of the non-aviation services provided by the Meteorological Office. Evidence of these trends was to be apparent in much that was heard and seen by the course members in the succeeding two weeks.

A number of the lectures bore directly on the problems of weather forecasting. There were visits to the Central Forecast Office and to London Airport and lectures on the jet stream, the use of electronic computers to produce prognostic charts, objective forecasting by statistical techniques, meso-meteorology and mountain waves. Related topics dealt with were the development of meteorological instruments and the handling of meteorological data. Non-aviation services were covered in another lecture and in a visit to the London Weather Centre. The problems of the general circulation and of long-range forecasting were explained in several notable lectures, and the work of the Meteorological Office in this field was seen in the Climatological Research Branch.

On the physical research side, the course learned about the meteorology of the stratosphere and in particular about the experiments of the High Atmosphere Research Branch. They were able to see this branch and some of the instruments

now being made. The physics of clouds was dealt with in lectures and in visits to the Imperial College Experimental Station at Silwood Park, Ascot and to the Meteorological Research Flight at Farnborough. Kew was visited to see the work on radiation, while the final two days (when the course members stayed in Cambridge) were devoted respectively to turbulence topics and to agricultural meteorology. The Meteorological Office Experimental Station at Graveley was seen on 12 April and Rothamsted on the last day.

It appeared that all concerned considered the venture highly successful; the British Council reception at the White Hart Hotel, Windsor on Tuesday, 10 April for those who helped with or took part in the course was a happy occasion. Meteorologists have cause to be grateful to the British Council and in particular to Mr. G. L. Hitchcock, O.B.E., Director of Courses and Miss U. K. Bell, the Course Officer, for organizing a course which has fostered good international relations within their profession.

A. GILCHRIST

METEOROLOGICAL OFFICE DISCUSSION

Meteorological satellites

The last Monday Discussion of the season was held at the Royal Society of Arts on 19 March 1962. The meeting opened with the showing of a general instructional film entitled "The inconstant air". Mr. C. J. Boyden then gave an account of a recent visit to an International Meteorological Satellite Workshop which was held at Washington.

Mr. Boyden described the TIROS satellites, four of which have been launched since April 1960. All are in orbit 400–500 miles above the earth's surface and circle the earth in about 100 minutes but, as expected, the useful life of each has been only a few months because of deterioration of some part of the complex mechanism. A TIROS satellite operates on power provided by solar batteries. It takes cloud photographs on command from a ground station in a sequence of 32 pictures at 30-second intervals, and transmits them on request. Continuous recording of radiation measurements in several wavebands is also made and can be stored for one orbit. A limitation on the acquisition of data is imposed by the location of the read-out stations, and a drawback of TIROS is that it maintains an attitude which is more or less fixed in space, so for much of the time the cameras are not pointed towards the earth. Nevertheless over 70,000 photographs have been received so far and an enormous amount of radiation data has yet to be analysed.

The interpretation of cloud photographs is a complex process taking several hours, involving not only the recognition of cloud detail but the accurate location of the longitude–latitude grid. The results are transmitted both by facsimile and in code in the form of a nephanalysis, which depicts cloud boundaries and the broad types and amounts of cloud. Its usefulness to the forecaster is considerable in areas of the world where observations from the ground are sparse.

With satellite meteorology still in its infancy there is every promise of great advances both in the scope of observations and in the vehicle itself. Already the radiation readings provide estimates of cloud top temperature and thus an indication of its height. Three more TIROS satellites will be put into orbit and in the meantime the first NIMBUS will be launched. This will follow a polar

orbit and face the earth at all times. Next will come AEROS, which at 22,300 miles from the earth will remain above a fixed point on the equator, its cameras continuously covering a hemisphere.

Most of the audience had not had the opportunity of using nephanalyses in forecasting, but the subsequent discussion showed the keen interest in the potentialities of satellites and an appreciation of the remarkable technical achievements already made.

REVIEWS

Mesures en Météorologie, by A. Perlat and M. Petit. 9½ in. × 6¼ in., pp. 393, illus., Gauthier-Villars (Service Publicité) 55 quai des Grands-Augustins, Paris (VI^e), 1961. Price: 55 N.F.

M. Perlat, having been President of the World Meteorological Organization Commission for Instruments and Methods of Observation for about eight years, is well known internationally as an authority on the subject of this book. His co-author, M. Petit, also is well known for his published work on the techniques of upper air measurements. The aim of their book is the study of the general conditions and requirements for the measurement of the various meteorological quantities, the methods in use and the factors involved in reducing the basic data to the required form for synoptic and climatological use. The treatment is generally on the theoretical side and concentrates on general principles rather than on the practical details of instrumentation; the theory and the principles, however, are illustrated by descriptions of typical instruments in which they are employed. Not unnaturally, many of the instruments described are of French design.

The book opens with a chapter on the performance and errors of measuring instruments, including a clear account of the theory of response time. Roughly half of the book is concerned with methods used in surface observations of pressure, temperature, radiation, humidity, wind, visibility, cloud and precipitation. The other half of the book is devoted mainly to radiosonde and radar methods of upper air measurement and includes a chapter on captive balloon and kite techniques, but the special requirements for aircraft measurements are not considered. Sferics measurements are covered and the book concludes with a chapter on meteorological observing stations, both manned and automatic.

In one or two of the descriptions of equipment the information is too brief to be of much use to the reader. For example, a few lines are given to a French prototype "station parlante", an automatic station which can be called up by telephone at any time and will give in plain language the weather observations at the time of the call, but the book gives no information about the design. On the other hand, in discussing the layout of meteorological observing stations the authors go to the unusual length of recommending lawn-like plants, other than grass, which they consider suitable for the plots on which the instruments are exposed. They are very enthusiastic about *Lotus corniculatus* (Bird's-foot trefoil) and, for stations near the sea, *Armeria maritima* (thrift). It would be interesting to know if these recommendations are acceptable internationally.

Relatively few references to original sources of information are given in the book and the reviewer was a little surprised to find that in the section on dew-point hygrometry no mention is made of the Dobson-Brewer instrument or, in

the description of differential barographs, of the Shaw-Dines microbarograph. The book concludes with a detailed list of contents but an alphabetical index would have been more useful. As a very clear and interesting exposition of the theory and general principles of meteorological measurements the book is strongly recommended.

F. J. SCRASE

Meteorological factors influencing the transport and removal of radioactive debris, WMO Technical Note No. 43. Ed. by Dr. W. Bleeker. 11 in. x 8½ in., pp. xii + 171, illus., World Meteorological Organization, Geneva, Switzerland, 1961. Price: Sw. fr. 8.—.

The major part of the radioactive fission products created by high-yield thermonuclear tests enters the stratosphere and is brought down to the earth's surface gradually over a period of months or years. The full effect of the tests is, therefore, not immediately felt at the surface, and in order to make a reasonable assessment of the hazards to man arising from certain isotopes, it is necessary not only to make measurements of the deposition occurring at a given time, but also to be able to predict the rate of fallout in the future. In order to see whether any basis could be found for forecasting future world-wide fallout, a comprehensive survey of the problem was made during the seventh session of the United Nations Scientific Committee on the Effects of Atomic Radiation held in January 1960. A number of meteorologists attended the meetings and gave papers on various aspects of the problem, and a selection of the papers has now been published in the WMO "Technical Note" under review. A few papers which merely presented data, or which had appeared elsewhere in the literature, have been omitted.

The opening paper is a fairly detailed summary by Dr. L. Machta (United States Weather Bureau) of the available information on the meteorological aspects of world-wide fallout. He begins by indicating briefly the difference between "close-in" and "world-wide" fallout, the latter being divided into "tropospheric" and "stratospheric" fallout. The rest of the paper is concerned only with the world-wide stratospheric component of fallout, and contains sections dealing with the physical and chemical properties of the particles, with the observed distribution of fallout in soil, in rain and in air near the ground and aloft, with the transport and diffusion of the radioactive debris in the stratosphere, through the tropopause and in the troposphere, and with the processes which lead to the removal of the particles from the atmosphere. This survey formed the background for the remaining papers, and is in itself a good and useful account of the subject. The only major fault is an almost complete neglect of the work, carried out by N. G. Stewart, D. H. Peirson, R. N. Crooks and others at the Atomic Energy Research Establishment (A.E.R.E.), Harwell, on the world-wide distribution of fission products in rain and on the variation of activity with height in air over the United Kingdom. This work had added considerably to our knowledge in this field, and is worth a good deal more than the passing mention given to it by Machta.

The three papers which follow deal respectively with the sampling of radioactive debris in air near ground level along the 80° W meridian, stratospheric sampling using balloons to carry filters well into the stratosphere, and tropospheric and lower stratospheric sampling by means of aircraft. These papers

contain a good deal of information and, although there is some doubt about the early balloon data, there is much here to interest the meteorologist. Professor Bleeker then discusses the tropospheric circulation and the way in which it influences the distribution of fallout. The meteorologist will be familiar with the substance of this paper, but he may be interested to see how quickly a radioactive cloud in the troposphere may at times be dispersed over a wide area. The next paper, by Professor H. A. Panofsky, is an interesting summary of the properties of the lower stratosphere, taken to be the layer between the tropopause and 100,000 feet. While recent work has not led to great changes in our ideas on the overall picture of the stratospheric circulation—it appears that weak reflections of the tropospheric flow are often evident at heights greater than suggested in this paper—more can now be said about the “sudden warming” phenomenon.

Dr. A. W. Brewer follows with a paper on the transfer of ozone from the stratosphere to the troposphere. Ozone is of interest in this context in that it is formed in roughly the height region into which the debris from high-yield tests is deposited. The model of a meridional circulation put forward by Brewer in 1949 to explain the observed distribution of water vapour, helium and, later, ozone in the stratosphere, seems to explain many of the observed features of the distribution of radioactive debris. Returning to the troposphere, Professor Bleeker gives an illustration of the activity changes on the passage of a double cold front over north-west Europe shortly after a nuclear test. Monsieur L. Facy goes on to describe a number of mechanisms which might contribute to the removal of radioactive particles from the atmosphere and their deposition on the surface. Not all of these mechanisms are equally effective: recent laboratory work by Goldsmith (to be published) indicates that the transport along the vapour pressure gradient is not an important factor in the scavenging of particles by cloud droplets.

Dr. M. Hinzpeter has attempted to derive information on the coagulation, fractionation and “residence time” of the fission product particles in the atmosphere. He deduces that the sub-micron radioactive particles coagulate with the larger neutral dust particles in the lowest layers of the atmosphere, since the two show very similar diurnal, weekly and seasonal variations. The second part of the paper attempts to show that time and space variations in the relative proportions of strontium-90 and caesium-137 are a result of the coagulation of the smaller caesium with the larger strontium particles. The argument is rather tentative, and is based on a number of assumptions, some of which are rather doubtful. As Machta has said in the first paper, there appears to be no evidence that such fractionation does occur. The third part is an attempt to derive a minimum “residence time” for nuclear weapon debris in the stratosphere.

Finally, Machta gives a brief summary of the results of the discussions and an epilogue which presents significant data on atmospheric radioactivity gathered up to about March 1961 and which includes new data on rhodium-102, released at above 30 kilometres over the central Pacific in August 1958 and on beryllium-7 and lead-210, two naturally occurring isotopes.

The general impression gained from a study of this “Technical Note” is that a vast body of data has been accumulated, often with great difficulty and at no little expense. The data are difficult to interpret, and the wide variety of “residence times” quoted is ample evidence of this. It is clear, however, that

the rate of removal of fission products from the stratosphere is strongly dependent upon the latitude and height of injection, and that it varies with season and from year to year. Debris injected into the lower stratosphere in arctic regions, for example, is almost completely removed within a year, while there is now evidence that an appreciable fraction of the debris injected at 30 kilometres or so over the tropical Pacific in 1954, 1956 and 1958 is still present in the stratosphere. It appears that the problem of forecasting future world-wide fallout has not yet been completely solved.

J. CRABTREE

OBITUARY

Leonard Joseph Dwyer—The news of the death, after a short illness, of Mr. L. J. Dwyer on 16 May 1962 came as a very great shock to all who knew him. Born in 1907, he had been Director of the Bureau of Meteorology in Melbourne since 1955, and was a member of the Executive Committee of the World Meteorological Organization. In the Second World War, as a squadron leader in the Royal Australian Air Force, he was engaged in forecasting for operations in the Pacific area.

The Director-General writes:

"I knew Len Dwyer intimately as a fellow member of the Executive Committee, W.M.O. His breezy, forthright personality and massive common-sense, coupled with a deep knowledge of the requirements of operational meteorology, made him an outstanding member and he will be sadly missed. During our years of joint service on the E.C., I never knew him depressed or worried, and he won many friends. After working hours he was always the best of company.

"Len Dwyer will be remembered as one of the men who have helped to make the profession of meteorology unique in its world-wide friendships. Like many others, I mourn not only the loss of a fine public servant but a close and valued friend. The annual meetings at Geneva will not seem the same without him."

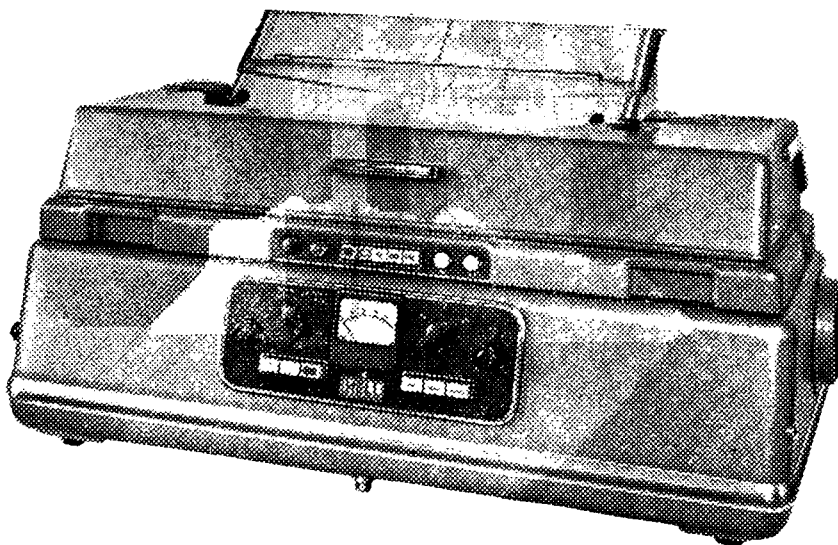
METEOROLOGICAL OFFICE NEWS

The Meteorological Office Football Club (Bracknell) has now completed its first season and can look back upon this with a feeling of satisfaction. A team was entered in Division II of the Ascot and District League and finished third in the competition. Of the 24 league games played, 14 were won, 2 drawn and 8 lost. Seventy-three league goals were scored and 63 conceded. Various cup competitions were also entered (without success) and the full playing record is: Played 31; won 16; drawn 2; lost 13; goals for 94; goals against 89. The chief goal-scorers were E. Ashby (M.O.14) and P. Underwood (M.O.5c)—20 each, R. Archard (M.O.3)—13, M. Crisford (White Waltham) and R. Hardy (M.O.18)—10 each.

The club is now looking forward to next season and the Secretary (J. R. Green, M.O.10b) would be pleased to hear from prospective new players or non-playing members. Staff serving at Heathrow, Farnborough, Odiham and other Offices near Bracknell might be interested to know that membership of the club is not limited to those serving at Headquarters. Training sessions in preparation for next season will commence during July.

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A REPORT ON A DISCUSSION "INTERACTION BETWEEN THE ATMOSPHERE AND THE OCEANS"

By L. JACOBS

A special all-day meeting took place at the Meteorological Office, Bracknell, on Tuesday, 16 January 1962.

The Chairman, Professor Sheppard, opened the meeting by explaining that the present discussion arose from a suggestion by the Meteorological Committee which was pursued by Dr. Sutcliffe. It had been agreed that it would be most useful to have a discussion between oceanographers and meteorologists on work currently in progress or projected in the United Kingdom on the interaction between the atmosphere and the oceans. The present meeting was a combined one of the Meteorological Research Committee and its two Sub-Committees, I and II, and Professor Sheppard welcomed the oceanographers who attended it.

Storm surges and meteorological disturbances of tides

Dr. J. R. Rossiter of the University of Liverpool Tidal Institute opened the discussion by giving an account of "Storm surges and meteorological disturbances of tides". He explained that even small meteorological disturbances could have economic importance in reducing the value of tidal predictions and instanced the Great Australian Bight where tide timing errors of up to two hours could occur through this cause. The larger storm surges were a hazard to property and even to life. The present subject was thus a very practical one and indeed a topical one as only the previous weekend there had been storm surges over the western coasts of the British Isles and in the English Channel.

Up to recent years, the work on storm surges, which had started at the Tidal Institute in 1928, had depended entirely on the semi-empirical method of obtaining appropriate equations, including meteorological variables, from a study of the basic hydrodynamical equations, and then using statistical methods, with carefully selected surges, to determine the empirical constants. Results had been reasonable—some hind-casting experiments had yielded correlation coefficients between observed and computed surges of as much as 0.95. The Admiralty Flood Warning Organisation adjacent to the forecasting office at Bracknell does in fact, by such methods, combine the data from the network of reporting tide-gauges with meteorological forecasts for the North Sea area to

issue warnings when dangerous levels are likely to be reached along the east coast. Such simple prediction methods fail, however, when assumptions implicit in the basic theory, of which the two main ones are of equilibrium conditions and of the astronomical tide being independent of the meteorological surge and vice versa, are only too often violated in our coastal waters. The assumption of equilibrium conditions was reasonably valid for the North Sea, but marked resonance effects can occur on the west coast, particularly in the southern Irish Sea, when secondary depressions cross the area—this was illustrated by a slide showing the synoptic situation on 18 October 1957. The second main assumption is valid only if the second- and higher-order terms in the hydrodynamical equation for the water movement can be ignored, and this is certainly not true in shallow water where, considering idealized one-dimensional flow, the non-linear terms involving friction become important.

Before going on to consider the modern approaches to direct solution of the hydrodynamical equations, Dr. Rossiter emphasized that, as this was such a difficult problem, the present empirical-cum-statistical method will continue to be of considerable service in many branches of surge research and forecasting. Models used in an attempt to solve the equations were of three types, small-scale physical, as at the Hydraulics Research Station, Wallingford; electronic, as at the National Institute of Oceanography and in Holland; and mathematical as at his Institute (and a number of other institutes). All models can incorporate bottom friction, wind stress on the sea surface and geostrophic forces; the mathematical model involves the use of a large electronic computer.

Dr. Rossiter then gave details of the one-dimensional mathematical model in use at his Institute; the main problems were the physical ones of assuming and ascertaining an average value of horizontal water velocity over the depth, and of trying out various values of bottom friction, and the mathematical ones of the representation of the shape of a channel, the boundary conditions at irregular coasts and the ideal size of the computation mesh. He made particular reference to his experience with a mathematical model of the River Thames; the present model would not yield the right answer without considering the interaction already present at the sea end which led to the formidable task of dealing with a two-dimensional model, necessary anyhow if wide bodies of water—with geostrophic force present—are to be considered.

In pointing out the need for a more complete mathematical theory, amenable to numerical solution, Dr. Rossiter mentioned that recent theoretical work, supported by small-scale tank observations, showed that surface wave phenomena, normally ignored since their period is assumed to be below that of the surge, can appreciably affect the surge height, so that this factor has also to be considered. He concluded by emphasizing that any method of surge forecasting is very largely dependent upon a reliable forecast of the synoptic situation, and in particular of the detailed wind field over the sea, for at least twelve hours ahead; the meteorologist could also help to ascertain the precise law which controls the response of the sea to wind stress.

Dr. Deacon of the National Institute of Oceanography said that the scope of the problem is enormous. For very slow changes the sea acts like an inverted barometer and in the open ocean a rise in atmospheric pressure of one millibar depresses the sea level by one centimetre. In an estuary the response is less. For more rapid changes the response is likely to be greater than one to one, because

of the partial resonances with natural periods of bodies of water on the coastal shelves or in bays or harbours, or because the pressure disturbance travels at about the speed of a free wave in the shallower coastal waters. This seems to be the main cause of the disastrous hurricane surges on the east coast of the United States of America, of the smaller ones which occur from time to time on our own west coast, and of the small unexpected surges which occasionally cause some confusion on our south coast beaches. In the North Sea the piling up of water trapped in a constricted area in front of the wind seems more important, but anti-clockwise movement of the surge down the east coast of Britain and northwards along the coast of the continent shows an important dynamic element.

Mr. Crease of the National Institute of Oceanography, in commenting that *Dr. Rossiter* had shown that the semi-empirical methods of prediction of storm surges are capable of high accuracy over a length of time sufficient to be of immediate practical use, emphasized that the relatively infrequent occurrence of large surges does, however, hinder the investigation of the dynamic coupling between atmosphere and ocean and, at the same time, the treatment of solitary waves is somewhat more awkward mathematically than that of periodic disturbances. There is the alternative approach of studying continuous records of sea level and atmospheric fluctuations by spectral analysis. By analysis of records from more than one station much should be learnt of the direction and rate of growth of surges in different parts of the spectrum.

Sir Graham Sutton pointed out that in the meteorological problem, equations of motion had to be filtered to eliminate sound and gravity waves. This was done by introducing the hydrostatic equation and the geostrophic approximation in the right places. He wondered whether this had been considered for the oceanographic equations. *Dr. Rossiter* said that at a conference at Hamburg last year there had been a discussion of the use of finite difference equations. Stability had not been discussed in much detail: some speakers had mentioned the question of smoothing, but this had been rather frowned on. He referred to the diagrams he had shown as illustrating a smoothing process.

Mr. Sawyer was surprised to see that the oceanographers were using the basic equations, as the meteorologist had considered it far simpler to introduce one function, e.g. a stream function in the analysis. *Professor T. V. Davies* of the University of Wales, Aberystwyth, wondered what the typical wavelength of the storm surge was. This length should give a guide to the grid spacing required. *Mr. Crease* pointed out that the geostrophic approximation was not appropriate as in this case the oceanographer was concerned with the inertia-gravity waves. The water is treated as incompressible, so sound waves do not confuse the picture.

Dr. Rossiter, replying to these points, stated that the non-linear terms of importance in estuaries and shallow seas made the use of only one variable extremely difficult mathematically. The period of the North Sea surges varied from 18 to 36 hours and the wavelength is therefore comparable with the length of the North Sea.

Dr. Hunt of Imperial College asked if it had yet been possible to compare results from the Tidal Institute model of the Thames with those obtained on the Port of London Authority model operated by the Hydraulic Research Station,

Wallingford. It is presumably easier to specify independent tide and current curves at the seaward end of the mathematical model than in the hydraulic. The latter, however, has the advantage of permitting more realistic distributions of velocity with depth. Regarding *Dr. Rossiter's* comments on the necessity of including both horizontal components of velocity when incorporating the region seaward of Southend, surely predictions for the one-dimensional region upstream of Tilbury, say, would not be sensitive to the detailed structure of the flow in this area so that a reasonable one-dimensional average might be used. *Dr. Rossiter* replied that a comparison of the physical and mathematical models will be made and will be useful. He hoped that the mathematical model will be of some practical importance; the model of the Thames for storm surge research is more useful if used as an adjunct to the model of the North Sea, where the two-dimensional analysis would be necessary.

Dr. Sutcliffe emphasized that it was essential for the meteorologists and the oceanographers who were considering similar mathematical problems, involving the equations of motion, to work closely together. He and his staff would be pleased to welcome any oceanographers who would care to visit this Headquarters for detailed discussion on this problem. *Cdr. Synnott* said that in his experience in the Flood Warning Organization (based at the Meteorological Office, Bracknell) the path of the depression was an important factor as with different paths the behaviour of storm surges was different, even if the winds were the same. He pointed out that negative surges were of particular importance, e.g. to the Port of London Authority; on the morning of the discussion the level of the Thames had been 5 feet lower than that predicted.

Mr. Sawyer stated that the details of wind structure were not known near the centres of depressions over the sea since information was limited to that provided by anemometers on the coasts; topography was important, e.g. near the Norwegian mountains. *Dr. Rossiter* said this point had been discussed at the Hamburg conference, when considering the North Sea. Estimates were made of the geostrophic wind but curvature of the air trajectory was not taken into account. When the latter was considered there was a negligible improvement to the result. He again emphasized that knowledge of winds near depressions over the sea was extremely important in this work.

Recent developments in the theory of wave generation by wind

Dr. O. M. Phillips of the Department of Applied Mathematics and Theoretical Physics, University of Cambridge introduced his topic "Recent developments in the theory of wave generation by wind" by stating that his aim was to present some of the physical ideas that had emerged in the last few years concerning this problem. There were two important mechanisms at work, resonance between the surface wave modes and the advected surface pressure fluctuations associated with the turbulent wind blowing over the water, and the gradual instability caused by the airflow over a surface already disturbed. Phillips¹ had discussed the resonance effect and had shown that the time scale of the fluctuations of a given wave-number is a maximum when the wind speed in the direction of wave propagation is just equal to the phase speed of free surface waves of the same wave-number; if this condition for resonance is satisfied there is maximum energy transfer from wind and waves.

Shortly after this paper was published, Miles² showed that if an airstream with a prescribed velocity profile blows over a water surface, then any small disturbance is dynamically unstable, but the amplification rate is very slow. The amplification factor in Miles's theory depends on the shape of the wind velocity profile and on the ratio of the wind component U along the direction of travel of the waves to the phase velocity c of the waves.

The Miles instability mechanism gives a rate of growth proportional to the magnitude of the disturbance already present so that the wave height is an exponential function of time. The resonance mechanism is independent of the waves already existing, and provides a linear rate of growth of wave energy. If the wind begins to blow over an initially calm sea the resonance from the atmospheric pressure fluctuations will give rise to a linear rate of growth which will, however, change to an exponential rate as the waves become large enough for the instability to take effect. However, for waves travelling at about the same speed as the wind, the resonance mechanism is operating at its best and the amplification rate of the instability is very slow. Recently Miles³ has given the combined effect an analytical form. An interesting result from the analysis is that if the waves start from rest then, for a given frequency and wind profile, the time elapsed until the transition between resonant and unstable growth is independent of the magnitude of the atmospheric pressure fluctuations. Of course the amplitude of the wave motion is proportional to the pressure fluctuations, but the transition time is a function only of the shape of the velocity profile and the ratio U/c .

Phillips⁴, assuming initial conditions of rest, calculated this transition duration as a function of the wind profile and U/c ; with a wave disturbance already existing, when the wind begins to blow, the time required for transition was decreased.

This summary of the present state of the theory showed that there were a number of important questions outstanding. Miles' ³ theory assumes a simple addition of the effects due to atmospheric turbulence and the airflow over the wavy surface but there may well be some interaction; he also assumes a logarithmic wind profile which Stewart⁵ certainly questions—and Dr. Phillips himself knew of many wind profiles over the sea which were certainly not logarithmic. There is the added point that when the transition duration is attained, the wave amplitudes may already be so large that the amplification factor calculated, assuming infinitesimal amplitude disturbances, may be in serious error. In spite of these questions a number of predictions from the theory had been borne out experimentally, as explained later by Dr. Phillips.

Dr. Phillips went on to point out that the wave growth by resonance and instability was limited by the waves breaking and forming white-caps because the particle accelerations cannot exceed g ; at this breaking stage the energy is lost from the wave system to turbulence in the water. The mathematics of the process was discussed by Phillips⁶ and expressions for the frequency spectrum and the two-dimensional wave-number spectrum were obtained for the limiting equilibrium or saturation state when breaking of the waves occurred. There had been good experimental support for these relations by measurements by Burling⁷ taken on Staines Reservoir, Middlesex; on the open ocean as a result of the Stereo-Wave Observation Project⁸ and by the National Institute of Oceanography group (Longuet-Higgins, Cartwright and Smith⁹) and by

small-scale experiments by Cox¹⁰ and Hicks¹¹. Dr. Phillips went on to consider the implications of these theories to the observation of ocean waves, to what extent the predictions are borne out by present measurements and what new observations might be made to provide further tests and further insight into the subject. He showed how one test of the theory was to check the identification between the frequency at which the steep forward face of the frequency spectrum is found at a particular duration and the frequency undergoing transition—when the wave amplitude grows rapidly. Phillips and Katz¹² had examined a number of observational spectra and found, as was expected, that the transition occurs not later than the theoretical values given by the Phillips'⁴ curve. This comparison was promising but hardly convincing since it meant attributing the premature transition to a more rapid rate of growth, to the existence of an initial wave state of low energy which, though undoubtedly present, was not measured.

However, a further prediction from the theory provides a more critical test. This is that the transition occurs for a given frequency first for the components travelling in the direction of the wind, so that the observed frequency of the steep forward face of the spectrum is strictly the transition frequency for components travelling in the wind direction. Components with the same frequency but travelling at an angle to the wind will not yet have undergone transition, so that the directional distribution of frequency components near the spectral peak should be strongly oriented towards the wind direction. At a slightly higher frequency, transition will have occurred over a range of angles and the directional distribution should be much broader. Some of the results of Lonquet-Higgins, Cartwright and Smith⁹ suggest this is so, as do casual observations at very short fetch and duration but definitive measurements have yet to be made. If the fetch and duration are large an appreciable part of the wave energy may be contained by components travelling at about the same speed as the wind, when, as shown earlier, the resonance mechanism is predominant. The wave energy should thus show directional maxima at angles $\pm \cos^{-1}(c/U)$ to the wind. The Stereo-Wave Observations Project⁸ results show this expected bimodal distribution. However, the meteorological conditions were not well defined and there is some uncertainty in the wind field. Further evidence for the existence of directional maxima is given by the Longuet-Higgins *et alii*⁹ experiments on a pitch and roll buoy.

Dr. Phillips also mentioned that another verification of the theory was to test the accuracy of a relation between the mean square surface displacement and the dominant frequency of the wave field, and this had in fact been discovered empirically by Hicks¹¹ in his observations of wind waves on a pond.

Mr. Cartwright of the National Institute of Oceanography emphasized the importance of this theoretical work on wave generation by Phillips and Miles, which gives a completely new look to the problem of practical wave forecasting in terms of meteorological data. It was hoped that these theories would eventually form a basis for forecasting methods which will supersede the crude existing methods with their many inconsistencies and failures. The National Institute of Oceanography is working on research in interpreting ocean waves in terms of these theories, but unfortunately it is a very difficult and slow process; the need is to measure directional spectra of waves in the open ocean

and this involves complicated instruments recording many wave characteristics simultaneously, which can only be handled by experts, and large quantities of data to be processed by electronic computer. Sufficiently simple meteorological conditions for direct testing of theoretical ideas are rare and too much time cannot be demanded of those on board a ship, or of skilled technicians, in order to wait for such conditions. The final fruits of this pioneer work of Phillips and Miles will come only after a long period of research, and greater effort could be applied to this research with advantage.

Mr. Lumb pointed out that Darbyshire¹³ had stated, in a recent paper, that a fully developed sea disturbance occurred after a period of 12 hours. He also mentioned that there was some theoretical basis for the logarithmic wind profile over the sea, but the sea is often colder than the air and there are many occasions when a logarithmic profile is not applicable.

The Chairman mentioned the long-term project being operated by Imperial College at Lough Neagh in Northern Ireland; this work had shown that there were many occasions when a non-logarithmic wind profile occurred. The height of observation in these experiments was over the range one to 16 metres and with wave amplitude up to one metre or more it was not possible to measure the wind profile below one metre. Consequently it was very difficult to test any assumption about the nature of the flow at levels below that at which the wind speed was less than the wave speed, as referred to by Dr. Phillips. *Burling's*⁷ work on Staines Reservoir involved a fetch of the wind up to one kilometre; in the Lough Neagh work there are fetches up to 25 kilometres.

Sir Graham Sutton drew attention to a similarity between one of the equations in Dr. Phillips' detailed presentation (involving the ratio of the second and first differential of velocity) and von Karman's definition of the mixing length in turbulence. He wondered what the relationship was to the normal turbulence theory in a sheared fluid. *Dr. Phillips* said this point had not so far been considered. He agreed with Sir Graham Sutton that a large value of this ratio meant a small mixing length and hence fine-grained turbulence. *Mr. Charnock* of SACLANT Research Centre, La Spezia, Italy emphasized that in any observational programme the structure of the wind field would need to be known at least as well as that of the wave field. Laboratory experiments could perhaps provide useful indications.

Exchange of energy across the ocean-atmosphere interface

Mr. D. H. Johnson, in opening the afternoon's proceedings by an account of the "Exchange of energy across the ocean-atmosphere interface", began by expressing the keen interest of the Climatological Research Branch of the Meteorological Office in this subject. It was well known that radiative processes by themselves result in a net atmospheric heat loss. This heat loss is made good by the turbulent transfer of energy from the earth's surface. Calculations have shown that much of this energy is transferred by evaporation taking place over the sea. Thus the importance of energy exchange across the interface to the thermally-driven atmospheric circulation is well established and well recognized in meteorology.

Mr. Johnson first illustrated the order of magnitude of the principal components in the energy exchange, namely the total flux of short-wave radiation,

direct and diffuse, the net flux of terrestrial long-wave radiation at the sea surface, the heat lost by the sea due to evaporation and the flux of sensible heat across the interface, by referring to typical values (Hay¹⁴ and Shellard¹⁵) of all these components for the ocean weather station "J" ($52\frac{1}{2}^{\circ}$ N, 20° W).

He went on to discuss the significance of the distribution of the energy exchange components over two or more oceans according to the computations of Jacobs¹⁶ for the North Atlantic and North Pacific, Budyko¹⁷ for the world's oceans, Albrecht¹⁸ for the Indian and Pacific Oceans and Privett¹⁹ for the oceans of the southern hemisphere. Neglecting secular change of the mean temperature of the oceans and the flux of heat from the interior of the earth, the mean annual net gain of radiation by the oceans as a whole, at the sea surface, must be balanced by the net loss due to evaporation and transfer of sensible heat. Owing to the poleward transport of heat by ocean currents, this balance is not maintained regionally and, for months or seasons, the heat stored by the oceans has to be taken into account. The seasonal and annual studies are generally thought to give the correct order of magnitude of the energy components and which regions of the oceans are generally effective as sources of energy for driving atmospheric circulations. The next meteorological requirements are for studies—none of which have so far been made—of energy exchanges on scales of days or weeks, which studies would be relevant, of course, to medium- and long-range forecasting problems and for providing the data to specify heating functions in numerical forecasting. There is a feedback with the ocean in that such studies of the atmospheric circulations might well call for a parallel treatment of the ocean.

Mr. Johnson explained how in the absence of sufficient direct measurements of solar radiation received at the sea surface various empirical formulae had been deduced in which such factors as cloudiness and sunshine were considered. There were no grounds, however, for assuming that the available formulae would give reasonably accurate estimates of the total solar radiation during periods of days, or weeks, when persistent circulation types prevail. Fortunately several years' total solar radiation measurements are now available for ocean weather stations "I" (59° N, 20° W) and "J" ($52\frac{1}{2}^{\circ}$ N, 20° W). Lumb (unpublished) has already made a preliminary examination of hourly fluxes in relation to cloud amount and type during 1960. The results of such studies might be inapplicable to some areas of the ocean due to lack of data, but they might at least be applied over a band of the Atlantic. The albedo of a water surface for direct solar radiation depends upon the altitude of the sun. Budyko²⁰ gives a table containing values of the average albedo for total solar radiation, expressed as a function of latitude and month; at 50° N the values range from 0.16 in January to 0.06 in June. Jacobs¹⁶ and Privett¹⁹ used somewhat lower values of the albedo due to Schmidt,²¹ the annual mean varying from 0.033 at the equator to 0.058 at latitudes 60° , but according to Laevastu²², who gave actual measurements of albedo obtained on U.S.S. "Rehobot", there was an error in Schmidt's calculations which resulted in the albedo being underestimated. Laevastu's data are in better agreement with Budyko's estimates than with Schmidt's, although they imply that even higher values (0.10 perhaps) might be applicable at 50° N in summer, over the ocean. Most measurements of the reflected radiation have been made over reservoirs and lakes.

Several writers remark that the effect of waves at sea is to increase the amount of radiation reflected, but quantitative allowance has been made only by Hay¹⁴ and Shellard¹⁵. When the sea freezes the albedo is greatly increased, being 0.5 for sea ice or 0.8 for ice covered with fresh snow according to Sverdrup²³. In the absence of much needed measurements of long-wave radiation at sea a variety of empirical formulae and constants have been derived for estimating the effective back-radiation, based on measurements made over land. Failing such direct measurements it would be profitable to relate values computed using radiation charts and the weather ship radiosonde ascents, to the surface observations, so that estimates might be made, at least over the main Atlantic shipping lanes, for use in shorter-period energy balance calculations.

Mr. Johnson then considered the exchange of latent and sensible heat by turbulent transfer and described the energy balance method used by Jacobs¹⁶, and later by Budyko²⁰, Hay¹⁴, Privett¹⁹ and Shellard¹⁵, to compute the average seasonal evaporation from the oceans. Since this is a large and important component of the energy exchange it is unfortunate that rough and ready methods have to be used for its calculation. Measurements of evaporation from pans aboard ships have been made, but are of doubtful use, because their relation with evaporation in the sea is difficult to assess. Laevastu²² considered that a reduction factor of 0.65 should be applied to the measurements to make them representative of evaporation from the sea; he gave an empirical formula for evaporation based on wind speed, vapour pressure at the sea surface and vapour pressure at a known height above the sea surface and quoted a similar formula due to Penman²⁴.

Mr. Johnson then described how the energy exchanges across the interface could be computed from the energy balance of the atmosphere and, in particular, mentioned the calculations of Clapp²⁵ for the normal winter heating in the lower part of the troposphere over the northern hemisphere by the thermodynamic energy equation and by the heat balance method; the difference between the derived distributions by these two calculations is, however, too large for the method to have any practical value as yet and in Clapp's opinion there are large errors in the values computed by thermodynamic energy equations due to neglect of the eddy terms and errors in the computed vertical motions. Dr. Tucker of the Climatological Research Branch is at present working on methods of computing the terms in the thermodynamic energy equations more accurately, in order to derive the patterns of heating for some typical circulation states.

In conclusion Mr. Johnson, following Houghton²⁶, mentioned that the additional storage of heat or heat deficit, represented by persistent sea temperature anomalies of order one or two degrees Celsius, can be of great importance to the atmospheric circulation. The mean amplitude of the annual variation of sea temperature through the top 100 metres, to the west of the British Isles, is about 4.5° C, which corresponds to a storage and release of 45,000 calories/cm², and anomalies of one or two degrees, if they extend to any depth, must represent a sizeable additional heat storage or deficit. The possibility has recently been considered in the Climatological Research Branch of using bathythermograph observations to study the vertical extent of sea temperature anomalies, whether

they are produced in depth by persistent atmospheric circulation types, rather than by the independent action of ocean currents and, particularly, what energy they put into the atmosphere during their life. However, an examination of bathythermograph records indicates unknown changes in calibration, which differ at different depths. There is a need for the accuracy of the bathythermograph observations in depth to be thoroughly tested, and for the true short-period random fluctuations of ocean temperatures to be measured at a fixed location. It is suggested that both purposes would be served by making a series of simultaneous soundings with a bathythermograph and the temperature-depth recorder recently developed at the Fisheries Laboratory, Lowestoft (Booker²⁷) for which an accuracy of 0.1°C or better is claimed.

Dr. Robinson pointed out the importance of measuring solar radiation and the radiation balance at the sea surface. During the I.G.Y. solar radiation had been measured at some 400–500 land stations but, at sea, the only observations were at the British ocean weather ships. If detailed observations are really required then every ship carrying meteorological instruments should also have a solarimeter—these are particularly easy to use in tropical seas. Budyko's atlas¹⁷ shows the zonal distribution of the radiation balance, but there is a discontinuity between land and sea over tropical and subtropical seas which has yet to be confirmed by measurement. In other respects the I.G.Y. observations, just mentioned, agreed with Budyko's atlas. *Mr. Charnock* thought that the major difficulty was the unsystematic nature of the observations of radiation. Weather ships apart, they were made sporadically and on random tracks. The number and the quality of marine meteorological observations was insufficient. Serious thought should be given to other observing systems without further delay. *Cdr. Frankcom* said that when the National Institute of Oceanography had offered to make meteorological observations on board *Discovery* he had suggested that solar radiation and net flux of radiation be measured. Such observations had not been considered so far for merchant ships, but he could certainly pick out suitable ships to do this work.

The Chairman stated that *Mr. Johnson's* paper presented two main problems. The climatic problem (Jacobs/Budyko) was very roughly solved, but the variation of heat balance in space and time from day to day and week to week was a very different problem. *Dr. Robinson* stated that satellites would yield measurements at the top of the atmosphere and ordinary radiation measurements can be made at the surface, but there must be sufficient coverage.

Mr. Sawyer wondered how the input of heat from the sea was to be introduced into the computations of the general circulation and what happens when the climate changes. The formula shown in the detailed presentation (due to Jacobs¹⁶) depends on sea and air temperatures which are not basic variables. If the sea is advecting more heat what would the heat transfer be? For dynamical calculations in the atmosphere a representative temperature near the surface is required in both air and sea, but it is not certain at what depth it should be; certainly the height in the air must be greater than that of a ship's height over the sea, and the height required for consideration certainly varies in different meteorological situations. *Dr. Ludlam* pointed out that the temperature would vary according to the distribution of cumulus cloud. *Dr. Deacon* said that oceanographers, like meteorologists, are interested in the climatology of the oceans. It even has some bearing on the problem of storm surges described

by Dr. Rossiter earlier in the programme since mean sea level fluctuates by a matter of inches from year to year and over the past 100 years shows an upward trend of about six inches. This begins to be large enough to be important to engineers as well as climatologists. From this and many other points of view it would be useful to know more about secular changes in temperature in oceanic squares where there are sufficient ships' observations and it would be useful if the Meteorological Office could provide facilities for more studies like those made by the late P. R. Brown^{28,29}. It would also be useful to have better knowledge and understanding of changes in the large ice-caps which would have a catastrophic effect if they were to melt substantially. There are too few oceanographers and meteorologists working on marine problems, and our ships continually crossing the oceans ought to have more ambitious recording instruments.

General circulation of the oceans

Mr. Crease of the National Institute of Oceanography, in introducing the last subject of the day—the “General circulation of the oceans”—pointed out that although the equations of motion of atmosphere and ocean were basically similar the boundary conditions were certainly not and, in particular, the oceanic longitudinal boundaries prevent the formation of zonal flows except, in a somewhat restricted sense, in the Antarctic. The energy supply of the oceans is almost entirely in the surface layers through the surface winds, by absorption of solar radiation and by exchange of heat with the atmosphere. Resulting from this the physical structure of the ocean is generally typified by a strong thermal gradient (thermocline) in the upper 1000 metres (and usually a salinity gradient also) of high stability while in greater depths the stability is low. He went on to discuss the circulation under four headings, the wind-driven circulation, thermo-haline circulation, Antarctic circumpolar current and transient flux motions of the deep water.

In view of the stability and location of the energy sources the most intense wind-driven circulation is to be expected in the upper layers. In central oceanic regions the flow is diffuse and it is generally assumed that outside the shallow surface frictional layer, about 100 metres or so thick, the motion is essentially geostrophic. *Mr. Crease* showed how this led to a useful relationship between the meridional transport and the curl of the wind stress. Since all the world's oceans, the Antarctic apart, are bounded effectively at their northern boundaries the total meridional transport may be found from the wind stress curl—neglecting any transport from ocean to ocean through the Arctic. However, details of the wind stress over vast areas are not well known for at least three reasons: lack of coverage of the area, the difficulty of wind velocity measurements and the deduction of U^* (friction velocity) from the observations.

Mr. Crease mentioned the difficulty that this equation relating meridional transport and the curl of the wind stress, does not allow for there being no mean net flow out of a closed basin. One solution of this problem by Stommel³⁰ Munk³¹ and others deals with lateral friction but neglects relative vorticity; this leads to the interesting conclusion that a frictional boundary current (by itself) is possible only on the western boundary—the presence of strong western currents is an established fact, e.g. Gulf Stream, Kuroshio. A second solution

(Charney³², Morgan³³) which considers the vorticity but not friction is consistent with the observed motion in low latitudes. Possibly because the frictional theory was the first to appear and gain acceptance, the possibility of eastern boundary currents has been somewhat neglected. Recently Carrier and Robinson³⁴ have discussed a full inertial theory which clarifies the situation. Their results lead to the interesting conclusion that there must be a strong zonal jet at the latitude of maximum zonal wind stress gradient. As a dissipating mechanism for the energy input they introduce narrow frictional boundary layers embedded in the inertial layers and further find that the region where the western boundary current joins the zonal jet must be a region of particularly large turbulence. It is just about here that the Gulf Stream appears to become very unstable.

Mr. Crease went on to show what could be deduced regarding the flow of currents from a knowledge of the temperature and salinity variation with latitude and depth and referred in particular to a diagram, obtained from the results of Wüst³⁵, which gave a simplified meridional section of the eastern basin of the Atlantic. Such temperature and salinity data are sufficient to define the topography of given pressure surfaces provided that the topography of the sea surface can be deduced by independent means. In principle the simple relationship with the wind stress curl, which he had mentioned earlier, is sufficient, together with the density distribution, to determine the sea surface profile but lack of knowledge of the wind stress curl and the problem of deciding what would be appropriate average processes make the method difficult to apply. Other indirect methods are used, which, with the continuity equation applied across a zonal section of the ocean, establish a plausible mid-depth level of no meridional flow (Wüst³⁵) which may be used as a reference depth for the estimation of the geostrophic flow in the interior. Mr. Crease outlined the thermo-haline circulation obtained by Stommel³⁶ and Stommel and Aarons³⁷ who extended the assumption that the flow is geostrophic, except at western boundaries, to a two-layer model of the ocean, which he presented in diagrammatic form. It is established that the only two major localized sources of deep water are the Antarctic bottom water and the North Atlantic deep water. There are no sources in the Pacific or Indian Oceans. Predictions, from this model, of boundary currents in the major oceans have so far been tested against observations only in the North Atlantic (Swallow and Worthington³⁸); a southerly flowing current was found under the Gulf Stream but later work suggests that a long series of observations will be required to establish the existence of a mean flow. The implications of inertial theories also remain to be considered. The boundary currents suggested by the model provide a possible explanation of the observed difference in surface flows in the North and South Atlantic; in the first case the wind-driven circulation is augmented by the upper layer of the thermo-haline flow and in the second it is diminished. The vertically integrated transport remains the same in both hemispheres.

The last two aspects of the circulation dealt with by Mr. Crease were those of the Antarctic, which provided the nearest approach to an unrestricted zonal ocean, and the recently discovered transient flux motions of the deep ocean. While observations are scarce in the Antarctic an outstanding feature is the Antarctic convergence (likened to the polar front—Eady³⁹) at which surface waters flowing with a northerly component (due to the zonal wind stress of the

westerlies) sink beneath water of subAntarctic origin (Deacon⁴⁰). A number of crossings of the convergence suggest that its position is stable to within a degree or two, so that perhaps the deeper waters exert the controlling influence upon it rather than the wind system (at the latitude of the convergence the deep water is rising over the north-flowing bottom water). The westerlies result in a general westward flow on both sides of the convergence as far south as 65°S where the prevailing easterlies give a reverse flow along the continental boundary. The dynamics are not well understood and Mr. Crease mentioned the different view of Stommel³⁶ and Wyrki⁴¹.

Finally Mr. Crease mentioned the important recent discovery, by measurements in the western Atlantic, of transient currents in the deep water with velocities of the order of 10 cm/sec; they appeared to have time scales of at least a week or two and space scales of the order of thirty miles (Crease⁴²) and are therefore at least one order of magnitude larger than the estimated mean flow, so that they certainly must be taken into account in considering the deep circulation in relation to the mean flow.

In reply to a query from *Dr. Sutcliffe* regarding the shape of the transient currents, *Mr. Crease* said the measurements were too few but with the present measurements there appeared to be no noticeable correlation in the east-west and north-south components of the transients; this matter certainly required further looking into as such currents might contribute significantly to the flux in deep water. Meteorologists could join in this study of the circulation and transfer at the sea surface.

Dr. Hunt pointed out that the thermal and wind-driven steady circulations are not the only significant mechanisms for energizing such currents. By virtue of the non-linear terms of the equations of motion, the tidal oscillations generate second-order currents which are functions of position. This is a three-dimensional extension on a tidal scale with Coriolis terms included, of the work on wave drift currents by Stokes⁴³ and more recently by Longuet-Higgins⁴⁴. These tide-induced currents can be calculated from co-tidal and co-range charts for each tidal constituent and in many areas contribute significantly to the observed circulation. There are also small vertical components vanishing naturally at the surface and at the bottom, but at mid-depths they are of the order of magnitude of the flow through the thermocline quoted by Mr. Crease, but not always of the same sign. They result in circulations in vertical sections similar to the results of Rayleigh⁴⁵ and Longuet-Higgins⁴⁴ for small-amplitude two-dimensional standing waves. As an example, a calculation of the tide-induced bottom currents in the North Sea produces a current chart which is very similar to the observed surface current chart but with the velocities reduced by 30–50 per cent. *Mr. Crease* stated that transient currents give similar motion but he was surprised to learn that they gave so large an effect.

The Chairman asked what was the order of the tidal currents in the open sea and *Mr. Crease* stated that this was 10 cm/sec. *The Chairman* wondered whether there was any other technique for studying transient currents besides that used by Swallow³⁸; experiments could be made at the ocean weather ships. *Mr. Crease* said that at the National Institute of Oceanography they had considered the possibility of studying a 100-kilometre square of ocean with uncomplicated topography; there would be moored buoys with bottom instruments and also an above-surface buoy recording the heat balance. *Dr. Tucker* said that in some

ways the general circulation of the atmosphere appears simpler than that of the oceans, but perhaps this is merely because observations are easier to make. A profitable line of inquiry in atmospheric studies has been the study of the amount of potential energy to kinetic energy conversion necessary to maintain the flow against the dissipating effect of surface friction and the direction of transfer between these two energy forms in the scale of eddy size. However, all motions of meteorological interest in the atmosphere are thermal in origin, whereas in the ocean frictional, thermal and saline effects are all important. Is it then possible, or better profitable, to formulate similar questions in oceanography? This approach could be important as regards the existence and effects of the transient systems mentioned by Mr. Crease. In the general circulation of the atmosphere we have been able to study energy conversion and energy fluxes with reference to three broad scales of motion: meridional motion, "standing" eddies and "local" eddies. The latter presumably correspond to possible transient oceanic systems, while "standing" eddies are analogous to major ocean currents. Oceanic observations obviously do not exist in sufficient accuracy, quantity or distribution in space for similar detailed examinations; but can the principles of this type of study be applied qualitatively to see if transient systems are necessary from dynamical or energy considerations? Mr. Crease said they would like to study the dynamics of such a limited area as he had mentioned but he wondered if the transient currents were on this scale. Dr. Sutcliffe wondered why the name "transient" had been used—are they there all the time? Mr. Crease said that when the National Institute of Oceanography were working off Bermuda last year there was one trajectory for a period of a week, say to the north-east and a week later in the same area the current might well be to the south-west (the investigation was made by having floats at certain depths, some currents were at 2000-metre depths and others at 4000-metre depths). His impression was that the Lagrangian scale was larger than the Eulerian.

Mr. Jones and Dr. Ludlam pointed out these variations also occurred in atmospheric motions, e.g. as recorded by smoke puffs. Dr. Sutcliffe asked whether these transient currents were geostrophic. Mr. Crease said they were usually, but not always. One example was when the 2000-metre speed was half a knot and the 4000-metre speed was one knot, the pressure gradient showing nothing like this change. Dr. Ludlam said we cannot continue to deplore the lack of data, there must eventually be complete synoptic networks. Mr. Tunnell wondered why more use was not made of the nine ocean weather ships. In discussions with Dr. Swallow of the National Institute of Oceanography it appeared feasible to survey the bottom of the oceans under the ocean weather ships and then to do soundings with floats up and down. Mr. Crease said they would have a similar problem with *Discovery* in the Indian Ocean Expedition; the proposal was to moor buoys and use notable points on the sea bottom as fixed markers.

Mr. Charnock drew attention to the difficulties which arise in present theories of the main thermocline if baroclinic disturbances are transferring heat upwards.

Dr. Angell remarked that oceanographers use trajectory methods first and consider synoptic methods later, whereas meteorologists have gone the reverse way. Mr. Crease said he would welcome the meteorologists' long experience in this general problem.

Mr. Crease wondered whether radiation thermometers would be of use to the oceanographers in their general study. Dr. Murgatroyd said that the Meteorological Research Flight had made no such measurements but measurements from the air had been made under the guidance of the Woods Hole Institute. Mr. Hay gave a few details of the American airborne radiation thermometer. Although this instrument is equipped with an improved bolometer it is still in the development stage and calibrations before and after flight trials have shown that uncertainties in readings are of frequent occurrence.

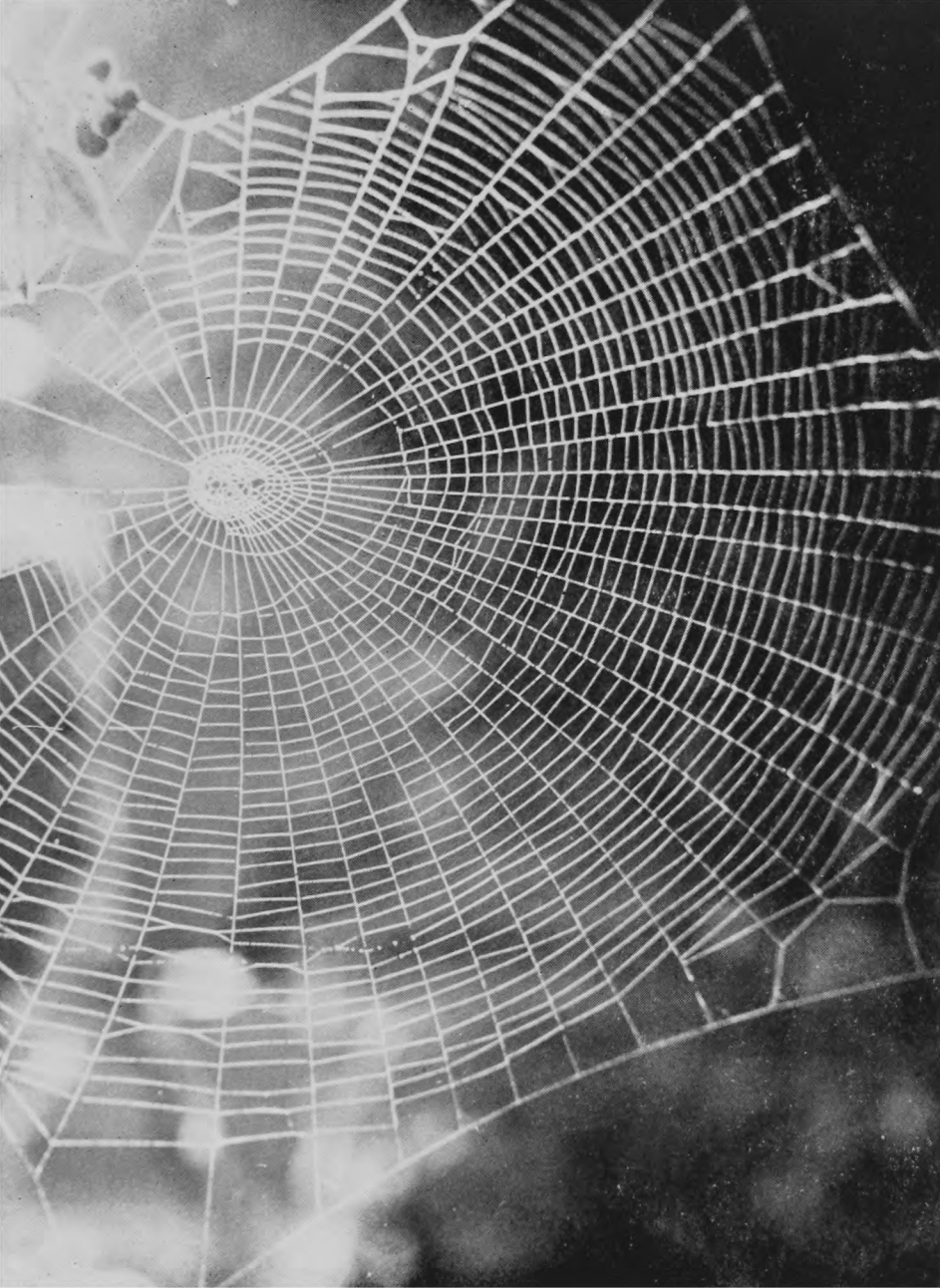
The Chairman summarized the day's discussion by stating how useful it had been for the oceanographers and meteorologists to come together to discuss the various problems which had been outlined in the four topics. The present formal meeting should lead to many informal future meetings between those concerned with similar problems, e.g. into the use of electronic computers for solving the equations of motion.

Dr. Sutcliffe, on behalf of the Meteorological Office, thanked all concerned for the work they had done in preparing and giving the papers and contributing to the discussion. He would be very pleased to arrange for any co-operation which the Meteorological Office could give in furthering research into this most important problem of the "Interaction between the atmosphere and the oceans".

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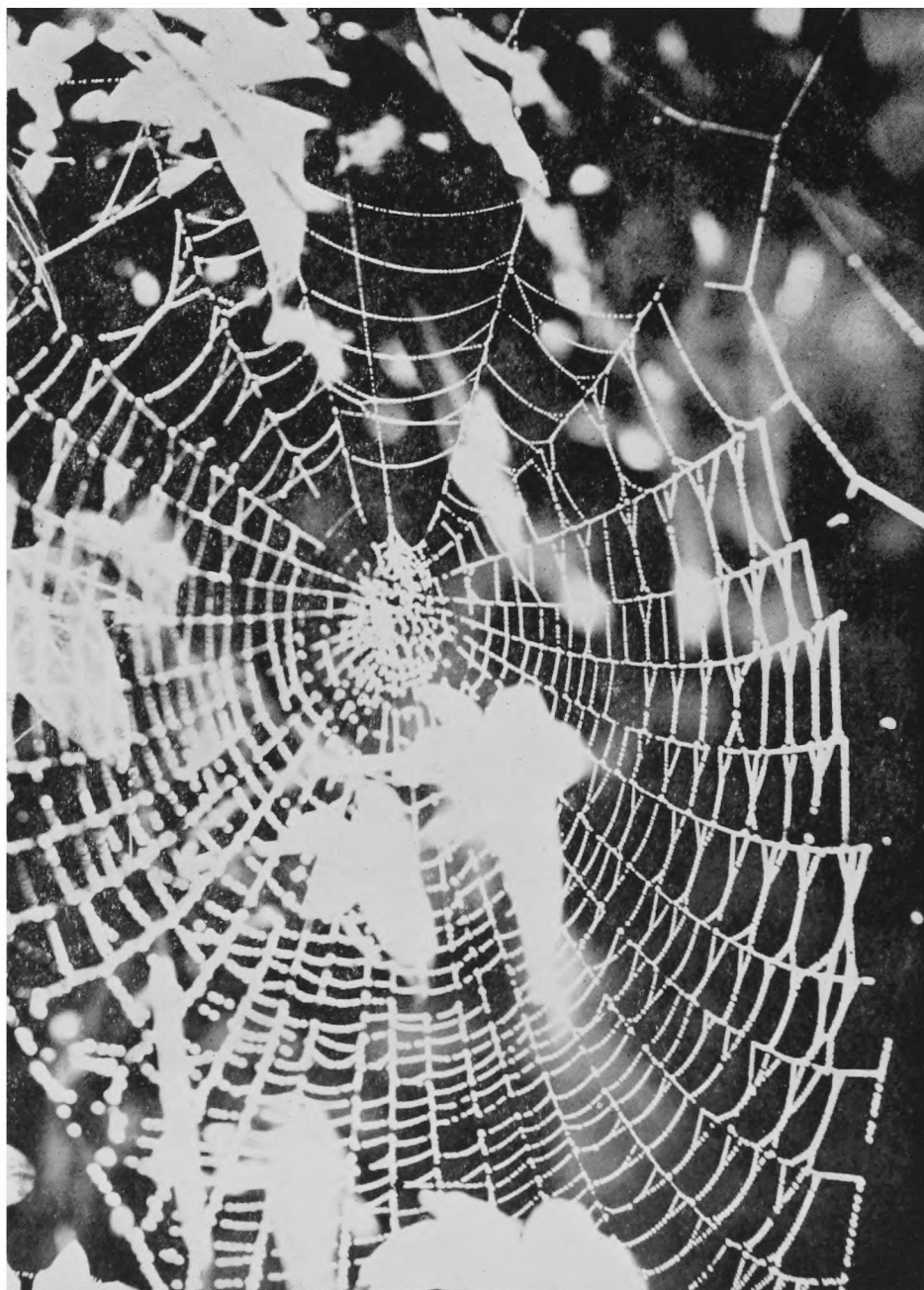
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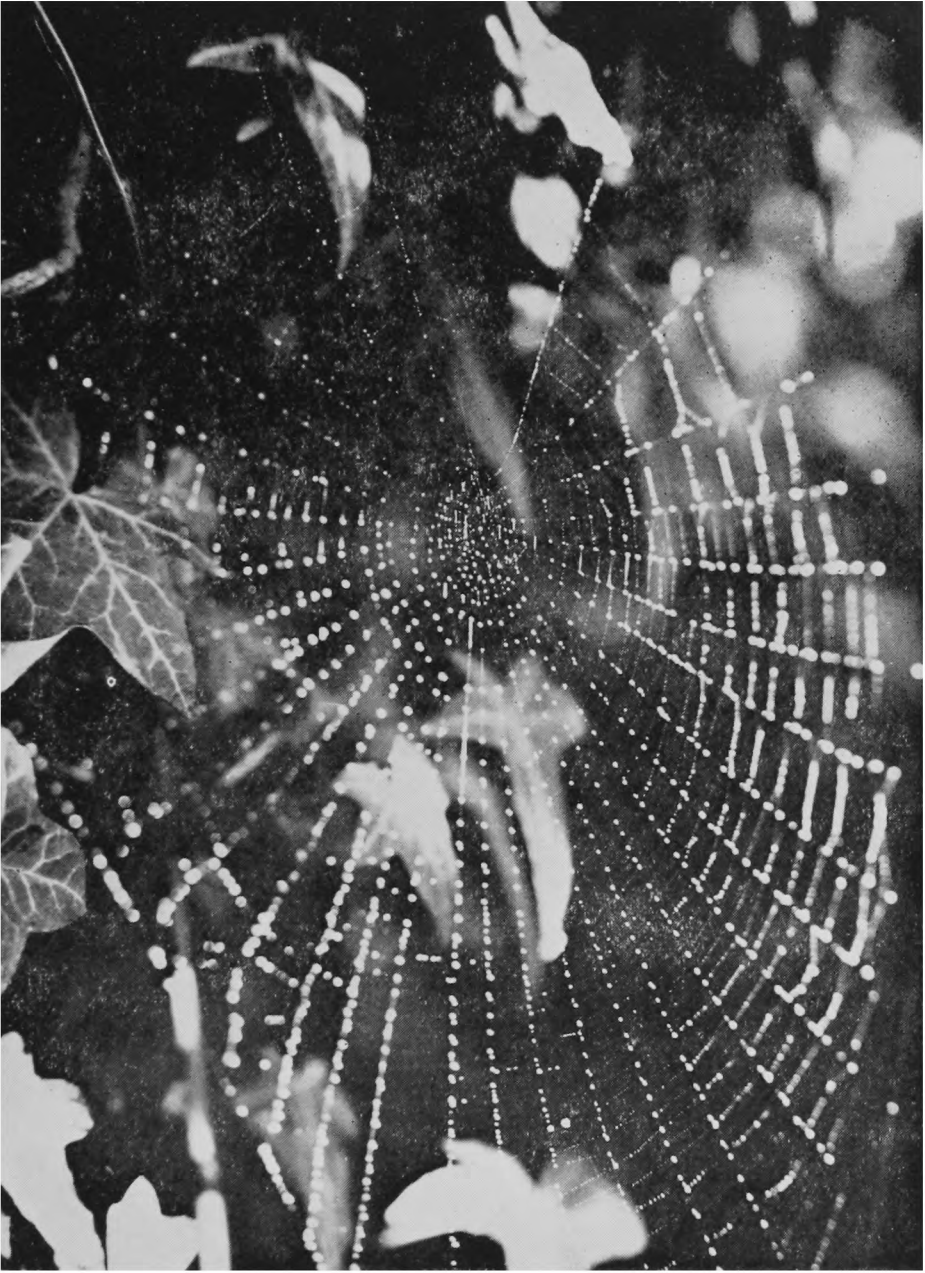
Photograph by R.K. Pilsbury

PLATE I—DROPLET-LADEN COBWEB AT 0705 GMT, 31 AUGUST 1961
(see p. 239)



Photograph by R. K. Pilsbury

PLATE II—DROPLET-LADEN COBWEB AT 0710 GMT
(see p. 239)



Photograph by R. K. Pilsbury

PLATE III—DROPLET-LADEN COBWEB AT 0730 GMT
(see p. 239)

To face p. 225



Photograph by R. K. Pilsbury.

PLATE IV—DROPLET-LADEN COBWEB AT 0735 GMT
(see p. 239)

WORLD METEOROLOGICAL ORGANIZATION

Third Session of the Commission for Synoptic Meteorology

By V. R. COLES

A little more than four years after its second session in New Delhi, the World Meteorological Organization Commission for Synoptic Meteorology (CSM) met for the third time on 26 March 1962. The conference was held in Washington and lasted for four weeks, with a total of over 70 representatives from 40 countries. The United Kingdom delegation consisted of Messrs. Coles, Starr and Harding from the Meteorological Office and Instr. Capt. Burnett from the Naval Weather Service.

All meetings took place in the International Conference Suite of the State Department Building which has recently been completed and is designed and fully equipped for such gatherings. The Assistant Secretary of State for International Affairs, Mr. Harlan Cleveland, welcomed the delegates on behalf of the United States and the conference then settled down to its work under the presidency of Mr. P. Kutschenreuter of the United States with Dr. S. N. Sen of India, as his deputy.

As at previous sessions, three committees were established. One was concerned with codes, another with telecommunications and the third with matters falling under neither of these headings. A number of items were inevitably considered by more than one committee.

There were long debates concerning proposed changes in both surface and upper air codes but it was finally decided that, in view of the many difficulties and problems involved, there should be no major changes in codes for the time being. However, the Commission decided that the Working Group on codes should be re-established to make recommendations for changes in both surface and upper air codes in time for the proposed new codes to be tested by all Members of the World Meteorological Organization before the next session of the Commission. A few minor changes in codes were, however, agreed. It was decided that sections 1, 10 and 11 of TEMP messages should be exchanged internationally and that indicator letters within the TEMP messages are essential for purposes of forecasting by electronic computers. In the SYNOP code it was agreed that the height of the base of low cloud, reported in the fifth group, should *always* refer to the lowest cloud in the sky, and agreement was reached on the definition of a squall for reporting purposes under figure 18 of the present weather code. However, the Commission was unable to come to a definite decision concerning the use of the metric unit of metres per second in place of knots for reporting wind speed because it was felt that the conversion from metres per second to knots for aeronautical purposes, although an easy one to make, involved a risk of error. The Executive Committee was therefore requested to take the appropriate steps to resolve the conflict.

The Commission also considered the reports of the other Working Groups established at the second session of the Commission. The report of the Working Group on the Guide to Synoptic Meteorological Practices was considered to correspond to the needs expressed at the second session of the Commission subject to certain amendments in order to incorporate decisions adopted at the 1962 session of the Commission. However, the methods to be used for the reduction of pressure to mean sea level, which were recommended by the Working Group

on pressure reduction methods, were considered by members to be rather complicated and it was decided that it is premature, at present, to recommend any method of pressure reduction for universal use. The recommendations contained in the report of the Working Group which was set up to examine and define quantitatively the terms used to describe the intensity of meteorological phenomena were accepted in the main though it was realized that other Technical Commissions of the World Meteorological Organization may be affected by such changes and may wish to comment before they are introduced. The recommendations also affect the present weather code so that, even if they are accepted by other Technical Commissions, they cannot be introduced before the next session of the Commission for Synoptic Meteorology. One of the most interesting reports to be considered came from the Working Group set up to consider the synoptic use of meteorological data from artificial satellites. The Commission agreed with the recommendation of this Working Group that the desirable minimum frequency of observations over any given area for general synoptic purposes should be every six hours and within three hours of the actual observations. Furthermore, the Commission recommended that the Secretary-General of the World Meteorological Organization be requested to endeavour to organize seminars on the synoptic use of meteorological satellite data at various locations throughout the world. The report of the Working Group on the forecasting of hail, turbulence in clear air and in cloud, icing and dense cirrostratus clouds was published before the third session of the Commission in the form of four excellent Technical Notes—numbers 37 to 40 inclusive.

Apart from the re-establishment of the Working Group on code matters several other Working Groups were re-established, including those on meteorological satellites and networks. In addition three new CSM Working Groups were established—one on qualifications and training of meteorological personnel, one on long-range forecasting, and a joint Working Group with the Commission of Aerology on numerical prediction.

The telecommunications committee spent much of its time considering the distribution of data in the northern and southern hemispheres. Five stations are involved in the northern hemisphere and three in the southern hemisphere and arrangements to provide linkages between the two hemispheres with the aim of affording synoptic world coverage were also discussed. The large volume of telegraphic traffic engendered by the interchange of meteorological data and the still larger volumes envisaged in the future, including TIROS and NIMBUS satellite data, raises the question of the use of higher telegraphic speeds. No firm position could be taken on this matter at the third session of the Commission but there exists, fairly widely, the feeling that faster speeds should be operated as early as economically practicable. A good deal of time between sessions and in the Working Group on meteorological telecommunications has been devoted to the standardization of the format of meteorological messages. This is particularly important to the electronic processing of coded data, either with an editing and re-routing function or for analytical work such as numerical forecasting. The third session of the Commission approved, with small modifications, the proposals of the Working Group. In the fullness of time an approved version of the new format will appear in all teleprinter page copy within the Office. Simultaneously, outstations and, in particular, teleprinter collecting centres

will be requested to adopt with scrupulous care the same format in their transmissions to Bracknell, for the value of such a format resides almost entirely in its universal application.

Towards the end of the session Dr. S. N. Sen of India, was elected as the new President of the Commission with Dr. Logvinov, of the U.S.S.R., as Vice-President.

There was much appreciation for the hospitality of our American hosts who arranged sightseeing tours of Washington and Mount Vernon, a visit to the White House and a picnic at the Gambrill State Park in Maryland as well as tours of the Weather Bureau National Meteorological Centre and Meteorological Satellite Activity at Suitland, Maryland and the Goddard Space Flight Centre.

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FIVE-DAY MEANS AND EXTREMES OF MAXIMUM AND MINIMUM TEMPERATURE AT LONDON AND GLASGOW

By M. H. FREEMAN, O.B.E., M.Sc.

A standard programme has been drawn up for the processing of surface observations punched on cards. One of the items is concerned with five-day means and extremes of maximum and minimum temperatures. For each five-day period, 1-5 January, 6-10 January, etc. (omitting 29 February), the daily maximum temperatures in the ten years 1949-58 were listed in order of magnitude, and the mean of the 50 values was calculated. From the list were read off the highest and lowest values and also the tenpercentile (decile) values. (Ten per cent of the temperatures are greater than the upper tenpercentile reading and ten per cent are lower than the lower tenpercentile reading). Similar data were extracted for the daily minimum temperatures.

In Figures 1 and 2 are shown graphs of the mean, the extremes and the tenpercentile (decile) readings for London (Heathrow) and Renfrew Airports. As would be expected the extreme values show considerable irregularity; the period is much too short for any significance to be attached to the individual peaks and troughs. The tenpercentile lines are less irregular and give a useful guide to a forecaster of the range of values within which he can fairly confidently confine his forecast of maximum or minimum temperature. He should only make a forecast outside these ranges when he has good grounds for so doing.

The diagrams are published to illustrate the kind of results to be expected from ten-year means. Nevertheless the curves also show several features of general interest. In summer the range of values taken by the maximum temperature is greater than that for the minimum temperature, and in the winter the reverse is true. The rate of drop in maximum temperature in autumn is greater than the rate of rise in spring; and the rather small range of maximum temperature in autumn is interesting.

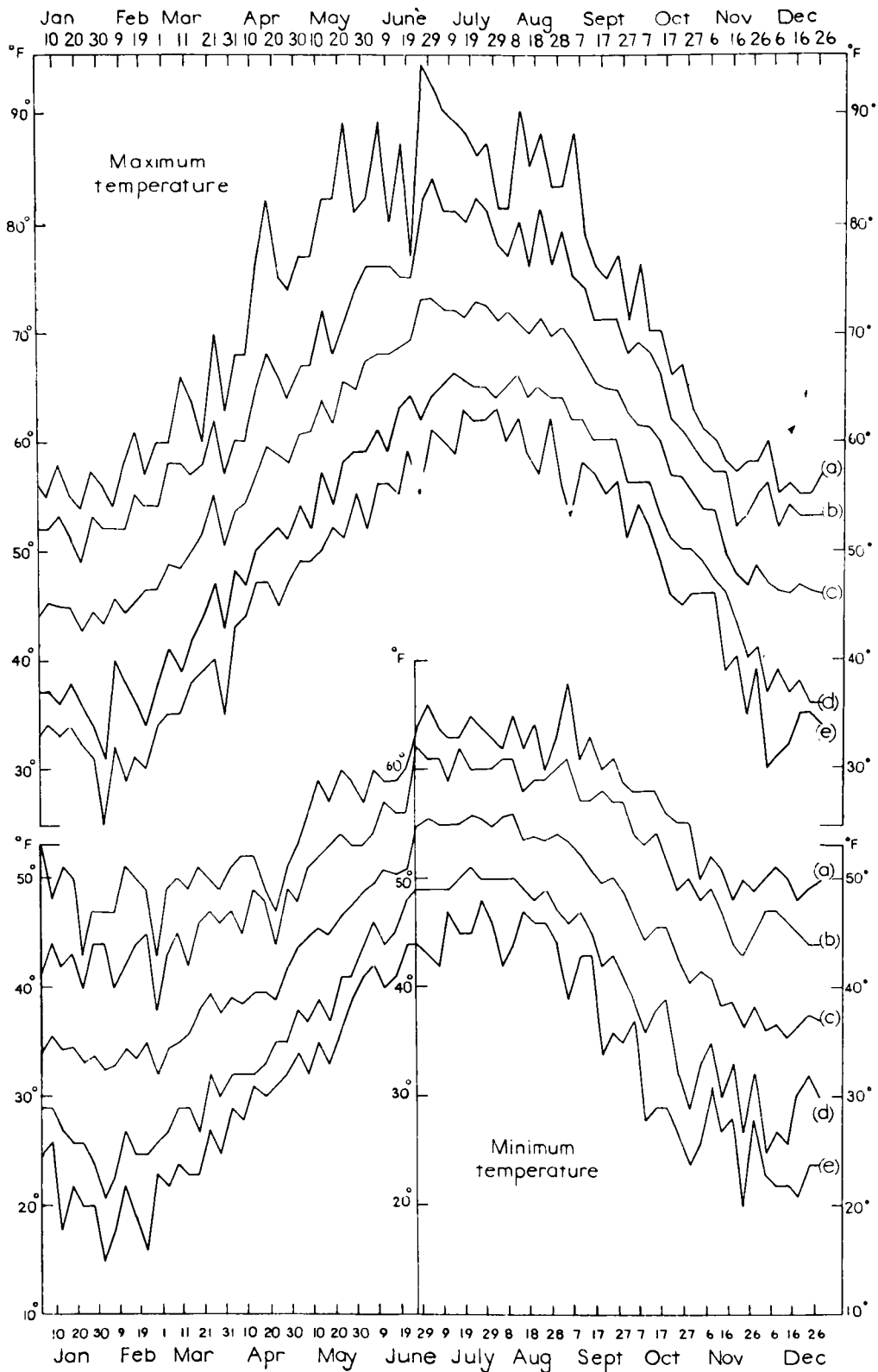


FIGURE I—FIVE-DAY MEANS, EXTREMES AND UPPER AND LOWER TENPERCENTILES OF MAXIMUM AND MINIMUM TEMPERATURE FOR LONDON (HEATHROW) AIRPORT, 1949-58

(a) upper extreme, (b) upper tenpercentile, (c) mean, (d) lower tenpercentile and (e) lower extreme.

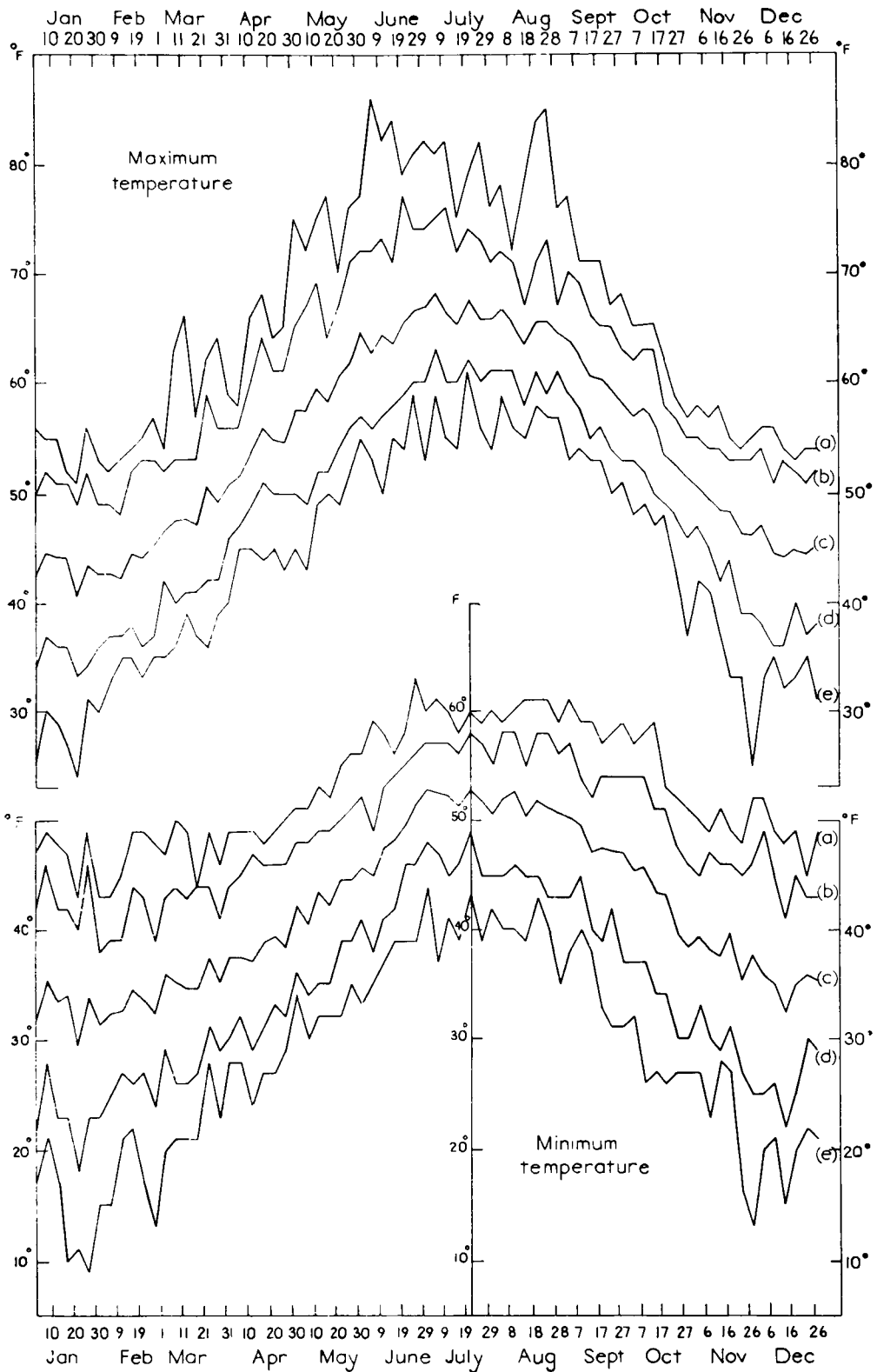


FIGURE 2—FIVE-DAY MEANS, EXTREMES AND UPPER AND LOWER TENPERCENTILES OF MAXIMUM AND MINIMUM TEMPERATURE FOR RENFREW AIRPORT (GLASGOW), 1949-58

(a) upper extreme, (b) upper tenpercentile, (c) mean, (d) lower tenpercentile and (e) lower extreme.

A LIGHTNING DISCHARGE TO A BALLOON AT CARDINGTON

By J. HODKINSON

An incident occurred at Cardington during the "Balthum" sounding at 0600 GMT on 14 December 1960, when a lightning discharge took place through the flying cable of the captive balloon and minor damage occurred to the recording equipment during conditions in which no other thundery activity was reported. The probable causes of the incident are discussed below.

During the 0600 GMT "Balthum" ascent on 14 December 1960, when the balloon had reached a height of about 2750 feet above ground, a blue flash was seen to jump from the steel flying cable to earth; at the same time minor damage was sustained in the recording equipment when a switch and two indicator lamps burnt out. No other damage to the balloon or instrumental equipment took place, and no personal injury occurred. At the time of the incident the weather was overcast with a moderate sleet shower in progress; prior to this time the night had been foggy with some very slight rain and drizzle. There were no other reports of lightning and no atmospheric were reported. A lightning flash counter installed at Cardington responded only to this single flash. At the time a high-pressure system over Scandinavia was linked through a ridge over the British Isles to another anticyclone near the Azores and an easterly airstream was maintained over Cardington. This airstream was unstable in the lower layers and was carrying some wintry showers from the North Sea into the Midlands. The Hemsby upper air soundings made at 2330 GMT, 13 December and 1130 GMT, 14 December, and reproduced in Figure 1, indicated that cumulus and stratocumulus cloud probably existed in layers up to about 6000 feet with occasional cumulus tops reaching to not more than 10,000 to 12,000 feet in association with showers. There was fairly extensive fog and low stratus below the main cloud layers. The lightning risk was forecast as "poor chance".

It is evident that an electric discharge occurred down the steel flying cable which the earthing system was unable to handle. There is inevitably a small resistance to earth so that temporarily the cable near the ground attained a high potential of sufficient magnitude for sparking to take place. The damage in the recording equipment was due either to a similar discharge taking place in the auxiliary recording cable or from induced currents generated by the large fluctuating currents in the neighbouring steel flying cable.

It is generally accepted that the main risk of lightning discharge to captive balloons occurs in association with the large space charges and the associated high potential gradients present in or near large cumulus or cumulonimbus clouds. Simpson¹ has examined the records of atmospheric electricity made at Kew during disturbed weather and has shown that very high fluctuating potential gradients were found in association with snow showers. It seems likely that during snow showers high potential gradients may occur in association with the space charges in cumulus of only moderate vertical extent and that these potential gradients may be approaching the same order of magnitude as those found near active thunderstorms where the cloud is usually of a much greater vertical extent.

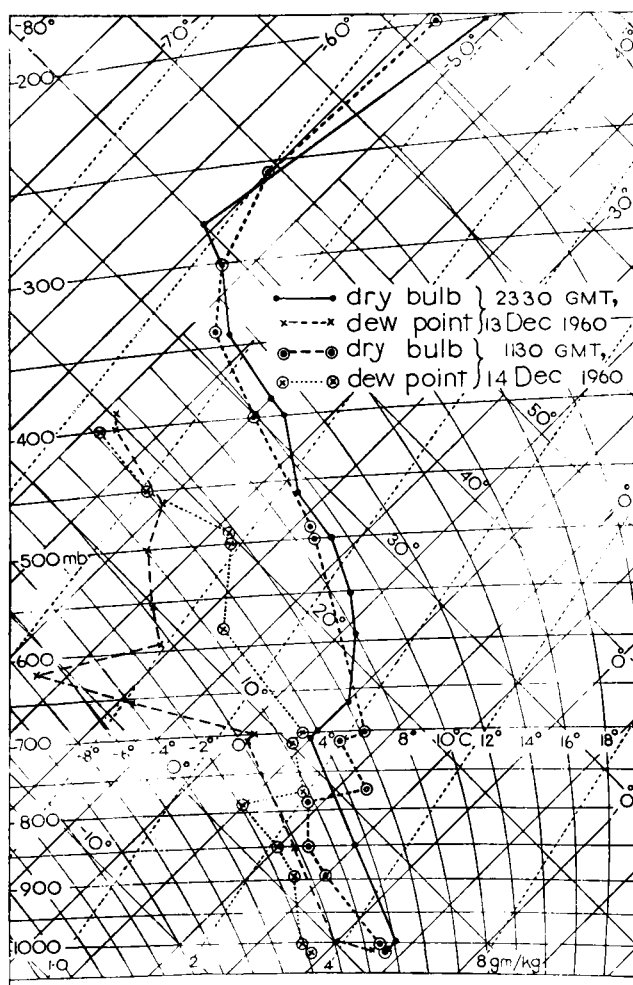


FIGURE 1—HEMSBY UPPER AIR ASCENTS FOR 2330 GMT, 13 DECEMBER AND 1130 GMT, 14 DECEMBER 1960

Davis and Standring² investigated the discharge currents found in the flying cables of captive balloons. They point out that the earthed flying cable, during this incident 2750 feet long, will short out an appreciable part of the gap between the cloud charges and the ground. Under these circumstances discharges to the balloon may occur from cloud charges which are too small or too widely distributed to produce lightning strokes to the open ground. The presence of the balloon may thus initiate lightning strokes where they would not otherwise take place and it is probable that this is the explanation of the incident at Cardington. It is probable that when precipitation is in the form of snow or sleet the risk of a similar incident may be greater than if it were in the form of rain showers. Two cases are on record where balloons were destroyed by lightning during snow showers but in each case a warning of high lightning-risk was in force.

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SOME ASPECTS OF THE FORMATION OF FOG OVER HIGHER GROUND

By W. R. SPARKS

Introduction.—The problem of forecasting radiation fog at stations above the general level of the surrounding countryside is a complicated one. Forecasters at aerodromes on higher ground were requested to study local variations in fog formation, and several hypotheses were put forward to explain the processes at work. A questionnaire was circulated to assist outstation forecasters to record observations, and to ensure that the data collected would be in a form amenable to statistical analysis. The questionnaire was designed to yield information on the formation of fog in valleys around aerodromes and on the deepening of the fog to affect the higher ground. A total of 81 completed, or partially answered, questionnaires were returned by eight stations. Sufficient data were obtained to test only one of the hypotheses statistically, but individual cases supporting other hypotheses were found.

Formation of fog in valleys.—It is supposed that on radiation nights saturation usually occurs first within a few feet of the ground and fog then forms there rapidly. However, on some occasions, probably mainly when an inversion is already present and the air is polluted, cooling is spread more uniformly through a layer several hundred feet deep and fog then forms more gradually through a deep layer. The observations given in Table I support this hypothesis.

	TABLE I No. of cases of gradual formation of fog	No. of cases of rapid formation of fog
Polluted air	13	6
Unpolluted air	2	16

The chi-squared test shows that the probability of this distribution occurring by chance, if pollution has no effect on fog formation, is less than 0.001.

Night cooling and fog in irregular terrain.—In the valleys and lower-lying areas within an area of moderate or strong relief, radiation fog may form in the usual way, but the low wind speed in the inversion layer and the increased density of the air may be such that the air is unable to surmount the neighbouring hillsides and is trapped in the valleys. When such stagnant pools of cold air have been formed in valleys, the air above them will continue to move under the influence of the large-scale pressure field (i.e., geostrophic wind) and the flow may indeed be stronger than during the previous day because of the reduced loss of momentum by turbulence. If the depth of the fog is less than the height of the hills this steady airflow will envelop the hilltops and the upper part of the slopes, and there will be little cooling in it because of its relatively brief contacts with the ground and it will be fog-free.

This hypothesis is supported by observations from Waddington and Swinderby on 1 November 1958. Waddington (231 feet above M.S.L.) and Scampton (215 feet above M.S.L.) are near the crest of the Lincoln Edge. The land slopes gently away to the east, but to the west there is a steep slope, with a drop of 150–200 feet on to the Witham–Trent plain. Swinderby (69 feet above M.S.L.) lies on this plain, about seven miles west-south-west of Waddington. At 0001 GMT on 1 November 1958 there was a ridge of high pressure over the

British Isles giving a north-westerly gradient wind over Lincolnshire. The surface wind at Swinderby became calm soon after midnight, and fog formed between 0100 and 0200 GMT at a temperature of 32°F; the minimum temperature in the screen was 29.6°F. At Waddington the surface wind was between west and south-west, 5–7 knots, throughout the night; there was no fog, and the minimum temperature in the screen was 33°F. There was never more than one okta of cloud at either station between midnight and dawn.

The steepness of the windward slope is a very important factor affecting airflow over a ridge or hill at night. A steep-sided valley is much more efficient in trapping cold air than a valley with gently-sloping sides, and it is supposed that the slow ascent of air up a gentle slope aids the formation of radiation fog.

An investigation was made locally at Scampton using data for the two years September 1953 to August 1955 inclusive. (Owing to the closing of Scampton, observations from Waddington were used for the last three months). In a second investigation use was made of data from Waddington and Swinderby for the three winters from November 1958 to February 1961 inclusive. Data from both investigations have been combined to give the result described in the following paragraphs.

There were 45 occasions when the surface wind across the Lincoln Edge had a westerly component and radiation fog formed at both high- and low-level stations. The average time of formation was 1.0 hours *earlier* at Swinderby than at the station on the Edge. There were 20 occasions when the surface wind across the Lincoln Edge had an easterly component and fog formed at both high- and low-level stations. The average time of formation was 0.8 hours *later* at Swinderby than at the high-level station.

These results are in accordance with the supposition that a steep slope to windward delays the formation of radiation fog at a high-level station, while a light wind up a gentle slope accelerates the formation of radiation fog at the top of the slope.

Characteristics of the airflow and effect on fog distribution.—The conditions of inversion and little turbulence on radiation nights are particularly favourable for the development of steady streamline flow over hills as described by Corby¹. Some of the characteristics of such flow in relation to the local

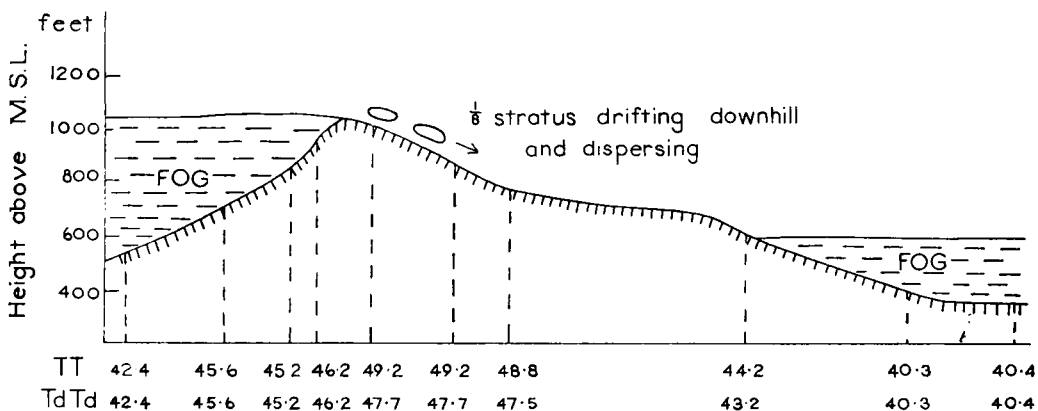


FIGURE 1—CROSS-SECTION OF VIEW EDGE ESCARPMENT SHOWING THE DISTRIBUTION OF FOG AND TEMPERATURE ON 25 SEPTEMBER 1960

TT = dry-bulb temperature in °F

TdTd = dew-point in °F

topography may have important effects on the fog distribution. Notable is the tendency for the flow to be strengthened on the lee slope of the hill, the wind blowing down the lee slope and following the ground contour. It may be supposed that lee slopes of hills will often be fog-free while the foggy stagnant inversion layer is increased in depth on the windward slope.

Observations supporting this hypothesis were made by Mr. J. E. Atkins on 25 September 1960 on the slopes of the View Edge escarpment in the vicinity of Craven Arms, Shropshire. The synoptic chart for 0600 GMT on 25 September 1960 showed an anticyclone centred over Northern Ireland, with a ridge extending south-east over Wales and southern England. The pressure distribution did not appear to favour any definite wind over Craven Arms. Figure 1 shows a cross-section of the fog and temperature distribution on the two slopes of the escarpment.

The main features of the observations made between 0618 and 0707 GMT were as follows:

(a) Conditions were generally calm except on the upper part of the dip slope where there was a wind of force 2 from west-north-west (i.e., down the slope).

(b) There was a difference of about 400 feet between the fog top over the scarp edge and the dip slope. Over the scarp edge the fog top was more or less level with the top of the escarpment, but patches were drifting over the crest and moving down the dip slope as small amounts of thin stratus which rapidly dispersed on descent.

(c) There was a difference of about 4°F between temperatures at corresponding levels on opposite sides of the escarpment, temperatures on the dip slope being the higher.

(d) There was a temperature inversion, on both slopes, of the magnitude that might be expected in the free air after a night of radiation fog.

A second run was made between 0840 and 0917 GMT as the fog was dispersing, mainly from the top downwards. On the eastern side of the escarpment (facing the sun) all that remained was mist at the lowest levels. On the western side, which was shaded by the escarpment, the fog top had lowered by some 300 feet. There was no longer a stronger wind near the crest than elsewhere—a very light wind (force 1) from the north-west affected all parts. The temperature contrast between the scarp edge and the dip slope not only persisted but extended down to the bottom of the slopes. The contrast was well illustrated by the fact that to the west of the escarpment lay an unbroken area of fog, whereas above the dip slope (facing the sun) convection had commenced and small cumulus clouds were forming. Above the mist and fog, visibility was very good.

Effect of the changing wavelength of lee waves on fog at a high-level aerodrome.—Under conditions of streamline flow the formation of lee waves is possible and this may cause variations in the depth of the foggy inversion layer to the lee of a ridge of hills.

The observations in Table II, made at Bovingdon on 7 December 1960, support this hypothesis.

It will be noted that each fall in visibility is accompanied by a drop in temperature and wind speed, while an increase is associated with an increase in wind speed and a rise (or reduction in the rate of fall) of temperature.

TABLE II

Time GMT	Wind deg/kt	Visibility yd.	Dry-bulb °F	Dew-point °F	amount	Cloud type	height (ft)	Remarks
1356	360/08	2200	39.1	38.5	$\frac{3}{8}$	St.	900	
1455	360/05	1800	37.8	36.3	$\frac{1}{8}$	Sc.	2,000	
1541	350/02	900			$\frac{1}{8}$	Ac.	12,000	
1553	340/02	900	33.4	33.2	$\frac{1}{8}$	Ac.	12,000	
1630	330/05	1100			$\frac{1}{8}$	Ci.	20,000	
1653	320/05	1200	32.4	32.2	$\frac{1}{8}$	Ci.	20,000	
1755	330/06	1300	33.3	32.8	$\frac{1}{8}$	Ci.	20,000	
1855	340/02	400	29.0	29.0	Nil			Fog 1850-1938
1938	330/03	1200						
1953	350/04	1100	31.0	30.7	Nil			
2027	350/02	400				Sky obscured		

It is supposed that lee waves, due to the topography upwind, were causing undulations of the fog top in the Bovingdon area, and that a gradual shortening of the wavelength caused the aerodrome to be affected alternately by crests and troughs in the wave pattern. Thus when Bovingdon was in a wave trough it was in relatively warm, free-flowing air, and when under a wave crest it was affected by the slower-moving foggy air. Examination of the Cardington BALTHUM (special reports of wind and temperature) for 1200 GMT on 7 December 1960 showed that lee waves, of short wavelength, were possible during the afternoon.

Conclusion.—Insufficient information was available to test the hypotheses thoroughly, but the investigation gave some support to them. The problem is a complicated one and many more data will be required. There is therefore a continued need for local investigations which pay due attention to station peculiarities; at this stage the most useful additions to our understanding of the problem will come by detailed field studies of individual occurrences.

REFERENCE

1. CORBY, G. A.; Air flow over mountains. *Met. Rep., London*, **3**, No. 18, 1956.

551.586 : 63

WEATHER AND FOOD

By R. G. VERYARD

"They take the flow o' the Nile
By certain scales i' the pyramid; they know
By the height, the lowness, or the mean, if dearth
Or poison follow. The higher Nilus swells
The more it promises; as it ebbs, the seedsman
Upon the slime and ooze scatters his grain
And shortly comes to harvest"

Antony and Cleopatra, II, VII, 20.

From time immemorial whether as hunter, farmer or fisherman man has had to cope with the elements in his search for food. Through the process of trial and error involving many painful experiences including mass starvation and forced migration, by domesticating and cultivating wild fauna and flora, by accumulating knowledge of the nature of seed, soil and weather, and so on, man has been able to maintain an ever-growing population. But there is still not enough food to go round. Although there are occasional gluts in some countries (incredibly, the surplus crop is sometimes destroyed!) there are millions who are

not adequately fed—yet within a few decades the present world population may have doubled itself! It is understandable therefore that increasing attention is being paid to the problem of feeding not only the undernourished peoples of today but the many more millions who will need feeding in the years to come.

Several of the United Nations special agencies are concerned with this problem. As long ago as 1951, UNESCO established an Arid Zone Programme aimed at the collection and dissemination of the results of research on arid zone problems and the giving of direct assistance to projects forming part of a co-ordinated research programme. Much money has been spent and a perusal of the “Arid Zone” newsletters and Reviews of Research published by UNESCO may give some idea of the progress achieved to date. As far as food production is concerned the progress must be regarded as rather disappointing. However, the United Nations body chiefly concerned has been FAO, the Food and Agriculture Organization. In July 1960, it launched a Freedom from Hunger Campaign, and at the inaugural ceremony in Rome, Mr. B. R. Sen, the Secretary-General of FAO, emphasized that “One man’s hunger and want is every man’s hunger and want; one man’s freedom from hunger and want is neither a true nor secure freedom until all men are free from hunger and want”. The Campaign is to continue until 1965 and is aimed at the progressive and lasting removal of hunger and malnutrition from the human scene and not merely at the provision of temporary relief. The United Nations and the other specialized agencies, including the World Meteorological Organization (WMO), were invited to contribute to the Campaign.

WMO had previously agreed to arrange joint FAO/WMO projects related to the application of meteorology to agriculture and had already undertaken to participate in a FAO/UNESCO/WMO project on agroclimatology in the arid and semi-arid zones of the Mediterranean region. In regard to this project a rather optimistic article in the January 1961 issue of the *WMO Bulletin* expressed the hope that the findings would result in “practical recommendations for extending or introducing into the region crop species with plant requirements which are met by the climatic conditions of the countries to be studied” and envisaged that “along with improved field cultivation and irrigation systems, this could certainly lead to an important increase of the native food production”. It remains to be seen how successful this project will be.

In response to the FAO invitation to participate in the Freedom from Hunger Campaign it was decided by the WMO Executive Committee that the main contribution of WMO should consist in the preparation and publication of a booklet entitled *Weather and food**. The intention was that this publication should be in a style suitable for the intelligent layman and should review the main relationships between climatic conditions and food production; special attention was to be given to unfavourable climatic factors and to the analysis and forecasting of weather which is adverse to food production and also to the means of reducing the impact of unfavourable weather conditions. The pamphlet, written by L. P. Smith of the United Kingdom Meteorological Office who has now become a well known authority on all aspects of agricultural meteorology, has recently been published by WMO as Basic Study No. 1.

* *Weather and food* (Freedom from Hunger Campaign—Basic Study No. 1), by L. P. Smith. 9 in. x 6½ in., pp. 80, illus., World Meteorological Organization, Geneva, Switzerland, 1962. Price: Sw. fr. 2.

Before discussing this pamphlet however, it is appropriate to mention that the July 1961 issue of the *WMO Bulletin* was specially devoted to the theme of the Freedom from Hunger Campaign. The aims of the Campaign and the relevance of meteorology in food production were presented in an inspiring article by B. R. Sen, the Secretary-General of FAO. He particularly emphasized how valuable it would be if extended and long-range forecasts could be issued and gave some very interesting particulars regarding the world's agricultural resources; he mentioned, for example, that the 10 per cent of the world's land surface which is at present under cultivation by no means marks the limit of the land which could be cultivated by making full use of available water, by proper soil management and so on. In an article on "Weather and fisheries" T. Laevastu of the Fisheries Division of FAO gave some useful information on the influence of weather on the abundance and availability of fish and urged that forecasts for coastal fisherman should be more detailed, especially in regard to winds, and should be extended to cover 48 hours and longer periods. P. M. A. Bourke, the President of the WMO Commission for Agricultural Meteorology presented under the heading "Meteorology and mud" a review of international collaboration in agricultural meteorology, whilst C. I. H. Aspliden, a WMO technical assistance expert, and R. C. Rainey of the Anti-Locust Research Centre, London discussed the findings of a WMO Technical Assistance Mission in an article entitled "Desert locust control". It appears that the movement and distribution of desert locusts, on the scale of synoptic meteorology, are not merely correlated with, but are to a very large extent determined by, the corresponding low-level wind fields and the authors went so far as to suggest that, in areas from which meteorological data are scarce, reports of locust distribution and movement might assist the synoptic analyst to decide between alternative constructions of the wind field! The authors also put forward the view that the forecasters concerned should acquire the same kind of acquaintance with the relevant operating characteristics of locust swarms as they have of the aircraft they serve. In the same issue of the *WMO Bulletin* is another article, by L. P. Smith, giving a preview and summary of the booklet *Weather and food* recently issued by WMO as Basic Study No. 1.

The booklet consists of three parts. The first deals with "The influence of Nature". The meteorological parameters, length of day, heat and light, clouds and sunshine, rain, snow and temperature are treated separately. As Smith points out in his article in the *WMO Bulletin*, this is not really satisfactory because plants consider them together—but the manner in which they do so is complicated and intricate and has yet to be fully understood. Following the discussion of individual elements there are sections dealing with disasters, pests and diseases, soils and climatic classification. In regard to the latter, Smith points out that because the relation between weather and plants is complex, it is not possible to devise simple classifications and even complex classifications such as those based on potential evapotranspiration are of limited value. From his experience of this matter as a President of the WMO Commission for Climatology, the writer is inclined to support the view that, allowing for what can be achieved by means of irrigation, the use of glass and shelter, the natural vegetation itself provides the best classification of the climates of the world for agricultural purposes. In this connexion, it is curious that for some crops, such as wheat, the optimum rainfall appears to be very near

the irreducible minimum; thus, in a country with an average rainfall which is an optimum for a given crop but where irrigation is impracticable, a few years below average could mean starvation.

The second part of the booklet discusses "The influence of Man". In the first section, entitled "Plants and animals", Smith reiterates the fact that because of the uncertainty of what meteorological factors are important, it is difficult to compare one climate with another; hence the possibility of introducing new breeds or varieties from other lands is not a simple matter. He goes on to say, however, that "the more we learn about the logical practical process of climate classification the easier such methods will become, and in fact tremendous advances have been made by this means"—but it is not clear what these advances are. The sections which follow deal with erosion, irrigation, shelter, pests and diseases. Whilst paying tribute to man's accomplishments, Smith rightly condemns his misdeeds, especially in regard to soil erosion; but one wonders whether misuse of the land has not often been due to a selfish or "couldn't-care-less" attitude rather than to simple ignorance of physical factors. Surely, over the centuries, Man must have learned *from experience* the folly of over-cropping and the indiscriminate cutting-down of trees without having to be told of his sins by the scientists! In regard to irrigation, Smith rightly emphasizes that the control of water is the key to development and that the meteorologist is one of the experts who can help to fashion the key—but it would have been pleasing to have been given some examples substantiating his claim that in temperate countries where crops may grow without irrigation, yields have at times been doubled or even trebled by means of skilled irrigation. One wonders if this applies to *all* crops? In the next section on pests and diseases, the statement that "the relations between weather and pests and diseases are slowly being discovered" is a polite way of calling attention to the present ignorance on the subject and points to the need for much more research. In this connexion, one would like to know the real economic value of the warnings which are issued regarding the onset of potato blight. The remaining sections in Part II of the booklet deal with fires and floods (is it impracticable for us to have an inland flood warning service in this country?), glass and other material aids, frost, forecasts, and weather control. In regard to the last subject, it is pleasing to note that Smith does not raise wild hopes of the large-scale modification of climate as has been suggested in some quarters. Part III of the pamphlet relates to "The Future" and here, perhaps, the author is somewhat optimistic, especially in these days of subsidies, credit restrictions and tariffs. He calls for new thinking (on the part of scientists, administrators, farmers and farm-workers—especially "applied" scientists *working together as a team*), new facts (certainly there are gaps in available meteorological data which ought to be filled, but how much more data are we to acquire and never work up?), new experience (from field experiments), new knowledge (Smith emphasizes the value of making known research efforts which have failed as well as those which have succeeded) and new services. In regard to the latter, the author contended in his article in the *WMO Bulletin* that if we could serve the farmer as we serve the pilot crop production could increase tomorrow! He also emphasizes the need for extended and long-range forecasts and points out that an accuracy of two correct forecasts out of three could be of inestimable

value. In connexion with the forecasting of the incidence of pests and diseases his claim that successful forecasts have been made "for days, weeks and even *months* ahead" enabling preventative and curative methods to be applied efficiently is a little surprising. One would have liked to have been given some examples. Regarding the need for more education the writer whole-heartedly endorses the author's view that "the one who makes the most use of meteorology is often the one who knows most about meteorology". The weather-wise farmer or fisherman can certainly make the best use of the forecasts provided for him. The concluding sections relate to new lands (but including the sea for, as Smith points out, in most countries sea fishing is still at the equivalent stage in agriculture of harvesting wild plants grown by chance) and new responsibilities (involving international co-operation in general and the WMO Technical Commissions in particular).

The pamphlet concludes with the author's suggestions for further reading—amounting to over 60 publications! This indicates the need for a comprehensive textbook on the subject. Maybe, FAO and WMO can sponsor such a publication. Certainly, WMO is to be congratulated on Basic Study No. 1. The author has succeeded admirably in meeting the requirements of the Executive Committee. He has dealt with a complicated subject covering a very wide field in a clear and entertaining style and, knowing his enthuasism, he can be forgiven if here and there he may have been a little starry-eyed. The booklet is well produced and illustrated and for two Swiss francs it is good value for money. All those who are interested in the subject should add the booklet to their library.

NOTES AND NEWS

The effect of wind on droplet-laden cobwebs

The photographs between pages 224–225 were taken at Dunstable on the morning of 31 August 1961 and show the effect of a gentle breeze on cobwebs heavily laden with droplets of water deposited during a fog. In Plate I, taken at 0705 GMT, the sun had just risen above the downs and was lighting up the web from the back; the drops can hardly be distinguished although the camera was only 13 inches away.

In Plate II, taken at about 0710 GMT, a gentle breeze was moving parts of the web, causing droplets to coalesce. Plate III was taken at about 0730 GMT and shows the same web as Plate II. The droplets had for the most part run to the intersections of the web, although in some parts, tiny droplets were still adhering to horizontal crosspieces.

Plate IV, taken at 0735 GMT, shows the droplets had all gone to the intersections and in some cases had formed quite large drops.

The Dunstable Meteorological Office observations, made about $1\frac{1}{2}$ miles from the site of the photographs, gave a clear night with falling temperatures until 0600 GMT when visibility dropped to 1500 yards with 8/8 stratus at 100 feet; at 0700 GMT visibility was 150 yards, sky obscured, temperature 10°C . Soon after this observation, the fog lifted rapidly to give stratus patches.

R. K. PILSBURY

HONOURS

The following award was announced in the Birthday Honours List published on 9 June 1962:

C.B.E.

Dr. A. C. Best, O.B.E., D.Sc., Director of Services, Meteorological Office

AWARDS

We have received information that Mr. G. C. Sclare, Scientific Assistant at Cardington, and Mr. I. D. Cattermole, Scientific Assistant at Oakington, have been successful in reaching the Gold Standard of H.R.H. the Duke of Edinburgh's Award Scheme.

They both attended at Buckingham Palace on 15 June 1962 for presentation of their awards by His Royal Highness the Duke of Edinburgh.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:

SCIENTIFIC PAPERS

No. 12—Some statistical relationships between the temperature anomalies in neighbouring months in Europe and western Siberia, by J. M. Craddock, M.A. and R. Ward

An estimate is made of the strength of the association between the departures from normal, during many years, of the mean temperature in different calendar months. This is carried out for each of about one hundred meteorological stations forming a network over Europe and western Siberia for all possible combinations of months up to a maximum separation of six months. It is found that strong evidence of association is almost confined to pairs of adjacent months, and to particular geographical areas which vary with the time of the year. The nature of the association is discussed.

No. 13—Three-parameter numerical forecasts at Dunstable—a study of the error fields, by C. E. Wallington, M.Sc.

Geographical distributions of errors in forecasts made with a three-parameter numerical model of the atmosphere show several distinctive features which may be used as an aid to interpreting the predictions. The distribution of errors in the numerical and conventional forecast have much in common. The neglect of topography, friction and possibly heating over the land in the model is evident, but the model is efficient at predicting broad-scale development and movement of pressure contour features over the sea some distance away from land masses and from the boundary of the computing area.

PUBLICATIONS RECEIVED

Philips technical review Vol. 21, No. 7—includes description of an automatic dewpoint hygrometer based on the Peltier effect. 11½ in. x 8 in., pp. 185–220, N. V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands, 1960. Price: 3s. 4d.

An outline of the climate of Greece, E. G. Mariolopoulos. 9½ in. x 6½ in., *illus.*, pp. 51, Meteorological Institute of the University of Athens, 1961.

Indicating and recording gauges. 11 in. x 8½ in., pp. 57, *illus.*, Negretti and Zambra Limited, 122 Regent Street, London, W.1. 1961.

THE METEOROLOGICAL MAGAZINE

Vol. 91, No. 1082, September, 1962

THE ROYAL VISIT TO THE METEOROLOGICAL OFFICE HEADQUARTERS

On 25 June, Her Majesty The Queen and His Royal Highness The Duke of Edinburgh visited Berkshire. The tour included a short visit to the Meteorological Office Headquarters, where the Royal Party were received by Mr. W. J. Taylor, Parliamentary Under-Secretary of State for Air, who presented Lord Hurcomb (Chairman of the Meteorological Committee), Sir Maurice Dean (Permanent Under-Secretary of State for Air) and Lady Dean, Sir Graham Sutton (Director-General of the Meteorological Office) and Lady Sutton, Dr. R. C. Sutcliffe (Director of Research), Dr. A. C. Best (Director of Services) and Mr. G. R. R. Benwell (Vice-Chairman of the Local Whitley Committee).

After the presentations in the Entrance Hall, the Royal party were taken to the Central Forecasting Office, the Communications Centre and one of the laboratories of the High Atmosphere Research Branch. In the Central Forecasting Office Her Majesty was able to see the preparation of the midday forecast for the BBC as well as some historic documents including FitzRoy's first published forecast and also the forecasts made for the Normandy landings in the last war and for the Coronation in 1953.

In the Communications Centre, Her Majesty received the following message over the teleprinter circuit:

On the occasion of the visit of Your Majesty and His Royal Highness, The Duke of Edinburgh to the Headquarters of your Meteorological Office, the staff at Lerwick, the most distant outstation in the United Kingdom and one of the oldest, send loyal greetings on behalf of the staff of all Meteorological Office outstations.

The text of her reply, which was broadcast to all Meteorological Office outstations, was as follows:

I thank the staffs of the Lerwick Meteorological Station and of all other outstations for the loyal greetings which they have sent to me and my husband on the occasion of our visit to the Meteorological Office Headquarters at Bracknell. We send our greetings and good wishes to them all and assure them of our interest in the important and invaluable work which they are doing.

ELIZABETH R.

In the M.O.19 (High Atmosphere Research) laboratory, the Royal visitors saw the five-inch rocket now being developed for the Meteorological Office, as well as apparatus for the satellite which is to be placed in orbit by the United States of America in the near future. They also saw work in progress on the construction of rocket sondes, on a new method of measuring the water-vapour content of the atmosphere and on the calibration of the ultra-violet spectroscope to be used in the satellite for the determination of the ozone content of the high atmosphere.

On descending again into the Entrance Hall, Her Majesty and Prince Philip signed a specially illuminated page of the visitors' book as a memento of the occasion. They then left to continue their tour of the new town of Bracknell, concluding with lunch at Easthampstead College.

This is believed to be the first occasion on which the reigning Sovereign has visited the Meteorological Office. It is pleasant to record that on this occasion the weather also rose to the occasion, so that the new buildings were seen at their best.

551.509.317:551.509.323:551.524.36

FORECASTING OF MAXIMUM SURFACE TEMPERATURE FROM 1000-500-MILLIBAR THICKNESS LINES

By C. J. BOYDEN

An earlier note¹ described how the daily mean temperature could be forecast from the expected 1000-500 mb thickness, allowance being made only for the season of the year. It would have been possible to incorporate other predictors, but the forecaster requires formulae that are simple and approximate rather than complex and precise, for the reason that most predictors themselves have to be forecast. It does not of course follow that an empirical relationship between two meteorological parameters ignores the physical effect of other elements, since an independent meteorological element is rare. Thus the thickness of the 1000-500 mb layer is basically a measure of mean virtual temperature, yet it is also related in a loose way to stability, cloudiness, precipitation and even wind.

It was not expected that thickness alone would prove a useful indicator of maximum surface temperature. It was evident that separate allowance would have to be made for cloudiness, whereas in a forecast of mean temperature this is not critical, largely because warm, sunny days are often followed by clear, cold nights. Nevertheless it was found that on about 70 per cent of days during the six summer months a useful indication of maximum temperature was given by the midday 1000-500 mb thickness, the recent history of the air, the sunshine total and the month. Wind speed, humidity and often rainfall were found to add little or nothing to the accuracy of the forecast. Thus we are left with predictors which, apart from sunshine, are given by routine forecast charts of the surface pressure pattern and the 1000-500 mb thickness, and call for no knowledge of current or past temperatures.

The assumption that maximum temperature can be related to 1000-500 mb thickness requires that the thickness shall define the mean temperature of the layer of air in which daytime heating is concentrated. The diurnal temperature rise will depend largely on the insolation which penetrates any cloud

existing during the morning or early afternoon. Thus it is not surprising that the 1000–500 mb thickness proved to be the major factor in determining the maximum temperature in unstable air, since temperatures build up to give a lapse rate close to the adiabatic. On the other hand the thickness of a layer of warm air from the Continent bore little relationship to its temperature structure and could not be used as a predictor of maximum temperature.

The relationships found were based mainly on the maximum temperature and other surface observations at Kew Observatory, and midday upper air soundings from Crawley. Data were examined for the years 1956–60, and initially for the months of June, July and August taken together. The methods of forecasting maximum temperature in these months were then modified if possible for the months of April, May and September, each being treated separately.

In addition to using the observations from Kew and Crawley it was important to include a stability parameter which could be forecast without undue difficulty. This factor was allowed for by classifying the air in which the maximum temperature was reached according to its trajectory over the previous 24 hours as given by surface geostrophic winds, the classification being determined by the sector in which most of the trajectory lay. The period of 24 hours was an arbitrary choice and no doubt a longer time would be better but is impracticable because of the uncertainty in the construction of long trajectories. Incidentally, the length of the 24-hour trajectory did not seem to influence the maximum temperature in a systematic way.

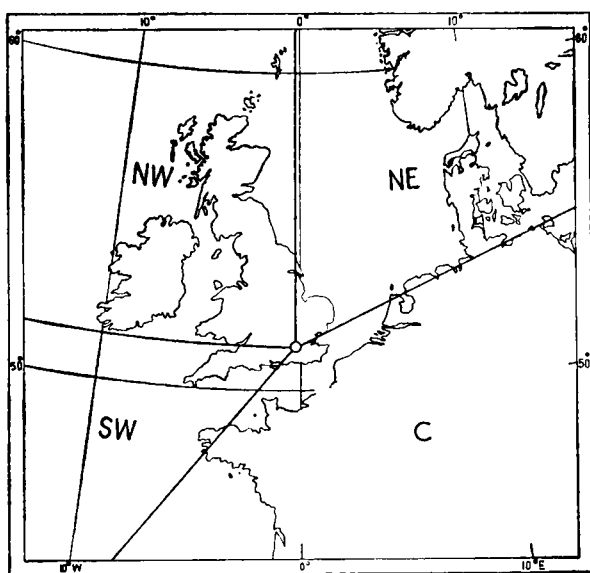


FIGURE 1—TRAJECTORY SECTORS

The trajectory sectors were eventually reduced to four, and to these was added a class to cover occasions when the trajectory had no definable direction. The classification (Figure 1) was as follows:

- | | |
|-----------------|---|
| NW (north-west) | Trajectories from between north and west. |
| NE (north-east) | Trajectories from between north and about east-north-east, thus excluding air which crossed the Netherlands and northern Germany. |
| SW (south-west) | Trajectories from between about south-west and west. |

- C (Continental) Trajectories from the mainland of Europe, disregarding Denmark and Scandinavia.
- St (stationary) Trajectories having no significant direction because the wind was light, or occasionally because the trajectory was more nearly circular than straight.

The distribution of trajectories during the years 1956–60 is given in Table I.

TABLE I—DISTRIBUTION OF TRAJECTORIES

	April	May	June	July	August	September	Total
NW	26	29	57	75	62	33	282
NE	56	34	22	12	8	15	147
SW	26	46	29	33	41	39	214
C	21	29	25	19	26	44	164
St	21	17	17	16	18	19	108

Maximum temperature in air from north-west sector

June, July and August.—A linear relationship was found between maximum temperature and the midday 1000–500 mb thickness, and the use of this single predictor gave a r.m.s. error of a little over 3°F. At the higher thicknesses there was a substantial temperature variation with sunshine, so allowance for this was made by incorporating the total sunshine for the day, this being regarded as a satisfactory substitute for the sunshine up to the time of maximum temperature. The forecasting diagram is shown in Figure 2, in which the maximum

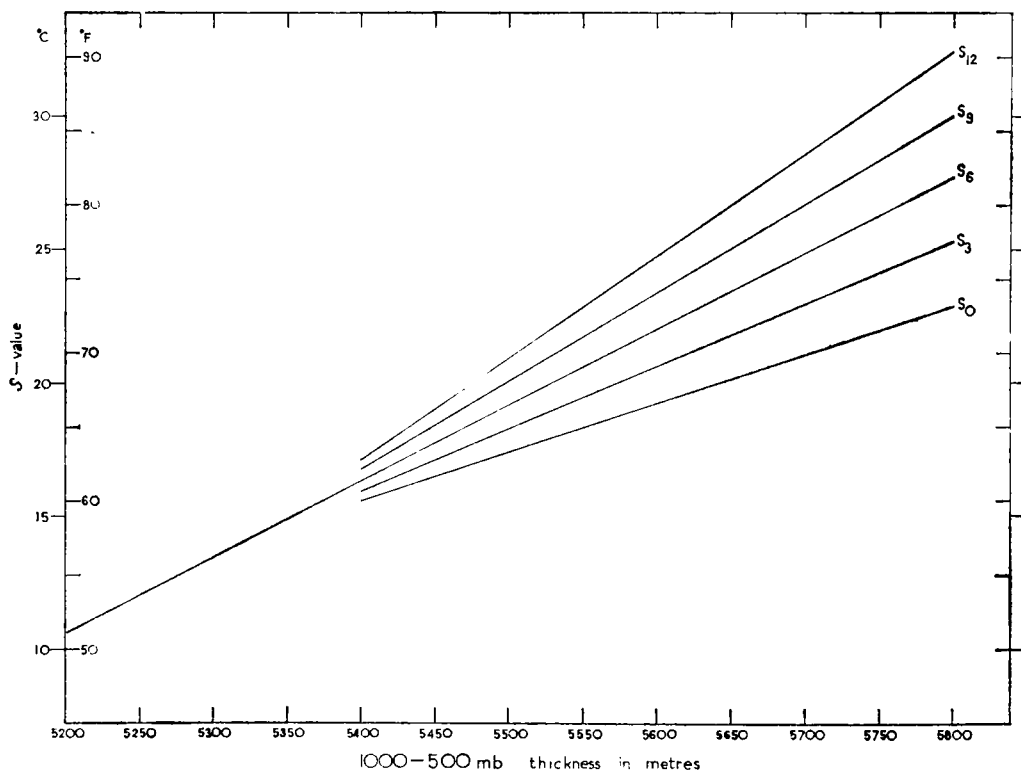


FIGURE 2—FORECASTING DIAGRAM FOR MAXIMUM TEMPERATURE

temperature for a forecast thickness is read against the expected hours of sunshine. The allowance for sunshine reduced the r.m.s. error to 2.3°F. (The temperature read on these lines will be referred to as S_0 , S_3 , S_6 , S_9 and S_{12} , the suffix denoting the total sunshine except that S_{12} includes all totals above 12 hours.)

April.—The method was found to be unsuitable and north-west winds were too infrequent for a satisfactory alternative to be established.

May.—The diagram was satisfactory provided 2°F was subtracted from all temperatures. The r.m.s. error was then 2.5°F .

September.—It was found that S_0 was a reasonable forecast regardless of the amount of sunshine. The r.m.s. error was 2.9°F , but because of the small slope of the S_0 line the relationship with thickness must be regarded as a loose one.

Maximum temperature in air from north-east sector

June, July and August.—The method developed for the north-west sector was applicable in air from the North Sea, and again precipitation could be ignored. One important modification was necessary, however, when the cloud remained unbroken all day. The comparatively small number of observations suggested the temperature was then best given by $S_6 - 9$. That a sunless day is much colder than one with only an hour of sunshine may reflect a substantial difference in the cloud thickness and therefore of its absorption of insolation.

Disregarding sunless days, the r.m.s. error was 2.8°F . Since sunshine in a north-easterly airstream is very difficult to forecast, the result of ignoring the amount was examined. The assumption of six hours sunshine on every occasion gave a r.m.s. error of slightly under 3.0°F . Thus a substantial error in cloud amount can be tolerated in forecasting the maximum temperature, provided the completely sunless day can be foreseen.

April.—April again proved a difficult month, and a curious feature was that sunshine appeared to be as important an independent parameter at low thicknesses as at high ones. The formula $T = S_6 + N - 12$, where N is the number of hours of sunshine, gave a r.m.s. error of 3.3°F , and no special allowance for sunless days seemed necessary. In view of the difficulty of forecasting N this result cannot be regarded as very helpful.

May.—With fewer observations than in April, $T = S_6 + N - 10$ gave a r.m.s. error of 3.1°F , which again is barely satisfactory.

September.—North-easterly winds were too infrequent for any relationship to be derived but, as with north-westerly winds, sunshine seemed to be of little importance as an independent predictor.

Maximum temperature in air from south-west sector.—The main characteristic of air from the south-west would seem to be its lack of uniformity. Fairly unstable maritime polar air may arrive from the same direction as subsided air of continental origin. Frontal cloud and precipitation occur frequently. The long sea passage tends to bring temperatures to a common level but nevertheless a worthwhile relationship emerged between maximum temperature, thickness and sunshine. R.m.s. errors lay between 2.4° and 2.8°F , values which reflect to some extent the rather small range of temperature that occurs with south-westerly winds. The relationships found were as follows:

<i>April</i>	$T = S_6 + N - 9$
<i>May</i>	$T = S_6 + N - 8$
<i>June, July and August</i>	$T = S_6 + N - 6$
<i>September</i>	$T = S_6 + N - 8$

Maximum temperature in air from Continental sector.—It was found impossible to derive the maximum temperature on the basis of the 1000–500 mb thickness because of the variability of the temperature distribution within the layer. The lowest 3000 feet or so were often isolated from the rest of the layer by an inversion or stable boundary, and significant day-to-day warming near the ground was not adequately reflected in the thickness rise. It soon became clear that temperatures in air from the Continent could be forecast only from consideration of individual upper air ascents, or by some method based on maximum temperature anomalies upstream. This limitation is unfortunate since 40 per cent of temperatures of 80°F or more occurred in air from the Continent, but it emphasizes the difficulty of forecasting successfully the very hot days. It seemed, too, that cloudiness was not particularly important in relation to maximum temperature but an outbreak of heavy rain lowered it substantially, so an almost random element is unavoidable on many occasions.

Maximum temperature in stationary air.—It was necessary to include this category but it relates to a situation which will often be forecast incorrectly or will occur without being forecast. When stagnant air can be forecast with a fair degree of certainty the maximum temperature can be estimated satisfactorily on the basis of its small day-to-day changes. Nevertheless, it is of interest that the maximum temperature during the months June, July and August was given by S_{12} , regardless of the amount of sunshine, with a r.m.s. error of about 3°F. An exception occurred when there was continuous rain during the normal period of temperature rise, in which case the maximum temperature was lower than S_{12} by about 6°F. The method was not applicable in April, May or September.

Summary.—The rules put forward in the preceding paragraphs are summarized in Table II (or Table III).

TABLE II—MAXIMUM TEMPERATURE AT KEW IN °F

	April	May	June, July and August	September
NW	—	Appropriate S - value less 2°	Appropriate S - value	S_0
NE	$S_6 + N - 12$	$S_6 + N - 10$	Appropriate S - value but $S_6 - 9$ if sunshine zero	—
SW	$S_6 + N - 9$	$S_6 + N - 8$	$S_6 + N - 6$	$S_6 + N - 8$
C	—	—	—	—
St	—	—	S_{12} but 6° lower if continuous rain occurs	—

Table III represents Table II transferred to °C, a small allowance being made in converting the constant for the fact that $N/2$ is used as an approximation to $5N/9$.

TABLE III—MAXIMUM TEMPERATURE AT KEW IN °C

	April	May	June, July and August	September
NW	—	Appropriate S - value less 1°	Appropriate S - value	S_0
NE	$S_6 + \frac{N}{2} - 6$	$S_6 + \frac{N}{2} - 5$	Appropriate S - value but $S_6 - 5$ if sunshine zero	—
SW	$S_6 + \frac{N}{2} - 5$	$S_6 + \frac{N}{2} - 4$	$S_6 + \frac{N}{2} - 3$	$S_6 + \frac{N}{2} - 4$
C	—	—	—	—
St	—	—	S_{12} but 3° lower if continuous rain occurs	—

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THUNDERSTORMS IN GREAT BRITAIN

By Lt. Col. ROBERT C. MILLER, U.S.A.F. and Major LOYD G. STARRETT, U.S.A.F.

Summary.—Problems of forecasting thunderstorms and related phenomena in Great Britain are discussed in the light of daily operational experience in a centralized forecasting facility. Particular attention is given to the thermal stability of the atmosphere, its measurement and its rôle in the forecasting process. It is found that severe convective activity is most closely related to the 500 mb temperature. The prevalence of activity with tops well below the 500 mb level is mentioned and the basis for forecasting the size of hail is discussed.

Climatology.—Great Britain has a great many thunderstorms, considering that it is located from about 50° to 59° N. Even in winter, thunder is heard somewhere in Great Britain about one day out of three, while in summer this ratio increases to three out of four. The geographic distribution of the storms varies somewhat from year to year, but may be best described as moderately frequent in the Midlands and south-east England, and relatively rare elsewhere¹. Figure 1 shows the distribution for the five years 1955–59².

The great majority of thunderstorms are reported during the normal season from early May to September. Figure 2 shows only the average distribution of thunderstorm *days*. To complete the picture, the activity in summer is normally much more intense and widespread than in winter. During the winter, the few thunderstorms that occur are found mostly on the western shores. In spring, the maximum activity is in south-eastern England and East Anglia. In summer, there is a marked increase in and north of the eastern Midlands, a normal northward migration for the season. Autumn has a relatively uniform distribution so that the annual pattern is determined almost entirely by the spring and summer storms.

The diurnal variation, Figure 3, shows no unusual characteristics. Coastal regions during the summer and inland areas at all seasons have a strong maximum of thunderstorms at about 1500 hours and a minimum at about 0700 hours. In the winter, coastal regions have their maximum number several hours after sunset and a pronounced minimum just before noon. Of course, these winter thunderstorms are relatively few and normally less vigorous than the summer variety. From the Kew Observatory records, it may be inferred that thunderstorm duration in winter averages about 20 minutes and frequently only one clap of thunder is heard. In the summer, the average is nearly 50 minutes. Convective activity just short of thunderstorm intensity is common in all seasons. Cumulonimbi are often reported hour after hour, sometimes by every station in a large area, without a thunderstorm report.

Summer thunderstorms also give rise to more reports of cloud-to-ground lightning, such being reported for about 60 per cent of the thunderstorms in summer and some 45 per cent in winter. About six times per year thunderstorms sweep across Great Britain in such waves that over half the area is affected. Nearly all these extensive storms occur during the months May to August².

While summer thunderstorms normally extend well above the 500 mb level, the winter type often do not. Tops of the latter average about 17,000 feet and have been reported at least as low as 12,000 feet.

Thunderstorm gusts in excess of 30 knots are quite rare in Great Britain. The great windstorms, for example, 26–27 November 1703¹ and 29 July 1956,

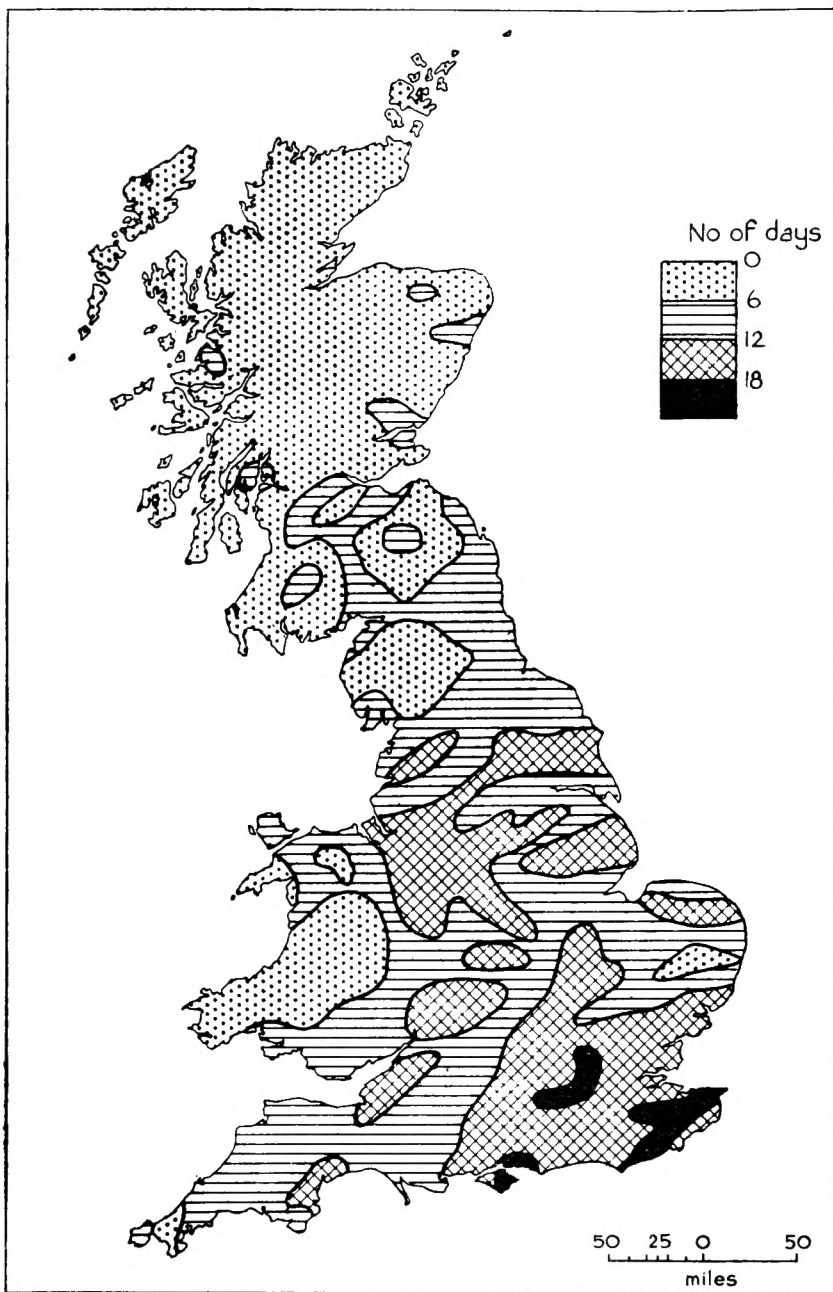


FIGURE 1—AVERAGE ANNUAL FREQUENCY OF THUNDERSTORMS IN GREAT BRITAIN,
1955-59

By courtesy of the Electrical Research Association.²

appear to be due almost entirely to extreme pressure gradients with no significant convective activity. It may be that damaging downdraughts in thunderstorms are due to local moisture discontinuities. Where relatively dry air meets cloud droplets or rain, evaporative cooling may result in rather extreme temperature gradients³. Such situations do occur in England, as on 5 September 1958, but they are uncommon.

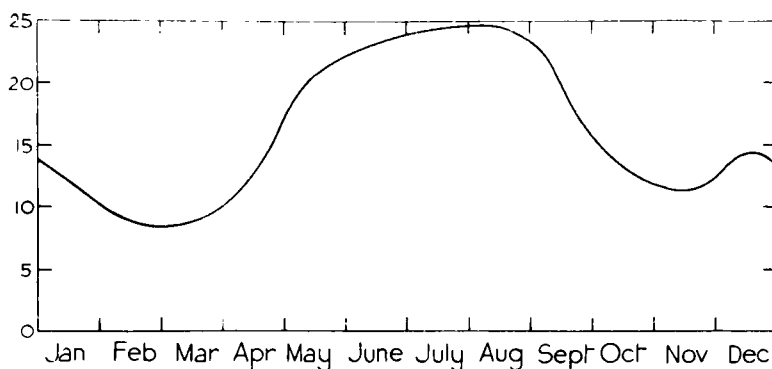


FIGURE 2—AVERAGE NUMBER OF THUNDERSTORM DAYS PER MONTH IN GREAT BRITAIN

These data represent neither intensity nor geographic extent.

In winter-type situations, showers of small hail frequently fall, either with or without thunder. These are common throughout Great Britain and are damaging chiefly when the amount of fall is excessive. Hail larger than a quarter-inch is relatively rare, especially north of 53°N and on the coasts. It occurs in summer-type situations, mostly during the season May through September. In the Horsham hailstorm of 5 September 1958, stones reached a diameter of three inches and weighed up to half a pound. At Tunbridge Wells on 6 August 1956, drifts of hailstones reached a depth of four feet.

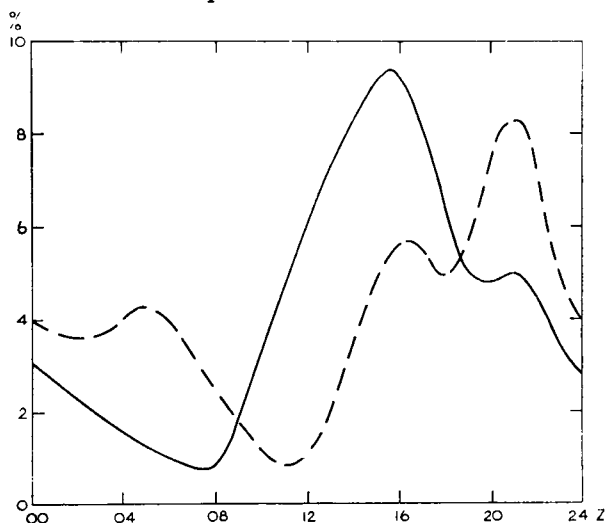


FIGURE 3—DIURNAL DISTRIBUTION OF THUNDERSTORMS IN GREAT BRITAIN

The solid curve is for inland areas at all seasons and also coastal regions during the summer. The dashed curve is for winter thunderstorms in coastal areas, i.e. within ten miles of the sea.

In England, tornadoes are commonly called "whirlwinds". Like large hail, the majority occur south of the fifty-third parallel during the summer season, though they have occurred in every month of the year. These storms are reported in the newspapers, with pictures and descriptions of the damage. Some are discussed or described in meteorological literature, but no complete compilation seems available. Brooks¹ (page 39) has mapped 23 of the most notable tornadoes in Great Britain.

The greatest thunderstorm flying hazard in winter is the rapid accumulation of ice. Radiosonde analyses justify forecasts of seldom more than moderate

turbulence and small hail. Convective cells are normally isolated or scattered and of limited height, very rarely forming anything like a solid squall line.

On the other hand, representative soundings for summer-type storms show rising parcels will be much warmer than the ambient air, requiring forecasts of severe turbulence and frequently large hail. Squall lines occasionally become continuous and thunderstorm gusts at the earth's surface can become damaging, as on 5 September 1958. No incident of aircraft encountering hail damage in the clear air outside the thunderstorm clouds has been noted in Great Britain, though this is rather common in America. It goes without saying that icing continues to be a major hazard.

A large portion of England's thunderstorms form to the south or south-west and drift over the Island. These form first over the water, France or Spain, then move with the deep wind flow, usually at about 15 knots. Those that develop early in the day over the English Channel and the south-west approaches, travel inland and cause a moving line of maximum thunderstorm activity that sweeps across England as indicated by the isochrones in Figure 4. The migration of later thunderstorms, together with those arriving from more distant

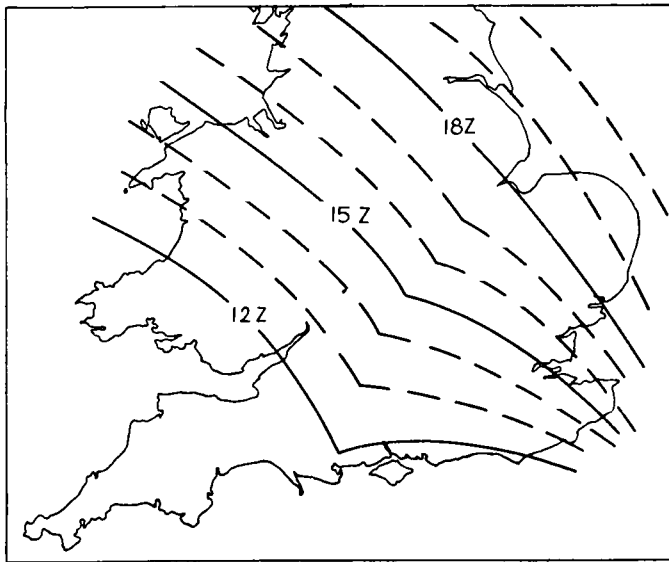


FIGURE 4—ISOCHRONES OF MAXIMUM THUNDERSTORM ACTIVITY IN GREAT BRITAIN

areas, form the nocturnal maximum that moves as shown by the isochrones in Figure 5⁴. The rapid dissipation of nocturnal thunderstorm activity in the west is probably due to the effectiveness of the Cotswold Hills and even the Chilterns in choking off the very low-level warm, moist air.

Forecasting.—Basically, there are three prerequisites for the formation of thunderstorms: thermal instability, moisture and trigger action. There have been numerous attempts to combine the first two in a stability or instability index. Most such indices are determined by raising a parcel of air from 850 mb to 500 mb and comparing it with the ambient air at this and lower levels. All indices examined are well founded and should be of some help, provided only that the data used are representative of the time and place for which the forecast is made. Any index used should be computed from a forecast sounding,

valid at the time of interest, for no stability index is conservative. Furthermore, each situation should be examined for a typical characteristics, which might require modification or adjustment of the pseudo-objective index.

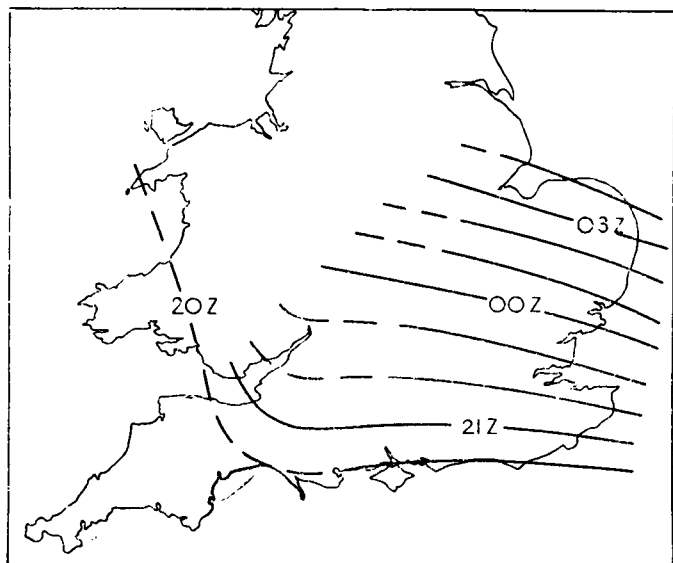


FIGURE 5—ISOCRONES OF MAXIMUM NOCTURNAL THUNDERSTORM ACTIVITY IN GREAT BRITAIN

Since all known attempts to combine two or more of the above criteria in one index seem to have severe limitations when used in forecasting, this paper will discuss the three parameters separately. But first, some general observations are in order.

Modern practical forecasting leans heavily on electronic computer and centralized analyses and prognoses. These are excellent for the gross patterns and movements, but need to be supplemented in three ways:

- (i) Local charts are needed to identify small, transitory perturbations, to locate features more precisely, and to time movements more accurately.
- (ii) The product of the centralized facility must be adjusted in the light of later and locally more complete data. Its interpretation must be based on special knowledge of terrain and local effects.
- (iii) Three-dimensional temperature, moisture, and stability analyses and prognoses must be provided locally, for they are not yet adequately furnished by centralized units.

Most thunderstorms in Great Britain, especially in the winter, occur under cold pools at 500 mb. They grow taller and more vigorous under and to the left of the jet stream. Inland thunderstorms of the winter type dissipate with spectacular suddenness at sundown, except for the stronger ones intensified by the jet stream. These sometimes persist most of, or even the whole night.

In order to determine the threshold thermal instability for thunderstorms, data for a hundred cases were collected. The 850–500 mb temperature lapse is plotted against the 500 mb temperature in Figure 6. The line of best fit, not shown, derived by the method of least squares, is $T_8 - T_5 = 20.7 - 0.3T_5$,

where T_8 is the 850 mb temperature and T_5 is the 500 mb temperature. Correlation is about 0.7 and the standard error of estimate 2.2°C . Subtracting the latter from the line of best fit gives $T_8 - T_5 = 18.5 - 0.3T_5$ as the tentative threshold of thunderstorm activity. This is shown in Figure 6 as a solid line, rising from left to right.

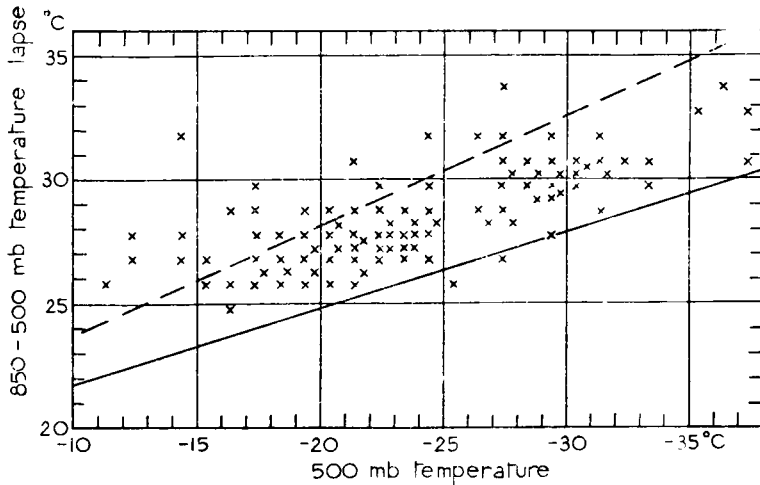


FIGURE 6—850-500 MB TEMPERATURE LAPSE AND 500 MB TEMPERATURE FOR THUNDERSTORMS

The solid line is the tentative threshold thermal instability for thunderstorms in Great Britain. It is one standard error of estimate below the line of best fit, derived by the method of least squares. The dashed line is the locus of 30-knot thunderstorm gusts. Only those cases lying above the dashed line were expected to produce gusts in excess of 30 knots. The total number of cases is 100.

It should be noted that low thermal stability, i.e., conditional instability, is a necessary but not a sufficient condition for thunderstorms to develop. Whenever the 850-500 mb temperature lapse exceeds $18.5 - 0.3T_5$, the moisture patterns and the possible trigger actions must be examined before a decision is made as to the forecast to be issued.

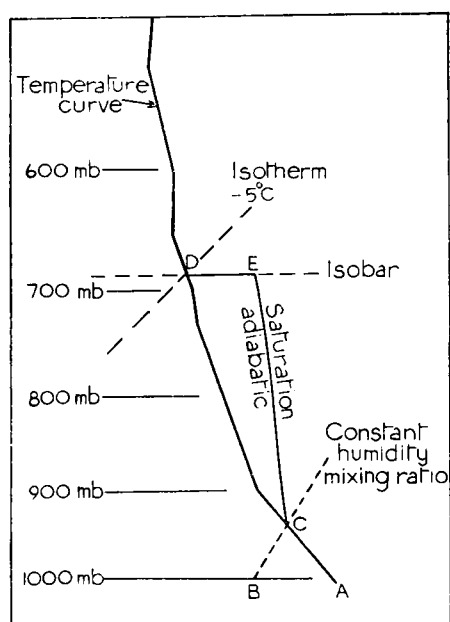
In order for thunderstorms to develop in Great Britain, in all except the most severe summer-type situations, the air at 700 mb and below must have relative humidity of 70 per cent or more. But when the temperature lapse, lower moisture and trigger action are strong enough, then thunderstorms will develop in spite of dryness in the middle layers and they will be especially severe. Middle-level dryness has the effect of dissipating cumulonimbi, but intensifying those that develop in spite of its presence.

Frequently air with rich moisture content and large temperature lapse rate persists in place for many hours and even days. Since its great energy can be released only when suitably triggered, the forecaster must be alert for any perturbation that may lift the air column. While fronts and troughs are sufficient, it must not be assumed that they are necessary to trigger thunderstorms or that their positions on the weather map are accurate. In fact, examination of past maps revealed that many of the fronts and troughs had their position and orientation greatly altered after reports of severe thunderstorm activity were received.

The rarity of thunderstorm gusts in excess of 30 knots has already been mentioned and illustrated in Figure 6. Whirlwinds or tornadoes are also relatively infrequent, probably due to the size of the Island, and no serious study of them has been attempted by the authors. They should probably be predicted when a thunderstorm situation is exceptionally strong, with very large hail indicated and vigorous trigger action expected.

Hail.—It is well to understand the reasoning behind forecasting aids, not only for background, but also as a basis for modification of results. Even the more objective aids require judgment and skill in application. The following discussion leads to a graph, Figure 8, that is essentially equivalent to one used with considerable success in America⁵.

It is assumed that hailstones grow to sizes over one quarter inch only if supported for a time above the freezing-level and that this support is provided by the impact pressure of an updraught against a spherical stone. Large hail is common only in summer-type situations, when the wet-bulb freezing-level is 2500 metres or so above the terrain, so it is assumed to form slightly above this level. Following Fawbush and Miller⁵, the computation will be made where the ambient temperature is -5°C . Air density at this level is estimated to be roughly $9 \times 10^{-4} \text{ gm/cm}^3$.



Liverpool sounding for 1200 GMT, 27 August 1960

FIGURE 7—ANALYSIS OF TEPHIGRAM FOR HAIL FORECASTING

In this example portion AC of the temperature curve falls on a dry adiabatic. B is the surface dew-point and C is the convective condensation level. DE and the thickness from C to DE are used in forecasting hail, see Figure 8.

To estimate the speed of an updraught from a sounding, it is assumed that a parcel of air is accelerated upward from rest at the convective condensation level. In Figure 7, ACD is the temperature curve and BC is the humidity mixing ratio line through the surface dew-point, making C the convective condensation level. Assume that the temperature of the rising parcel follows saturation adiabatic CE , while the temperature of the ambient air remains CD .

For practical purposes, the average difference in temperature may be taken as $\frac{1}{2} DE$ and the absolute temperature as 270°K . By the principle of Archimedes, the upward acceleration on the parcel is proportional to the difference in specific volumes and by Charles' Law, this is proportional to the difference in temperature. Let g stand for the acceleration due to gravity and H for the thickness of the air stratum between C and DE . Since the square of the speed of a particle starting from rest is twice the average acceleration times the distance, the square of the upward speed of our rising parcel is estimated at $(DE \times H \times g)/270$.

The density of a hailstone⁶ is roughly $9/10 \text{ gm/cm}^3$, so its mass is about

$$\frac{\pi d^3}{6} \times \frac{9}{10} \text{ grams,}$$

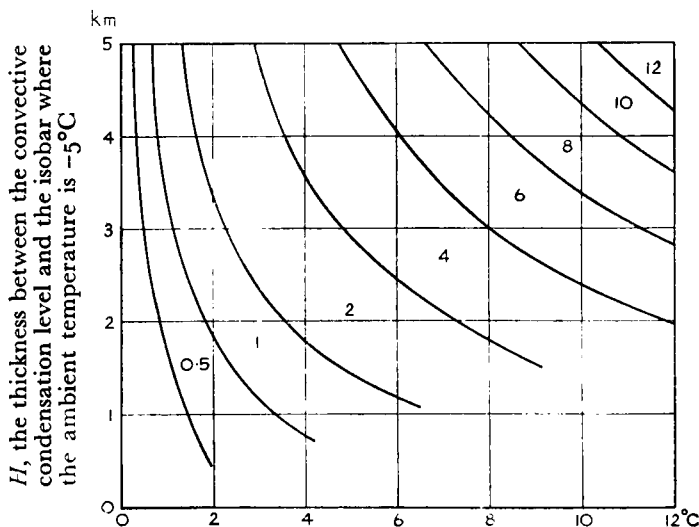
where d is the diameter in centimetres. From Humphreys' discussion of wind pressure⁷, the impact force of the updraught may be estimated as $3/4$ the kinetic energy, or $3/8$ of the air density times the square of the updraught speed, times the cross-sectional area of the hailstone. Equating the weight of the stone to the acceleration upward due to the updraught, it is seen that:

$$\frac{\pi d^3}{6} \times \frac{9}{10} \times g = \frac{3}{8} \times 9 \times 10^{-4} \times \frac{DE \times H \times g}{270} \times \frac{\pi d^2}{4},$$

$$\text{or } d = \frac{DE \times H}{48} \times 10^{-4}$$

d and H being in centimetres and DE in degrees Celsius. If H is measured in kilometres, then

$$d = \frac{DE \times H}{4.8}$$



DE , the excess of temperature of a parcel of air raised along the saturation adiabatic from the convective condensation level to the isobar where the ambient temperature is -5°C

FIGURE 8—FORECAST DIAMETER OF HAIL IN CENTIMETRES

A sounding may be evaluated by either this last equation, or its graph, Figure 8. For example, the sounding in Figure 7 indicates a possibility of two-centimetre hailstones.

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EVALUATION OF THE CYCLOSTROPHIC CORRECTION TO THE GEOSTROPHIC WIND

By M. H. FREEMAN, O.B.E., M.Sc.

Summary.—The magnitudes of the errors in the measurement of curvature of contours caused by map distortion are examined. For the most part the errors are not serious, but in certain circumstances, e.g. strong anticyclonic winds in low latitudes, allowance should be made for them. A simple method of evaluating the cyclostrophic corrections to the geostrophic wind is presented; it uses the same pair of tables for both cyclonic and anticyclonic motion.

Introduction.—Consider a particle of air moving on the earth's surface in a circle whose radius subtends an angle α at the centre of the earth. In Figure 1 P and Q are points at the ends of a diameter of this circle and S is its centre. If R is the radius of the earth, the radius of the circle will be $R \sin \alpha$ and the air must be subject to an acceleration $V^2/R \sin \alpha$ (where V is the speed) along PS . The component of this acceleration in the plane tangential to the earth's surface (along PT) is $V^2 \cos \alpha / R \sin \alpha$ and this is the term which must balance the accelerations due to the pressure gradient and the Coriolis force in the gradient

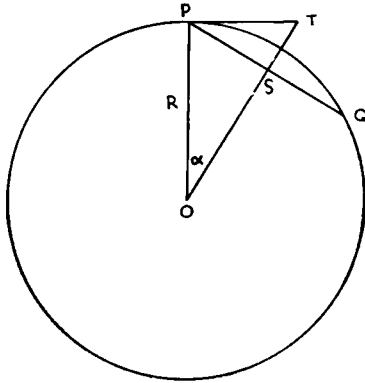


FIGURE 1—MOTION IN A CIRCLE ON THE EARTH'S SURFACE

wind equation. The effective radius of curvature is therefore $R \tan \alpha$, but this is not exactly what is normally measured from synoptic charts. For air moving cyclonically along the circle of latitude 60° , $R \tan \alpha$ is 1980 nautical miles; the contours are not effectively straight and the true correction for a geostrophic speed of 200 knots is -32 knots. On a chart drawn on a conformal conic projection with standard parallels at 60° and 30° the circle of latitude 60° has a radius of 2400 nautical miles and the correction that would be calculated

from this is -27 knots. In this example the discrepancy is not serious, but it is large enough to suggest that significant errors might arise in some circumstances. The electronic computer METEOR was used to evaluate the corrections for numerous small circles in various latitudes.

The effect of map distortion on radius of curvature.—The general formula for the radius of curvature at a point on the transformation onto a map of a circle on the earth's surface is much too complicated to be readily

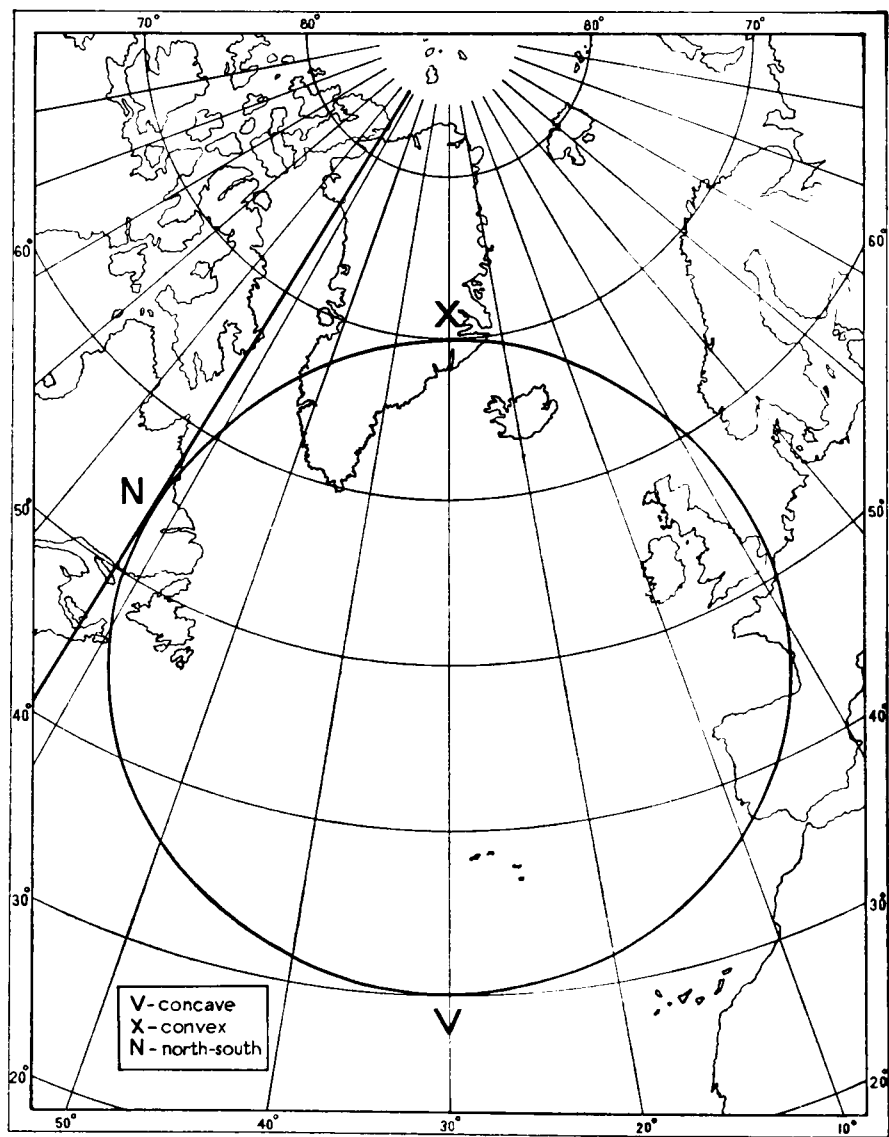
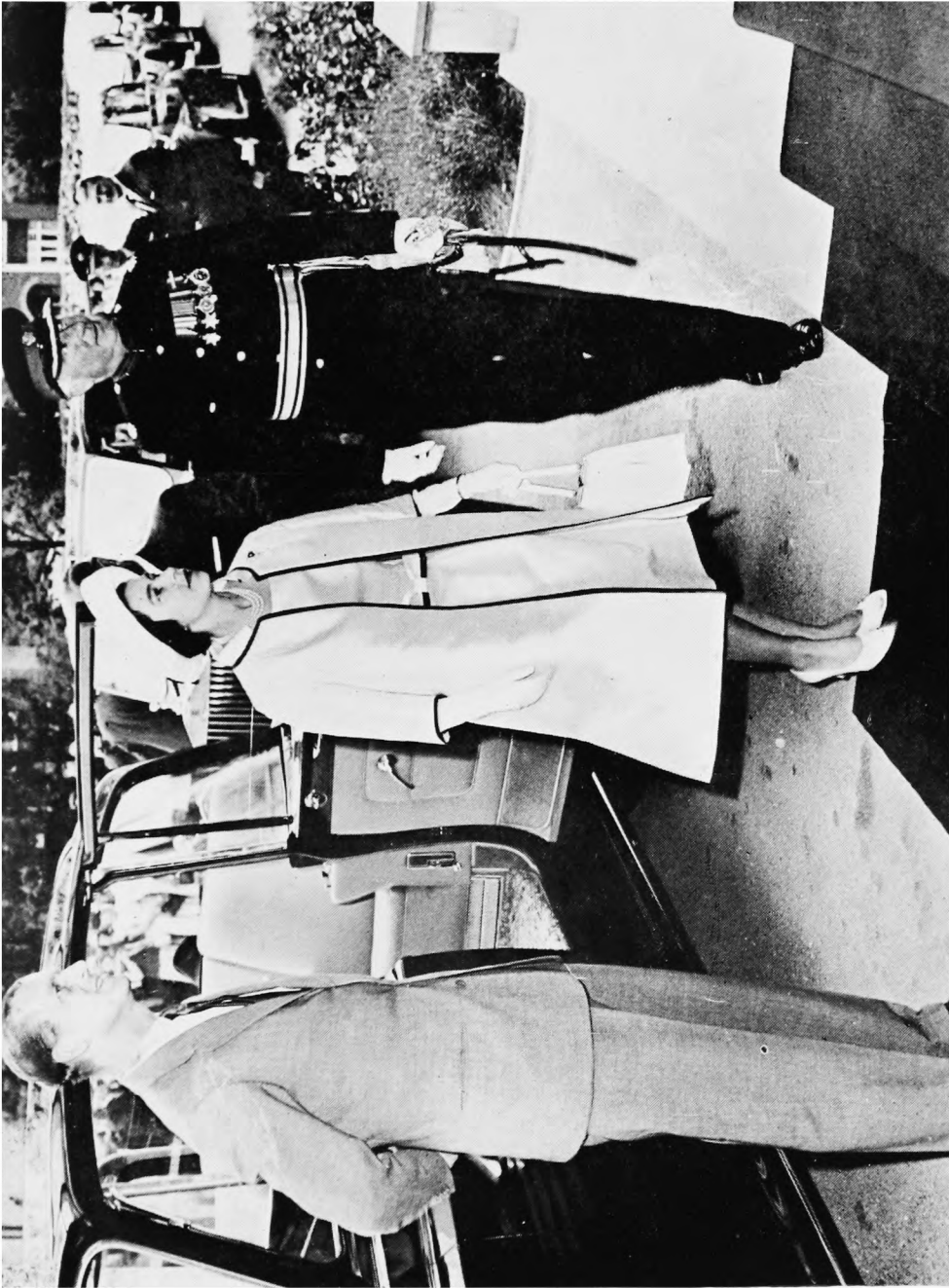


FIGURE 2—A SMALL CIRCLE ON A CONFORMAL CONIC PROJECTION WITH STANDARD PARALLELS AT 60°N AND 30°N

used. For selected circles the curvature on the map was therefore calculated using finite differences at three points as shown on Figure 2, namely (i) V the point farthest from the North Pole when the curve will be concave to the north and winds will be west in the cyclonic and east in the anticyclonic case,

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Bracknell News

PLATE I—H.M. THE QUEEN AND H.R.H. THE DUKE OF EDINBURGH ARRIVING AT
THE METEOROLOGICAL OFFICE, BRACKNELL ON 25 JUNE 1962



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PLATE II—H.R.H. THE DUKE OF EDINBURGH AND DR. R. C. SUTCLIFFE STUDYING
THE CURRENT SYNOPTIC CHART



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PLATE III---H.M. THE QUEEN AND SIR GRAHAM SUTTON EXAMINING THE
INSTRUMENT RING OF A SKYLARK ROCKET

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PLATE IV—H.M. THE QUEEN SIGNING THE VISITORS' BOOK

(ii) X the point nearest to the North Pole when the curve will be convex to the north and winds will be east for cyclonic and west for anticyclonic curvature, and (iii) N a point where a line of longitude is a tangent; winds will then be north or south. The three cases will for brevity hereafter be called concave, convex and N-S respectively.

For a given radius of curvature as measured on the map r_m , the correct value of the effective radius of curvature ($R \tan \alpha$) was calculated for each of the three cases. These radii will be denoted by r_v for the concave, r_x for the convex and r_n for the N-S case.

TABLE I—RADII OF CURVATURE CORRECTED FOR MAP DISTORTION FOR A CONFORMAL CONIC PROJECTION WITH STANDARD PARALLELS AT 30°N AND 60°N

Latitude	Shape of contours	Measured radius r_m (n mile)					
		500	1000	2000	3000	4000	5000
80°N	Convex	470	1190	5120	Large	Large	Large
	N-S	390	770	1550	2330	3090	3880
	Concave	330	580	910	1140	1300	1430
60°N	Convex	520	1100	2430	4070	6160	8890
	N-S	500	1000	2000	3000	4000	5000
	Concave	480	920	1700	2380	2960	3480
40°N	Convex	510	1000	1950	2850	3700	4510
	N-S	520	1030	2060	3090	4120	5150
	Concave	520	1060	2190	3380	4650	6010
20°N	Convex	450	850	1550	2140	2630	3060
	N-S	470	950	1890	2840	3780	4730
	Concave	500	1060	2420	4220	6720	10450

Table I shows for various latitudes and measured radii of curvature the correct effective radii of curvature in the three cases for a conformal conic projection with standard parallels at 30°N and 60°N. When the radius of curvature is small the errors due to map distortion are small except in the extreme north. For large radii of curvature the map errors become much larger, but then the cyclostrophic correction to the geostrophic wind is small and fortunately the discrepancies due to map distortion are mostly not serious. Table II(a) shows the corrections required to a geostrophic wind of 150 knots for cyclonically and anticyclonically curved isobars of various radii.

TABLE II(a)—CORRECTIONS REQUIRED TO A GEOSTROPHIC WIND OF 150 KT FOR (a) CYCLONIC (NEGATIVE FIGURES) AND (b) ANTICYCLONIC CURVATURE (POSITIVE FIGURES)

Conformal conic projection with standard parallels at 60°N and 30°N											
Latitude	Shape of isobars	Measured radius r_m (n. mile)									
		500		1000		2000		3000		4000	
		(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
80°N	Convex	-45	-	-25	112	-8	10	0	0	0	0
	N-S	-50	-	-34	-	-21	50	-15	26	-12	18
	Concave	-54	-	-40	-	-30	-	-26	-	-24	77
60°N	Convex	-46	-	-29	-	-16	29	-11	15	-7	9
	N-S	-47	-	-31	-	-19	40	-14	22	-11	15
	Concave	-48	-	-33	-	-21	54	-17	30	-14	22
40°N	Convex	-54	-	-38	-	-24	82	-18	36	-15	24
	N-S	-54	-	-37	-	-23	69	-17	32	-13	21
	Concave	-53	-	-36	-	-22	60	-16	28	-12	18
20°N	Convex	-73	-	-57	-	-42	-	-35	-	-30	-
	N-S	-72	-	-54	-	-37	-	-29	-	-24	74
	Concave	-71	-	-51	-	-32	-	-22	56	-15	26

Dashes indicate that balanced flow is not possible.

TABLE II(b)—CORRECTIONS REQUIRED TO A GEOSTROPHIC WIND OF 150 KT FOR
(a) CYCLONIC (NEGATIVE FIGURES) AND (b) ANTICYCLONIC CURVATURE (POSITIVE
FIGURES)

Equidistant azimuthal projection with standard parallel at 60°N

Measured radius r_m (n. mile)

Latitude	Shape of isobars	500		1000		2000		3000		4000		5000	
		(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
80°N	Measured	-44	-	-29	-	-17	32	-12	18	-10	13	-8	10
	Convex	-34	-	-19	39	-7	9	-2	3	0	0	0	0
	N-S	-47	-	-31	-	-19	40	-14	22	-11	15	-9	11
	Concave	-43	-	-28	-	-19	40	-16	27	-14	22	-13	19
60°N	Measured	-47	-	-31	-	-19	40	-14	22	-11	15	-9	12
	Convex	-48	-	-33	-	-21	52	-16	29	-13	21	-12	17
	N-S	-47	-	-31	-	-19	39	-14	22	-11	15	-9	11
	Concave	-46	-	-30	-	-17	30	-11	15	-8	10	-6	7
40°N	Measured	-54	-	-38	-	-24	76	-17	33	-14	22	-11	16
	Convex	-61	-	-46	-	-32	-	-27	-	-23	69	-21	50
	N-S	-52	-	-35	-	-22	58	-16	28	-13	19	-10	14
	Concave	-58	-	-39	-	-21	54	-13	20	-8	10	-4	5
20°N	Measured	-71	-	-53	-	-36	-	-28	-	-23	64	-19	41
	Convex	-85	-	-69	-	-55	-	-48	-	-44	-	-41	-
	N-S	-64	-	-47	-	-31	-	-23	71	-19	39	-16	27
	Concave	-80	-	-60	-	-37	-	-23	66	-12	19	0	0

Dashes indicate that balanced flow is not possible.

The correction for N-S isobars always lies between the correction for convex and concave isobars, and for cyclonic curvature r_n is a good approximation to r_x and r_v , and r_m is very nearly as good. For anticyclonic curvature the discrepancies are greater but in most of the circumstances which are likely to occur in the atmosphere r_n will still be a reasonably good approximation to r_x and r_v . This will not always be so in high and low latitudes, nor when the wind is strong in middle latitudes. It is noteworthy that for an anticyclonic wind of 150 knots and a radius of curvature as great as 2000 nautical miles the correction to the geostrophic wind can range from 29 to 54 knots in latitude 60° and from 60 to 82 knots in latitude 40°.

Similar sets of figures were computed for the two map projections most commonly used for circumpolar hemispheric charts. For the polar stereographic with standard parallel at 60° the pattern of results followed those for the two standard parallel conic projection fairly closely. For the equidistant azimuthal projection on the plane of 60°N, used in the Meteorological Office, the relations between r_x , r_v and r_n are more complicated. From latitude 60°N to 20°N r_x is the smallest of the three but otherwise there is no consistent pattern of their relative sizes. The measured radius r_m always lies somewhere between the greatest and least of r_x , r_v and r_n , and r_m is probably the best single value to use. Table II(b) shows the corrections to a 150-knot geostrophic wind for various radii of curvature on an equidistant azimuthal projection.

In the method of evaluating the cyclostrophic correction given in the next section the tables required will use r_m , the radius as measured. The more precise values, r_x , r_v and r_n can readily be incorporated for those occasions when the refinement is justified and the necessary figures are presented in Tables III(b) and (c).

Evaluation of the cyclostrophic correction to the geostrophic wind.—

A number of practical methods of evaluating the cyclostrophic correction to the geostrophic wind have been described. Gilbert's¹ method is one of the most complete, but it requires three fairly large tables and gives the answers as percentage corrections, whereas it is often more convenient to find directly the absolute magnitude of the correction. For balanced motion under the pressure gradient, Coriolis and cyclostrophic forces, the gradient wind equation can be written:

$$V = G - \frac{V^2}{fr'} \quad \dots (1)$$

where V is the gradient wind, G the geostrophic wind, f the Coriolis parameter and r' the radius of curvature of the air trajectory, taken positive for cyclonic and negative for anticyclonic curvature. The curvature of the trajectory is related to r , the radius of curvature of a contour line or isobar by the formula:

$$\frac{1}{r'} = \frac{1}{r} \left[1 - \frac{C \cos \psi}{V} \right] \quad \dots (2)$$

where C is the speed of movement of the pressure system and ψ is the angle between the direction of motion of the pressure system and the contour lines, and the motion is balanced. (See, for example, Petterssen²). After substituting for r' from equation (2) and putting $G - C \cos \psi = D$ the gradient wind equation (1) can be solved to give:

$$G - V = \frac{1}{2} [(fr + G + D) \pm \sqrt{(fr + G + D)^2 - 4GD}]$$

The negative square root is taken for cyclonic curvature and the positive root for anticyclonic.

For cyclonic curvature, $(fr + G + D)$ is positive and equal to $+Q$, say; $G - V$ is the correction which has to be subtracted from the geostrophic wind and its magnitude is $\frac{1}{2} [Q - \sqrt{(Q^2 - 4GD)}]$. For anticyclonic curvature, $(fr + G + D)$ is negative and equal to $-Q$, say, and $V - G$, the correction which has to be added, is also given by $\frac{1}{2} [Q - \sqrt{(Q^2 - 4GD)}]$. In both cases the correction takes the same form, being subtracted for cyclonic and added for anticyclonic curvature. When $(fr + G + D)$ and GD have been evaluated the size of the cyclostrophic correction to the geostrophic wind can be obtained from a single table.

The steps necessary are:

- (i) Measure r , the radius of curvature (in nautical miles) of the contour and calculate fr . Table III(a) has been constructed to give this directly. If account is to be taken of the distortions due to map projection Table III(b) or (c) can be used; the necessary adjustments to allow for the contours being convex, N-S, or concave have been incorporated. Interpolation will be needed when the orientation of the contour is intermediate between two of these three values.

TABLE III(a)—VALUES OF fr WHERE f IS THE CORIOLIS PARAMETER AND r THE RADIUS OF CURVATURE

	Measured radius of curvature (n. mile)													
Lat.	200	300	400	500	600	800	1000	1200	1500	2000	2500	3000	4000	5000
80°	100	150	210	260	310	410	520	620	770	1030	1290	1550	2060	2580
70°	100	150	200	250	290	390	490	590	740	980	1230	1470	1970	2460
60°	90	140	180	230	270	360	450	540	680	910	1130	1360	1810	2270
50°	80	120	160	200	240	320	400	480	600	800	1000	1200	1600	2000
40°	70	100	130	170	200	270	340	400	500	670	840	1010	1350	1680
30°	50	80	100	130	160	210	260	310	390	520	650	780	1050	1310
20°	40	50	70	90	110	140	180	210	270	360	450	540	720	900

TABLE III(b)—VALUES OF fr , WHERE f IS THE CORIOLIS PARAMETER AND r IS THE RADIUS OF CURVATURE CORRECTED FOR MAP DISTORTION

		Conformal conic projection with standard parallels at 60°N and 30°N.													
Latitude	Shape of isobars	Measured radius of curvature (n. mile)													
		200	300	400	500	600	800	1000	1200	1500	2000	2500	3000	4000	5000
80°	Convex	90	130	190	240	300	440	610	820	1260	2640	7790	∞	∞	∞
	N-S	80	120	160	200	240	320	400	480	600	800	1000	1200	1600	2000
	Concave	70	110	140	170	200	250	300	340	390	470	540	590	670	740
70°	Convex	90	140	200	250	300	420	550	690	930	1400	2030	2890	6170	∞
	N-S	90	140	180	230	270	360	450	540	680	910	1140	1370	1820	2270
	Concave	90	130	170	210	250	320	390	450	540	670	790	890	1070	1210
60°	Convex	90	140	190	240	290	390	500	610	780	1100	1450	1850	2790	4030
	N-S	90	140	180	230	270	360	450	540	680	910	1130	1360	1810	2270
	Concave	90	130	180	220	260	340	420	490	600	770	930	1080	1340	1580
50°	Convex	80	130	170	210	250	340	420	510	640	870	1100	1340	1830	2350
	N-S	80	120	170	210	250	330	410	500	620	830	1040	1240	1660	2070
	Concave	80	120	160	200	250	330	400	480	600	790	980	1160	1510	1850
40°	Convex	70	100	140	170	200	270	340	400	500	660	810	960	1250	1520
	N-S	70	100	140	170	210	280	350	420	520	690	870	1040	1390	1730
	Concave	70	110	140	180	210	280	360	430	540	740	930	1140	1570	2020
30°	Convex	50	80	100	130	150	200	240	290	350	460	550	650	810	960
	N-S	50	80	100	130	160	210	260	310	390	520	650	790	1050	1310
	Concave	50	80	110	140	160	220	280	340	440	610	800	1000	1470	2050
20°	Convex	30	50	60	80	100	120	150	180	220	280	330	380	470	550
	N-S	30	50	70	80	100	140	170	200	250	340	420	510	680	850
	Concave	30	50	70	90	110	150	190	230	300	430	580	760	1200	1870

TABLE III(c)—VALUES OF fr , WHERE f IS THE CORIOLIS PARAMETER AND r IS THE RADIUS OF CURVATURE CORRECTED FOR MAP DISTORTION

		Equidistant azimuthal projection with standard parallel at 60°N.													
Latitude	Shape of isobar	Measured radius of curvature (n. mile)													
		200	300	400	500	600	800	1000	1200	1500	2000	2500	3000	4000	5000
80°	Convex	140	220	300	390	480	690	920	1180	1660	2780	4680	8710	∞	∞
	N-S	90	130	180	220	270	360	450	540	680	900	1130	1360	1810	2270
	Concave	130	190	250	300	360	450	540	630	740	900	1040	1160	1350	1510
70°	Convex	110	160	220	270	320	430	540	640	800	1060	1320	1580	2080	2570
	N-S	90	140	190	230	280	380	470	560	700	940	1170	1410	1880	2350
	Concave	110	160	220	270	330	440	550	660	830	1110	1400	1690	2280	2880
60°	Convex	90	130	180	220	260	340	420	500	610	780	950	1100	1380	1630
	N-S	90	140	180	230	270	360	450	550	680	910	1140	1360	1820	2280
	Concave	90	140	190	240	290	390	490	600	770	1070	1410	1780	2630	3720
50°	Convex	70	110	140	170	200	270	330	380	470	590	710	810	990	1150
	N-S	80	130	170	210	250	340	420	510	630	840	1060	1270	1690	2110
	Concave	70	110	150	190	230	320	410	510	660	950	1280	1680	2730	4370
40°	Convex	50	80	100	130	150	200	240	280	340	430	500	570	700	800
	N-S	70	110	150	190	220	300	370	450	560	750	940	1120	1500	1880
	Concave	60	90	120	150	180	250	320	400	520	770	1070	1450	2590	4900
30°	Convex	40	50	70	90	100	130	160	190	230	280	330	380	450	520
	N-S	60	90	120	150	190	250	310	370	470	620	780	930	1240	1560
	Concave	40	60	80	100	120	170	220	280	370	560	790	1110	2190	5240
20°	Convex	20	30	40	50	60	80	90	110	130	160	190	220	260	290
	N-S	50	70	90	110	140	180	230	270	340	460	570	690	920	1150
	Concave	20	40	50	60	70	100	130	170	230	340	500	710	1530	∞

(ii) Measure G , the geostrophic wind (in knots), and $C \cos \psi$, the component of the motion of the pressure system along the direction of G , and find the difference $D = G - C \cos \psi$. If $C \cos \psi$ and G are in opposite directions $C \cos \psi$ will be negative and D will be greater than G . This will occur, for instance, to the north of an eastward-moving depression.

(iii) Evaluate $fr + G + D$ and GD , taking r as positive for cyclonic curvature and negative for anticyclonic.

(iv) Read off the correction from Table IV, the correction being subtracted when the curvature is cyclonic and added when it is anticyclonic. Dashes in the table indicate that balanced motion is not possible.

If the motion of the pressure system can be ignored D is equal to G , and GD becomes G^2 . A second column, containing $\sqrt{(GD)}$ has been included in Table IV, so that when $C \cos \psi$ is zero the table can be entered knowing G , and GD or G^2 need not be evaluated.

TABLE IV—CORRECTIONS TO GEOSTROPHIC WIND FOR GIVEN VALUES OF

 $|fr + G + D|$ AND GD

		Values of $|fr + G + D|$																
GD	\sqrt{GD}	100	150	200	250	300	400	500	600	700	800	900	1000	1200	1500	2000	2500	3000
1000	32	11	7	5	4	3	3	2	2	1	1	1	1	1	1	1	0	0
2000	45	28	15	11	8	7	5	4	3	3	3	2	2	2	1	1	1	1
3000	55		24	16	13	10	8	6	5	4	4	3	3	3	2	2	1	1
4000	63		35	23	17	14	10	8	7	6	5	4	4	3	3	2	2	1
5000	71		50	29	22	18	13	10	8	7	6	5	4	4	3	3	2	2
6000	78			37	27	22	16	12	10	9	8	7	6	5	4	3	2	2
7000	84			45	32	26	18	14	12	10	9	8	7	6	5	4	3	2
8000	90			55	38	30	21	17	14	12	10	9	8	7	5	4	3	3
9000	95			68	44	34	24	19	15	13	11	10	9	8	6	5	4	3
10000	100			100	50	38	27	21	17	15	13	11	10	8	7	5	4	3
12000	110				65	48	33	25	21	18	15	14	12	10	8	6	5	4
14000	119				85	58	39	30	24	21	18	16	14	12	9	7	6	5
16000	127					69	45	34	28	24	21	18	16	13	11	8	6	5
18000	134					83	52	39	32	27	23	20	18	15	12	9	7	6
20000	141					100	59	44	35	30	26	23	20	17	13	10	8	7
22000	148					128	66	49	39	33	29	25	23	19	15	11	9	7
24000	155						74	54	43	36	31	28	25	20	16	12	10	8
26000	161						82	59	47	39	34	30	27	22	18	13	10	9
28000	167						90	64	51	43	37	32	29	24	19	14	11	9
30000	173						100	70	55	46	39	35	31	26	20	15	12	10
35000	187						129	84	65	54	46	41	36	30	24	18	14	12
40000	200						200	100	76	63	54	47	42	34	27	20	16	13
45000	212							118	88	72	61	53	47	39	31	23	18	15
50000	224							138	100	81	68	59	53	43	34	25	20	17

The correction should be subtracted for cyclonic curvature and added for anticyclonic curvature. Dashes indicate that balanced motion is not possible.

For most purposes corrections smaller than 10 per cent of the geostrophic wind can be ignored. If the value of fr is greater than about $8G$ for cyclonic curvature or $12G$ for anticyclonic curvature the correction will be less than 10 per cent. If Table III(a), or (b) or (c), indicates a value of fr greater than these limits there is no need to carry the evaluation further. With strong winds in low latitudes, especially if the curvature is anticyclonic, very large radii of curvature can still produce important corrections to the geostrophic wind.

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FLUCTUATIONS IN STRATOSPHERIC WINDS OVER ASCENSION ISLAND

By R. A. EBDON

Recent articles^{1, 2, 3, 4} have drawn attention to a fluctuation with a period of 23–29 months in the zonal component of stratospheric winds over tropical regions. The evidence for suggesting this fluctuation came principally from stations situated either in the northern hemisphere or very close to the equator. In extending the work farther into the southern hemisphere Veryard⁵ was able to show that the fluctuation existed over Australia, and Farkas⁶ has drawn attention to the fluctuation in the stratospheric zonal wind components at Nandi (17°45'S, 177°27'E). It has now been possible to analyse high-level data for Ascension Island (07°58'S, 14°24'W) using data on microfilm supplied by the United States Weather Bureau for the period September 1957–August 1961. The purpose of this note is to record that the data for Ascension Island confirm some of the main findings regarding stratospheric zonal wind components published earlier for other tropical stations.

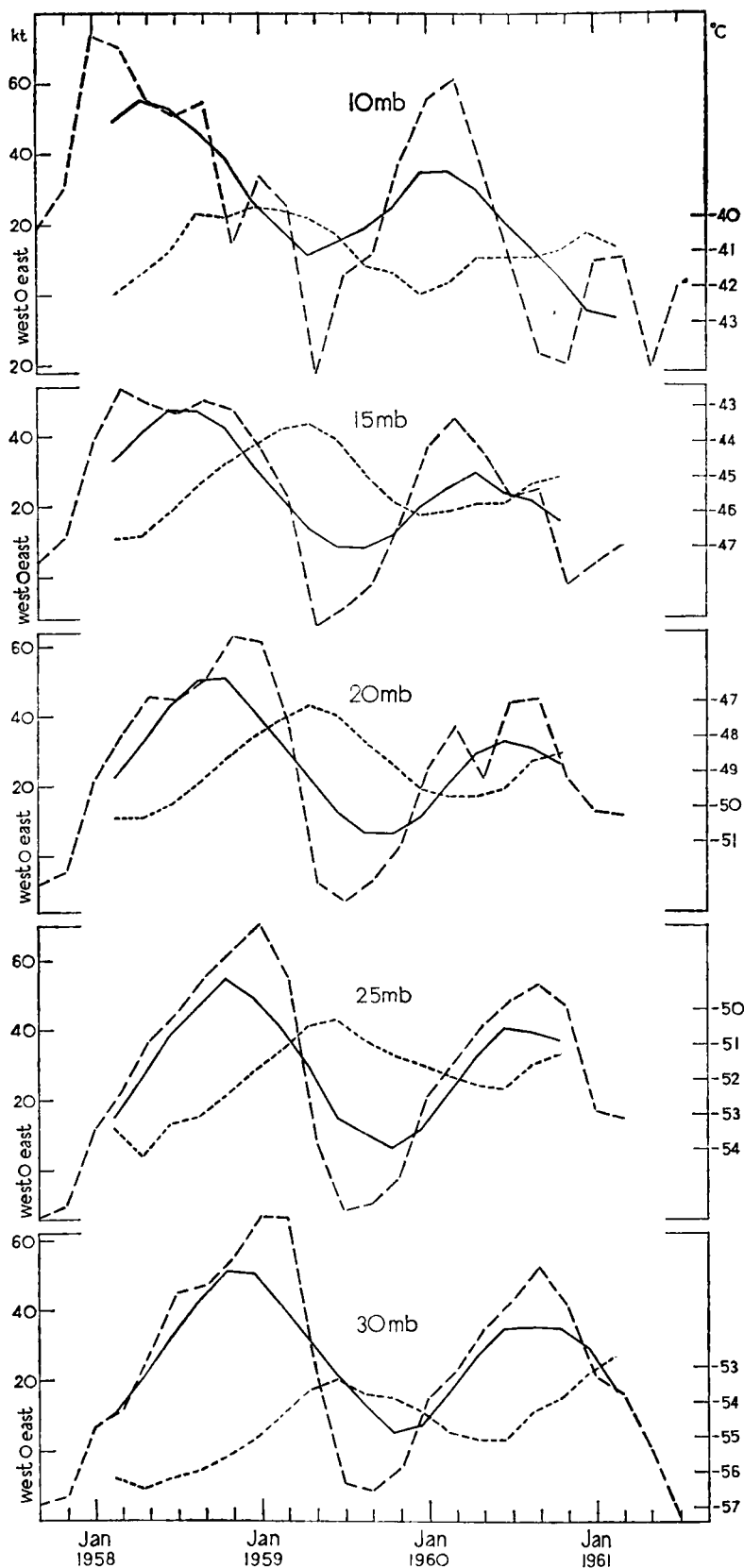


FIGURE 1—ZONAL WIND COMPONENTS AND TEMPERATURES AT ASCENSION ISLAND

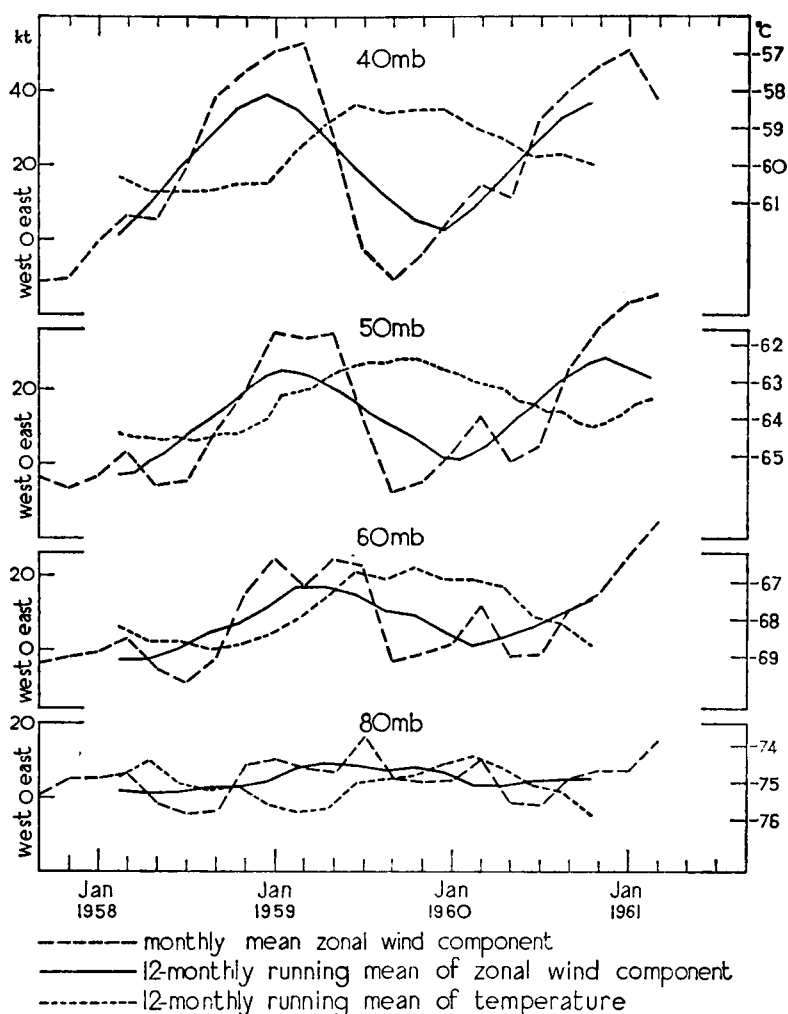


FIGURE 1—ZONAL WIND COMPONENTS AND TEMPERATURES AT ASCENSION ISLAND (*continued*)

Monthly mean zonal wind components and temperatures were obtained for alternate months for the 100, 80, 60, 50, 40, 30, 25, 20, 15 and 10 mb levels using two ascents per day. The levels for which data are available changed to 100, 50, 30 and 10 mb from April 1961. (The only monthly means based on less than 10 observations were those for May 1959, July and September 1960 at the 10 mb level, but in May 1959 there were more than 10 temperature observations.) The zonal wind component curves in Figure 1 show that during the short period for which data are available there was a fluctuation in the zonal wind component with a periodicity of about 20–25 months. As at other tropical stations the range of the fluctuation decreases with diminishing height and the estimates of the range at Ascension Island based on measurements from the first peak to the trough and from the trough to the second peak on the curves of 12-monthly running means are given in Table I. These figures suggest that the range of the fluctuation probably reaches a maximum near 25 mb and it is of interest to note that the mean easterlies of the stratosphere at levels up to 10 mb also show a maximum at this level.

TABLE I—RANGE OF FLUCTUATION AT ASCENSION ISLAND

Level mb	Range from 1st peak to trough kt	Range from trough to 2nd peak kt	Mean zonal wind speed (Sept. 1957–July 1961) kt
10	45	25	+24.1*
15	41	22	+23.7
20	47	28	+24.6
25	48	36	+27.0
30	47	32	+21.7
40	37	34	+20.5
50	24	27	+12.4
60	16		+7.9
80	8		+5.4

* easterly wind indicated by + sign.

Vertical profiles of the mean monthly zonal wind component between 100 mb and 10 mb were drawn for alternate months from September 1957–March 1961 and, as would be expected, the year-to-year variations for individual months were very considerable. To illustrate this point Figure 2 shows the vertical profiles for September for the years 1957–60 and for March for the years 1958–61.

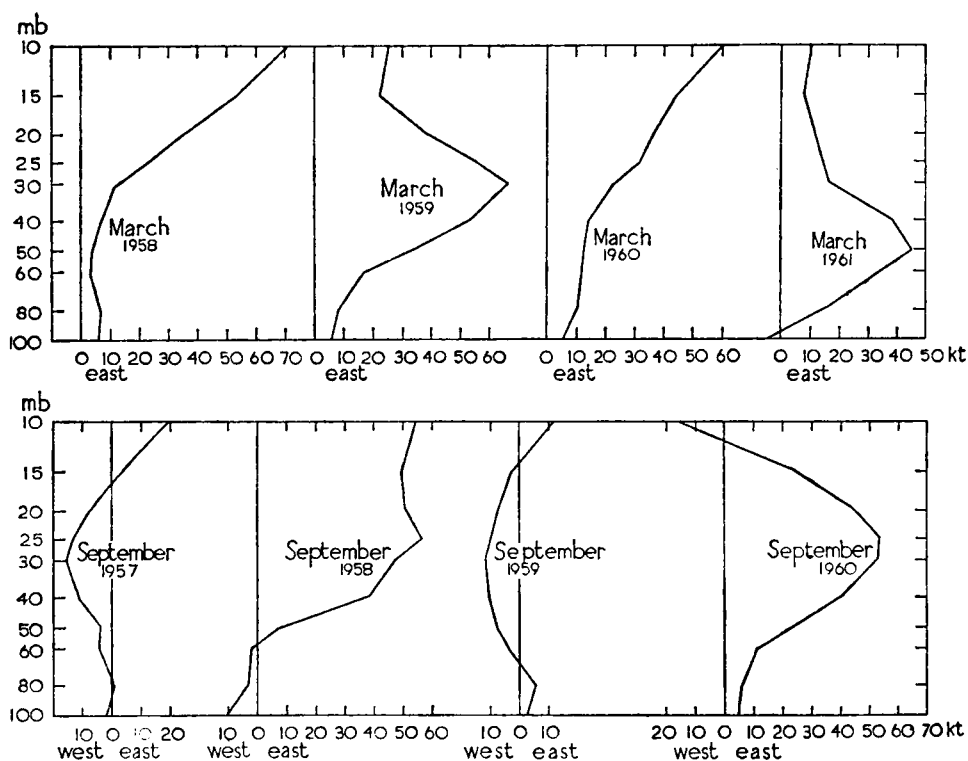


FIGURE 2—VERTICAL PROFILES OF THE MEAN MONTHLY ZONAL WIND COMPONENT (KT) ABOVE 100 MB AT ASCENSION ISLAND

In spite of the short period of record at present available it will be seen from Figure 1 that the 12-monthly running means of stratospheric temperatures also display a fluctuation with a similar period to that found in the zonal wind components. At Ascension Island it appears that the wind and temperature curves are out of phase by about eight months at all the levels considered. The curves show that the range of the fluctuation increases with height—from 1.5°C at 80 mb to 2–3°C at 30 mb and above (it may be that the range is

decreasing again at 10 mb). At Canton Island ($02^{\circ}46'S$, $171^{\circ}43'W$) however the curves showed quite clearly that the range, as indicated by 12-monthly running means, decreased from $3-4^{\circ}C$ at 80 mb to $1.5-2.5^{\circ}C$ at 30 mb and the lag between the temperature change and the wind change increased with height from 1-2 months at 80 mb to about 7 months at 30 mb.

The curves of 12-monthly running means of the zonal wind components at 60 mb for Aden ($12^{\circ}49'N$, $45^{\circ}02'E$), Nairobi ($01^{\circ}18'S$, $36^{\circ}45'E$), Lae ($06^{\circ}44'S$, $147^{\circ}00'E$) and Ascension Island are shown in Figure 3. (For Lae wind data at 65,000 feet supplied by the Australian Commonwealth Bureau of Meteorology were used.) The use of 12-monthly running means removes the marked annual variation (from strong easterly in summer to light easterly or light westerly in alternate winters) at Aden and facilitates comparison with the other stations

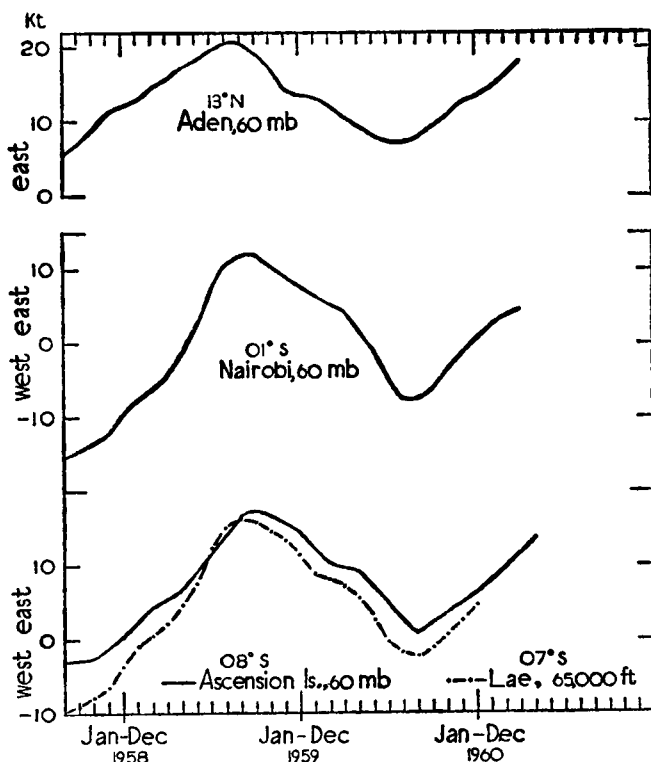


FIGURE 3—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT 60 MB

which are situated nearer the equator where, during the last ten years or so at least, the behaviour of the stratospheric winds has been dominated by a periodicity of about 26 months. It will be seen that the fluctuation appears to be in phase from $13^{\circ}N$ to at least $8^{\circ}S$ and that the latitudinal variation of the fluctuation is such that the range apparently increases from Ascension Island to Nairobi and then decreases to Aden. The 50 mb zonal wind component curves for Canton Island and Ascension Island (based on values for every month) are given in Figure 4. These confirm the in-phase relationship and show a decrease (attributed to latitude) in the range from about 36 knots at Canton Island to about 27 knots at Ascension Island.

The results so far obtained suggest that the effects of the approximately 26-month periodicity, although decreasing with distance from the equator, are

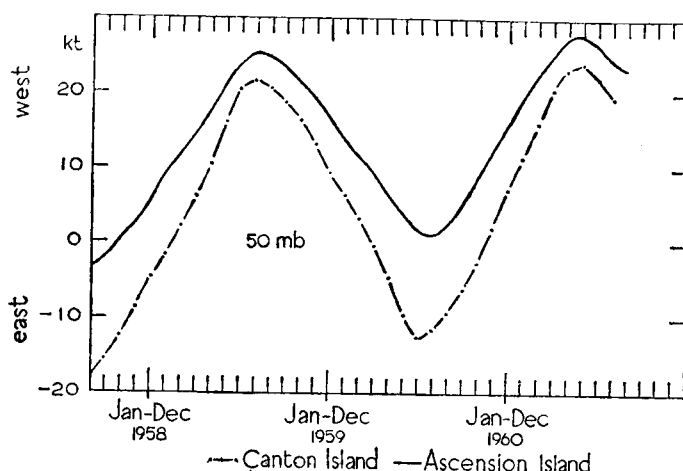


FIGURE 4—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT 50 MB

still discernible at about 20°N and 20°S . Zonal wind components for Khartoum ($15^{\circ}36'\text{N}$) and San Juan ($18^{\circ}28'\text{N}$)² and Nandi ($17^{\circ}45'\text{S}$)⁶, although all subject to a marked annual variation, do show the fluctuation.

It has been mentioned in earlier reports of the work on this subject that Canton Island provides one of the longest upper wind records in existence near the equator. Daily values are available in the New Zealand *Daily Weather Bulletin*. For reference purposes the monthly mean zonal wind components at 50 mb (based on one ascent per day) up to April 1962 are shown in Figure 5.

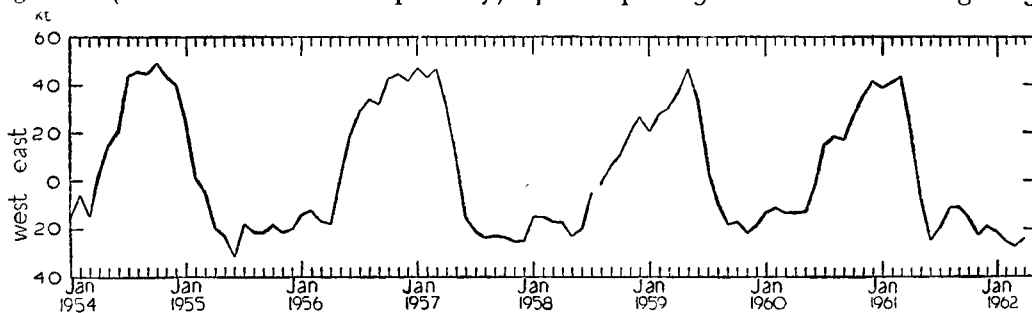


FIGURE 5—MONTHLY MEAN ZONAL WIND COMPONENTS AT 50 MB AT CANTON ISLAND

It will be noticed that there has been no major change in the behaviour of the fluctuation during the last eight years or so.

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NOTES AND NEWS

Meteorological Office Colloquium, 9 May 1962

On the afternoon of 9 May 1962, Professor J. Bjerknes, Head of the Department of Meteorology at the University of California at Los Angeles (U.C.L.A.), gave a talk at the Meteorological Office, Bracknell on "Climatic trends in ocean temperatures". He said that his basic aim was to introduce physical reasoning into the study of climatic change, with special reference to the interaction between ocean and atmosphere. Using mean annual pressure data for Vestmannaeyjar (Iceland) and Ponta Delgada (Azores) for the period 1895–1960, and mean sea surface temperatures for 5° "squares" at 30°N between the Azores and Iceland, graphs were drawn which show clearly a strong negative correlation between the anomalies of the annual mean pressure difference Azores/Iceland and the anomalies of the annual sea surface temperature in the vicinity of 30°W. This indicates a negative correlation between the strength of the westerlies and the sea temperature. Charts were then shown giving isopleths of the change of annual mean pressure (Δp) from 1902 (characterized by weak westerlies) to 1904 (characterized by strong westerlies), together with isopleths of sea temperature change (ΔT) over the North Atlantic between the Azores and Iceland. For a value of Δp of + 7 mb, ΔT was negative over a wide area and greatest (– 2.5°C) in the region 50°–55°N, 30°–35°W. This was also the region of the greatest increase of the westerlies. By contrast between 1904 (strong westerlies) and 1909 (weak westerlies) ΔT was positive over a wide area and was again greatest (+ 1.5°C) in the region 50°–55°N, 30°–35°W. Since westerly winds in this region are usually associated with cold air masses the sea temperature fall can be explained by an increased rate of loss of heat by evaporation and turbulent exchange between sea and atmosphere and by increased advection of colder water from the north-west by wind-produced ocean currents.

Professor Bjerknes then went on to consider sea temperature changes which occur when relatively weak or strong westerlies are maintained over a period of several years. He examined the difference in sea temperature between a long period of predominantly weak westerlies (1880s and 1890s) and one of predominantly strong westerlies (1900–30). Since the intensification of the Iceland low is linked with an intensification of the Azores high, isopleths of the change of mean annual sea surface temperature between the two periods showed west of 30°W a cooling north of 50°N, and a warming south of 50°N, the total relative change between 35° and 45°W amounting to 1.5°C across a few degrees of latitude in the vicinity of 50°N. This increase of sea surface temperature gradient is favourable for the deepening of polar front lows moving north-eastward in the vicinity of 50°N, 30°–50°W, and should therefore tend to maintain a negative anomaly of pressure near Iceland, although the history of any individual low will be determined by the large-scale atmospheric flow pattern at the time. Hence, owing to the ocean–atmosphere interaction a period of strong westerlies tends to be self-maintaining.

During a short discussion which followed the opening statement, Professor Bjerknes was asked whether there appeared to be any well marked period for trends towards stronger or weaker westerly situations. In reply he stressed that there was no identifiable period for such trends. The year 1921 marked the

commencement of a trend towards weaker westerlies, proving that there are external factors, not yet understood, which can quite abruptly overcome the self-maintaining tendency which results from the interaction between ocean and atmosphere.

F. E. LUMB

Languages of meteorological literature

This note puts on record a count of the languages in which books and papers, excluding those, such as yearbooks, devoted solely to observations and summaries of observations, were received in the library of the Meteorological Office during the six months October 1960 to March 1961.

A general count was made and also a count of those publications classified under Universal Decimal Classification number 551.511, Mechanics and thermodynamics of the atmosphere in general. The count under 551.511 is the more important as giving an indication of the proportion in the various languages of the new research work which scientists may need to read. It is therefore given first in Table I.

TABLE I—BOOKS AND PAPERS CLASSIFIED UNDER 551.511

	Books and papers		Pages	
	number	percentage	number	percentage
English	96	55	2221	70
Russian	38	22	562	18
German	10	6	121	4
French	6	4	87	3
Japanese	8	5	53	2
Italian	2	1	26	<1
Bulgarian	3	2	20	<1
Hungarian	3	2	19	<1
Spanish	2	1	19	<1
Chinese	3	2	18	<1
Polish	1	<1	9	<1
Czech	1	<1	6	<1
Afrikaans	1	<1	3	<1

The general count, which is given in Table II, necessarily includes many minor notes and review articles as well as many pages of data.

TABLE II—BOOKS AND PAPERS IN GENERAL

	Books and papers		Pages	
	number	percentage	number	percentage
English	1369	51	28,562	52
Russian	659	24	14,510	26
German	184	7	4,145	8
French	98	3	1,418	3
Japanese	104	4	1,077	2
Italian	34	1	814	1
Spanish	21	<1	714	1
Polish	13	<1	610	1
Czech	24	<1	541	<1
Chinese	74	3	493	<1
Dutch	14	<1	405	<1
Hungarian	50	2	357	<1
Portuguese	6	<1	288	<1
Croat	19	<1	223	<1
Afrikaans	11	<1	78	<1
Norwegian	1	<1	10	<1
Swedish	1	<1	9	<1
Danish	1	<1	28	<1

The figures confirm what is common knowledge among meteorological librarians, that English is by far the major language of meteorological publication with Russian now easily second and German, French and Japanese next but well behind Russian. Table II is much less accurate than Table I as a measure of relative lengths of text in different languages but the order of the major languages is the same in both.

English is, of course, the major language of publication of meteorological research in many countries, notably the Scandinavian countries and Japan, besides the British Commonwealth and the United States.

The only other statement of the relative proportions of publications in various languages known to the writer is that due to Rigby¹ covering the over 24,500 abstracts published in the American Meteorological Society's "Meteorological abstracts and bibliography" during the years 1950 to 1954. Rigby's list of percentages for the first eight most frequently occurring languages in his count was:

	%		%
English	58	Spanish	2
German	21	Italian	2
French	7	Japanese	2
Russian	5	Dutch	1

The increase in the proportion of Russian in the Meteorological Office count for October 1960–March 1961 over Rigby's count for 1950 to 1954 is probably due more to the much greater ease of acquisition of Russian meteorological literature in western countries in recent years than to increase in publication in the U.S.S.R.

The importance of a knowledge of Russian, the second language of meteorological publications, or access to an adequate service of translation from that language is enhanced by the almost total absence of foreign language abstracts in Russian publications. Most of the research papers in languages other than Russian are accompanied by an abstract in English at least.

It should be mentioned in conclusion that the figures for individual months differ markedly because publications of some languages, Russian in particular, arrive in large collections at intervals. Those for the first and second three months, however, differ so little from the overall values as to suggest the six-monthly ones give an adequate description.

G. A. BULL

REFERENCE

1. RIGBY, M.; Editorial. *Met. Abstr., Lancaster, Pa.*, 7, 1956, No. 1, p. iii.

Circle of State Librarians

On Saturday, 16 June 1962 a party of members of the Circle of State Librarians—a professional association through which matters of interest to Government Libraries can be discussed and contacts between staff cemented—made the new Meteorological Office Headquarters the venue for its 1962 Summer Outing. The party totalling almost 50 with the attendant library staff was entertained to morning coffee, lunch and afternoon tea and a varied programme of business and entertainment was provided. In addition to the main attraction

of the day—a tour of the library and its activities—visits to the central forecast office, communications centre, computer room, punched-card installation and archives were much enjoyed.

Meteorology in Scientific Papers

Approximately half of the effort of the Meteorological Office is devoted to research into meteorology. As in most government scientific establishments the emphasis is inclined towards applied research rather than to the pure research which is often undertaken within the various science departments of the universities. But whether man is searching for truth for its own sake, and his own satisfaction, or whether he is looking for new facts to be used to develop new methods and techniques which will accrue to the economic benefit of the community, and of the world, it is essential and right that his findings should be made known to the world and to his colleagues. Not only is a source of information thereby provided for all who need it, but also a forum for open discussion and free criticism of his work.

There are a number of ways in which the results of meteorological research may be presented in printed form. There are, of course, the Learned Journals and the specialist periodicals. These normally demand conciseness and brevity. The number of articles submitted is too great to admit undue length, either in the text, diagrams or by the inclusion of long tables of original data. It is, however, often necessary for long reports and detailed investigations to be made known, and it is the duty and function of the employing authority to provide a means through which this aim can be achieved. The Meteorological Office has faced the problem and supplied an answer since the beginning of the present century.

During the first years of the century there was no formal publication series. Individual reports appeared from time to time. One of the earliest was the "London fog inquiry, 1901-02" (1903). Another was "Barometric gradient and wind force" (1908), and the well known "The life history of surface air currents: A study of the surface trajectories of moving air" (1906). The latter, now out of print, foresaw the Norwegian polar front ideas which were to burst upon the meteorological world more than a decade later.

It was not until 1912 that the first number of the *Geophysical Memoirs* series appeared. This series has continued up until the present time. 1962 marks the fiftieth anniversary of the publication of the first number, now out of print. This was "Effect of the Labrador Current upon the surface temperature of the North Atlantic; and of the latter upon air temperature and pressure over the British Isles". The Memoir was, in fact, the first of two parts on the subject, part 2 following in 1914. The most recent *Geophysical Memoir* to be published is No. 105, "Upper winds over the world, Part III", while No. 106 in the press is entitled "A meso-synoptic analysis of thunderstorms on 28 August 1958".

The *Geophysical Memoirs* series is intended to be a medium for substantial researches, particularly those involving the presentation of a considerable mass of data in tables and charts. In general they serve as basic material for further research and do not bring novel and speculative theories to the attention of the scientific world.

It was soon found that there was a need for a less ambitious publication for individual investigations of a briefer and less profound kind. Thus in 1918 the first issue of a new series, called *Professional Notes* appeared. These continued until in 1959 the final title, No. 126, "A synoptic study of anomalies of surface air temperature over the Atlantic half of the northern hemisphere" concluded a long succession of personal contributions to meteorological knowledge.

In 1948 a third series commenced. It was called *Meteorological Reports* and the numbers contained surveys of the state of knowledge of aviation meteorology in certain parts of the world and reviews of what was known in certain specialized fields, also mainly related to aviation. This series had a relatively short life terminating in 1959 with No. 22, "Aviation meteorology of the West Indies".

Finally, it was decided to combine *Professional Notes* and *Meteorological Reports* in a new series called *Scientific Papers*, to be used for the publication of scientific researches which are not appropriate to *Geophysical Memoirs* and of the results of studies and inquiries of a practical or applied nature. The first number "Airborne measurements of the latitudinal variation of frost-point, temperature and wind" was launched in mid-1960. It is intended that *Scientific Papers* will consist of separately published monographs and include subjects both on pure meteorological research and on the application of meteorology to transport and industry. It is printed on a larger size of page than the discontinued series in order to enable the diagrams, an important feature of most meteorological publications, to be larger and clearer.

In just under two years a total of 15 numbers have appeared. Another two are in the press. The subject range over the field of meteorology from such geographical studies as "The rainfall of Malta", No. 3, to "Pressure variation over Malaya and the resonance theory", No. 4, and "Forecasting in the Falkland Islands and Dependencies", No. 7; and from the contemporary problems of heat balance and energy exchange "Some calculations of terms in the energy balance at ocean weather stations I and J in the North Atlantic", No. 11, to the latest work in numerical prediction "An experiment in the verification of forecast charts" No. 9, and "Three-parameter numerical forecasts at Dunstable—a study of the error fields", No. 13. The most recent results in the subject of numerical weather prediction will appear shortly in *Scientific Paper* No. 16, "An experiment in operational numerical weather prediction". Another interesting paper is No. 12 "Some statistical relationships between the temperature anomalies in neighbouring months in Europe and western Siberia". This not only makes a useful contribution in itself to long-range forecasting but it shows the kind of way in which this problem can be and is being attacked, and the brightness of the guiding light that shines, though but dimly, from the results.

A feature of the series is that H.M. Stationery Office will accept from customers a standing order for numbers as they are published. The cost is reasonable enough, even at the rate of a little over one every two months, which seems to be the present rate of production. Such a subscription will indeed ensure that the reader is kept up to date with the ever advancing expansion of knowledge in meteorological science. Meteorologists, students of weather science and workers in allied and fringe subjects will not find it unrewarding.

A. H. GORDON

New Zealand Meteorological Service

Dr M. A. F. Barnett retired from the post of Director of the New Zealand Meteorological Service on 30 June 1962. He has been succeeded by Dr. R. G. Simmers.

OFFICIAL PUBLICATION

The following publication has recently been issued:

SCIENTIFIC PAPER

No. 14—*Variation of the difference between two earth temperatures*, by P. B. Sarson, M.A.

In the study and analysis of earth temperatures it is often necessary to compare data from one station with those from another or with data from the same station at a different depth. Despite the natural smoothing of the data by the slow diffusion of heat from above or below, earth temperatures often show greater differences between neighbouring stations than between stations a hundred miles or more apart. These differences arise from variations in diffusivity: the diffusivity depends not only on soil type but also on drainage. Nevertheless, by forming simple systematic differences it is possible to compare data from such neighbouring stations in some detail, and even to make estimates of missing data or extend the period of means generally within $\pm 1.0^{\circ}\text{F}$ accuracy. The method depends on the natural smoothing by heat diffusion, such errors as do arise being solely attributable to the variation with time of the coefficient of thermal diffusivity caused by large variations in sunshine or rainfall.

This paper gives a theoretical explanation of the types of variation over long periods of the differences observed between earth temperatures at the same or neighbouring stations. Illustrations are provided of the conclusions that can be derived from the study of these variations.

METEOROLOGICAL OFFICE NEWS

Retirement.—The Director-General records his appreciation of the services of:

Mr. D. H. Clarke, Senior Experimental Officer, who retired on 3 June 1962 after over 35 years' service. After seven years in the Royal Air Force as a W/T operator, during which time he worked for the Meteorological Office at Cranwell and overseas, he joined the Office as a Temporary Clerk III at Aldergrove in 1926. In 1932 he was transferred to Croydon, was promoted to Assistant II in 1938 and to Assistant I in 1942. He will be remembered as the Head of the W.A.A.F. training school in 1942–43 and as an instructor at the Meteorological Office Training School in 1943–44. He will, however, probably be best remembered in his administrative capacity at Dunstable where he served from 1948 until he retired and was involved in the arrangements for the move to Bracknell last year.

THE METEOROLOGICAL MAGAZINE

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551.501.8:551.515.4:551.558.1

VERTICAL AIR MOTION IN SHOWERS AS REVEALED BY DOPPLER RADAR

By J. R. PROBERT-JONES, B.A. and W. G. HARPER, M.Sc.

The Doppler principle has had many and varied applications in physics and in astronomy, but has only recently been applied to meteorology as a radar technique. The Meteorological Research Unit of the Meteorological Office at Malvern, with the active help of the Royal Radar Establishment, Ministry of Aviation has been applying it to a study of precipitation processes. A Doppler radar working at centimetric wavelengths, pointed vertically, will measure the fallspeeds of precipitation, and if it is also a pulsed radar it will measure these fallspeeds at any specified height. In warm-front rain, where the vertical air motion is small (a few centimetres per second) we can in effect measure the free air terminal fallspeeds of the raindrops, and, from the intensity of the echo received from each velocity interval, we can obtain information on the variation of drop distribution with height ^{1, 2}.

Quite a different method of analysis is necessary in convective precipitation, where updraughts and downdraughts can be expected to have values measured in metres per second rather than centimetres per second, and where the velocities measured by the Doppler radar will be the free air fall velocities of the precipitation particles modified by these vertical air motions. Plate I(a) (facing p. 276) is a Doppler pattern from the active portion of a moderate summer shower with its top at about 5 km. This record was obtained on 8 June 1961 at Pershore, Worcestershire using the 3.2 cm 10 kw pulsed Doppler radar described by Boyenval¹. The equipment was used pointing vertically. Height elements, each about 150 m (500 ft) in depth, are displayed along the vertical axis, and precipitation fall velocities along the horizontal axis, in channels 1 m/sec wide. The zero velocity channel is defined by the strong echo in the lowest height elements, which is caused by transmitter break-through and by sidelobe reflections from stationary ground targets. Since we are working at 3.2 cm wavelength and are using a comparatively low output power we can assume that we are not detecting cloud particles as such, but only the precipitation present.

Above the 0°C level at 1.5 km in Plate I(a) the pattern shows considerable

variability with height, with substantial excursions from the mean*, but the whole pattern can be seen to trend first one way and then the other with height. The radar beam is quite a narrow one (up to May 1960 it was 3° wide to half-power points, or 260 m at height 5 km, and less in proportion at lower heights; but in May 1960 a larger aerial was installed giving a beam 1.7° wide, or 150 m at height 5 km) and is unlikely to have enclosed both a region of upward and one of downward air motion at any one time and at any one level. We can therefore attribute the breadth of the velocity spectrum, which changes only gradually with height, primarily to the range of particle sizes present at each level, and the main zigzag effect to the spatial variability of the vertical air motion. At 3 km and at 4 km in Plate I(a) some precipitation is actually rising at 1 to 2 m/sec, and it is clear that at these levels upward air motion must be present.

By comparison with this variability the pattern found towards the rear of the same shower (Plate I(b)) is a very simple one. It has a strong resemblance to the patterns obtained in warm-frontal rain. The low velocities above the 0°C level, their narrow spectrum, and the rather small excursions from the mean suggest that this is a fallout zone with only snow and ice crystals present, and that there is little vertical air motion at these levels.

Below the 0°C level, however, at both times, in the first kilometre or so above the ground, the pattern changes very little with height. The simplest interpretation is that there is a stable spectrum of raindrop sizes, and a rather uniform vertical air motion at these levels. The spectrum extends to the 9 m/sec channel at 1250 GMT, but only to 6 m/sec at 1235 GMT. We shall show that this is partly an effect of vertical air motion, but mainly of maximum drop size. The rainfall at the ground was very light at 1235 GMT. This will be examined in more detail later. In both patterns the precipitation echo disappears completely below about 400 m. This is entirely an instrumental effect, caused by receiver paralysis in the first few microseconds after the emission of the radar pulse, and does not imply any weakening of the precipitation near the ground.

An interesting feature is that an acceleration zone has been present at the melting level in all the Doppler shower records so far examined. At first sight this seemed surprising, because it was known from experience that a bright band, which is the accepted indicator of melting effects on a conventional weather radar, though often seen in showers on a normal range-height radar, is certainly not always present. Browne³, however, working at Cambridge, England with a vertically-pointing 3 cm radar, had reported that bright band effects were nearly always detectable in showers as well as in stratiform rain, and our Doppler records, though rather few in number, seem to support his claim. It may be that in shower conditions bright bands are seen less often on range-height radars than on vertically-pointing radars because with the range-height display we are usually working at much greater ranges where width of beam results in poorer discrimination. There would thus be a tendency to mask weak bright band effects. It is understandable that a pulsed Doppler radar, with its ability to sort the components of precipitation by virtue of their varying fallspeeds, might detect an acceleration effect at the melting level on occasions when spatial variability of the particle distribution tended to mask

**Care must be taken when examining the patterns to exclude any effect due to the harmonic component which is seen in Plate I(a) as a weak mirror image of the main trace.*

it on an ordinary display. Plate I(a) is probably an example of this. The rain-fall rate at the ground at this time was small, but there was almost certainly much heavier precipitation aloft which could have blotted out a small intensity maximum at the melting level on an RHI radar. Three-centimetre range-height records were in fact taken on this storm but a bright band was not seen.

Method of analysis.—The assumption which has been made in order to derive vertical air velocities in showers is based on this consistent detection of an acceleration zone at the melting level in the Doppler records. It is suggested that to explain it there must have been a component of the precipitation just above the 0°C level in these showers consisting of large ice crystals or snowflakes, and that these collapsed on melting to form raindrops with much higher fall velocities than the snow. There may in addition have been super-cooled waterdrops or other forms of precipitation such as graupel or hail present, but our Doppler technique would record them in greater downward velocity channels than the snow, and they would not mask the acceleration effect at the right-hand edge of the recorded pattern. The snowflakes and ice crystals which we infer were melting in the acceleration zone must have grown at a substantially higher level, and it is assumed as the basis for the analysis that they are present at all higher levels in the precipitation. Only small concentrations would be needed for detection since with the vertically-pointed aerial the ranges of detection are short. Measurements made by Langleben⁴ show that snowflakes and ice crystals have a free fall velocity of about 1 m/sec ($\pm \frac{1}{2}$ m/sec). Our method therefore is to define the right-hand edge of the pattern to the nearest metre per second at each level, correct it by 1 m/sec, and so obtain a value of vertical air motion for each height element.

Before considering the implications of this method the recording technique must be described in more detail. An effectively continuous record of the Doppler display is obtained by using special Vinten cameras, in which the shutter is open continuously apart from the short interval, a small fraction of a second, when the film is being moved on. An exposure is taken every five seconds and each is therefore a five-second integration of the pattern. This has seemed acceptable because we do not see obvious changes or rapid oscillations in velocity within a five-second period; in fact the time variation in the velocity pattern has been sufficiently slow that only each second or third frame in the analysis has been used. In a shower extending to 6 km and taking 20 minutes to pass over the radar this gives us over 4000 measurements. They are plotted on an open scale of height against time, and isopleths are drawn at intervals of 1 m/sec. Very little smoothing has been necessary, but individual measurements differing by 1 m/sec from the surrounding values have been ignored. The smallest features drawn in the patterns are from two or three contiguous values. Finally, a horizontal scale in kilometres is added, based on the assumption that the shower is moving with the speed of the wind at 3 km, and the pattern is then redrawn to a uniform scale in the vertical and horizontal, and is reduced to a convenient size.

To extend the analysis below the melting level a different assumption is necessary. From an assumed continuity of vertical air motion at the melting level the terminal velocity of the drops present immediately below this level can be inferred, and from the further assumption that there will be little change in the terminal velocity of the largest drops in their fall to the ground (the largest drops are least modified in size by evaporation during fall) we can

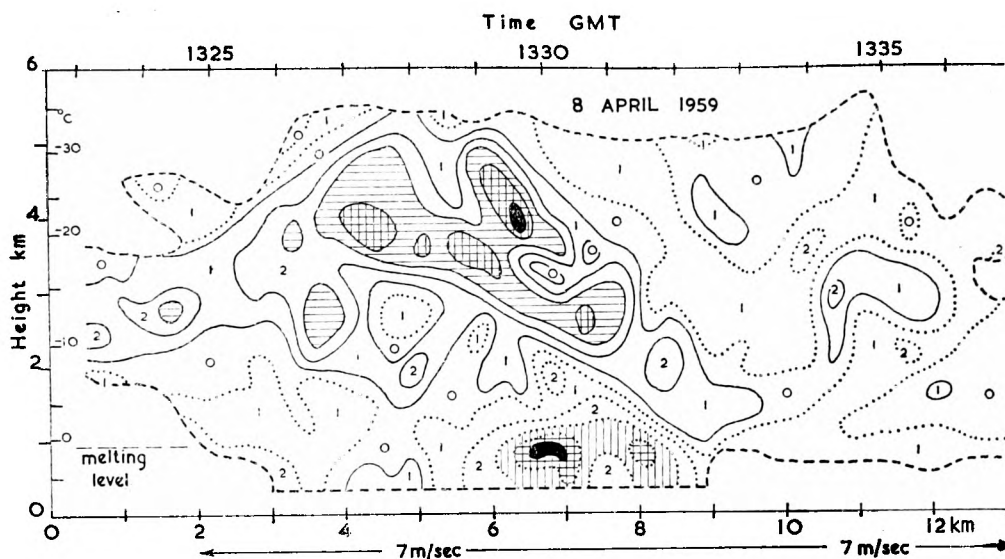


FIGURE 1—THE PATTERN OF VERTICAL AIR MOTION IN THE SHOWER OF
8 APRIL 1959 (*continued opposite*)

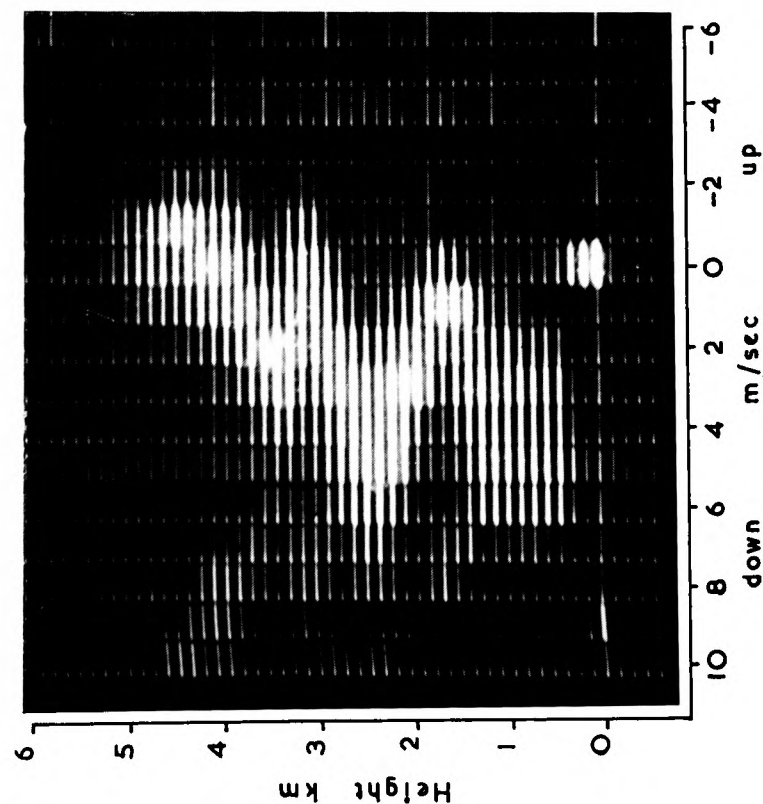
The left-hand side being earliest in time is the leading edge of the shower. Wind speeds are given in knots ($1 \text{ m/sec} = 2 \text{ kt}$).

interpret the left-hand edge of the pattern below this in terms of vertical air motion. The method does not take into account any change of drop distribution due to shear across the beam.

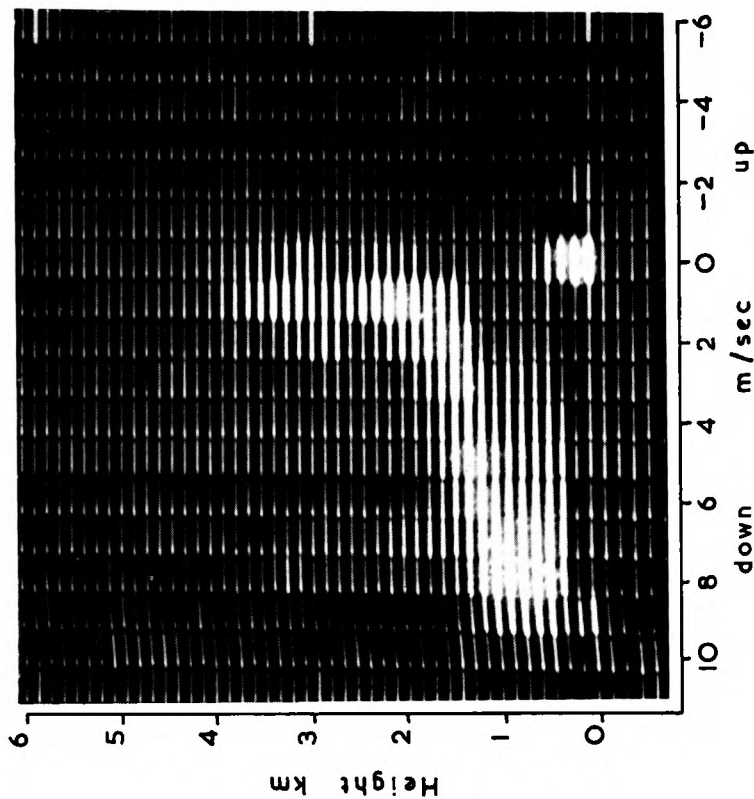
It must be borne in mind when studying the patterns that each is a single cut through the shower. Further, since the horizontal velocities of the showers were substantially greater than the vertical velocities which were measured, the patterns will be more closely akin to instantaneous range-height patterns than to the patterns that would be recorded if one could move one's axis of measurement with the storm. In all cases (e.g. Figure 1) the left-hand side being the earliest in time is the leading edge of the shower. The isopleths have values $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$. . . m/sec. For simplicity the zones between them have been labelled 0, 1, 2 . . . m/sec, upward motion being enclosed by full lines and downward motion by dotted lines. We present here the patterns obtained in three moderate showers.

Shower of 8 April 1959.—On both 8 and 9 April 1959 moderate showers were widespread over England and Wales in moist unstable westerlies of maritime polar origin, but amounts of rain were small. 1.5 mm of rain were measured in the shower which gave echo in the vertically-pointing beam of the radar from 1323 to 1349 GMT on 8 April. Cloud at the time was reported as Cu and Cb with base at 450 m.

The first minute or so of echo overhead was missed, and the start of record shows echo only between 1.5 and 3.5 km, entirely above the melting level which was at 1.0 km (Figure 1). Three minutes later echo extends to the ground, and the echo top in the beam is at 5 km, where the temperature is -30°C . The pattern falls into three main sections. The first from 1323 to 1333 GMT is clearly the most active part of the shower. It contains the strongest upward and downward air motions. The great majority of upward air motion occurs above 2 km, with downward motion largely below this level. The



(a) Active section at 1235 GMT



(b) Decaying section at 1250 GMT

PLATE I—PULSED DOPPLER RADAR RECORDS FROM A SHOWER ON 8 JUNE 1961 AS IT MOVED OVER THE RADAR



Crown Copyright

PLATE II—MACHINE OPERATORS AT WORK IN THE PUNCHED-CARD INSTALLATION
IN THE METEOROLOGICAL OFFICE, BRACKNELL



Crown Copyright

PLATE III—DAILY FORECAST CONFERENCE AT THE METEOROLOGICAL OFFICE,
BRACKNELL

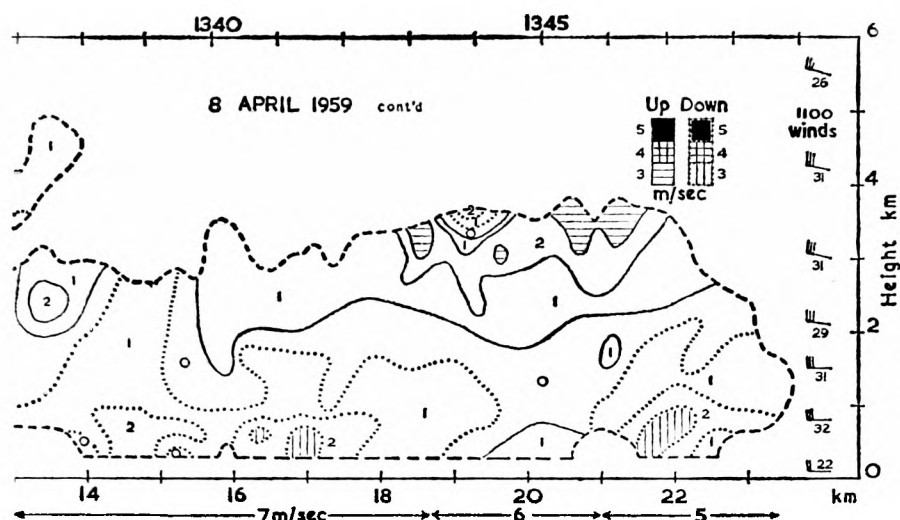


FIGURE 1—THE PATTERN OF VERTICAL AIR MOTION IN THE SHOWER OF
8 APRIL 1959—*continued*

upward motion is present initially in cells of 2 to 3 m/sec, but the maximum values of 4 to 5 m/sec are found at the 4 km level, and seem to occur beneath the highest tops. A surprising feature is the tilted zone of upward motion. It does not seem possible to explain it as an effect of wind shear. The winds given in the diagrams were measured at Aughton, 75 miles north of the radar site, but it seems from the uniform pressure pattern prevailing at the time, that the local winds at Pershore are not likely to have been very different. The strongest downward air motions, also 4 to 5 m/sec, are found at low levels, just before precipitation ceased at the ground at 1332 GMT.

In the second section from 1333 to about 1339 GMT the vertical air motions are small and apparently disorganized, small downward motion predominating. It is clearly a region of decay. The third section from 1339 to 1349 GMT may in effect be a separate shower. It is again more organized, with upward motion above 2 km and downward motion below. The upward motion of 3 m/sec occurring in the highest echo top in this section possibly represents an actively developing cell. The inferred terminal velocities of the largest drops, entered below the horizontal scale of kilometres in the diagram, are 7 m/sec for most of the shower, falling to 5 m/sec at its end. The values correspond to drop diameters of 2.5 mm decreasing to about 1.5 mm. A tailing off of this kind accords with experience, and is of course the effect of differential fall velocities in wind shear. The raingauge also showed a maximum rainfall rate in the early part of the shower.

An analysis was also made of the breadth of the spectrum of velocities throughout the shower. It is not shown here, but its main features are described. Below the melting level the breadth was 8 m/sec in the early part of the shower, and a fairly steady 7 m/sec in the final section, but in section two its maximum was only 4 m/sec and its average only 2 m/sec. Above the melting level it was as high as 7 to 8 m/sec in the cells of maximum updraught, suggesting that the maximum growth was associated with them. In the almost detached precipitation recorded at 1337 GMT at around 4 km the echo was restricted to one and occasionally two channels, strongly suggesting that this was a decaying tower

falling away as snow. The comparatively slow changes found with height and time suggest that small-scale turbulence is contributing rather little to the breadth of the spectrum.

Very roughly we can see in Figure 1 a spacing of cells and regions of upward and downward air motion of about 1 to 2 km, both in the horizontal and the vertical. This is substantially greater than the resolving power of the systems either in the vertical or the horizontal, and one can be confident that it is not a scale imposed by the equipment.

Shower of 9 April 1959.—On the next day showers were again widespread, and some stations not more than 100 miles from the observing site reported hail, probably graupel. The cloud at Pershore was reported as Cu and Cb with base 600 m. Winds were lighter, and as a result the time scale of the shower

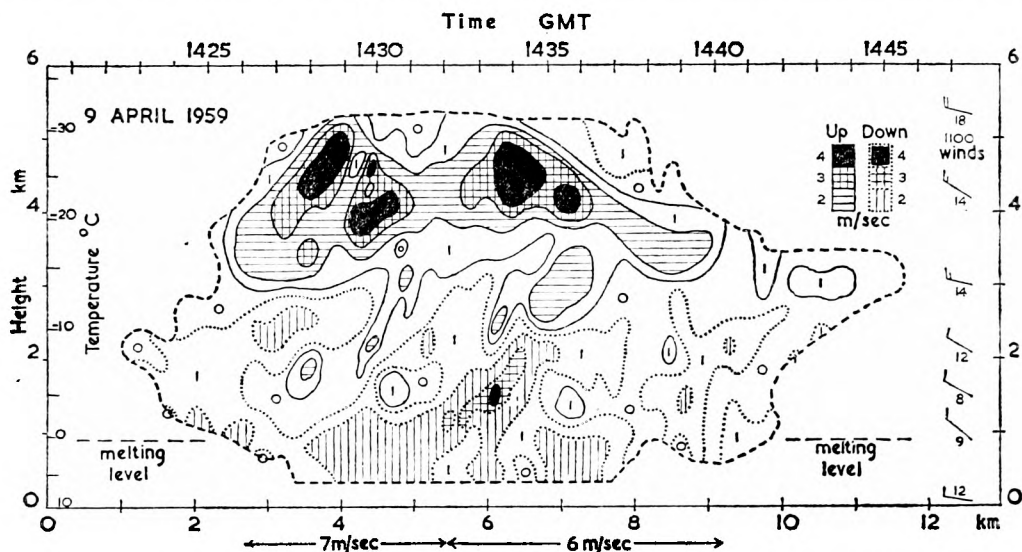


FIGURE 2—THE PATTERN OF VERTICAL AIR MOTION IN THE SHOWER OF 9 APRIL 1959

The left-hand side is the leading edge of the shower. Wind speeds are given in knots.

recorded on the Doppler radar (Figure 2) appears more compressed. The rain-gauge record shows that the rainfall rate was a maximum, 8 mm/hr, at the beginning of the shower. The gauge recorded 0.7 mm of rain, a modest shower. The terminal velocities deduced for the largest drops, 7 m/sec falling to 6 m/sec, fit reasonably with this. They imply a maximum drop diameter of 2.5 mm falling to 2.0 mm.

The pattern shows some obvious similarities to the shower of 8 April, but it should be noted that in Figure 2 the full black zones are 4 m/sec whereas in Figure 1 they were 5 m/sec. The upward air motion is concentrated in the top forward half of the shower, while the downward motion is largely below. The strongest upward motion of 4 m/sec is close to the top of the echo. The downward motion is shown as mainly 2 m/sec, but there is one cell of 3 to 4 m/sec in the middle of the shower just above the melting level, which was again close to 1 km.

There are other similarities between the two patterns. The first echo appeared well above the 0°C level, between 2 and 2½ km, and it was five minutes before

the shower reached the ground at the radar site, about the same time lag as on the 8th. At this time the echo top had almost reached its maximum of 5.3 km (temperature -31°C). The shower at the ground seems to have lasted for ten minutes, from 1427 to 1437 GMT, and then the echo base lifts and the echo top descends, the tail of precipitation being seen at 3 km at 1445 GMT. The Doppler pattern in the tail of this shower had all the characteristics of the decay stage (e.g. Plate I(b)), with echo above the melting level almost entirely restricted to the downward velocity channels of 1 and 2 m/sec. We can assume with confidence that this was the slow fall-out of snow, the remnants of earlier activity. The spacing of cells of air motion is again roughly 1 to 2 km. These patterns will be discussed further in a later paragraph.

Shower of 8 June 1961.—We have a complete Doppler record of this shower, and in addition range–height radar records from a 3-cm AN/TPS-10. An extract from these range–height records is given in Figure 3 covering the shower's history and movement for rather more than an hour before it reached the station, and for almost an hour after it had passed. We had not been equipped to obtain range–height records in 1959. The range–height patterns are not uniform in scale in the horizontal and vertical as are the vertical air motion patterns, but are much compressed in range as compared with height. It will be seen that the echo top rose from 5.0 to 6.5 km between 1118 and 1134 GMT, it was 5.5 km at both 1254 and 1303 GMT, but was 6.0 km again at 1324 GMT. At 1233 GMT 6.1 km was recorded by the Doppler radar. Throughout the whole period from 1134 to 1324 GMT the shower seems to have retained the same general form, with active towers at the front of the shower and decaying echo towards its rear. New growth seems to have been taking place almost underneath the overhang at the leading edge. The cores of strong echo shown

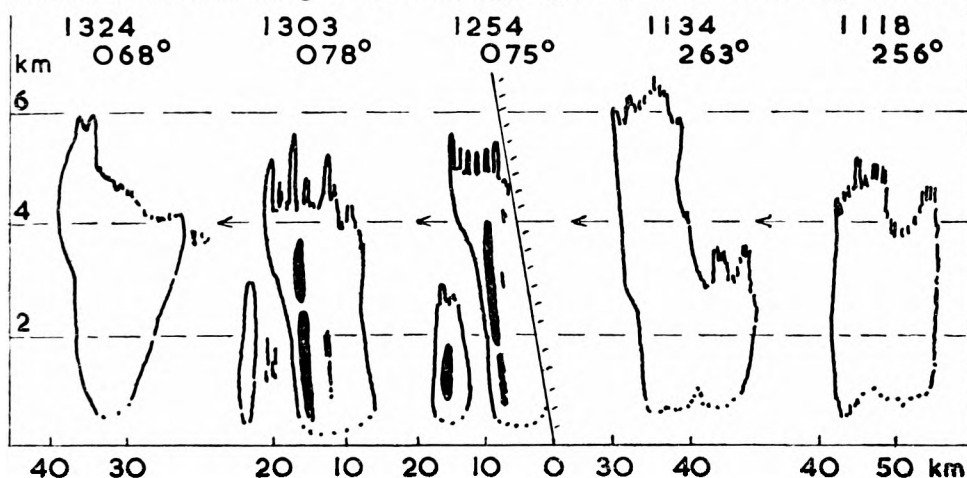


FIGURE 3—RANGE–HEIGHT CROSS-SECTIONS OF THE SHOWER OF 8 JUNE 1961 AT FIVE DIFFERENT TIMES SPREAD OVER A TWO-HOUR PERIOD FOR COMPARISON WITH THE DOPPLER RECORD OF FIGURE 4

Times and azimuths are given. The horizontal scales in kilometres give the distance from the radar site at each time. The shower passed directly over the radar site from 1230 to 1255 GMT, and in the pattern for 1254 GMT its trailing edge is not yet clear of the scanning beam of the range–height radar.

in Figure 3 were revealed by gain reduction, and are seen to be close to the leading edge at low levels. They show only slight forward shear. A bright band

was not seen in these patterns, even at reduced gain. At 1254 GMT, when the range of viewing was very short, six fairly uniformly spaced towers could be seen, but comparison with a photograph taken on the same azimuth at 1253 GMT shows that not all were of equal intensity or were at the same stage of development, for some were rising and others were falling back. The spacing of these towers is about 1.5 km, or perhaps 2 km if some allowance is made for them being scattered in azimuth within the beam. Despite its modest size and intensity there was clearly an efficient renewal mechanism in this persistent shower.

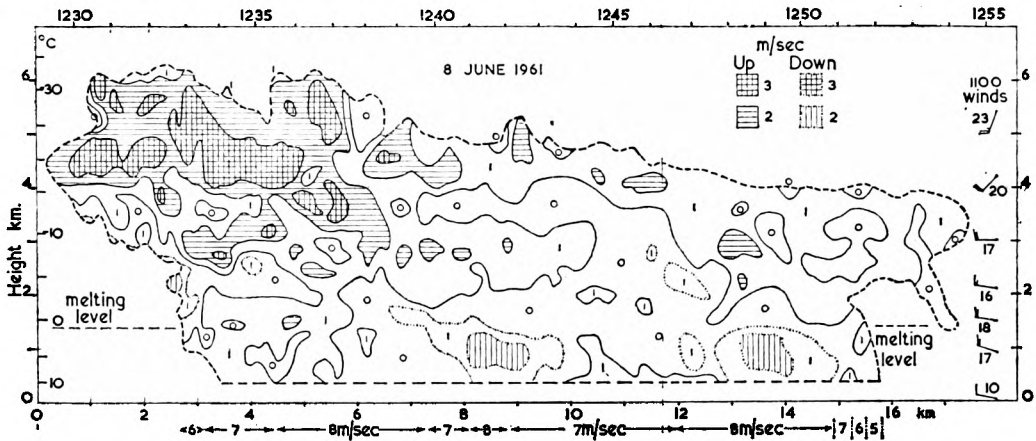


FIGURE 4—THE PATTERN OF VERTICAL AIR MOTION IN THE SHOWER OF 8 JUNE 1961

The left-hand side is the leading edge of the shower. Wind speeds are given in knots.

The vertical air motion diagram is given at Figure 4. It shows overhang at the leading edge, echo tops reaching 6.1 km in the leading part of the storm, lowering towards the final tail of the shower just above the 3 km level. The strongest upward air motion is found mainly above 4 km, and is almost entirely restricted to the front half of the shower. One can see a suggestion of three towers at a spacing of about 2 km in the pattern of the strongest upward motion, centred at about 1231, 1233 and 1236 GMT, with an echo-free gap about 1 km deep at 1235 GMT. There are further small protrusions at 1239 and 1242 GMT. These features are not dissimilar to those of the echo tops of Figure 3 when the differences of scale are borne in mind.

A surprisingly small amount of downward air motion is found in this analysis compared with the two we have presented earlier, but there is some similarity in the location of the 2 m/sec isopleths, which lie below the melting level and towards the rear of the shower section, with the main cells of downward air motion in Figures 1 and 2.

The two displays of Plate I were taken from this shower. At 1235 GMT (Plate I(a)) there is a fairly broad spread of velocities of 4 to 6 m/sec at most levels, suggesting the presence of liquid water drops or of hydrometeors of similar fallspeed to water drops, but at 3 km it reaches a maximum of 8 m/sec. This could be entirely an effect of drop size, or it could be partly an effect of shear of the vertical air motion within the beam, e.g. if parts of both an up-draught and a downdraught were included within the pulse volume. Plate I(b) taken at 1250 GMT is typical of the pattern towards the rear of the shower,

except during the brief recurrence of irregular motion at 1248 GMT. The spread of 2 m/sec, occasionally 3 m/sec, above the melting level in Plate I(b) suggests that snow only is present.

The maximum drop diameter derived from our matching process lies between 2 and 3 mm for most of the shower, tailing off rapidly at the end. But although the Doppler record suggests that rain was reaching the ground from 1234 to 1252 GMT, the rain-gauge recorded a measurable rate only from 1242 to 1247 GMT, with maximum 4 mm/hr. The reason may have been that the southern edge of the shower only skirted the rain-gauge, which is 400 m from the radar site at Pershore, and was slightly south of the cross-section recorded by the radar on this occasion.

Discussion.—A feature of the patterns is their complexity. Perhaps one should not be surprised at this. Attention will be drawn to certain features, however, which may be important, and tentative conclusions drawn from them.

(i) In the showers of 8 and 9 April, where there was little variation of wind direction with height, and almost negligible shear of precipitation across the plane of the height-time section, a rough balance between the regions of upward and downward motion is found. On 8 June there was a pronounced unbalance, and it is reasonable to think that this was the result of the substantial wind components across the section at the higher levels on that day (see (v) below).

(ii) The radiosonde ascents show that on all three days shower development was set off by diurnal heating, and that only the rather shallow layer of air heated by the ground would have been convected. The wind patterns given in Figures 1, 2 and 4 suggest that, with a shower movement controlled by the 700 mb wind, there would have been a relative inflow of this surface-heated air into the lower front of the storm. This is without doubt a common feature in such showers.

(iii) In the showers of 8 and 9 April there was little variation of wind direction with height, and therefore negligible shear of precipitation across the plane of the height-time sections. We can for this reason expect to find reasonable continuity in the patterns of vertical air motion between low and high levels.

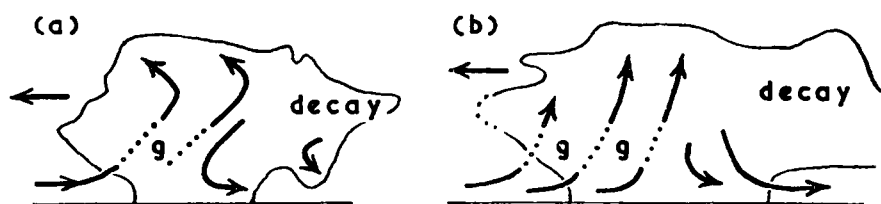


FIGURE 5—SIMPLIFIED PATTERNS OF AIR MOTION SUGGESTED FOR THE SHOWERS OF (a) 9 APRIL, AND (b) 8 APRIL 1959

The movement of the showers is from right to left.

In Figure 5 we have suggested where these upward and downward motions may be occurring. On 9 April (Figure 5(a)) two sloping zones of upward motion are shown (compare Figure 2) in which the vertical component of the air velocity intermittently reaches 2 m/sec. As is implied in the diagram the rearward of the two may be an updraught in which the supply of warm air from low levels has been cut off. The reversal of slope in the stronger up-

draught above 3 km is consistent with the wind shear present at the time, for the increase of westerly wind above 3 km would have just this effect. The main downward flow has the same slope as the updraughts at medium levels, and lies just behind and beneath the cut-off thermal. It probably leaves the shower either to the sides or to the rear of the section. An almost parallel flow, with its maximum 2 m/sec can perhaps be seen in the tail of the shower, as is suggested by the smaller arrow.

The immediate impression gained from Figure 1 is of updraught from the lower centre to the upper forward region of the shower of 8 April, but this is quite inconsistent with the existing wind shear, and is unlikely to have been the true pattern. We think that the updraught structure must have been more nearly that of Figure 5(b), with inflow into the front of the shower at a low level, and then a more nearly vertical updraught than in Figure 5(a). There should have been no reversal of slope because the wind did not increase above 3 km. Perhaps some slight imagination is needed to see this in Figure 1; a linkage is suggested from the 2 m/sec cell of upward motion at height 2 km, 1328 GMT, to that of 4 m/sec at $3\frac{1}{2}$ km, 1329 GMT, and to 5 m/sec at 4 km, 1329 $\frac{1}{2}$ GMT; and a second updraught region from the 3 m/sec cell at $2\frac{1}{2}$ km, 1326 $\frac{1}{2}$ GMT, to the 4 m/sec cell at 4 km, 1327 $\frac{1}{2}$ GMT, continuing to the echo top at $5\frac{1}{2}$ km, 1328 GMT. These are spaced at about 2 km on the section, which is about the same separation found for the updraughts in Figure 2. This suggests that the small cell of upward motion of 3 m/sec at $2\frac{1}{2}$ km, 1324 $\frac{1}{2}$ GMT, which is a further 2 km upwind may be a newly developing thermal. The downdraughts are difficult to define in Figure 1 and little reliance should be placed on this section of Figure 5(b).

There is admittedly a lack of continuity in the updraughts through and just above the 0°C level. These portions of the flow lines are dotted in Figure 5 and marked with the letter 'g'. This may well have resulted from the local failure of the assumption that snowflakes or ice crystals are present, for appreciable growth of ice crystals will not occur within the updraught until the temperature has fallen to perhaps -10°C, and it is perhaps unlikely that enough ice crystals or snowflakes will have been caught up in the rising air to be detectable. If in this part of the updraught the slowest-falling particles are small water drops of diameter 0.5 to 1.0 mm with free fallspeeds of 3 to 4 m/sec we shall have underestimated the updraughts here by 2 or 3 m/sec. There is no reason to expect any real uniformity of speed in updraughts. They will usually reach their maxima at upper levels, because of increased buoyancy due to release of latent heat of fusion in regions where supercooled water droplets are freezing, and to the fallout of precipitation. This is probably the reason for the occurrence of the maxima of upward air motion high up, where the air temperatures were -20° to -30°C, in the examples. Lack of uniformity may also arise from the cessation of an updraught or from new development, for updraughts in their early stages, especially at low levels, may not have precipitation in them, and will then not appear at all in the Doppler analysis. Precipitation carried across the beam may also confuse the pattern.

(iv) Another feature in these air motion patterns calling for comment is the almost complete absence of downward air motion at high levels in the active parts of the showers of 8 and 9 April. We can suggest two possible reasons for this. The first is the more obvious one, and stems from the dependence on the

presence of precipitation as an indicator of air movement. It is that compensatory downward air motion is occurring outside the region of precipitation, and so is not revealed by the Doppler analysis. There is no echo-free region within the precipitation boundary of our sections where it could be occurring, and it is perhaps rather unsatisfactory to have to infer that downward air motion at high levels is all occurring elsewhere. This is particularly so since evaporative cooling by falling precipitation, with resulting air density increase, is likely to be a contributory cause of local downdraught, and the probability of occurrence of downward air motion should perhaps be greater where precipitation is present.

The second reason is an instrumental one. In attributing the breadth of spectrum to the range of particle sizes present (p. 274) it is in effect assumed that the radar beam is narrow compared with the regions of updraught and downdraught examined. By deriving a single value of air motion from the right-hand edge of the Doppler pattern we are in fact more nearly recording the strongest upward air velocity (or the weakest downward velocity) contained within the beam at each time. The method gives the correct maximum value for updraught velocity, but overestimates the size of the updraught by an amount equal to the beam width. In Figures 1 and 2 the beam was 210 m wide at height 4 km (the level at which the maximum updraughts are found), but the cells of upward motion are mostly a kilometre or so across, so that the effect is not very important. But further, the method underestimates the size of downdraughts by an amount equal to the beam width, and also underestimates the maxima of downward air velocity. This will also be unimportant in the decaying regions where we find isopleths of downward motion that are measurably broad; but in the active portions of showers, downdraughts that are equal to or less wide than the beam will contribute to the breadth of the Doppler spectrum, but will be entirely lost from the air motion analysis.

(v) This was one reason why the Doppler radar was equipped with a larger aerial in 1960, giving a beam only 1.7° wide (120 m wide at 4 km). We have obtained insufficient shower records with it as yet to decide if a greater proportion of downward air motion is being revealed. The pattern of 8 June (Figure 4) was obtained with this narrow beam, and it seems at first sight that the same difficulty arises. There is a complication however. With the strong cross-wind which was present on this occasion above 3 km continuity of vertical air motion would not be expected between low and high levels in a single section through the shower, and it is likely that the main downward motion was occurring in an adjacent section. The effect of this shear across the beam can be seen in the range-height cross-sections of Figure 3. The stronger cores of echo at 1254 and 1303 GMT do not extend above 4 km, the level at which the cross-wind component has become substantial, undoubtedly because the precipitation is blowing northwards out of the $\frac{1}{2}$ km wide beam. Further, although the cores are at the leading edges of low-level echo, they are clearly not linked with the leading towers at high levels. This suggests that the leading towers, and therefore probably all the towers seen in this section, are being supplied by updraughts which were to the south of the section, and is supported by the fact that the overhang is at 4 km on azimuth 075° but is nearer 3 km on 078° . With these winds the overhang could only have occurred at or above 3 km. The low rainfall at the rain-gauge, which was to the south of the recorded

section, is also explained by the precipitation being blown northward from the active part of the storm.

Conclusion.—The vertical air motion patterns obtained from Doppler radar records in showers are the first that have been inferred directly. A special feature is that continuous height–time sections are obtained. The patterns in the three showers studied in this paper seem plausible, with two possible exceptions, (i) that updraughts just above the 0°C level may have been underestimated, and (ii) that some of the downward air motion at high levels will not have been detected in the analysis if present in local downdraughts 100 or 200 m in width or if occurring outside the regions of precipitation. We have so far found significant downdraughts only below 700 mb (3 km). The showers we have studied are, however, only modest ones, with rather low rainfall rates, but with improved equipment we hope to examine more active storms.

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551.509.317:551.509.324.2

FORECASTING WET SPELLS AT LONDON

By C. A. S. LOWNDES

Introduction.—For this investigation a wet spell was defined as a period of five days at Kew with (i) at least 15 millimetres of precipitation and no day with less than one millimetre or (ii) at least 20 millimetres with one such day or (iii) at least 25 millimetres with two such days. Lowndes¹ found that in many cases the wet spells were preceded by an outbreak of surface northerlies over the Atlantic and associated trough development in the surface isobars to the west of the British Isles. A study of 500-millibar charts showed that the northerlies were associated with 500-millibar troughs which first appeared over the Atlantic in various longitudes, mainly between 60°W and 20°W . Some were weak over the western Atlantic but intensified during their progression eastward. The average longitude of the trough about 24 hours before the start of a wet spell at London was 30°W in the winter months and 20°W in the summer months. Many of the troughs became slow-moving and some quasi-stationary between 20°W and 0°W . A study was made of 500-millibar contour troughs between 60°W and 0°W over the 10 years 1950 to 1959 and any wet spells which were associated with them were noted. It became clear that the best indicators of wet spells were troughs between 30°W and 20°W and between 20°W and 10°W . No reliable forecasting rules could be based on troughs west of 30°W . A spell indicated by a trough between 10°W and 0°W was nearly always indicated earlier by the same trough between 20°W and 10°W .

Data used.—It was decided to study all 500-millibar contour troughs between 30°W and 20°W and between 20°W and 10°W and to measure their intensity in terms of the 500-millibar height anomaly at 45°N . It became clear, however, that other parameters would be required to distinguish between troughs which were associated with wet spells and those which were not. In a

number of cases, troughs which were not associated with wet spells quickly relaxed on approaching a blocking anticyclone or ridge of high pressure over the British Isles. It was decided therefore to measure the "blocking tendency" in terms of the surface pressure at Valentia or London. This parameter successfully indicated many of the troughs which were not associated with wet spells. However, it was obvious that further parameters were required before a useful forecasting rule could be obtained.

On many occasions, when no wet spell occurred, the spacing to the next upwind trough was short and the trough to the west of the British Isles quickly relaxed or progressed, or was subject to both processes simultaneously. It was therefore decided to measure the spacing between the trough to the west of the British Isles and the next upwind trough and to measure the intensity of the upwind trough in terms of the 500-millibar height anomaly at 45°N .

It was found possible by use of these parameters to obtain rules for the forecasting of wet spells for most months of the year. The data extracted were as follows:

1. (a) The maximum negative 500-millibar height anomaly reached on the trough axis at 45°N between 30°W and 20°W (decametres).
 (b) The surface pressure at Valentia at this time (millibars).
 (c) The spacing to the next upwind trough at this time (degrees of longitude).
 (d) The 500-millibar height anomaly on the upwind trough axis at 45°N (decametres).
2. (a) The maximum negative 500-millibar height anomaly reached on the trough axis at 45°N between 20°W and 10°W (decametres).
 (b) The surface pressure at London at this time (millibars).
 (c) The spacing to the next upwind trough at this time (degrees of longitude).
 (d) The 500-millibar height anomaly on the upwind trough axis at 45°N (decametres).

The data were extracted for the 10 years 1950 to 1959. Mean 500-millibar heights at latitude 45°N for longitudes at 10-degree intervals from 10°W to 120°W are given in Table I; from it the mean 500-millibar height can be obtained for any five-day period. Table I is based on five-year monthly means for the period 1949 to 1953 published by Berlin University.²

The critical values of the parameters were found to vary according to the season of the year. The year was therefore divided up into periods during which certain critical values were found to be effective. The periods are as follows:

- (a) November to February
- (b) March and September
- (c) June, July and August.

A successful forecasting rule could not be obtained for April, May and October. In both April and May only four spells occurred during the 10 years. It is possible that a forecasting rule might be obtained for these months from a larger sample of data, when available.

Forecasting wet spells at London in November to February.—For troughs between 30°W and 20°W a diagram was plotted (Figure 1) of the

TABLE I—500 MB HEIGHT AT 45°N (FIVE-DAY MEANS)

Period	10°W	20°W	30°W	40°W	50°W	60°W	70°W	80°W	90°W	100°W	110°W	120°W
500 decametres +												
1-5 Jan.	63	63	62	58	52	47	43	43	42	45	48	50
6-10 Jan.	63	63	62	58	52	47	43	43	42	44	46	49
11-15 Jan.	63	63	62	57	52	47	44	43	42	44	45	47
16-20 Jan.	63	63	61	57	51	47	44	42	42	44	45	47
21-25 Jan.	62	63	60	56	51	46	43	41	42	45	46	48
26-30 Jan.	61	63	60	55	50	44	44	40	42	45	47	50
31 Jan.-4 Feb.	59	62	59	54	49	42	40	39	42	46	49	51
5-9 Feb.	58	62	58	53	48	41	39	38	42	46	50	52
10-14 Feb.	58	61	57	52	46	40	37	37	42	47	51	53
15-19 Feb.	57	59	56	51	44	39	38	38	42	47	51	53
20-24 Feb.	58	58	55	51	42	39	38	38	42	47	51	53
25 Feb.-1 Mar.	58	57	55	50	42	40	39	39	42	47	51	52
2-6 Mar.	59	57	54	50	43	40	39	39	43	47	50	52
7-11 Mar.	59	57	54	51	44	42	41	41	43	47	50	51
12-16 Mar.	59	57	54	51	45	43	41	41	43	47	50	51
17-21 Mar.	59	58	55	52	47	43	42	42	44	48	51	52
22-26 Mar.	59	59	56	53	49	45	43	43	45	50	53	54
27-31 Mar.	60	60	58	55	50	45	44	44	47	52	55	55
1-5 Apr.	60	61	60	57	52	47	45	45	49	53	56	57
6-10 Apr.	60	62	62	59	53	48	45	46	50	55	58	59
11-15 Apr.	60	63	63	61	54	49	47	47	52	57	60	60
16-20 Apr.	60	64	63	61	56	51	48	49	53	58	60	61
21-25 Apr.	60	64	63	61	56	52	50	52	55	59	61	62
26-30 Apr.	61	64	63	61	57	54	52	55	58	61	63	63
1-5 May	61	64	63	61	57	55	55	58	60	62	64	63
6-10 May	61	63	63	61	58	57	57	60	62	64	65	64
11-15 May	61	62	64	62	59	58	59	62	64	66	66	65
16-20 May	62	62	64	62	60	60	61	64	66	67	66	65
21-25 May	63	63	65	62	61	61	63	66	68	68	68	67
26-30 May	64	64	65	62	62	62	65	68	70	70	69	68
31 May-4 June	66	66	66	64	63	63	67	70	71	72	71	69
5-9 June	69	69	68	66	66	65	68	72	73	73	72	70
10-14 June	72	72	70	69	68	67	70	73	75	75	74	72
15-19 June	74	74	73	72	71	69	72	75	76	76	74	73
20-24 June	77	77	75	75	73	72	73	76	77	77	76	74
25-29 June	78	78	77	77	76	75	75	78	78	79	78	76
30 June-4 July	78	79	79	79	77	77	77	79	79	80	80	78
5-9 July	78	79	79	80	78	79	78	79	80	81	82	80
10-14 July	78	79	80	80	79	80	79	80	81	83	84	82
15-19 July	78	79	80	81	79	80	79	80	81	83	84	83
20-24 July	78	79	80	82	80	80	79	80	81	83	84	83
25-29 July	77	79	81	82	80	79	78	79	81	83	84	82
30 July-3 Aug.	77	79	81	82	81	78	78	79	80	82	83	81
4-8 Aug.	76	79	81	82	81	77	77	79	80	82	83	81
9-13 Aug.	76	79	80	82	80	76	76	78	80	82	83	80
14-18 Aug.	76	78	80	81	79	75	75	77	80	82	83	80
19-23 Aug.	76	78	80	81	78	75	74	77	78	81	82	80
24-28 Aug.	75	78	80	80	78	75	74	76	77	80	81	79
29 Aug.-2 Sept.	75	77	80	80	77	75	73	74	75	78	80	79
3-7 Sept.	74	76	79	79	76	75	72	73	74	77	79	78
8-12 Sept.	73	76	78	78	75	74	72	72	72	76	79	78
13-17 Sept.	73	74	76	76	75	74	71	70	71	75	78	78
18-22 Sept.	73	73	74	74	73	73	70	69	70	74	77	77
23-27 Sept.	72	72	72	71	72	71	70	68	69	73	76	75
28 Sept.-2 Oct.	71	70	70	69	71	70	69	68	69	72	74	74
3-7 Oct.	71	68	68	67	68	68	67	67	68	71	73	74
8-12 Oct.	69	67	66	66	66	66	67	67	67	70	72	71
13-17 Oct.	68	66	66	66	65	65	65	66	66	69	71	70
18-22 Oct.	67	65	65	65	65	64	64	65	64	67	70	69
23-27 Oct.	66	65	65	65	65	63	63	63	63	65	68	68
28 Oct.-1 Nov.	65	64	65	66	65	62	61	60	58	63	67	67
2-6 Nov.	64	64	65	66	65	62	59	56	55	61	65	65
7-11 Nov.	62	63	65	67	65	61	56	52	52	58	64	64
12-16 Nov.	62	63	65	67	65	59	53	47	49	56	62	63
17-21 Nov.	60	63	65	67	65	58	49	43	48	55	61	62
22-26 Nov.	60	63	64	66	63	55	46	41	47	53	59	61
27 Nov.-1 Dec.	60	63	64	64	61	52	44	40	46	51	57	59
2-6 Dec.	60	63	64	62	57	49	43	40	44	50	56	58
7-11 Dec.	60	63	64	61	55	47	42	40	43	48	54	56
12-16 Dec.	61	63	63	60	53	46	41	41	42	46	52	55
17-21 Dec.	62	63	63	59	53	46	41	42	42	46	51	54
22-26 Dec.	62	63	63	58	53	46	42	43	42	46	50	53
27-31 Dec.	63	63	62	58	52	46	43	43	42	45	49	51

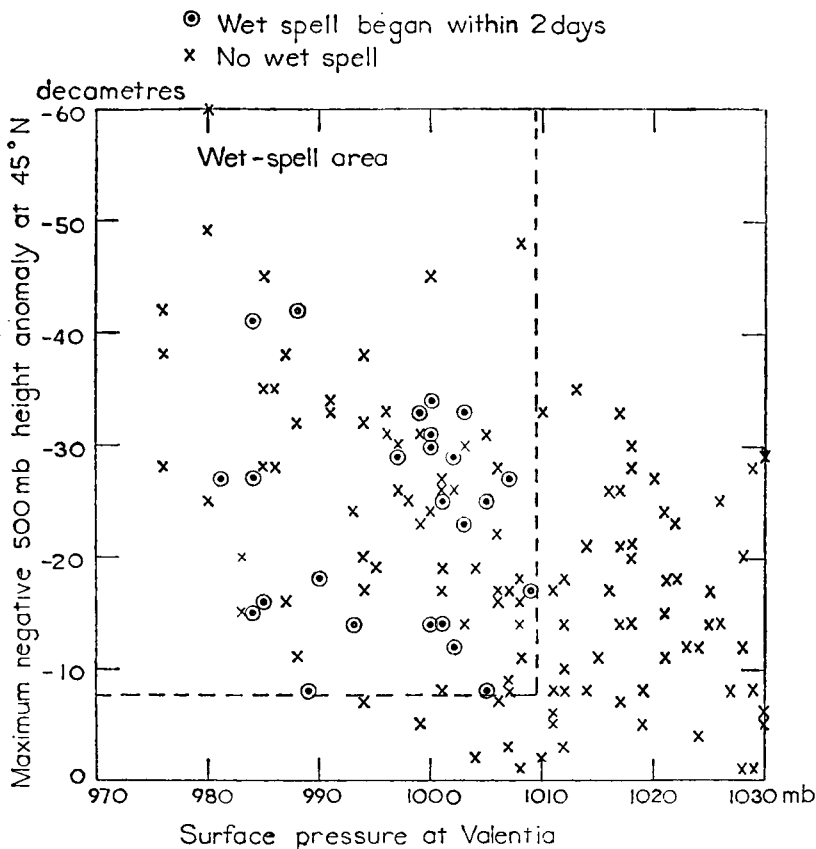


FIGURE 1—WET SPELLS AT LONDON (KEW), NOVEMBER TO FEBRUARY (10 YEARS)
FOR TROUGHS BETWEEN 30°W AND 20°W

maximum negative 500-millibar height anomaly at 45°N against the surface pressure at Valentia at the time of maximum anomaly. If a wet spell began within two days of the time of maximum anomaly or if a spell had already begun and continued for a further five days, a circle was plotted. If no wet spell began within two days, a cross was plotted.

All the wet-spell plots are enclosed within the area indicated. This suggests that for a trough to be associated with a wet spell, the negative 500-millibar height anomaly must reach eight decametres and at the same time the pressure at Valentia must be less than 1010 millibars.

A similar diagram (Figure 2) was plotted for troughs between 20°W and 10°W. In this case, the pressure at London was used instead of the pressure at Valentia. Most of the wet-spell plots fall within the area indicated. This suggests that for a trough to be associated with a wet spell, the negative 500-millibar height anomaly must reach 11 decametres and at the same time the pressure at London must be less than 1008 millibars.

A study of all cases within the "wet-spell areas" showed that if the spacing between the trough to the west of the British Isles and the next upwind trough was above a certain critical value, a wet spell usually occurred. However, it was clear that some upwind troughs in high latitudes and some in low latitudes could be ignored. Upwind troughs with no troughed contour south of 50°N and single-contour troughs south of 40°N were not significant. Weak troughs

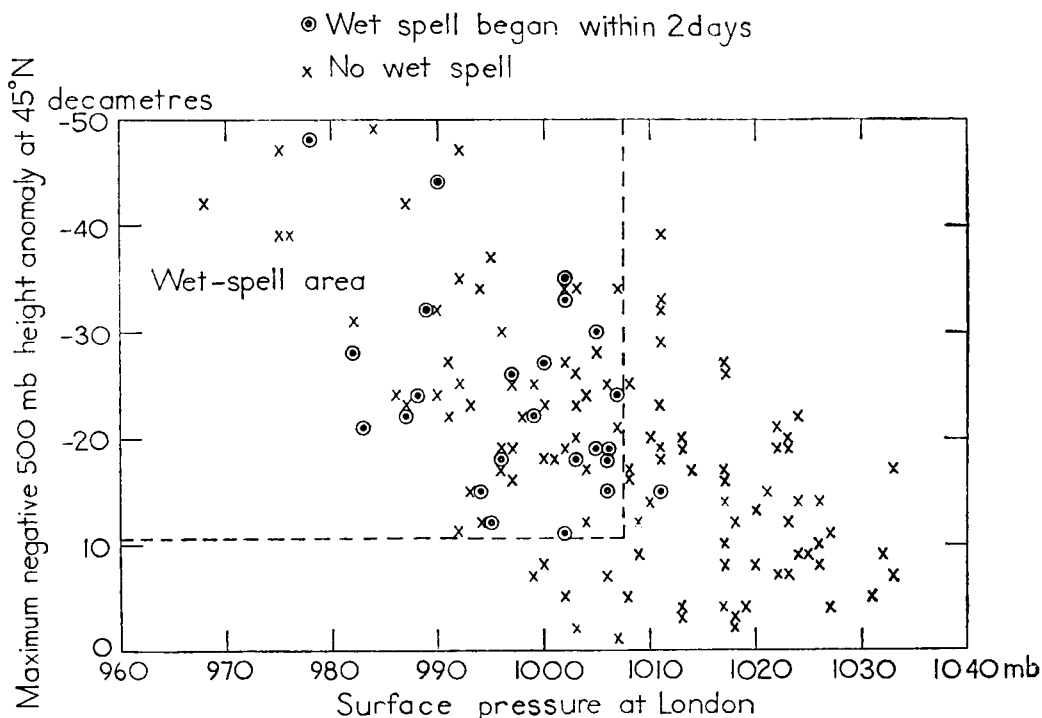


FIGURE 2—WET SPELLS AT LONDON (KEW), NOVEMBER TO FEBRUARY (10 YEARS),
FOR TROUGHS BETWEEN 20°W AND 10°W

with no associated 1000–500-millibar thickness troughs could also be ignored.

For troughs between 30°W and 20°W a diagram was plotted (Figure 3) of the maximum negative 500-millibar height anomaly at 45°N between 30°W and 20°W against the spacing to the next significant upwind trough. The graph can be divided into two areas as indicated. The critical value of the spacing appears to be about 50°. There is some suggestion that for strong troughs it is somewhat higher. Of the 14 cases in the “wet-spell area” 11 were associated with wet spells. (Trough measurements made during a wet spell which had already been indicated were not plotted.)

TABLE II—DATE OF BEGINNING OF SPELL WITH REFERENCE TO DATE d OF
MAXIMUM NEGATIVE ANOMALY BETWEEN 30°W AND 20°W

Date	Number of cases
Spell already begun	5
d^*	3
$d + \frac{1}{2}$	1
$d + 1$	2

* Spell began within six hours of the time of occurrence of maximum negative anomaly.

Table II shows that the spells had either already begun or that they started within 24 hours of the time of occurrence of the maximum negative anomaly. (The large number of occasions when the spell had already begun is partly due to the use of the maximum negative anomaly as a parameter. On many occasions the troughs intensified during their movement from 30°W to 20°W. The derived forecasting rules define a critical value of the negative anomaly, often less than the maximum value, and therefore in practice an earlier indication of the wet spell will sometimes be obtained. This is borne out by the results of a test of the forecasting rules on the two years 1960 and 1961 given at the end

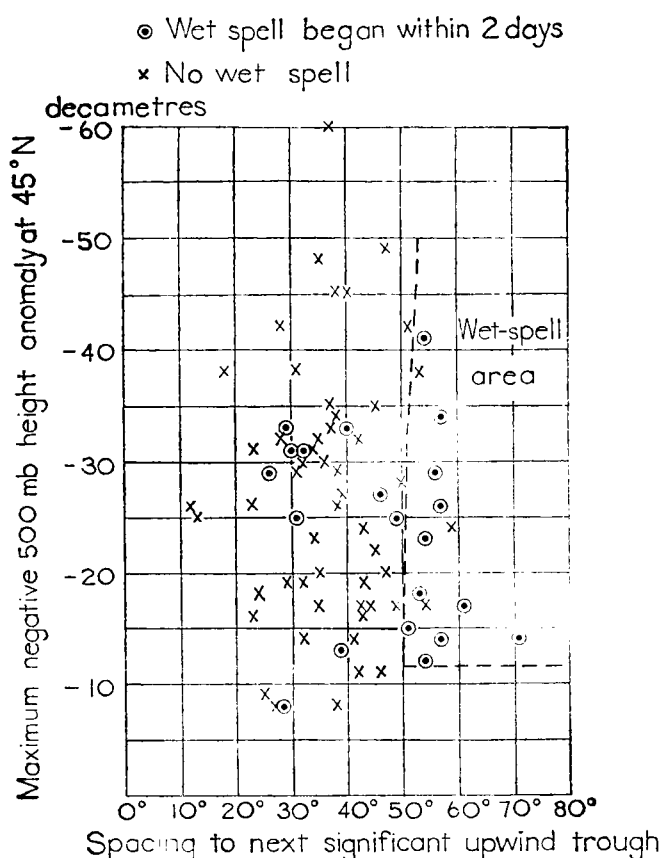


FIGURE 3—WET SPELLS AT LONDON (KEW), NOVEMBER TO FEBRUARY (10 YEARS), FOR TROUGHS BETWEEN 30°W AND 20°W WITH NEGATIVE 500-MILLIBAR HEIGHT ANOMALY AT $45^{\circ}\text{N} \geq 8$ DECAMETRES AND PRESSURE AT VALENTIA ≤ 1009 MILLIBARS

of this paper. The same considerations apply to troughs between 20°W and 10°W .)

For troughs between 20°W and 10°W a diagram was plotted (Figure 4) of the maximum negative 500-millibar height anomaly at 45°N between 20°W and 10°W against the spacing to the next significant upwind trough. The graph can be divided into the two areas as indicated. The critical value of the spacing appears to increase from about 50° for the weaker troughs to over 60° for intense troughs. Of the 15 cases in the "wet-spell area", 13 were associated with wet spells. (Trough measurements made during a wet spell which had already been indicated were not plotted.)

TABLE III—DATE OF BEGINNING OF SPELL WITH REFERENCE TO DATE d OF MAXIMUM NEGATIVE ANOMALY BETWEEN 20°W AND 10°W

Date	Number of cases
Spell already begun	4
d	5
$d + \frac{1}{2}$	3
$d + 1$	1

Table III shows that the spells had either already begun or that they started within 24 hours of the time of occurrence of the maximum negative anomaly. In a number of cases a spell was indicated by a trough between 30°W and 20°W

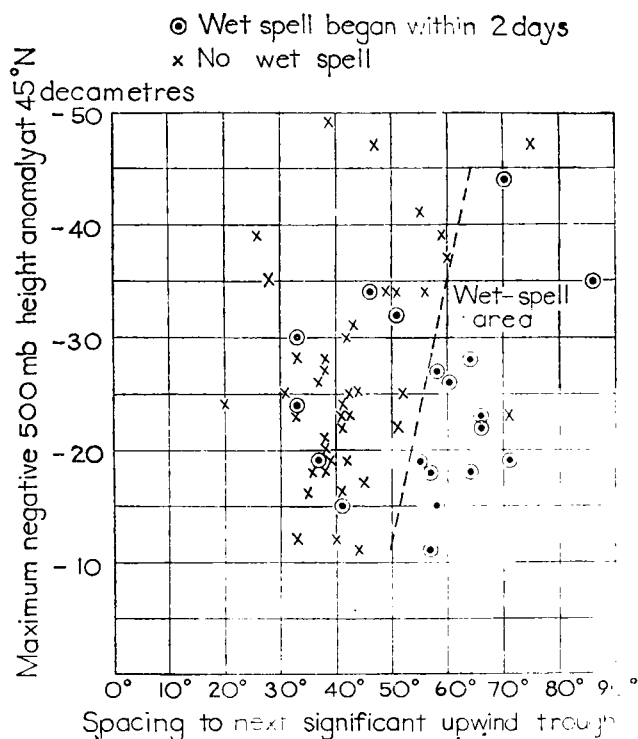


FIGURE 4—WET SPELLS AT LONDON (KEW), NOVEMBER TO FEBRUARY (10 YEARS), FOR TROUGHS BETWEEN 20°W AND 10°W WITH NEGATIVE 500-MILLIBAR HEIGHT ANOMALY AT 45°N ≥ 11 DECAMETRES AND PRESSURE AT LONDON ≤ 1007 MILLIBARS

and again by the same trough between 20°W and 10°W. However, some spells were indicated by troughs between 30°W and 20°W and not by troughs between 20°W and 10°W, and vice versa. Of the 34 wet spells which occurred during the 10 years, 19 were indicated by troughs between 30°W and 10°W.

Rules for forecasting wet spells at London in November to February

Rule based on troughs between 30°W and 20°W

- (1) Take note of each chart on which a 500-millibar trough is situated between 30°W and 20°W.
- (2) On each chart, obtain the longitude of the trough to the nearest degree by measuring the longitude of the point of intersection of the trough axis with the 45°N line of latitude and estimate the 500-millibar height at this point to the nearest decametre. Calculate the 500-millibar height anomaly.
- (3) Note the surface pressure at Valentia to the nearest millibar.
- (4) Obtain the longitude of the next significant* upwind 500-millibar trough by estimating the mean longitude of the trough axis to the nearest degree. Calculate the spacing between the two troughs.
- (5) If the negative 500-millibar height anomaly between 30°W and 20°W is ≥ 12 decametres and the pressure at Valentia is ≤ 1009 millibars, plot the

* A significant upwind trough is defined as having at least one troughed contour south of 50°N and an associated 1000–500-millibar thickness trough. If entirely situated south of 40°N, a single contour trough should be ignored. If the upwind trough is complex and more than one estimate of its longitude can be made, the estimate which is further to the east should be taken.

500-millibar height anomaly between 30°W and 20°W against the spacing to the next upwind trough on the graph (Figure 3). If the plot falls within the "wet-spell area" a wet spell is likely to begin within 24 hours of the time of the trough. Sometimes the wet spell may have begun already and a continuation for a further five days is likely.

Rule based on troughs between 20°W and 10°W

- (1) Take note of each chart on which a 500-millibar trough is situated between 20°W and 10°W .
- (2) On each chart, obtain the longitude of the trough to the nearest degree by measuring the longitude of the point of intersection of the trough axis with the 45°N line of latitude and estimate the 500-millibar height at this point. Calculate the 500-millibar height anomaly.
- (3) Note the surface pressure at London to the nearest millibar.
- (4) Obtain the longitude of the next significant* upwind 500-millibar trough by estimating the mean longitude of the trough axis to the nearest degree. Calculate the spacing between the two troughs.
- (5) If the negative 500-millibar height anomaly between 20°W and 10°W is ≥ 11 decametres and the pressure at London is ≤ 1007 millibars, plot the 500-millibar height anomaly between 20°W and 10°W against the spacing to the next upwind trough on the graph (Figure 4). If the plot falls within the "wet-spell area" a wet spell is likely to begin within 24 hours of the time of the trough. Sometimes the wet spell may have begun already and a continuation for a further five days is likely.

Forecasting wet spells at London in March and September.—For troughs between 30°W and 20°W a diagram was plotted (Figure 5) of the maximum negative 500-millibar height anomaly at 45°N against the surface pressure at Valentia at the time of maximum anomaly. All of the wet-spell plots fall within the area indicated. This suggests that for a trough to be associated with a wet spell the negative 500-millibar height anomaly must reach 11 decametres and at the same time the pressure at Valentia must be less than 1010 millibars.

For such cases, a diagram was plotted of the maximum negative 500-millibar height anomaly at 45°N between 30°W and 20°W against the spacing to the next upwind 500-millibar trough with a negative or zero anomaly at 45°N (Figure 6). The graph can be divided into two areas as indicated. The critical value of the spacing appears to increase from about 50° for the weaker troughs to about 55° for intense troughs. Of the 11 cases in the "wet-spell area" nine were associated with wet spells. (Trough measurements made during a wet spell which had already been indicated were not plotted.)

TABLE IV—DATE OF BEGINNING OF SPELL WITH REFERENCE TO DATE d OF MAXIMUM NEGATIVE ANOMALY BETWEEN 30°W AND 20°W

Date	Number of cases
d	2
$d + \frac{1}{2}$	1
$d + 1$	2
$d + 1\frac{1}{2}$	1
$d + 2$	3

Table IV shows that the spells started within two days of the time of occurrence of the maximum negative anomaly. Of the 14 wet spells which occurred

* See footnote on p. 290.

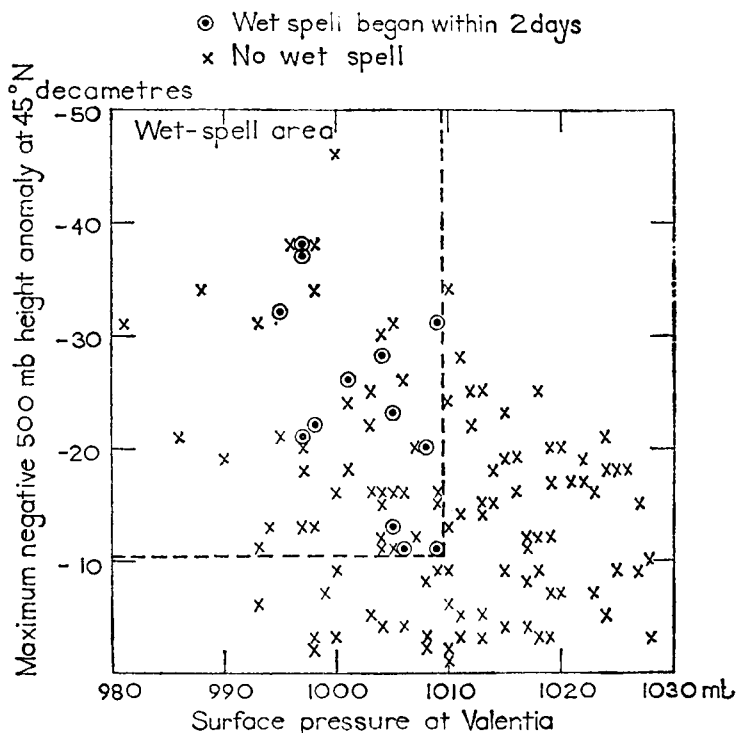


FIGURE 5—WET SPELLS AT LONDON (KEW), MARCH AND SEPTEMBER (10 YEARS), FOR TROUGHS BETWEEN 30°W AND 20°W

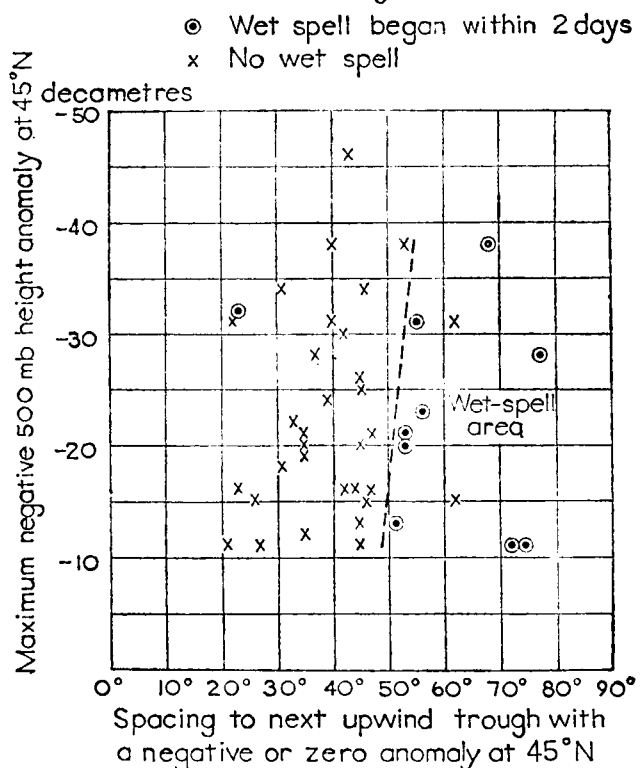


FIGURE 6—WET SPELLS AT LONDON (KEW), MARCH AND SEPTEMBER (10 YEARS), FOR TROUGHS BETWEEN 30°W AND 20°W WITH NEGATIVE 500-MILLIBAR HEIGHT ANOMALY AT $45^{\circ}\text{N} \geq 11$ DECAMETRES AND PRESSURE AT VALENTIA ≤ 1009 MILLIBARS

over the 10 years, nine were indicated. No useful forecasting rule could be derived from measurements of troughs between 20°W and 10°W .

Rules for forecasting wet spells at London in March and September

- (1) Take note of each chart on which a 500-millibar trough is situated between 30°W and 20°W .
- (2) On each chart, obtain the longitude of the trough to the nearest degree by measuring the longitude of the point of intersection of the trough axis with the 45°N line of latitude and estimate the 500-millibar height at this point. Calculate the 500-millibar height anomaly.
- (3) Note the surface pressure at Valentia to the nearest millibar.
- (4) Obtain the longitude of the next upwind 500-millibar trough with a negative or zero anomaly at 45°N using the same procedure as in (2) above. Calculate the spacing between the two troughs.
- (5) If the negative 500-millibar height anomaly between 30°W and 20°W is ≥ 11 decametres and the pressure at Valentia is ≤ 1009 millibars, plot the 500-millibar height anomaly between 30°W and 20°W against the spacing to the next upwind trough on the graph (Figure 6). If the plot falls within the "wet-spell area" a wet spell is likely to begin within two days of the time of the trough.

Forecasting wet spells at London in June to August.—For troughs

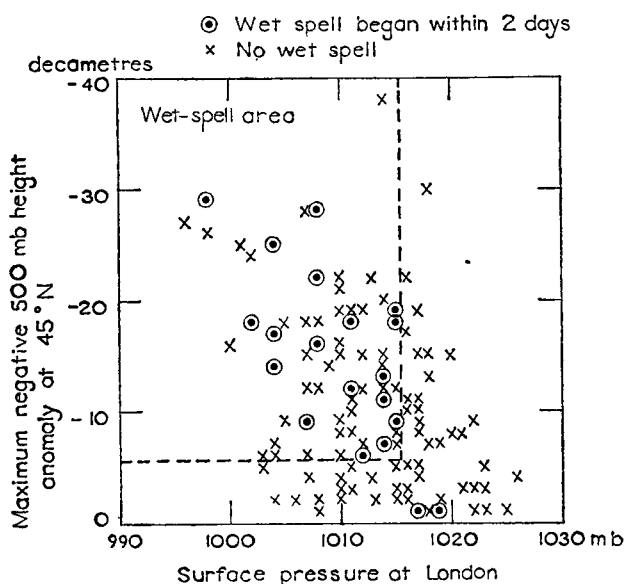


FIGURE 7—WET SPELLS AT LONDON (KEW), JUNE TO AUGUST (10 YEARS), FOR TROUGHs BETWEEN 20°W AND 10°W

between 20°W and 10°W a diagram was plotted (Figure 7) of the maximum negative 500-millibar height anomaly at 45°N against the surface pressure at London at the time of maximum anomaly. Most of the wet-spell plots fall within the area indicated. This suggests that for a trough to be associated with a wet spell, the negative 500-millibar height anomaly must reach six decametres and at the same time the pressure at London must be less than 1016 millibars. Many of the forecast failures indicated by crosses within the "wet-spell area" were found to be associated with situations where the next upwind

500-millibar trough with a negative anomaly at 45°N was west of 79°W. Excluding these cases, a diagram was plotted of the maximum negative 500-millibar height anomaly at 45°N between 20°W and 10°W against the spacing to the next upwind 500-millibar trough with a negative anomaly at 45°N

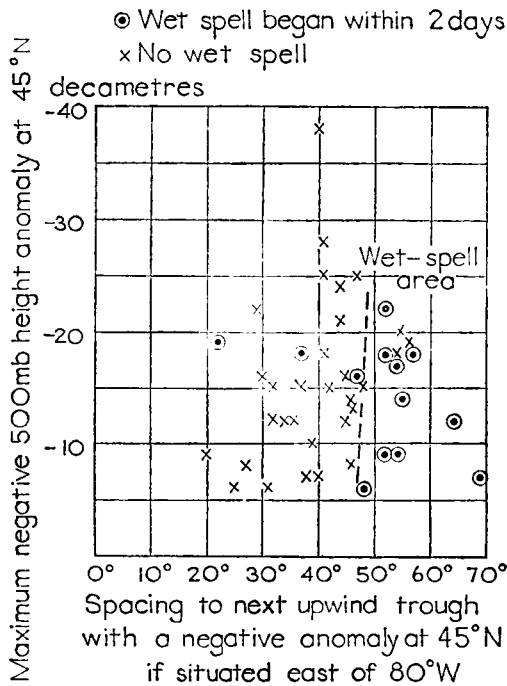


FIGURE 8—WET SPELLS AT LONDON (KEW), JUNE TO AUGUST (10 YEARS), FOR TROUGHS BETWEEN 20°W AND 10°W WITH NEGATIVE 500-MILLIBAR HEIGHT ANOMALY AT 45°N ≥ 6 DECAMETRES AND PRESSURE AT LONDON ≤ 1015 MILLIBARS

Excluding cases where the next upwind trough with a negative anomaly at 45°N was west of 79°W

(Figure 8). The graph can be divided into two areas as indicated. The critical value of the spacing appears to be just under 50°. Of the 13 cases in the “wet-spell area” 10 were associated with wet spells. (Trough measurements made during a wet spell which had already been indicated were not plotted.)

TABLE V—DATE OF BEGINNING OF SPELL WITH REFERENCE TO DATE d OF MAXIMUM NEGATIVE ANOMALY BETWEEN 20°W AND 10°W

Date Spell already begun	Number of cases
d	1
$d + \frac{1}{2}$	3
$d + 1$	3
$d + 1$	1
$d + 2$	2

Table V shows that the spells mostly started at varying times within two days of the time of occurrence of the maximum negative anomaly. Of the 25 spells which occurred over the 10 years, 10 were indicated. No useful forecasting rule could be derived from measurements of troughs between 30°W and 20°W.

Rules for forecasting wet spells at London in June to August

- (1) Take note of each chart on which a 500-millibar trough is situated between 20°W and 10°W .
- (2) On each chart, obtain the longitude of the trough to the nearest degree by measuring the longitude of the point of intersection of the trough axis with the 45°N line of latitude and estimate the 500-millibar height at this point. Calculate the 500-millibar height anomaly.
- (3) Note the surface pressure at London to the nearest millibar.
- (4) Obtain the longitude of the next upwind 500-millibar trough with a negative anomaly at 45°N using the same procedure as in (2) above. If the longitude is $\geq 80^{\circ}\text{W}$ a wet spell is unlikely. If $< 80^{\circ}\text{W}$, calculate the spacing between the two troughs.
- (5) If the negative 500-millibar height anomaly between 20°W and 10°W is ≥ 6 decametres and the pressure at London is ≤ 1015 millibars, plot the 500-millibar height anomaly between 20°W and 10°W against the spacing to the next upwind trough on the graph (Figure 8). If the plot falls within the "wet-spell area", a wet spell is likely to begin within two days of the time of the trough. Occasionally the spell may have begun already and a continuation for a further five days is likely.

The 500-millibar contour and surface isobaric patterns associated with the forecast wet spells.—In the months November to February, on 13 out of 19 occasions the 500-millibar trough between 30°W and 10°W became slow-moving or quasi-stationary between 20°W and 10°W . On six occasions the trough quickly progressed beyond 0°W and either another trough moved from the west and became slow-moving between 20°W and 10°W or a strong, wide belt of westerlies, in which minor troughs progressed rapidly to the British Isles, formed across the Atlantic. On two occasions the westerlies were centred at 45°N and on one occasion at 53°N .

On surface charts, about half the wet spells were associated with large, slow-moving depressions in the region of the British Isles. The other half were associated with situations in which the main depression was situated south of Greenland, near Iceland or north of the British Isles and secondary lows or waves moved from the south-west or west across the British Isles or along the Channel region. (The six occasions on which the 500-millibar trough between 30°W and 10°W quickly progressed were all associated with the latter situation). About half the situations were blocked, on seven occasions by a high over Russia and on two occasions by a high over Scandinavia.

In March and September, on eight out of nine occasions the 500-millibar trough between 30°W and 20°W became slow-moving or quasi-stationary between 30°W and 0°W . On one occasion the trough quickly progressed beyond 0°W and a new trough developed at 20°W and became quasi-stationary between 20°W and 10°W . On surface charts, the wet spells were associated on six occasions with a situation in which the main depression was situated south of Greenland, south of Iceland or north of the British Isles and secondary depressions or waves moved from the south-west or west across the British Isles or along the Channel region. On the other three occasions, depressions were slow-moving to the south-west or south of the British Isles with blocking highs situated south of Greenland, near Iceland or over Scandinavia.

In the months June to August, on seven out of ten occasions the 500-millibar trough between 20°W and 10°W became slow-moving or quasi-stationary mainly between 10°W and 0°W but on one occasion between 0°E and 10°E . On the remaining three occasions, the trough quickly progressed beyond 0°W and another trough moved from the west and became slow-moving between 20°W and 0°W .

On surface charts, the wet spells were associated on eight occasions with depressions which, in the main, moved very slowly from the south-west across England or the Channel region. Only two of these situations were blocked, one by a high to the north of the British Isles and one by a high over Scandinavia. In both these cases the depression moved along the Channel region. The remaining two spells were associated with a situation in which the main depression was situated north of the British Isles and secondary depressions or waves moved from the south-west or west across the British Isles or the Channel region. There was no blocking on these occasions.

Incidence of thunderstorms.—Lowndes¹ showed that, over the period 1950 to 1959, wet spells (as defined) were often associated with reports of thunderstorms in southern England. He found that during the summer half of the year nearly all the spells were associated with thunderstorms but that during the winter half only about one third to a half were similarly associated.

In the months November to February, 10 of the 19 spells forecast by the rules were associated with thunderstorms in southern England. In March and September, thunderstorms occurred during seven out of nine of the spells and in the months June to August, during nine out of ten of the spells.

Conclusion.—The rules which have been derived for forecasting wet spells at London obtained the following degree of success over the period 1950 to 1959. For the months November to February, 19 of the 34 spells which occurred were forecast and there were four forecast failures. For March and September, nine of the 14 spells which occurred were forecast and there were three failures. For June, July and August, 10 of the 25 spells which occurred were forecast with three failures.

The rules were tested on the two years 1960 and 1961. For the months November to February, six of the 10 spells which occurred over the period were forecast and there was one forecast failure. Four of the six spells were indicated by troughs between 30°W and 20°W and two by troughs between 20°W and 10°W . For March and September, one of the three spells which occurred was forecast with no failure. For June, July and August, four of the six spells which occurred were forecast and there were two failures.

The time lapse between the criteria being satisfied and the beginning of the spell ranged from six to 36 hours for 10 of the 11 successful forecasts. In one case the spell had already begun.

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FORMATION OF WAVES ON WARM FRONTS IN THE VICINITY OF THE BRITISH ISLES

By D. C. E. JONES

Introduction.—A difficult problem which sometimes confronts the forecaster is to decide whether or not a wave will develop on a warm front. Although such a wave may appear as a somewhat insignificant feature of the surface chart, the weather associated with it may be important because of the accompanying rather narrow and fairly fast-moving belt of low cloud and precipitation which often moves into or towards a ridge of high pressure. A wave also tends to retard the movement of the front for a while.

The development of a wave on a warm front and its effect on the weather may be illustrated by events which occurred on 28 February 1961. Late on 27 February and early on the 28th there were indications that a weak ridge would cross the British Isles on the 28th during daylight hours followed sometime later by a warm front. However, with the pressure still rising steadily over the British Isles rain was first reported in north-west Ireland at 0700 GMT. The rain which was associated with a warm-front wave spread rapidly and had reached the south-east of England by the early afternoon. A day which had been expected to be mainly dry over most of England and Wales, under the influence of a weak ridge, turned out with very little warning to be very cloudy with slight or moderate rain in many places.

The formation of warm-front waves in relation to the 1000–500 mb thickness field has been studied by Sawyer¹, who found that the significant criteria for wave development are a slow-moving primary depression and a strong thermal gradient (40–80 knots) of warm-front type ahead of the primary depression and somewhere to the east of it.

Experience has shown, however, that waves are sometimes not accompanied by this 1000–500 mb thickness pattern. It was therefore decided to study the association with features of the pattern at higher levels and this note deals with an investigation of the development of warm-front waves in relation to the flow at levels above 500 mb. Some of the characteristics of the waves during the 12–24 hours following their formation are described.

Selection of the warm-front waves.—In order to obtain a sample of waves the existence of which is known with confidence, it was decided that only waves which formed either over or fairly near to the British Isles would be examined and that selection would be confined to those that produced an appreciable effect on the weather over some part of the country. All the Central Forecasting Office charts for the major synoptic hours for the seven years from 1 January 1955 to 31 December 1961 were examined, and situations which satisfied the following criteria were listed:

- (a) a warm-front wave formed within a distance of approximately 400 miles of the British Isles, persisted for at least 12 hours, and crossed over some part of the land areas of the British Isles;
- (b) during its passage over the country the wave produced some precipitation along its track.

In connexion with this selection of cases it must be remembered that the sparsity and uneven distribution of ship reports makes the synoptic analysis

over the Atlantic particularly difficult when dealing with features such as warm-front waves which frequently produce very little distortion of the surface pattern. On this account there is considerable uncertainty regarding the initial position of some of the waves selected for study on the eastern Atlantic.

Characteristics of warm-front waves.—Twenty-eight waves were noted during the seven years concerned—an average of one warm-front wave affecting the British Isles in three months. The positions at which they first appeared

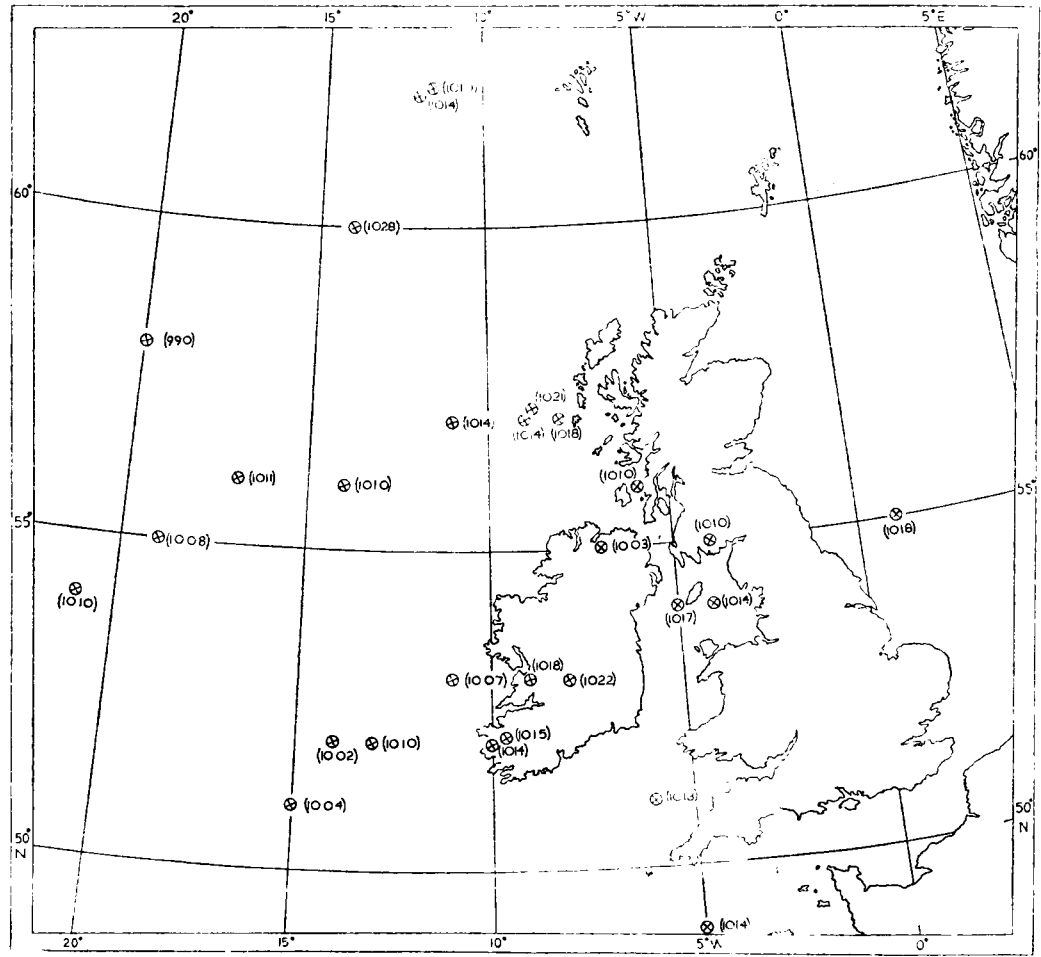


FIGURE 1—POSITIONS OF FORMATION OF WAVES STUDIED
 Figures in brackets are surface pressures at the time of formation.

are shown on a map in Figure 1. In the 12 to 18 hours after formation, their direction of motion varied between 060 and 170 degrees, the average being about 110 degrees.

Figure 2 presents the frequency of various speeds in the form of a histogram. A fairly wide range of speeds was observed, 50 knots being the highest in the sample studied and 33 knots the average.

The frequency of various central pressures at the time of formation is shown in Figure 3. A range varying from 990 to 1028 mb was found but 19 of the 28 waves formed at a point where the pressure was between 1010 and 1020 mb. In most cases the wave was translated along the warm front without deepening

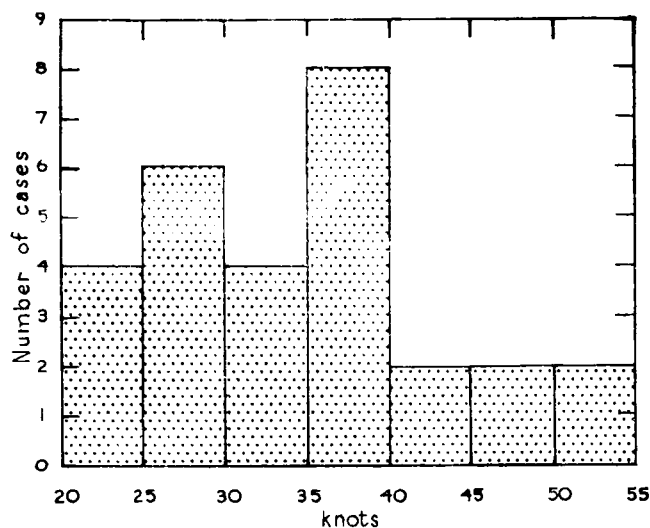


FIGURE 2—FREQUENCY OF SPEEDS OF WARM-FRONT WAVES

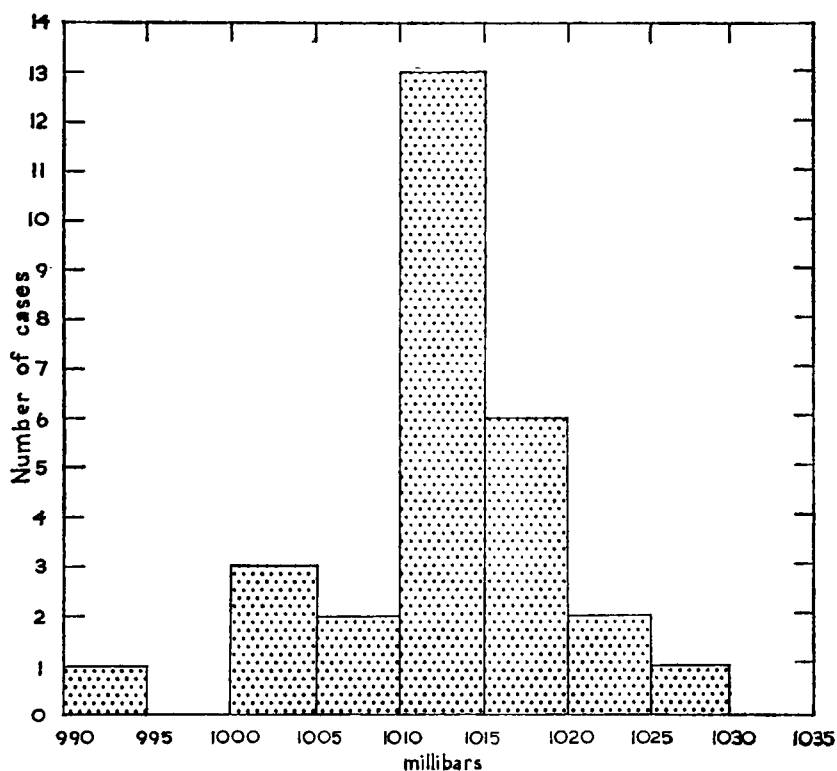


FIGURE 3—FREQUENCY DISTRIBUTION OF CENTRAL PRESSURE OF THE WAVES AT THE TIME OF FORMATION

and in a substantial number of occurrences the central pressure was rising as the wave moved into or towards a region where the pressure was already high. There were no closed isobars (drawn at 2 mb intervals) associated with 22 of the waves and only one had more than two closed isobars.

The above characteristics are in reasonable agreement with previous findings¹ but it must be remembered that the previous investigation was concerned with a sample taken from a wide area extending from the Rockies to the Urals whereas the present sample was drawn from a much smaller area near the British Isles.

Examination of waves in relation to high-level charts.—The suggestion has been made in two recent papers^{2, 3} that stratospheric thickness charts (200–100 or 300–100 mb) might prove valuable in forecasting warm-front waves. In an attempt to investigate the value of this suggestion, the waves were examined in relation to the 300–100 mb charts but the result was inconclusive, probably because of the uncertainty in the construction of the 300–100 mb thickness field from the 300 and 100 mb charts.

The waves were next examined in conjunction with the broad features of the 300 mb contour charts and it was found that 22 had formed near the right entrance to a jet stream in which the maximum speed of the jet exceeded 60 knots. These 22 cases were further examined as follows.

The direction of motion of the waves in relation to the general direction of

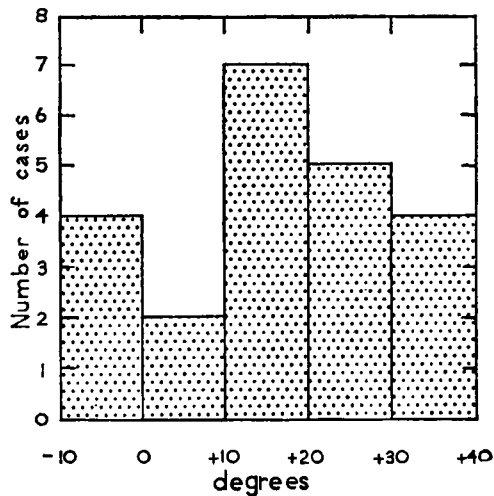


FIGURE 4.—DIRECTION OF MOTION OF WAVE IN RELATION TO THE 300 MB JET
Positive values indicate deviation to the left, that is towards the cold air.

the contours of the jet on the 300 mb chart was noted and Figure 4 gives this information in the form of a histogram. The direction of movement of the waves is very close to the direction of the 300 mb contours, being on average inclined at an angle of about 15 degrees towards the cold air.

An attempt was made to correlate the wave speeds with the 300 mb wind speed as measured from the contour charts by taking the average speed over a distance of about 200 miles across the flow in the region of the jet stream and along the path of the wave (Figure 5). The wave speed was found to be approximately one-third of the jet stream speed at 300 mb and about half of the 300 mb wind speed along the path of the wave. These rules gave slightly smaller mean errors than the rule suggested by Hoyle⁴ for the speed of warm-sector waves in straight 1000–500 mb thickness patterns. Also, from a practical point of view, it was found generally easier to obtain representative wind measurements from the 300 mb charts than from the thickness charts because on many occasions the wave travelled along a path where the thermal wind was changing rapidly at right angles to the path thus making it difficult to obtain a representative mean thermal wind.

The waves travelled on the warm side of the jet stream at a distance mainly between 100 and 250 miles from the axis of the jet stream which was itself moving slowly east or north-east, with a speed rarely exceeding 20 knots.

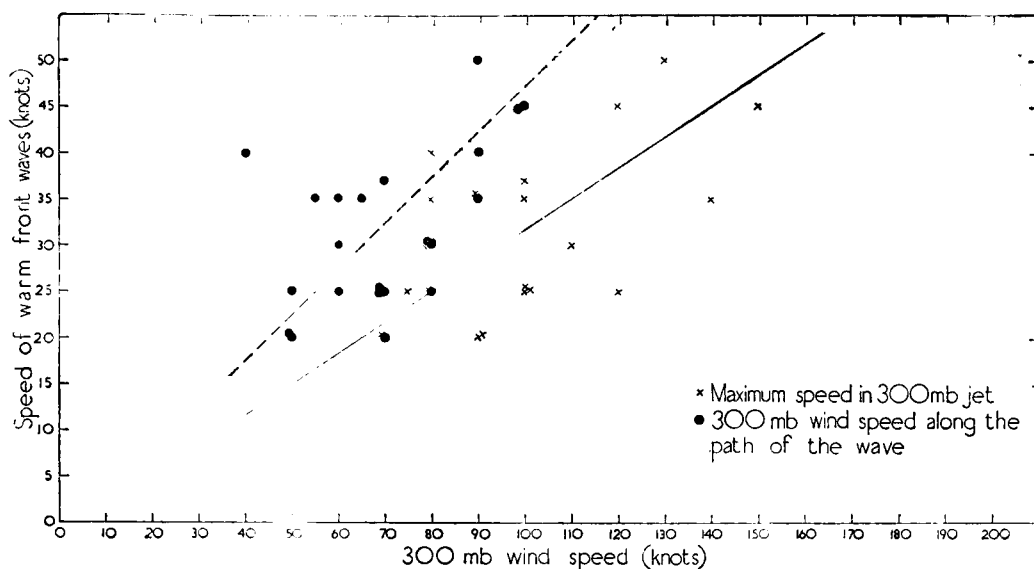


FIGURE 5—SPEED OF MOVEMENT OF WARM-FRONT WAVES PLOTTED AGAINST 300 MB WIND SPEEDS

Speeds were measured over 200 miles taken across the flow in both cases.

In 20 out of the 22 cases the warm front was to the east of the 300 mb ridge and remained in this position for a considerable time before the wave formed. It is difficult to fix a time when the situation first becomes favourable for a wave to form. The process is probably gradual but a time lag of the order of 12 to 24 hours seems usual from the time that the warm front gets to the east of the ridge and into a position somewhere near the right entrance to the jet. During this period of 12 to 24 hours before the formation of the wave, on nearly all occasions the 300 mb pattern remained substantially unchanged over the British Isles and the eastern Atlantic. A depression somewhere near or over Scandinavia (but sometimes between Iceland and Scandinavia) with an anticyclone to the south or south-west of the British Isles, is a typical surface situation in which the waves formed.

Regarding the remaining six waves which did not form near the right entrance to a jet stream, four of them were associated with jet streams (one not far from a jet exit). The fifth was to the east of a ridge and might possibly be classed as being near the entrance to a narrow jet but this was rather doubtful. The sixth was near a confluence in which the wind maximum was too low to be classed as a jet stream.

It was concluded that a rule which might be of some use in predicting wave formation is that, the warm front must become slow-moving near the right entrance to the 300 mb jet and on the east side of a 300 mb ridge.

An example of a wave which formed off north-west Ireland and moved across the north of England at a speed of about 20 knots is shown in Figures 6(a)–(c).

Forecasting test.—In order to assess the practical value of this suggested rule using the 300 mb chart, a forecasting test was made on all the warm fronts that crossed the British Isles, without producing waves, during the two years 1958 and 1959. There were 85 fronts, nine of which were not associated with a 300 mb ridge because the fronts were rather weak and superficial. Of the

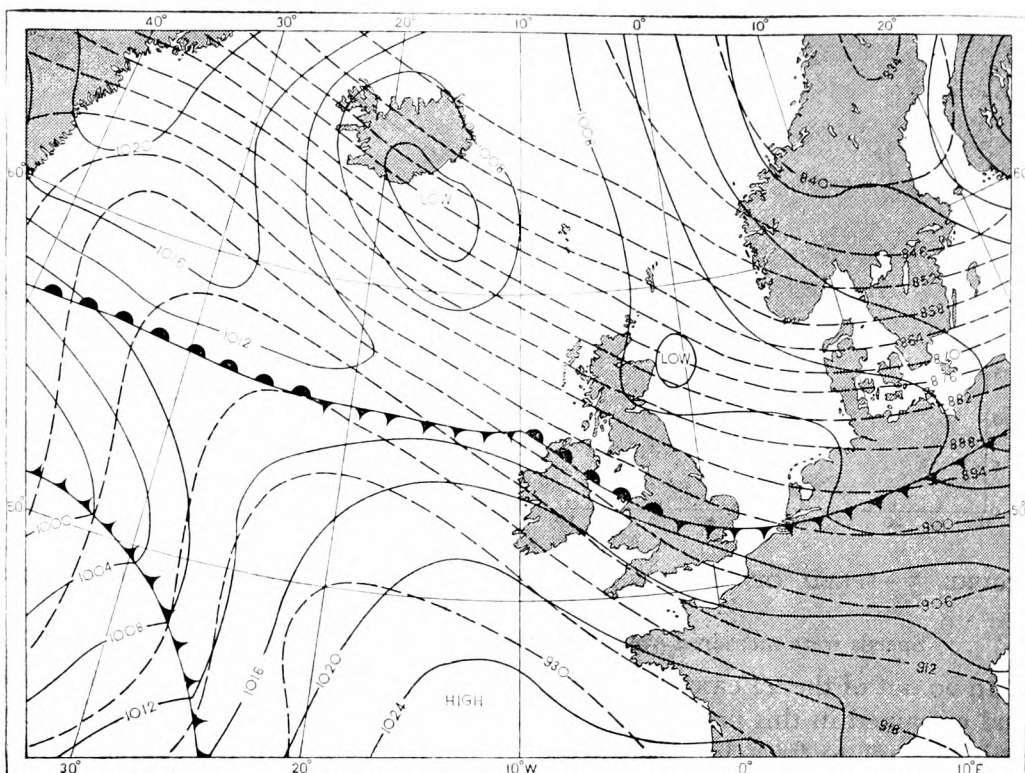


FIGURE 6(a)—SURFACE AND 300 MB CHART FOR 0001 GMT, 31 MARCH 1961

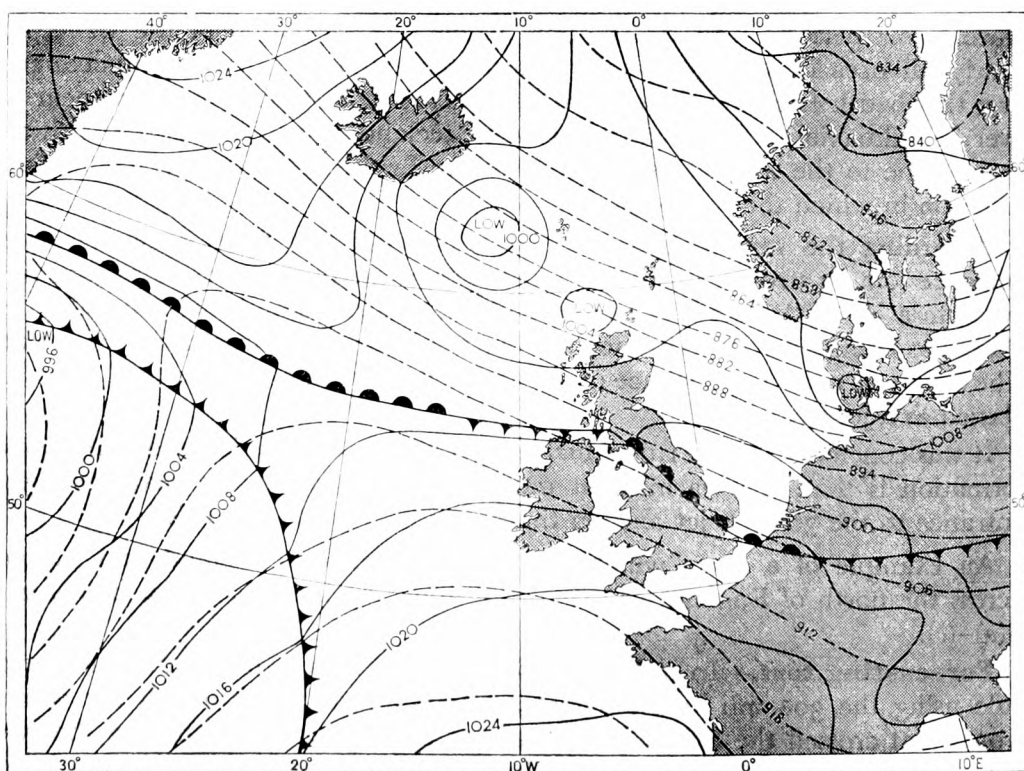


FIGURE 6(b)—SURFACE AND 300 MB CHART FOR 1200 GMT, 31 MARCH 1961

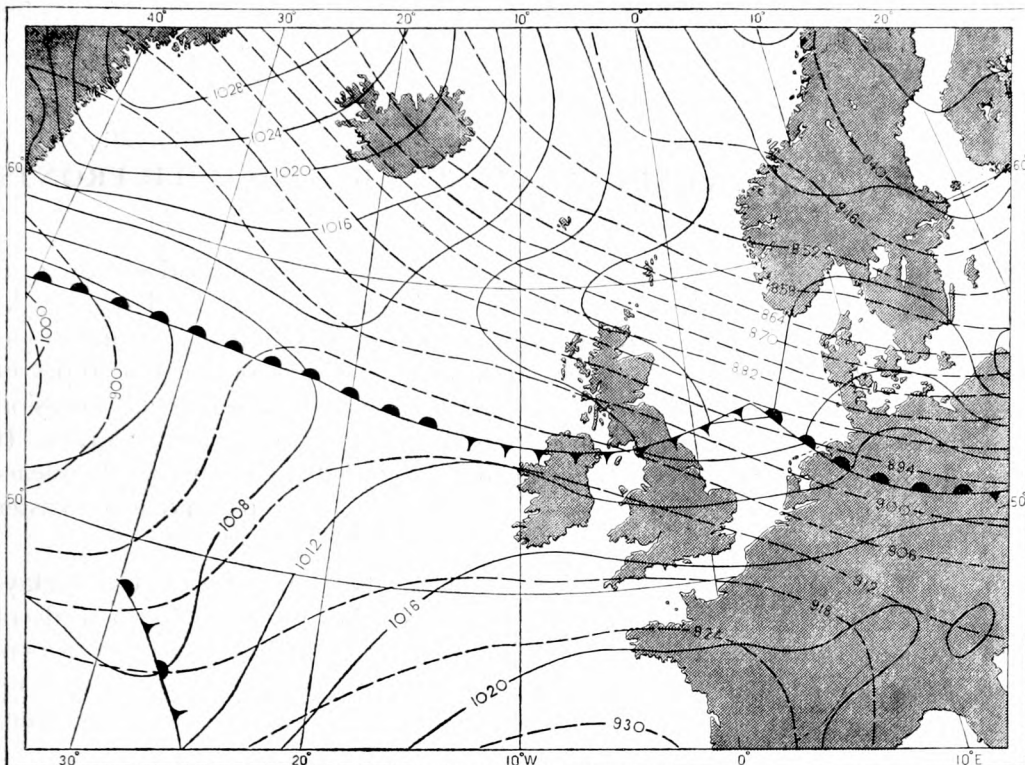


FIGURE 6(c)—SURFACE AND 300 MB CHART FOR 0001 GMT, 1 APRIL 1961

remaining 76, it was judged that nine satisfied the double requirement of being in the vicinity of a jet entrance and to the east of the 300 mb ridge. Thus by taking into account the 11 waves which occurred in the two years, the result of the test for the two years is that of the 96 warm fronts, which either crossed or reached the vicinity of the British Isles, 17 of them would be expected to wave but only eight actually did so. Three waves would have formed without being forecast.

Conclusion.—Some of the characteristics of warm-front waves which formed in the vicinity of the British Isles during the last seven years were examined. A notable feature is that their frequency is small, being on average only about four a year. Their speed varied from 20 to 50 knots and their direction of motion varied between 060 and 170 degrees.

The possible use of charts above 500 mb for predicting their occurrence was investigated. It was found that an empirical rule which requires the warm front to be in a position near the right entrance to a jet stream on the 300 mb chart, and also to the east of the 300 mb ridge, was reasonably successful in view of the small number of occasions on which waves develop. This method showed about the same degree of accuracy as Sawyer's method¹ using the 1000–500 mb thickness pattern. It has the advantage that it is based essentially on a wind field at one level, and direct observations are therefore available to the forecaster every six hours.

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551.515.8:551.589.5

UNEXPECTED DELAYS IN CLEARANCES BEHIND COLD FRONTS

By R. M. MORRIS

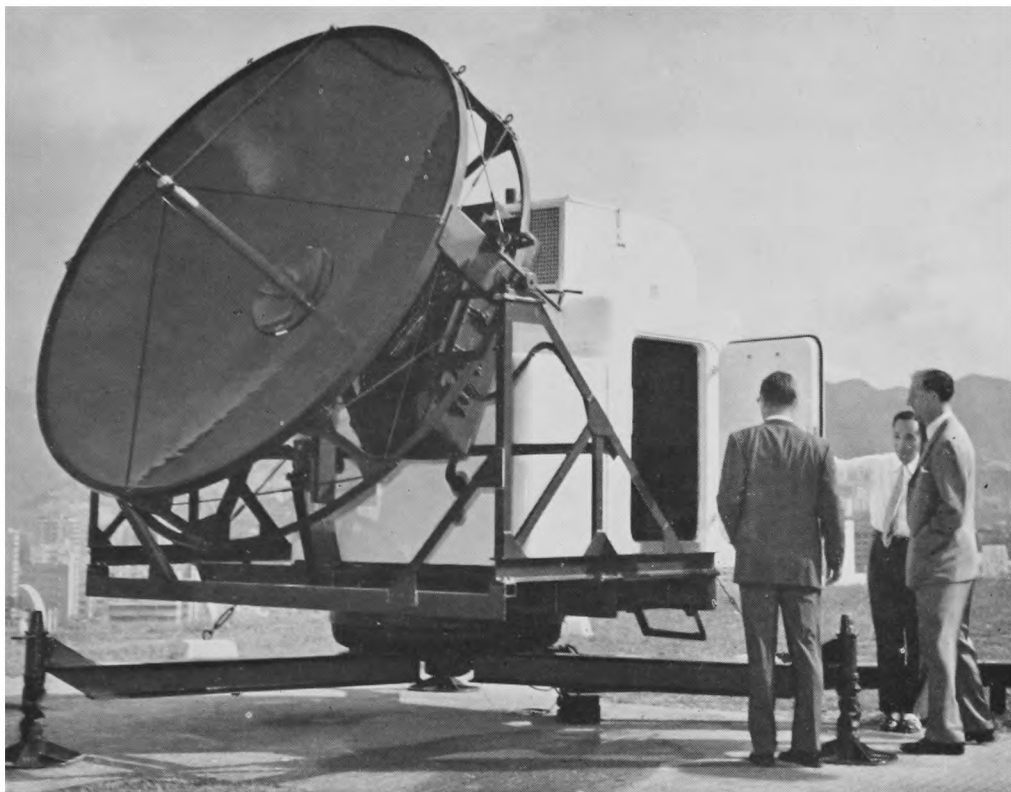
At the passage of an anafront precipitation is fairly heavy and steady rain continues for some time behind the front while clearance of cloud is slow. At the passage of a katafront amounts of precipitation are slight or nil and cloud clears rapidly and often completely. The characteristics of the two types of cold front are well known and recognition of the type on a particular occasion usually enables the times of clearance to be forecast with fair accuracy. It occasionally happens, however, that an unexpected delay occurs in the clearance of low cloud, and sometimes in the clearance of rain, and a forecaster can be caught unawares.

In 1959 forecasters at meteorological offices where such unexpected delays were experienced were invited to list future occasions in order that a study of the problem could be made. Between October 1959 and June 1961, 45 cases of delays were noted. The length of the delays ranged from two or three hours up to fifteen hours. Fifteen occasions were reported from Kinloss, ten from Manchester, and between five and ten from Ballykelly, Nutts Corner, Chivenor and St. Mawgan; three occasions were reported from Gaydon, one from each of Prestwick and Ternhill, and no occasions from Aldergrove, Valley, Manby, Stradishall and Bovington. Considering that about 100 cold fronts would have crossed the British Isles in the period of observation, it is seen that at any one place a delay in clearance is not very frequent. The phenomenon seems to predominate in Northern Ireland, the western coast of England, and additionally the Moray Firth.

Mostly the delays were local, occurring at one meteorological office only, but on nine dates a delay was experienced at two offices and on three of these at three offices. On six of the nine dates the delay was in the clearance of rain and not in the lifting of low cloud.

It soon became clear that two separate problems were involved; a delay in clearance of rain was not necessarily accompanied by a delayed clearance of cloud at low levels, low enough, that is, to impede aircraft operations, and a delay in clearance of low cloud was not always associated with a delayed clearance of rain. In the case of rain the problem appears to be on a broad, synoptic scale affecting a few places, whereas in the case of low cloud it is on a local, meso-scale, often affecting one place only.

Delay in cessation of rain.—On 24 of the occasions the frontal surface lay near radiosonde stations and the upper air data were used to construct time cross-sections. Two cases were complex involving a new frontal system with precipitation spreading ahead. In the remaining 22 cases the behaviour of the thermal trough in the 1000–500 mb thickness field was examined for meridional extension or relaxation. The results of the examination are given in Table I. Although the sample is a small one, it suggests that delays in clearance of rain are associated with relaxing, rather than with extending, troughs.



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PLATE IV—HONG KONG ROYAL OBSERVATORY'S RADIOSONDE STATION AT
KING'S PARK

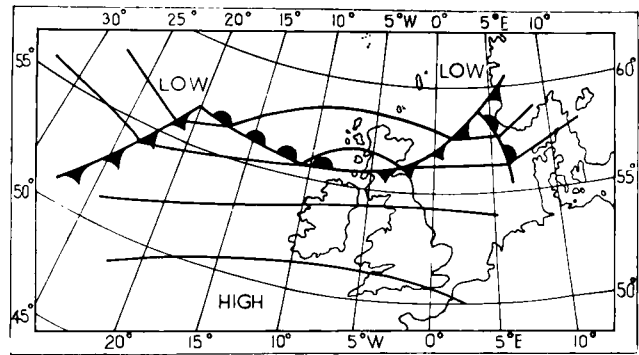
His Excellency the Governor of Hong Kong, Sir Robert Black, is shown about to enter the operator's cabin of the wind-finding radar on 18 July 1962.



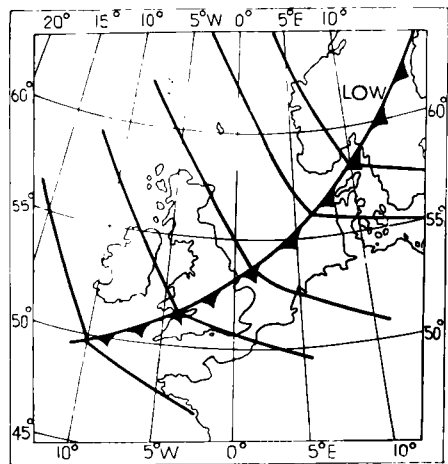
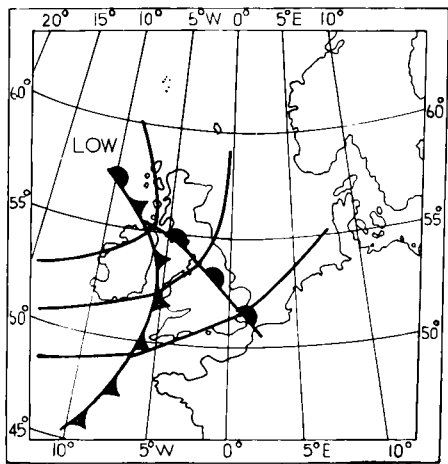
By courtesy of B.E.A.

PLATE V—CAPTAIN R. FOWLER OF B.O.A.C. (LEFT) AND CAPTAIN D. MASON, A.F.C.
OF B.E.A. (RIGHT) WITH DR. A. C. BEST, C.B.E., D.S.C.

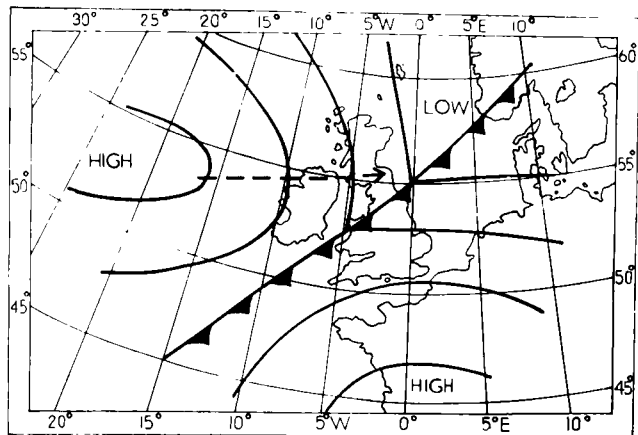
(see p. 306)



Type I—Cold front returning as warm front



Left. Type II(a)—Cyclonically dominated; main centre west of British Isles
Right. Type II(b)—Cyclonically dominated; centre and front moving with little retardation



Type III—Anticyclonic curvature

FIGURE 1—CLASSIFICATION OF RELAXING TROUGHS

Accordingly, 91 examples of relaxing troughs were studied to see whether the associated surface patterns could be classified and, if so, whether one class could be associated with area of delay in the cessation of rain. It was found possible to classify almost all the relaxing troughs into three types, as follows:

Type I—Cold front returning as a warm front. This is a mobile type with a non-developing ridge behind the cold front and little change in wind direction across the front.

Type II—Cyclonically dominated. The isobars behind the cold front are cyclonically curved or straight. The main centre may (a) linger west of the British Isles or (b) move into Scandinavia with the cold front progressing well into the Continent with little retardation.

Type III—Anticyclonic curvature. The isobars ahead of the cold front are curved anticyclonically and a new cell of high pressure is developing in the cold air. With marked anticyclonic curvature, *there is a considerable change in wind direction across the front.*

These types are illustrated in Figure 1. Type I comprised about one third of the cases and rain behind the cold front was insignificant or nil. Type II comprised about half the cases and again the rain behind the cold front was mostly insignificant, although there was sometimes substantial rainfall ahead of it. Type III was rare, comprising about one sixth of the cases, and it was in this category that delays in the cessation of rainfall were found to occur.

In Type III, when the wind shear is well marked, minor ripples move along the front and despite the overall rise of pressure, a large area of medium cloud and rain appears to spread back over the cold air and move only very slowly. Good examples occurred on 10 May 1958, on 29 January and 31 May 1959, and on 12-13 January 1961.

TABLE I—RELATION BETWEEN THE THERMAL TROUGH AND THE DELAY IN THE CLEARANCE OF RAIN

Precipitation in rear	Relaxing troughs	Unchanging troughs <i>number of occasions</i>	Extending troughs	Total
None	5	2	2	9
Short period	1	5	0	6
Long period	5	2	0	7
Total	11	9	2	22

Re-examination of the 22 cold fronts, on which Table I is based, showed that those with significant rainfall in the cold air which could not be ascribed to waves on the cold front were all associated with the growth of an upwind upper ridge and some intensification of surface pressure in the cold air, a characteristic of Type III. The relative infrequency of Type III is consistent with the rarity of unexpected delays in the cessation of rain.

Delay in clearance of low cloud.—As has been stated above, delay in clearance of low cloud varies from place to place and does not appear to be a broad feature of a certain type of front, although fronts with minor waves may effectively contribute. Local topography is evidently an important factor and, as delays are rarely experienced inland, proximity to the sea seems to be important also. Rain falling through cold air could cause a delay in the clearance of low cloud but on the whole a delay in clearance of rain and low cloud simultaneously is rare.

Examination of the distribution of winds, temperature and humidity aloft indicated a retardation in the surface layers and often at higher levels also, relative to the layer between about 900 and 800 mb. The "nose" thus formed at about 850 mb appears to descend later to the ground, trapping a pocket of warmer air. The retardation of the surface layers relative to those at about 900 mb is common at cold fronts and it does not appear that this effect alone can distinguish those with delayed cloud clearance from those without.

The following parameters are among those which it is thought may be related to an unexpected persistence of low cloud behind a cold front:

- (a) Wind speed and direction in the cold air.
- (b) Adjacent sea temperature.
- (c) Fall of wet-bulb potential temperature across the front.
- (d) Difference between the sea temperature and the wet-bulb potential temperature in the cold air.
- (e) Stability in the lower layers on either side of the front.
- (f) Rain falling through the cold air.

The rarity of the phenomenon hampers the accumulation of sufficient data for a statistical study. A minor study of the parameters listed above in 24 cold fronts indicated that the relative importance of parameters varies from place to place. At Prestwick, for example, the difference between the sea temperature and the wet-bulb potential temperature in the cold air yields a fair correlation with persistence of low cloud, whereas at Manchester there is no such correlation; at Manchester there appears to be some correlation with rain delays whereas there is no correlation of this sort at Aldergrove or Kinloss. The highest correlation found was with wind direction in the cold air at Kinloss; it was approximately 0.70.

It is believed that no single forecasting rule will apply at every place and that, probably on account of the importance of local topographic effects, progress in formulating rules will depend upon a study of local parameters whenever the phenomenon occurs.

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NOTES AND NEWS

Meteorological Office awards to captains and navigators of civil aircraft

The valuable assistance given by British airline pilots in supplying the Meteorological Office with weather reports made in flight was recognized in a ceremony held at the headquarters of the Guild of Air Pilots and Air Navigators on 12 July 1962.

The Master of the Guild, Captain J. T. Percy, opened the ceremony and introduced Dr. A. C. Best, Director of Services of the Meteorological Office. Dr. Best spoke of the importance of aeronautical meteorology. This was particularly emphasized by the fact that the term "non-aviation inquiries" was frequently used to include together all questions which were not related to flying.

Dr. Best then presented handsome briefcases to Captain Derek Mason, A.F.C., a senior B.E.A. pilot, and to Captain Raymond Fowler, master of

Boeing 707 flights with B.O.A.C. The awards were made for "long and meritorious service in the provision of weather reports".

In replying the pilots said that they hoped the assistance they were able to give in making the observations would help to repay some of the invaluable service continuously provided to pilots and aircrew by the Meteorological Office.

Books are being sent to the following captains and navigators for their weather reports:

Captain B. E. P. Bone, B.O.A.C.	Captain G. Thomas, B.U.A.
Captain E. Caesar-Gordon, B.E.A.	Captain B. J. Thwaites, B.E.A.
Captain W. N. C. Griffiths, B.O.A.C.	Captain F. A. Tricklebank, B.E.A.
Captain A. C. Hellary, B.U.A.	Navigator T. N. Bailey, B.O.A.C.
Captain A. R. Martin, B.E.A.	Navigator J. F. H. Clarke, B.O.A.C.
Captain N. A. Mervyn-Smith, B.O.A.C.	Navigator R. E. Holloway, B.O.A.C.
Captain M. H. Reveller, B.O.A.C.	Navigator J. W. Morgan, B.O.A.C.
Navigator T. K. Prince, B.O.A.C.	

OFFICIAL PUBLICATION

The following publication has recently been issued:

SCIENTIFIC PAPER

No. 15—*The errors of the Meteorological Office radiosonde, Mark 2B*, by D. N. Harrison, O.B.E., D.Phil.

The author presents the results of a long series of experiments designed to test the accuracy of the instruments which are used to obtain daily observations of temperature and humidity at high levels in the atmosphere. The possible origin of instrumental errors of various types and their effect in synoptic meteorology are briefly discussed, and references are given to other work in the same field.

PUBLICATION RECEIVED

Steam fog in Greek seas, by B. D. Kyriazopoulos and G. C. Livadas. 9 $\frac{5}{8}$ in. x 6 $\frac{3}{4}$ in., pp. 88, *illus.*, Meteorological Institute of the University of Thessaloniki, 1961.

METEOROLOGICAL OFFICE NEWS

Sports activities.—The second Annual Sports Meeting organized by the Bracknell Social and Sports Club was held on the evening of 28 June, in fine weather, at the Palmer Park Running Track, Reading.

The various events, open to all members of the Staff of the Meteorological Office, were well supported. A strong contingent from London Airport all acquitted themselves well, and there were also competitors from Abingdon, Bomber Command, High Wycombe, Larkhill, Manchester, Porton and Uxbridge.

There was one new record established namely, 220 yards men, by Mr. J. Miller, M.O.2, in a time of 24.1 seconds. M.O.2 and M.O.9 shared the cup awarded annually to the Branch gaining the most points at the Sports.

Among the many spectators were Sir Graham Sutton, C.B.E., F.R.S. (Director-General) and Lady Sutton and Dr. A. C. Best, C.B.E. (Director of Services) and Mrs. Best. The presentation of prizes was made, at the conclusion of a very successful evening, by Dr. R. C. Sutcliffe, C.B., F.R.S. (Director of Research) and Mrs. Sutcliffe.

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THE METEOROLOGICAL MAGAZINE

Vol. 91, No. 1084, November 1962

FOREWORD BY THE DIRECTOR-GENERAL OF THE METEOROLOGICAL OFFICE

This number commemorates the coming-of-age of a body of which the Meteorological Office is justly proud. In a period when committees have tended increasingly to expand and proliferate, the Meteorological Research Committee (MRC) has remained a compact body, pursuing its allotted task of advising on "the general lines on which meteorological research should be developed". In doing so it has done much to forge links between the professional meteorologists and the university physicists and mathematicians who constitute the majority of its non-official members.

It is stimulating for the Office to know that not only can it rely on the wisdom and experience of those who teach and study other aspects of the science of which meteorology is a part, but also that its research work is regularly assessed in discussions that have always been notable for their frankness. Even a large institution like the Meteorological Office could lose impetus and falter were it to confine debate within its walls, and perhaps the most valuable part of the work of the MRC is the new light that from time to time it sheds on the many problems that beset meteorologists.

As Dr. Scrase shows in the opening article in this number, the MRC owes its existence mainly to the foresight and patience of Sir Nelson Johnson, and the encouragement and support of Professor Sydney Chapman, but there is a comparable debt to other founding fathers, notably Sir David Brunt, Professor G. M. B. Dobson, and Sir Charles Normand. The Meteorological Office now holds a notable position in the field of meteorological research, and it is pleasant to be able to thank them and their fellow members for the part they have played in bringing this about.

THE HISTORY OF THE METEOROLOGICAL RESEARCH COMMITTEE

By F. J. SCRASE

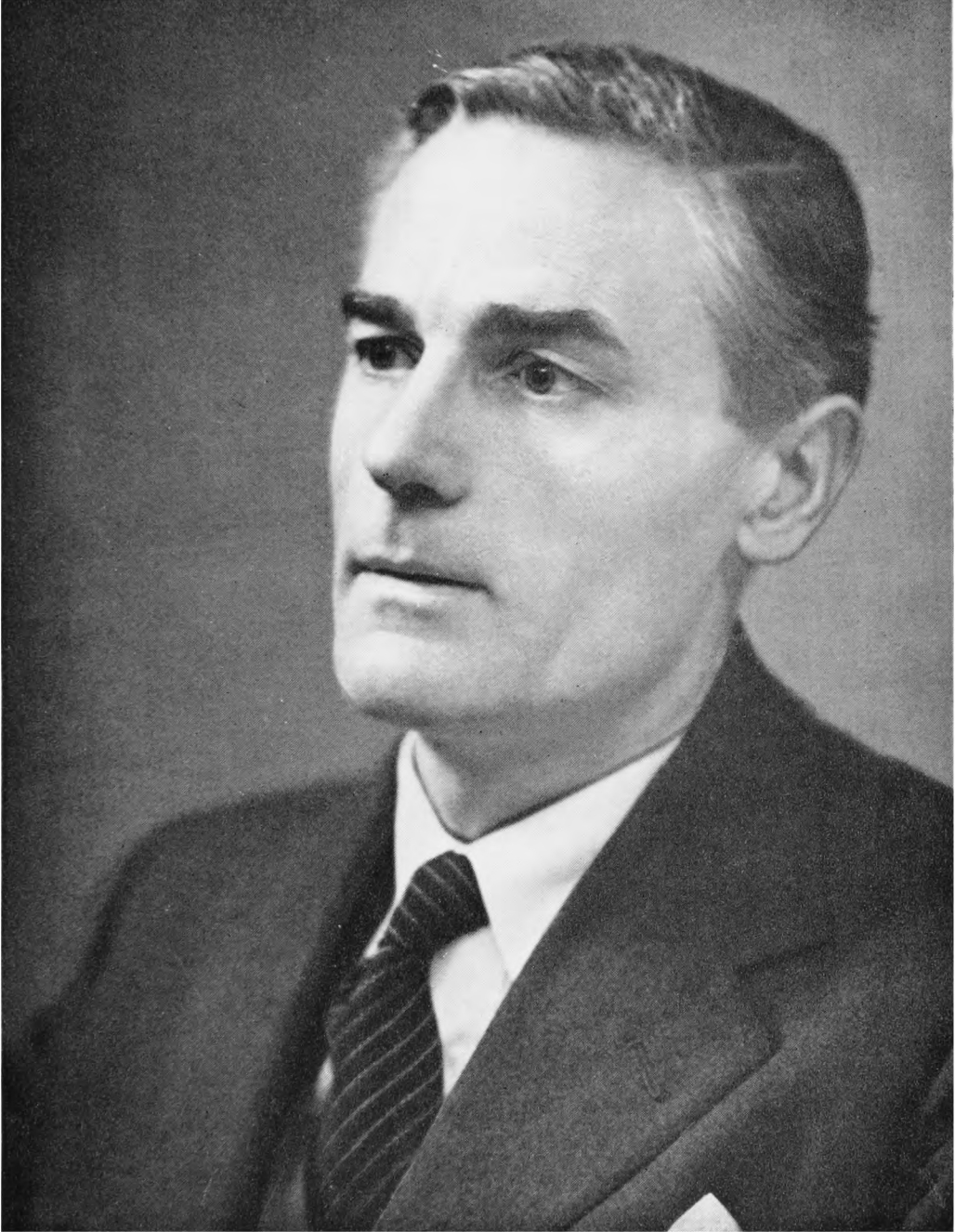
Secretary of the MRC, 1957 to 1961

The advent, on 7 November 1962, of the 21st anniversary of the formation of the Meteorological Research Committee (MRC) is an appropriate occasion for recording its early history. The idea that there should be such a committee goes back to 1938, when it originated with Professor Sydney Chapman, his formal proposal being made at a meeting of the Meteorological Committee on 29 November of that year. Chapman recorded his recollections of the beginnings of the MRC in a letter written to Sir Graham Sutton soon after the death of Sir Nelson Johnson in 1954. At first Chapman pursued his idea privately with Sir Henry Lyons, the senior Royal Society representative on the Meteorological Committee. As members of a committee of three appointed to advise the Air Ministry on the appointment of a successor to Sir George Simpson, Chapman and Lyons decided to take the idea seriously into account and Chapman records that "when N. K. Johnson was invited to an interview he was acquainted with our thoughts on the desirability of a Meteorological Research Committee. With his experience at Porton the idea was one that he naturally favoured. After his appointment he had a number of interviews with me at Imperial College on the matter, and took steps to get approval from the Air Ministry for the institution of the Committee".

Acting on N. K. Johnson's enthusiastic recommendation, the Secretary of State for Air, Sir Archibald Sinclair, appointed the MRC on 7 November 1941 with the following membership: Prof. Sydney Chapman (Chairman), Prof. D. Brunt, Dr. G. M. B. Dobson, Prof. G. I. Taylor, the Director of the Meteorological Office and representatives of the Admiralty (Capt. L. G. Garbett), the Air Staff (Group Capt. H. J. Saker) and of the Director-General of Civil Aviation (Mr. C. B. Collins). The terms of reference were:

- (i) to advise the Secretary of State for Air as to the general lines along which meteorological research should be developed.
- (ii) to advise and assist in the carrying out of investigations and research within the Meteorological Office.
- (iii) to receive reports on meteorological investigations carried out in the Meteorological Office or on behalf of the Air Ministry and to make recommendations for further action.
- (iv) to co-ordinate the investigations performed in the Meteorological Office with related activities carried out elsewhere, both in this country and abroad.
- (v) to make an annual report to the Secretary of State for Air.

The MRC held its first meeting on 10 December 1941 at the rooms of the Royal Aeronautical Society at Hamilton Place, London W.1. The secretary was Miss Flora Jones, B.A. At first the Committee devoted its attention primarily to problems of direct importance to the war effort, concentrating on investigations having an immediate application and likely to be solved in a reasonably short time; one example was the physics of condensation trails. Soon after his appointment as Director, N. K. Johnson planned to set up an organization within the Meteorological Office to undertake research and development, which



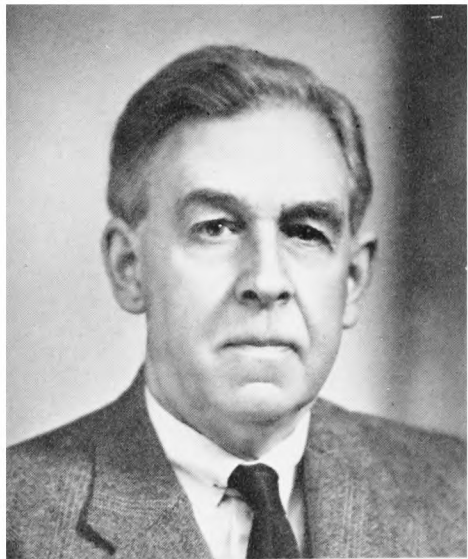
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PROFESSOR P. A. SHEPPARD, CHAIRMAN OF THE METEOROLOGICAL RESEARCH
COMMITTEE

(see p.311)



PROFESSOR S. CHAPMAN, F.R.S. FIRST
CHAIRMAN (1941-47)



Reproduced by courtesy of Elliott & Fry, Ltd.
PROFESSOR G. M. B. DOBSON, C.B.E., F.R.S.
(1947-52)



Reproduced by courtesy of Elliott & Fry, Ltd.
PROFESSOR SIR DAVID BRUNT, K.B.E. F.R.S.
(1952-55)



Reproduced by courtesy of Waller Stoneman, F.R.P.S.
PROFESSOR SIR CHARLES NORMAND, C.I.E.
(1955-58)

hitherto had been left largely to the initiative of individuals. The operational requirements of the war delayed the full realization of these plans, but the facilities needed to undertake the wartime problems along the lines recommended by the MRC were provided within the Office as far as was then practicable.

The new committee issued an announcement in the scientific journals that it would welcome contact and co-operation with university departments or other institutions engaged on work bearing on meteorology. This met with a favourable response and close collaboration with the universities and research bodies has been maintained throughout the 21 years since the MRC was formed; the high proportion of membership on the committee from such institutions has, in fact, ensured this.

Another important step followed from the wartime restriction of the MRC programme to problems of military application. This was for the Air Ministry to invite the Royal Society to co-operate with the MRC by undertaking research on certain aspects of meteorology which, though of fundamental importance for the advance of the subject, might not have an immediate practical application. The problem particularly recommended for study was that of radiation in the atmosphere, with special reference to radiation equilibrium conditions in the stratosphere. The Council of the Royal Society accepted the invitation to co-operate with the MRC and entrusted the immediate responsibility for the work to the Gassiot Committee. Arrangements were made for a grant to be allocated from Air Ministry funds to enable the Gassiot Committee's programme of work to be undertaken at a number of university centres. The idea for this co-operation again originated with Prof. Sydney Chapman, as a further passage from his letter indicates. He wrote "at about the time of the institution of the MRC it became likely, in my opinion, that there would be long-range problems of meteorology that might more suitably be undertaken under the auspices of the Royal Society than directly under the MRC as then envisaged. Egerton* and I went for a brief stay in Merton's* home in Hereford to discuss this question and there, I think at the suggestion of Egerton, it was decided to enlarge the scope of the Gassiot Committee to include such long-term meteorological research. This has proved to be a useful innovation for the Gassiot Committee, giving it much more importance and fruitfulness".

In March 1942 membership of the MRC was widened to include the Director of Scientific Research at the Ministry of Aircraft Production, Dr. D. R. Pye, and in May 1945 the Secretary of State, Mr. Harold Macmillan, agreed to increase the external scientist membership from four to five and invited Sir Charles Normand to serve on the committee. Prof. Chapman continued as chairman until 1947 when he was succeeded in turn by Prof. G. M. B. Dobson (1947-52), Sir David Brunt (1952-55) and Sir Charles Normand (1955-58). Since 1958 Prof. P. A. Sheppard has been chairman. At the end of the war the programme of research was revised with two objects, (*a*) to give greater prominence to longer term aspects of research and (*b*) to enable advantage to be taken of any increased facilities for flying resulting from the change-over from wartime to peacetime conditions.

*Prof. A. C. G. Egerton and Prof. T. R. Merton were, respectively, Secretary and Treasurer of the Royal Society at the time.

The MRC has, from the start, taken a close interest in meteorological investigations from aircraft. Originally such investigations for the Meteorological Office were made with the assistance of the High Altitude Flight of the Aircraft and Armament Experimental Station at Boscombe Down, but later these arrangements were changed by constituting the Meteorological Research Flight as a separate Meteorological Office unit at the Royal Aircraft Establishment at Farnborough. Other special research units which were established at the suggestion or with the support of the MRC were a radar weather research unit, formerly at East Hill near Dunstable and now stationed at the Royal Radar Establishment at Malvern, and an agricultural meteorology research unit at Cambridge. Soon after the war, in consultation with the Agricultural Research Council, a programme was drawn up of special investigations required by agriculturalists and steps were taken to carry out this programme with the co-operation of Rothamsted Experimental Station and the School of Agriculture at Cambridge.

From the time of its formation in 1941 the MRC has always maintained close liaison with the Aeronautical Research Council (A.R.C.). The latter, in fact, abolished its Meteorological Subcommittee and agreed to refer all its meteorological problems to the MRC which, in turn, arranged to keep the ARC informed of developments in meteorological research. In July 1947 the MRC appointed representatives to serve on Gust Panel No. 1, set up by the ARC to advise on investigations needed to obtain a reasonable knowledge of gusts. Consideration of the report of this panel led to the formation, in 1949, of a permanent Gust Research Committee, with Sir Geoffrey Taylor as chairman and with up to half the membership nominated by the MRC. The terms of reference are to consider investigations needed to increase the knowledge of gusts in the atmosphere at all heights and to report annually to the ARC and the MRC. The work of the Gust Research Committee is of importance not only to aviation but also to designers of ballistic missiles.

The widespread use of radio and radar during the war led to a number of problems concerned with meteorological aspects being referred to the MRC, and in 1943 it appointed a subcommittee, with N. K. Johnson as chairman, to advise on certain experiments then being carried out under the sponsorship of the Ultra-Short-Wave Panel of the Scientific Advisory Committee of the Ministry of Supply. The subcommittee was first called the S/W Radio Meteorological Subcommittee but the name was soon changed to the Joint Meteorological Radio Propagation Subcommittee and the terms of reference were widened to embrace radio-meteorological problems in general. It continued in existence until November 1950 (having held 25 meetings by then) when it was agreed by the MRC that the meteorological problems of radio propagation could be included within the scope of a recently formed Physical Subcommittee, while specialized radio aspects could receive attention by the Tropospheric Wave Propagation Committee of the Radio Research Board, on which the Meteorological Office is represented.

At its 50th meeting in July 1947 the MRC agreed to a proposal to form three subcommittees to deal respectively with instruments, synoptic and dynamical problems and physical problems, with Prof. P. A. Sheppard, Sir Charles Normand and Sir David Brunt as chairmen. These three subcommittees continued to meet four or five times a year until March 1959 when it was

decided to merge two of them into the Instruments and Physical Subcommittee, the other continuing as the Synoptic, Dynamical and Climatological Subcommittee. Membership, which is recommended by the MRC, is composed of scientists from the universities, representatives from government research establishments and senior members of the research branches of the Meteorological Office. From time to time the MRC has also set up temporary panels to consider and advise on special problems. For example, one such panel was formed, with representatives from the Ministry of Supply, to consider investigations relating to ice accretion on aircraft. Another was set up to advise on research in tropical meteorology.

One of the duties of the MRC is to review the research programme, which is revised annually, and to recommend the priorities which should be given to the items on the programme. Up to 1958 nearly all of the papers considered by the MRC and its subcommittees were detailed reports, prepared by members of the Meteorological Office Staff, on the individual items of the programme. In all, more than a thousand of these Meteorological Research Papers were prepared and a large number of them were subsequently published in scientific journals or as official publications. In 1958, however, it was decided to modify the reporting procedure in order to facilitate adequate consideration of the state of the main research subjects and the future course of investigations. The series of Meteorological Research Papers was discontinued and instead papers, restricted to the use of the MRC and its subcommittees, are now prepared on the more general aspects of the main problems. These papers are supplemented by six-monthly and annual progress reports on the more important items of the research programme.

Mention has already been made of the arrangement, started during the war, by which research grants were made by the Air Ministry direct to the Royal Society for disposal through its Gassiot Committee. In 1960, following a recommendation by the Brabazon Committee that these grants should be channelled through the MRC, the latter accepted the responsibility of advising on the administration of such grants and set up a Research Grants Subcommittee composed of the chairmen of the MRC and of the two scientific subcommittees, with the Director of Research, under the chairmanship of the Director-General. The function of this subcommittee is to scrutinize and advise on applications for grants for extra-mural research in meteorological problems. The Gassiot Committee, however, continues in being and some of its work is still being supported by Air Ministry grants on the recommendation of the MRC. The latter considered that it would be advantageous for the Meteorological Office to be more widely concerned with the support of extra-mural research and that the new arrangements should strengthen the study of meteorology at the universities and also help to bridge the gap between meteorology and the subjects bordering on meteorology (such as the photochemistry of the atmosphere) which the Gassiot Committee would continue to foster. Close co-operation with the Gassiot Committee is being maintained by arranging joint meetings to discuss the Gassiot research programme. The history of the Gassiot Committee and its encouragement of meteorological research has recently been recorded by Dr. D. C. Martin.¹

The most recent step in the progress of the MRC was taken in March 1961

when the Secretary of State for Air approved a revised constitution and more up-to-date terms of reference for the committee. The composition is now (a) a chairman and such number of other non-official scientist members as may be invited to serve by the Secretary of State, (b) the Director-General and two Directors of the Meteorological Office, (c) officers representing the Admiralty, the Air Staff, the Ministry of Aviation and the War Office. Under the revised terms of reference the MRC will advise the Secretary of State for Air on the general lines along which meteorological and geophysical research should be developed within the Meteorological Office and encouraged externally. It will review progress and report annually.

Probably the most useful function that the MRC serves is to facilitate discussion and the exchange of views between the research scientists in the Meteorological Office and their opposite numbers in the universities and other government departments. With the concentration of the research branches at the new Meteorological Office headquarters at Bracknell it is hoped that the external members of the MRC will have more opportunities of inspecting research in progress and of making closer contacts with those actively engaged on the research projects.

In concluding this brief history of the MRC it is appropriate to pay tribute to the two men who shared the responsibility for creating such a valuable means of co-ordinating meteorological research. That the success of the MRC is in large part due to Prof. Sydney Chapman's initiative in the early days and his enthusiasm as chairman in the first six years few would deny, but Chapman himself very generously says, in the letter already mentioned, that "of course it is to Johnson that the main credit for the success of the MRC is due. He took the deepest interest in its work and organized a successful research branch in the Meteorological Office".

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RESEARCH ORGANIZATION AND FACILITIES

By R. C. SUTCLIFFE, C.B., O.B.E., F.R.S.
Director of Research, Meteorological Office.

On an occasion of this kind, when we are taking stock after a period of years and especially when that period has seen the growth of our research organization from very small beginnings, it is natural to think in terms of historical development and to see much of interest in the way in which objectives have been defined and difficulties overcome. On the other hand, it may be that the historical record is of primary interest only for those few who have taken part in the step-by-step advance and can look backwards with a sense of achievement. Since most readers will probably be more interested to see the Meteorological Office as it is than as it was or might have been, I shall make little reference to the way things have evolved from the early days of the Meteorological Research Committee when there was, I believe, only one scientific officer post exclusively devoted to research, to the present time when the Directorate of Research stands side by side with the Directorate of Services, taking a large share of the scientific effort. Even so, it is easy to

overstate the change that has taken place. Throughout the century of the life of the Meteorological Office, scientific research has been carried out and on a considerable scale although the word "research" was not always used as freely as it is today. As a scientific institution, the Meteorological Office under Sir Napier Shaw was very much alive and the few scientists employed combined research with service without the need to define boundaries. The lack of balance came some years later when the very rapid expansion of advisory services for aviation during and following World War I led to the appointment of many full-time meteorological practitioners for aviation forecasting duties, with no more time for research than has the average medical practitioner today. Service demand rapidly outgrew the scientific base on which it stood, and, to change the metaphor, the Office consumed its seed corn by absorbing creative thinkers of proved ability into the insatiable technical and administrative system until, towards the outbreak of World War II, the Office, although employing numerous staff with excellent academic records, could barely claim a research scientist of the first rank on, so to speak, the active list. The erection on this foundation, even in twenty years, of a research structure to take its place in the modern world, alongside other scientific research institutions, has not been performed without stresses and strains and the revealing of weaknesses. Senior staff with limited research background have had for a time to turn their hands to unaccustomed work and in some cases with such success as to give the lie to the fable of the scientist burnt out at forty. But this phase of growth and makeshift is practically at an end. The leaders of the research groups are more and more becoming research workers of long experience and established position in the world of science, with collaborators who have entered research as a career. What is more, the new buildings at Bracknell provide for the first time a headquarters with the physical facilities of a scientific institution. It is to the description of the present state of affairs, relatively stable after a turbulent period of growth, that I shall devote the remainder of this article.

It will surprise no one to find that this account of a research organization is a description of my research directorate but I must, in order to avoid too gross a misunderstanding, first insist that the division of the Office into two directorates, of "services" and of "research", is the kind of administrative dichotomy which often needs to be imposed even when the distinction in function is far from clear cut. It must be kept in mind that the Meteorological Office is a co-ordinated scientific institution existing to advance the science and to serve the public and that, with the two directorates living together under the same roof with staff in principle and often in the event interchangeable, all-round efficiency is much enhanced by mutual aid and the sharing of facilities to a degree which would be impracticable were there two distinct bodies responsible for public services and scientific research respectively. There are for example one major library, one division for data storage and data processing services, with both mechanical punch-card and advanced computing systems, and one division for basic staff training. All these are in the Directorate of Services where, incidentally, most of the applied research directly related with aviation, agriculture, hydrology or industry is carried out. On the other hand, outside interests continually call upon the Office for advice on problems in atmospheric science less directly concerned with weather and climate but in

which an active research programme is in hand. Examples concern atmospheric pollution or radioactivity, turbulence related with diffusion or with bumpy flying conditions, radio propagation, cloud physics (ice formation, rain and hail erosion on aircraft), solar radiation, atmospheric ozone and other rare constituents, problems of rockets and artificial satellites, atmospheric electricity, allied problems of geophysics (seismology and geomagnetism), and a wide range of inquiries related with advanced instrumentation. In all these cases and many others the expert knowledge of research workers is at the disposal of outside interests and to that extent the public service greatly benefits without the need to carry specialists within the Directorate of Services itself. The Office possesses, I am firmly convinced, an effective and healthy combination of public service and scientific research which is in some ways unusual, perhaps unique—for the profession of meteorology has its unique features—but which it would be most unwise and perhaps disastrous to disrupt.

The research directorate divides immediately and conveniently into two parts, deputy directorates, labelled “dynamical” and “physical”, with functions not too far removed from the usual connotations of these terms in meteorology. Dynamical research is concerned with the large motions of the atmosphere on the scale of hundreds or thousands of kilometres, those motions which are recognized as the main structural features of weather and climate, fronts and jet streams, depressions and anticyclones and so on, and have immediate relevance to weather forecasting. The total strength of the scientific officer class of the deputy directorate stands at 24, divided into four branches each headed by a senior principal scientific officer. The whole of the work is concentrated in laboratories at Bracknell and is largely a matter of discussing data obtained from all parts of the world, using synoptic analysis, graphical and statistical techniques and, of quickly growing importance, the mathematical methods appropriate to a branch of fluid mechanics. It was in this work that electronic computing was first used in the Office and research in numerical weather prediction still makes a major call upon the facilities. A Ferranti Mercury computer, installed in 1959 at Dunstable and moved to Bracknell when the new building was occupied, has served excellently for research but the elaboration of mathematical models and the need for great speed and complete reliability has justified the purchase of a replacement computer of notably better performance although, at the time of writing, the choice among the number of different systems now available has yet to be made. The requirement is for something comparable with the fastest and largest capacity machines at present being marketed and even this may be unsuitable for calculations of great intricacy such as arise in the full three-dimensional problems of rain-producing systems or in the world-wide problems of the general circulation of the atmosphere and the theory of climate. The most advanced computer, the ATLAS, now being built to Government order, is therefore likely to have its uses for meteorological research.

The deputy directorate for physical research with 35 posts in the scientific officer class is of more varied character primarily because, whereas in large-scale dynamical research the raw data are mainly provided by regular observations of the synoptic and climatological networks, in physical research the making of special observations employing instrumentation designed for the purpose is half the battle. At the Bracknell Headquarters we have drawing

offices and workshops and numerous laboratories fitted with all modern conveniences—compressed air, vacuum, and electric power in a range of voltages. Two wind tunnels and two cold chambers maintaining temperatures down to -40°C are special features. The provision of well equipped physics laboratories has introduced a new dimension into the planning of research, and many things which in former times would have been beyond our reach may now be undertaken at our own headquarters. Interesting work in progress includes, for example, the wind-tunnel study of airflow over the Rock of Gibraltar, analyses of freezing nuclei and natural ice crystals obtained in the air, and the development of instrumentation for use in rockets and satellites.

A further facility of the greatest value is the 30-acre experimental site at Easthampstead, only three miles from Bracknell. Excellent buildings on the site provide useful workshops and laboratories and allow instrumental testing and field experiments in favourable conditions. A new programme of work on turbulent diffusion has been started here and, amongst other things, we are developing and testing completely automatic meteorological observing and reporting systems with remote recording, either continuously or by interrogation, in the laboratories at Bracknell.

A considerable proportion of our research in atmospheric physics must however continue to be carried out by detachments elsewhere than at Bracknell to take advantage of special facilities which are to be found at other establishments. Of these the historical priority goes to the observatories—the Meteorological Office outstations at Kew, Eskdalemuir and Lerwick—each of which is a scientific laboratory with its own library and workshop facilities, having special responsibilities not only for maintaining complete meteorological records but also for certain additional geophysical recording, particularly in geomagnetism and seismology. As the years pass the emphasis changes but everything points to the wisdom of maintaining these observatories in perpetuity as going concerns which may at any time meet a new need. Kew has one of the world's longest records of unbroken meteorological observations, a valuable asset in the context of climatic variation, while its facilities have lately been turned to the study of visibility and of radiation budgets as applying to an urban site. A recent story of some interest concerns seismological observations which, until only a few years ago, were languishing in this country with Kew Observatory keeping the records more by tradition than for any great interest excited by them. Then suddenly, in part stimulated by the defence interest in the detection of underground test explosions, the need for new data on seismic events of many kinds, microseisms in particular, became recognized all over the world; a site more suitable than Kew, with its high level of background noise, was looked for and the best that could be found in the country was near our observatory at Eskdalemuir where the ancient Silurian rock emerges. At the present time new and up-to-date instrumentation is being installed there and we shall have once more a first-class station. The creation of a Gassiot Fellowship in Seismology has permitted the Office to appoint for a term of years an expert from outside while a similar provision for geomagnetism is having a correspondingly stimulating effect. We may be sure that the three observatories have many unknown purposes still to serve in the future course of geophysical exploration.

To several other research outstations I can make only passing reference. At

Cambridge, in association with the School of Agriculture of the University, we possess a small but new and attractive laboratory and workshop where one or two scientists and their technical assistants may pursue appropriate field research on such topics as the energy balance and moisture balance of cultivated land. At Cardington the availability of captive balloons has permitted special observations within the first few thousand feet above the ground and the splendid open site with the facilities of the Royal Air Force station have been found valuable in several other ways: experiments on fog clearance and rainfall observations from a close network of synchronized recording rain-gauges are two examples of research tasks which fitted well into the Cardington programme. Then again there is the story of radar meteorology. After many years of experimenting at East Hill, a site near Dunstable, the justification for maintaining a station solely for the purpose was questioned and the decision had been taken to close down when new possibilities of advanced Doppler radar emerged and are now being pursued at the Royal Radar Establishment at Malvern by a combined team including a Meteorological Office detachment.

This account of outstation facilities will be closed with a reference to two units having outstanding records of achievement. The first of these is Porton, the Chemical Defence Research Establishment now under the War Office, where a Meteorological Office research group has been a continuous feature for some 40 years and may fairly claim to have contributed more than any other single institution in the world to the solution of the problems of atmospheric turbulence and diffusion near the earth's surface. It was here that full-time research was introduced early in the Office primarily to tackle the World War I problem of gas warfare and, much as we may deplore the cause, the outcome in knowledge and in scientific leadership has been remarkable. That consecutive heads of the Meteorological Office did their pioneer research work in the Porton group is evidence enough that in the early days the scientific need was well recognized, largely at the instigation of Sir David Brunt, and the work continues to be productive nearly half a century later.

Lastly I refer to the Meteorological Research Flight established at the Royal Aircraft Establishment at Farnborough. This unit, at present having three aircraft, a Canberra, a Hastings and a Varsity, serviced and flown by the Royal Air Force on tasks designed and executed by Meteorological Office personnel, is certainly a proud possession. It was long unique in the world since, elsewhere and even in America, the permanent assignment of aircraft and aircrew for meteorological research took a long time to arrange. The aircraft, instrumented to the scientific needs, backed up by laboratories, workshops and computers to meet any requirement, and flown anywhere within range from pole to equator, have provided data unobtainable by any other means and have contributed in a quite remarkable way to our knowledge of clouds and precipitation, ice formation on aircraft, condensation trails, clear air turbulence, atmospheric ozone and water vapour in troposphere and stratosphere, and many other mysteries of atmospheric structure.

In the following pages the two deputy directors of research will tell something of our scientific achievements and plans. My aim has been to give an impression of a research organization of no mean size employing some 60 scientific officers capable of pursuing meteorological research on a broad front and provided with the assistant staff, modern tools and other facilities, aircraft, balloons,

rockets, laboratories, workshops and computers, suited to the age. Although much has been accomplished I believe that the 21st Anniversary of the Meteorological Research Committee which this number of the *Meteorological Magazine* commemorates may well be taken also as the coming of age of research in the office, with the great work of maturity still lying ahead. It is an enticing prospect.

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PHYSICAL METEOROLOGY : ACHIEVEMENTS AND PROSPECTS

By G. D. ROBINSON

Deputy Director of Physical Research, Meteorological Office

Organized research in physical meteorology by Meteorological Office staff was not unknown even before the formation of the Meteorological Research Committee (MRC). In the years between the wars the meteorological section at Porton (already mentioned on page 318), pioneered the quantitative investigation of atmospheric processes near the earth's surface and it seems appropriate to remind readers of this number of the *Meteorological Magazine* that N. K. Johnson, F. J. Scrase, P. A. Sheppard and O. G. Sutton all saw service there. The observatories at Lerwick, Eskdalemuir and, particularly, Kew offered opportunities for practice of physics out-of-doors and for the sounding of the upper atmosphere by balloon-borne instruments. There were thus some resources of staff and tradition on which to draw when the need and the will to expand research in these fields came and the MRC was established. In this article I try to sketch the progress made in the 21 years since this expansion began. I make no attempt to define physical meteorology—it is not a self-sufficient science—and offer no apologies to any synoptician or climatologist who may feel at times that I am trespassing. I cite some published work: the papers chosen are examples only and are not intended to give a full, or even a representative, indication of the amount and nature of the research in physical meteorology which has been brought to the attention of the MRC.

The structure and movement of the atmosphere near the tropopause.—

Perhaps the most significant achievement of those who planned the research effort in the early days of the MRC was the earmarking of aircraft of advanced performance for meteorological research, and I do not think it can be questioned that the most original contribution of what developed into the Meteorological Research Flight has been the work of its high-altitude aircraft. This arose initially from the systematic use of one remarkable instrument, the frost-point hygrometer of Brewer and Dobson. (See photograph between pages 324 and 325.) The phenomena of aircraft condensation trails and their degree of persistence focused practical attention in wartime on determination of the water vapour content of the lower stratosphere, but in 1949 A. W. Brewer¹ gave these observations a much wider significance when he effectively used water vapour as the tracer of a slow circulation, on a global scale, responsible for the exchange of air between troposphere and stratosphere. In following this lead Mosquito and Canberra aircraft of the Meteorological Research Flight have flown at high levels from 10°S to 80°N, and have used observations of ozone and radioactive debris as additional evidence, concentrating attention on the neighbourhood of sub-tropical and frontal jet streams. Figure 1 is an example of this work taken from a paper by J. Briggs and W. T. Roach to be published this year. It shows the concentration of water vapour and ozone in the neighbourhood

of a frontal jet on 3 October 1960, with the indication that dry, ozone-rich stratospheric air is entering the troposphere through the tropopause gap. In returning from a flight of this kind on 21 February 1962, a Canberra aircraft of the Meteorological Research Flight was lost, and its crew and meteorological observer severely injured—the first major accident suffered by the flight since its formation.

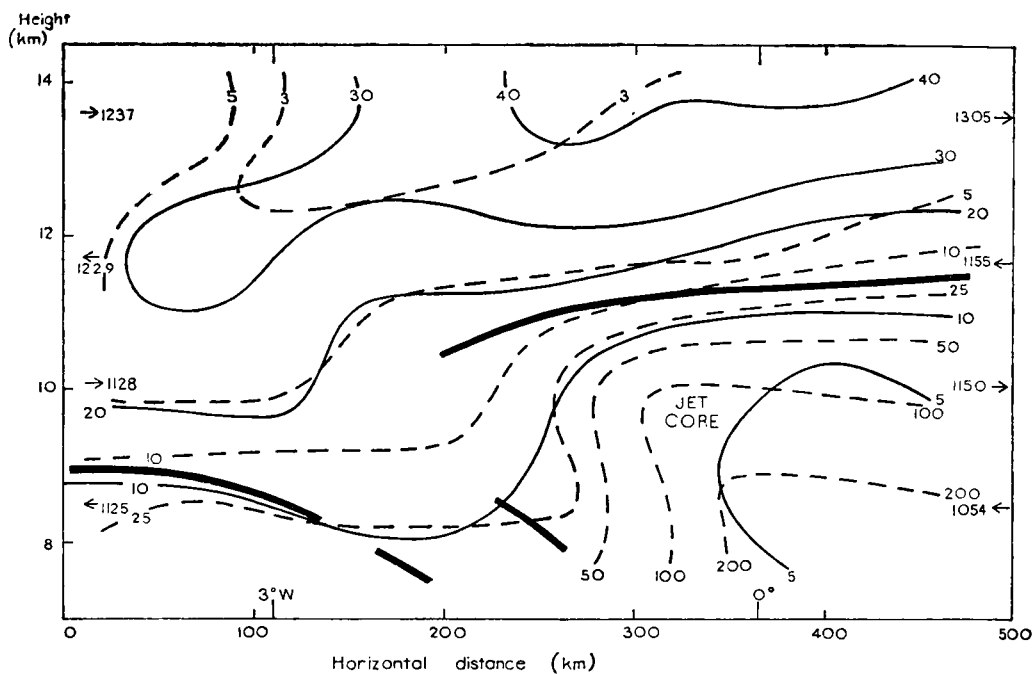


FIGURE 1—OZONE AND WATER-VAPOUR CONTENT OF THE AIR IN THE NEIGHBOURHOOD OF A JET STREAM [Briggs & Roach]

— Ozone content (mols $\times 10^8$).

--- Water-vapour content ($\mu\text{g/g}$).

The thick lines and dashes indicate the positions of the tropopause and frontal surfaces. The times (by the arrows indicating direction of aircraft) are in GMT.

Cloud morphology and the structure of fronts. Cloud physics.—In parallel with the activity of the high altitude aircraft, the larger aircraft of the Meteorological Research Flight—Halifax, Hastings, Varsity—have explored the troposphere, concentrating attention on clouds and cloud systems. Over the years many flights have been made to explore frontal structure and reference to J. S. Sawyer's² analysis of some of the results will show how radically these modify the early textbook models in some respects. The use of radar to investigate precipitation was just becoming a possibility when the MRC was formed, and the East Hill (near Dunstable) radar station of the Meteorological Office, alone and in conjunction with aircraft, was used to investigate the structure and development of cumulonimbus clouds and the movement of more widespread precipitation systems. The close association between the movement of precipitation belts and the 700 mb wind shown by W. G. Harper and J. G. D. Beimers³ is an example of the help which radar can provide for the synoptic meteorologist. With the development of more advanced radar techniques, new possibilities opened to the meteorologist, and a coherent pulsed Doppler radar is now being used to investigate the pattern of vertical air movement in cumulonimbus clouds.

The smaller-scale aspects of cloud physics have been probed by both aircraft and radar. Systematic sampling for number and size of condensation nuclei, chloride particles, cloud particles and precipitation particles has been a task of the Meteorological Research Flight for many years—a task involving many hours of laborious work at the microscope. In detail it may be that there are as many size distributions of cloud and precipitation particles as there are precipitating clouds, but some generalities on clouds and raindrops have emerged. “Freezing nuclei” and ice particles offer more difficult problems, and much work on ice clouds and mixed water-ice clouds remains to be done. The pulsed Doppler radar offers a method of determining the size distribution in rain from layer clouds; it is more sensitive for the larger drops and less so for the smaller ones than the aircraft methods, and one of the more rewarding moments in an often frustrating investigation came when, as recorded by J. R. Probert-Jones,⁴ the two techniques were found to give concordant results in the region of overlap (Figure 2).

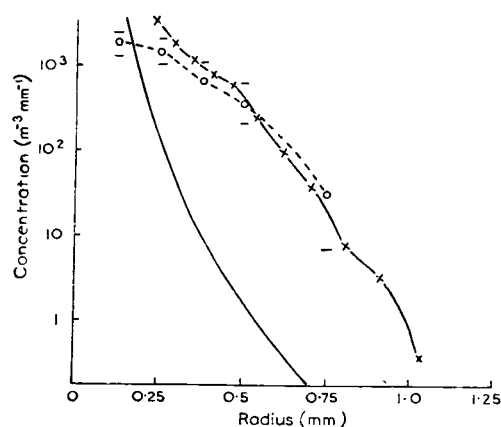


FIGURE 2—DROP-SIZE DISTRIBUTIONS ON 16 APRIL 1959, 1528 GMT, AT 1500 M
[Probert-Jones]

× — × Radar concentrations.

o --- o Aircraft concentrations with their upper and lower 5% probability limits.

———— Radar threshold curve.

Sampling of cloud particles from aircraft is obviously complicated by the problem of the efficiency of the sampler. It is not so clear that similar problems arise if the sample is taken on the ground. Figure 3 is taken from a report by K. H. Stewart⁵ on the composition of fogs. It contrasts the results of using a standard sampling instrument (the “cascade impactor”) in the standard way with those obtained from consideration of the distribution of light scattered at small angles and transmissivity in different spectral ranges in the visible and infra-red. In passing I would like to commend a study of this report to those physicists who feel that the days of “sealing wax and string” are gone forever.

Radiation in the atmosphere.—There can be few better illustrations of the conservatism of the climatologists of a generation ago than the fact that the Meteorological Office made no continuous records of the amount of solar radiation falling on a fixed surface until 1946. Since that date much work has been done at Kew Observatory on techniques of recording, and the errors of records of solar illumination and radiation. The more difficult task of recording terrestrial radiation and the radiation balance was taken up at Kew at about the same time as it began to be studied, by somewhat different techniques, in

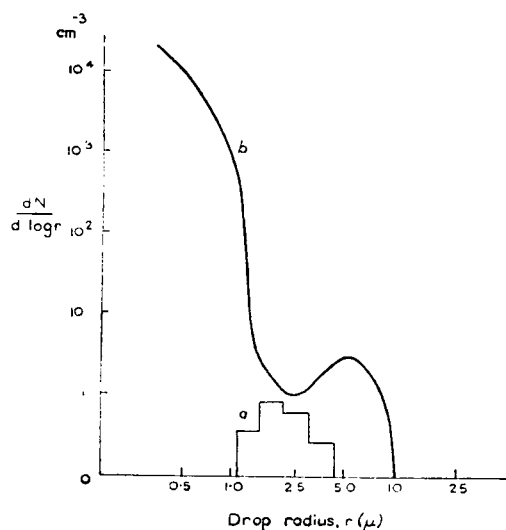


FIGURE 3—DROP-SIZE DISTRIBUTION IN FOG AT KEW ON 20 DECEMBER 1956, 2320 GMT [Stewart]

dN = number of drops in size range r to $(r+dr)$.

a — cascade impactor results.

b — “best fitting” curve compatible with optical attenuation, scattering, and impactor results.

Total scatter coefficient from histogram (a) = 0.56 km^{-1} .

Total scatter coefficient from curve (b) = 1.3 km^{-1} .

Total scatter coefficient observed = 1.2 km^{-1} .

America, Germany and Russia. Radiation balance was one of the elements proposed for wide-scale study during the International Geophysical Year (IGY), 1957–58, and the results of preliminary trials at Kew of methods later adopted at several overseas stations during the IGY are discussed by G. D. Robinson⁶. The Meteorological Office took the initiative in instituting continuous radiation measurement at sea. Solarimeters are part of the normal equipment of the North Atlantic weather ships, and attempts to measure radiation balance during the IGY were partially successful and reflect great credit on those concerned with handling the equipment at sea.

Aircraft of the Meteorological Research Flight have for some years been equipped with instruments measuring the upward and downward flux of solar radiation, and results have been published on the albedo of the earth's surface and of clouds, and on the absorption of solar radiation both in “clear air” and cloud. The measured albedos are close to those which were expected—it is interesting that Meteorological Research Flight aircraft and the American TIROS weather satellites report the same albedo for a wide area of the Sahara Desert—but both in “clear air” and cloud the measured absorption of solar radiation is higher than can be accounted for by any published theories. Some clouds have been found to absorb more than 20 per cent of the solar radiation incident on them. In connection with this programme the absorption of solar radiation in a clean atmosphere was recomputed using the most modern values of the relevant absorption coefficients. Both aircraft and surface measurements of solar radiation indicate that absorption by atmospheric aerosol is important locally, and may be an appreciable term in the earth's radiation balance.

Atmospheric turbulence and diffusion. Micrometeorology.— This field of study has always been most actively pursued in the Meteorological Office. O. G. Sutton's text *Micrometeorology*,⁷ which sets out the position of the subject soon after the end of World War II, and F. Pasquill's recently published *Atmospheric Diffusion*,⁸ contain sufficient evidence of this.

A considerable change in approach to the diffusion problem has occurred in the period under review. Let us consider the movement of a particle in a direction perpendicular to the mean wind. Its velocity in this direction is u and its displacement X . After time T its displacement is

$$X(T) = [u]_T \cdot T$$

where $[u]_T$ is the mean velocity over time T .

If we now take the mean over an ensemble of particles we have for the mean square displacement after time T .

$$\overline{X^2}(T) = \overline{[u]_T^2} \cdot T^2$$

To study the dispersion of particles released continuously from a point source we must study the function $\overline{[u]_T^2}$. If the variance of u in time t is u_t^2 and this has a limiting value u_∞^2 (a necessary assumption in all mathematical treatments of turbulence statistics) and if we write $V(t) = u_t^2/u_\infty^2$, it can be shown that $\overline{[u]_T^2}/u_\infty^2 = 1 - V(T)$ and we can readily establish the following relations between this "variance function" and the autocorrelation (R) and spectrum (F) functions familiar in statistical descriptions of turbulence

$$R(t) = 1 - \frac{1}{2} \frac{\partial^2}{\partial t^2} [t^2 V(t)], \quad F(n) = \int_0^\infty R(t) \cos 2\pi n t dt$$

$$V(t) = \int_0^\infty F(n) [1 - \sin^2 \pi n t / (\pi n t)^2] dn = \text{approximately } \int_{1/(2t)}^\infty F(n) dn$$

To exploit this method of determining or predicting the diffusion of particles in the atmosphere we must relate $V(t)$ —a description of events following the particles and not very amenable to observation—to some readily made measurement, and this in turn, particularly in large-scale problems, to the synoptic weather map. The relation of dispersion statistics to turbulence statistics determined at a point—"Lagrangian" and "Eulerian" statistics—has figured largely in the work of F. Pasquill and his colleagues over the past few years.

The exchange of heat and moisture between air and ground plays a prominent rôle in many meteorological problems, ranging from the general circulation of the atmosphere to local fog formation, and is a central theme in agricultural meteorology. It may be studied in many ways and on many scales. A Meteorological Office unit in close association with the School of Agriculture, Cambridge University, has worked in this field, and reported frequently to the MRC since the end of World War II, being concerned mainly with evaporation from growing crops and its estimation by methods at once reasonably simple, accurate, and applicable to short intervals of time. Similar work has been carried out at Kew Observatory, and also at Cardington where moored balloons have been used to carry instruments away from the immediate neighbourhood of the surface to heights around 3000 feet. Examples of this type of work may be found in N. E. Rider's⁹ study of the profiles and flux of momentum, heat and water vapour in the lowest two metres of the atmosphere and in a series of reports to the MRC on the formation of fog in relation to the structure of the lowest 2000 feet of the atmosphere.

Exploration of the high atmosphere.— The greatest change in meteorology since the inception of the MRC is without doubt the enormous expansion of our knowledge of the three-dimensional structure of the atmosphere, a consequence of the availability of an instrument, the radiosonde, reliable enough and cheap enough to be used regularly in a wide network of observing stations, and a vehicle, the small extensible balloon, capable of carrying it regularly to pressure levels around 50 mb. Within the last few years it has become possible to visualize an extension of observations to 5 to 10 mb by the use of extensible balloons, and to unlimited heights by the exploitation of rocket and satellite techniques. Such an extension requires no justification to the meteorologist, who has never had reason to question the definition of meteorology as the scientific study of atmospheres, so it was natural that the Meteorological Office, with the support of the MRC, should form a unit to take advantage of the new opportunities to study the high atmosphere by all available means. Plans have been made for the inception of regular soundings by rockets from a base in the Hebrides and, by arrangement with the Royal Society's National Committee for Space Research, instruments are being prepared to measure the distribution of ozone in the atmosphere from an artificial earth satellite. These instruments have already been tested on a "Skylark" rocket launched from Woomera, Australia, and the vertical distribution of ozone has been determined to its upper limit at the time of this ascent. (See photograph opposite page 324.)

An examination of what is known about the temperature field of the atmosphere between 20 km and 100 km, coupled with computations of its radiative heating and cooling, led R. J. Murgatroyd and F. Singleton¹⁰ to propose a

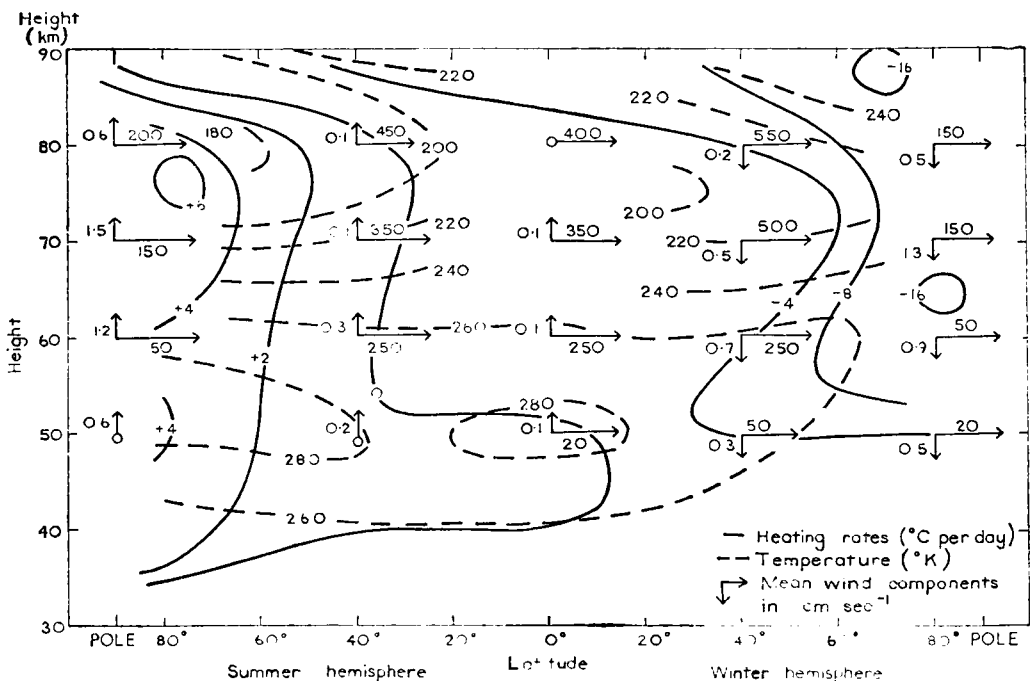
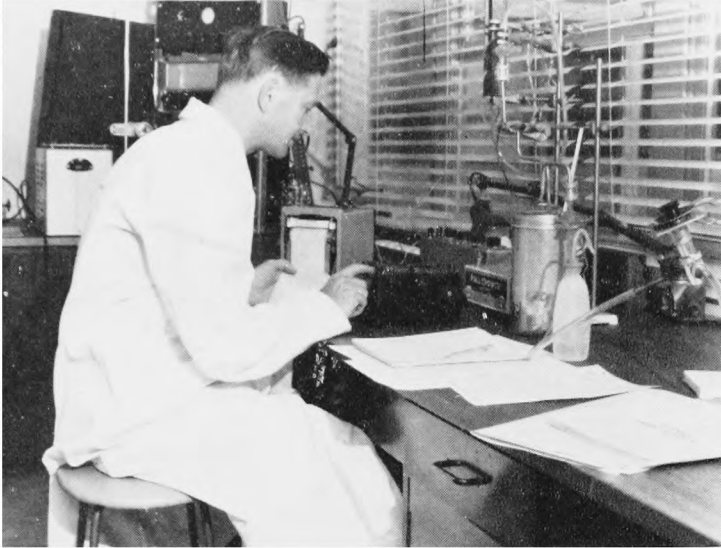


FIGURE 4—COMPUTED HORIZONTAL AND VERTICAL COMPONENTS AT THE SOLSTICE OF A MEAN MERIDIONAL CIRCULATION IN THE MESOSPHERE, WITH THE AIR TEMPERATURES AND RADIATION-TREATING RATES ON WHICH THEY ARE BASED

[Murgatroyd & Singleton]



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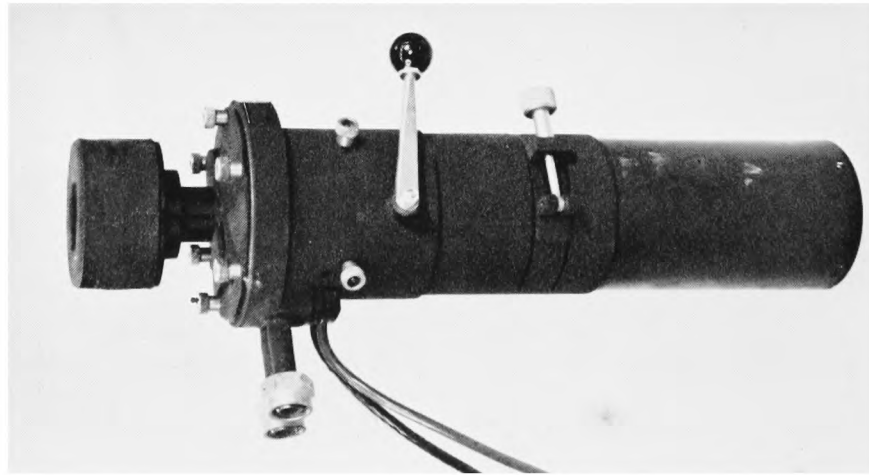
AN EXPERIMENTAL HYGROMETER, DESIGNED FOR USE AT HIGH ALTITUDES ON FREE BALLOONS, UNDERGOES TEST AND CALIBRATION IN THE BRACKNELL LABORATORIES



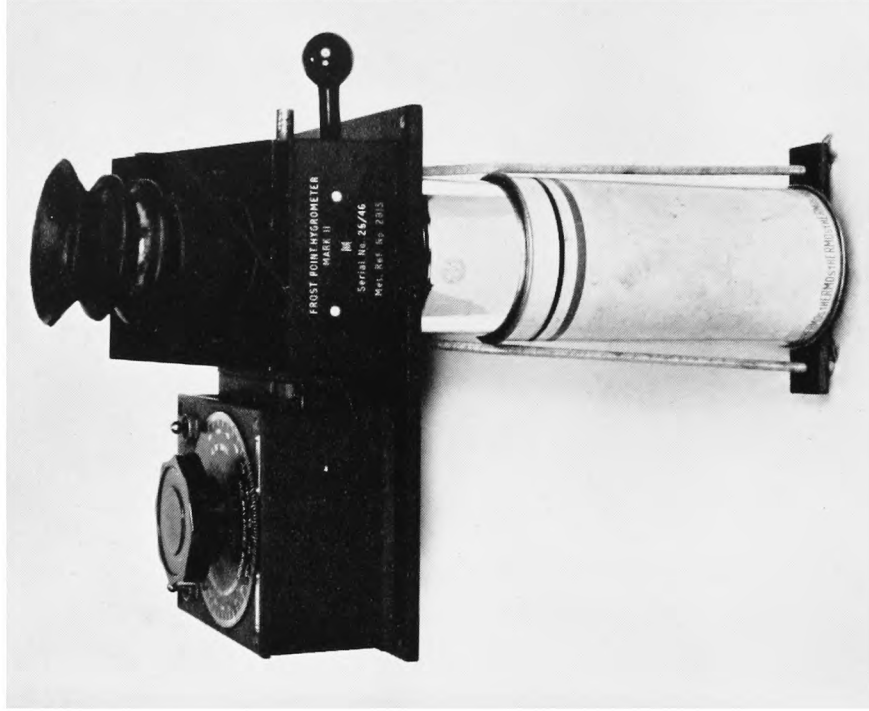
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AT THE BRACKNELL LABORATORIES A FINAL CHECK IS MADE ON EQUIPMENT TO MEASURE THE VERTICAL DISTRIBUTION OF OZONE, MOUNTED IN THE INSTRUMENT COMPARTMENT OF A "SKYLARK" ROCKET.

RESEARCH IN THE METEOROLOGICAL OFFICE—PHOTOGRAPHS OF INSTRUMENTS USED IN RESEARCH WORK ARE SHOWN ABOVE, AND ALSO ON THE FOLLOWING THREE ART PLATES AND ON THAT OPPOSITE p.338.



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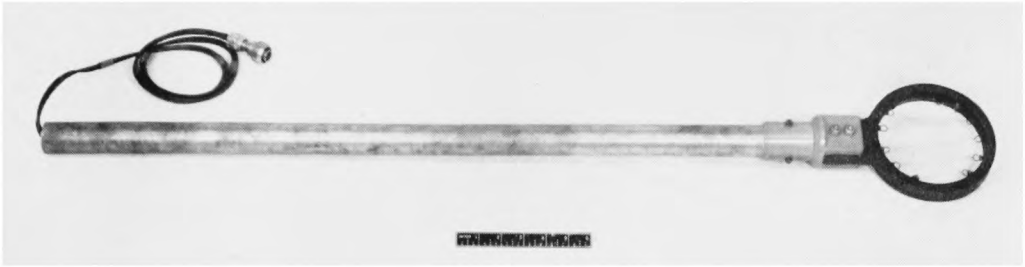


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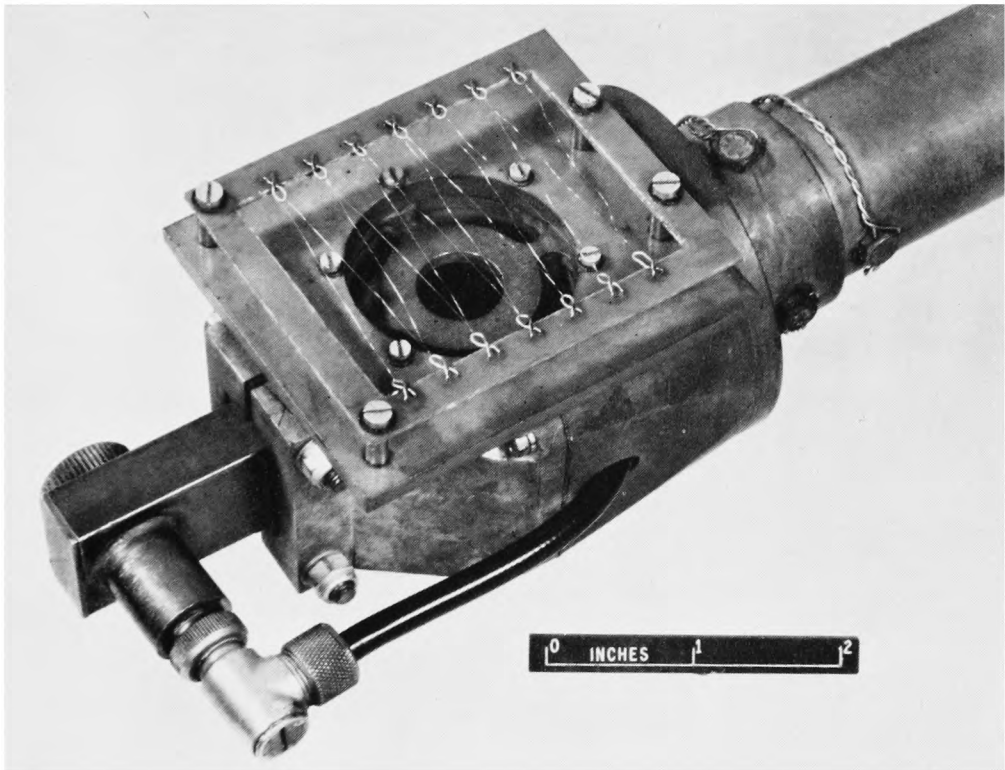
TWO MODELS OF THE DOBSON-BREWER FROST-POINT HYGROMETER.

Left: model with pressurization facilities and liquid nitrogen cooling, as used on Canberra aircraft.

Right: model with CO₂-alcohol cooling, as used on Hastings and Varsity aircraft.



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**OTHER INSTRUMENTS USED ON AIRCRAFT OF THE METEOROLOGICAL RESEARCH
FLIGHT.**

Top: Probe of a hot-wire water content meter for determining the concentration of water and ice in clouds.

Bottom: Cavity of a microwave refractometer and a rapid-response resistance thermometer.



Crown copyright

PYRHELIOGRAPHS AT KEW OBSERVATORY.

Thermopiles mounted on heliostats measure the intensity of solar radiation in spectral regions defined by filters.



Photograph by J. F. Moir

RECORDING RADIATION AT SEA.

A radiation balance-meter exposed, in unusually calm conditions, on one of the ocean weather ships. The sensitive surface is shielded from the radiation from the ship, and its output added to that of an instrument, covering the other hemisphere, similarly mounted on the other side of the ship. The radiometer is stabilized against roll but not against pitch.

meridional circulation compatible at its lower boundary with that suggested by Brewer but posing unanswered dynamical and thermodynamical problems at higher levels. Figure 4 illustrates the upper part of this circulation at the solstice.

Prospects.— It is clear from this summary that under the guidance of the MRC the Meteorological Office's work in the domain of physical meteorology has been concerned to a great extent with observations out of doors, with perhaps less emphasis on laboratory physics, numerical experiment, and theoretical investigation than would be desirable in a completely balanced programme. This reflects a provision of facilities for observation in some respects unique. There is also evident a tendency to treat those aspects of physical meteorology which have an immediate bearing on the larger scale problems of climate and weather (tracer studies of the general circulation, radiative properties of clouds, energy transformations at the surface), or those with direct application to problems in aviation, architecture or public health (water and ice in clouds, recording of illumination, diffusion of atmospheric pollutants). This tendency reflects the Meteorological Office's position as a public service.

This survey is written at a time when the Meteorological Office's opportunities for outdoor observation are for the first time matched by the provision of adequate laboratory facilities in the new buildings at Bracknell and Farnborough. It is profitless to attempt to predict the future of a research project in any detail, but in broad outline the plan for the next few years is clear. The new techniques for sounding the high atmosphere must be exploited to the full to map the winds, temperatures, composition and radiative state of the atmosphere above the 10 mb level until the mean state and the structure of the disturbances are as well known there as in the troposphere. In the field this will require the co-operation of many agencies, but there is also the need for much laboratory work on sensors, particularly of temperature and radiation, for use on balloons and rockets, and for mathematical investigations on heat balance and possible circulations. It seems likely that weather satellites will operate continuously, and the refinement of current proposals to employ satellite-mounted instruments at various levels to measure the temperature, some aspects of atmospheric composition and the radiative fluxes, offers a considerable challenge to the laboratory physicist. The precision required of temperature or density measurements in the upper atmosphere, if they are to be properly integrated with the observed wind structure, is readily seen to be very high indeed—it is of course not yet approached in the upper levels of balloon-sonde ascents.

It is likely that the Meteorological Office's first rocket-sonde and its first satellite experiment will both be launched in 1963. Rocket soundings for ozone content will continue, and balloon soundings for ozone, water vapour and radiative flux should follow.

In the domain of cloud microphysics attention is likely to be directed to the ice phase and particularly to the freezing nuclei whose nature, numbers, mode of action and indeed importance to the natural freezing process are all still in varying degrees doubtful. Some aspects of the initiation of precipitation may be clarified by the use of millimetric radar and a combination of radar techniques may be used to investigate the hail problem.

The availability of cloud pictures from satellites will facilitate the study of cloud populations and more quantitative work in this field can be envisaged using photographs from aircraft. Detailed and recondite treatments of the radiative properties of an entirely gaseous atmosphere may have obscured the fact that cloud is perhaps the most important atmospheric radiator, and more attention, empirical and theoretical, to its incidence and radiative properties is overdue.

Quasi-theoretical estimates of the heat budget at the earth's surface differ by amounts which are very significant when attempts are made to link them with circulation studies. An urgent, if rather unglamorous task for the physical meteorologist is to improve methods of recording solar and terrestrial radiation and to encourage such measurements, particularly at sea, because progress in satellite instrumentation is such that it seems likely that the radiation field at the upper limit of the atmosphere will soon be better known than that at the earth's surface. For the same reason an extension to the oceans of the investigations of energy and mass transfer carried on over land surfaces is required.

I began this survey with the remark that physical meteorology was not a self-sufficient science. If we except investigations directed to immediate practical applications, almost all the work I have mentioned contributes to the clarification of some aspect of the central problem of meteorology, the general circulation of the atmosphere. What is required is a mapping of the flux of energy in its various forms as comprehensive as that mapping of temperature and wind which has hitherto been the climatologists' main concern; this mapping involves the application of techniques, both experimental and mathematical, which are the concern of physical meteorology, and which take their place alongside those of the mathematicians and climatologists as essential to our fuller understanding of the atmosphere.

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RESEARCH IN SYNOPTIC AND DYNAMICAL METEOROLOGY AND IN CLIMATOLOGY, 1941 TO 1962

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To glance through the pages of the minutes of the Meteorological Research Committee (MRC) and its Subcommittee II (Synoptic, Dynamical and Climatological Subcommittee) is to review the progress in dynamical and synoptic meteorology of the past two decades. In some respects—particularly in regard to dynamical meteorology and in our knowledge of the upper troposphere and lower stratosphere — progress has been such as to open up entirely new lines of thought and development, while on other topics papers which were presented and discussed at the Meteorological Committee 15 or 20 years ago would have been as acceptable today as they were then.

The main streams of research in climatology and in dynamical and synoptic meteorology are discussed in the following paragraphs. However, such a brief review must necessarily omit many interesting topics to which the Committee devoted its attention at various times.

Dynamical meteorology and numerical weather prediction.—

Twenty-one years ago, when the MRC was formed, the radiosonde was only just coming into effective operational use and current knowledge of the free atmosphere was limited to that obtained from the few regular aircraft soundings available and from pilot balloons in clear weather. Prior to World War II it had been possible to draw limited upper air charts to the 500 mb level over a restricted area of western Europe, but with the outbreak of war the area became even more limited.

Without a working familiarity with the three-dimensional temperature and wind structure of the weather systems occurring day by day, progress in the dynamical study of depressions, anticyclones, etc., was necessarily limited. The stimulus for development of the subject came from the expansion of regular upper air charts for most of the troposphere. Drawn primarily for the purposes of wartime aviation over an expanding area, the charts became more complete and comprehensive after the war as the continental networks of radiosondes were expanded and linked by the weather ships.

The need to forecast the upper wind distribution led during the war to the development of the techniques of thickness analysis by the Upper Air Analysis Unit at Dunstable* under Dr. S. Petterssen, and to an increasing understanding of the rôle played by temperature advection and vertical motion in the changes of upper air structure which accompany weather systems on the scale of depressions and anticyclones. Particularly important was the contribution of Dr. R. C. Sutcliffe who, recognizing that the pattern of the 1000–500 mb thickness lines is broadly representative of the temperature distribution through the troposphere, showed how the dynamical and thermodynamical equations could be linked to relate cyclonic and anticyclonic development to the patterns of thickness lines and contours of isobaric surfaces. His fundamental paper was published in the *Quarterly Journal of the Royal Meteorological Society* in 1947,¹ and is important also in its stress on the rôle of the vertical component of

*Units of the Meteorological Office formerly at Dunstable are now at Bracknell.

vorticity.

Further exploitation of these ideas was rendered possible by the establishment in 1948 of a branch at Dunstable for research in short-range forecasting, a step largely due to the foresight of Sir Nelson Johnson, then Director of the Meteorological Office. Studies at Dunstable in the following years showed that it was possible to evaluate many important terms in the dynamical equations from synoptic charts on the basis of the geostrophic wind equation. On the more practical side it was demonstrated how rules based on Sutcliffe's dynamical theory could be applied in a qualitative manner to practical forecasting of the movement and development of particular weather systems. These rules were tested in close co-operation with the routine forecasters at Dunstable and are largely summarized in an important paper by Sutcliffe and Forsdyke² published in 1950. They are now part of the accepted technique of forecasting.

As early as 1948 we find the MRC discussing the application of the electronic computer then projected at the National Physical Laboratory to the forecasting problem, and recommending the direction of mathematicians to this problem. However, the steps towards numerical weather forecasting came gradually later, partly under the stimulus of the early work by Charney^{3,4} in America and partly as a direct development from the numerical formulation of Sutcliffe's development equation. From the first, attention at Dunstable was directed to a formulation of the numerical forecasting problem which would permit the prediction of both surface and upper air charts, the fundamental paper⁵ being considered by the MRC in 1952—attention in America and Sweden being then directed primarily to the barotropic treatment applying only in mid-troposphere.

The results of computations of 24-hour changes in the pressure field on electronic computers in London and Manchester were so encouraging that in 1954 we find the MRC (Subcommittee II) recommending "an intense effort in numerical forecasting with the aid of an electronic computer under the control of the Meteorological Office". Such a machine was provided, and became available in January 1959 when it became possible to carry out extended experiments in numerical weather prediction on a current basis.⁶ These have continued intermittently since and have established that upper air charts can be computed with a standard close to that achieved by current subjective methods, but the accuracy of the surface charts predicted by numerical methods remains at present a little below that of the subjective methods. (See the example of a numerical forecast in Figure 2 on page 331.)

Along with the development of numerical weather forecasting has gone the studies of objective analysis and data processing which enable a computer to read the paper tape punched as messages come in by teleprinter, to extract relevant upper air reports, ships' reports, and so on and to interpolate from these the values of the heights of various upper air surfaces at a specified grid of points on the map which are required to initiate a numerical forecast. The latest methods developed by Corby⁷ and his co-workers provide a standard of analysis as acceptable for the start of a numerical forecast as can be achieved by the more conventional methods of plotting and drawing charts.

There is no doubt that the work of the last twenty years has given an insight into the fundamental dynamics of depressions and anticyclones from which we can say that the basic mechanisms are now understood. For numerical predic-

tion we need more than this and it is already clear that several secondary processes, orography, friction, latent heat release in precipitation and so on all play a part, so that the improvement of the standard of numerical prediction to a state in which it clearly surpasses subjective methods will call for the painstaking development and improvement of numerical methods to take into account these effects. We can have confidence that such improvement will be effected over the next ten years or so, but every additional factor considered makes the satisfactory formulation of the problem and computation of results more difficult, and progress must be expected to be slow.

Medium range forecasting.— Since its earliest meetings the MRC has stressed the need to develop methods of medium- and long-range forecasting. Under the urgent pressure of wartime requirements in 1942 an experiment was carried out to predict the pressure field over periods from a few days to a month or two, employing harmonic analysis and symmetry points in time series. The experiment was abandoned after about 18 months as a failure.

Medium-range forecasting was not again seriously attempted until 1948 when Sir Nelson Johnson set up a branch at Dunstable for the purpose, under the direction of Dr. R. C. Sutcliffe. Following the experience of a similar team operating in the U.S.A. under Dr. J. Namias, attention was directed to the largest scales of atmospheric motion as displayed on northern hemisphere charts of 500 mb flow, 1000–500 mb thickness, and surface isobars. (By this date the upper air network permitted the regular construction of such charts.) It was soon found that, with experience, extrapolation and dynamical argument based on Sutcliffe's theory of development could be applied to these charts to prepare forecast charts for two and three days ahead, with a sufficient accuracy to provide a useful guide to the weather over the next four days.

This work provided the stimulus for a considerable number of studies of the large-scale and long-lasting features of the upper flow pattern—the long waves, cut-off cold lows, etc. A background of knowledge has thus been provided for the medium-range forecaster, but actual experience of working with circumpolar upper air charts is probably the most valuable asset of the medium-range forecaster.

The preparation of four-day forecasts along these lines was incorporated in the work of the Forecast Division on an experimental basis in 1952 and has gradually become an established part of the routine for giving guidance as necessary beyond the usual 48-hour outlook.

The main requirement in this field is probably to codify and consolidate the forecaster's experience. Some success has been attained in providing more objective rules for weather developments over periods of a few days,^{8,9} and there is some indication from America that numerical forecasting methods applied to hemisphere charts can give useful guidance up to three days ahead.

Long-range forecasting.— In addition to the abortive experiment in long-range forecasting to which reference has been made, studies were also conducted by Sir Gilbert Walker in the early years of the MRC into the association between Arctic sea-ice and European weather.¹⁰ However, this work also failed to provide a basis for long-range forecasting.

In 1952 the MRC (Subcommittee II) again turned its attention to the problems of long-range forecasting and the study of the longer-period weather

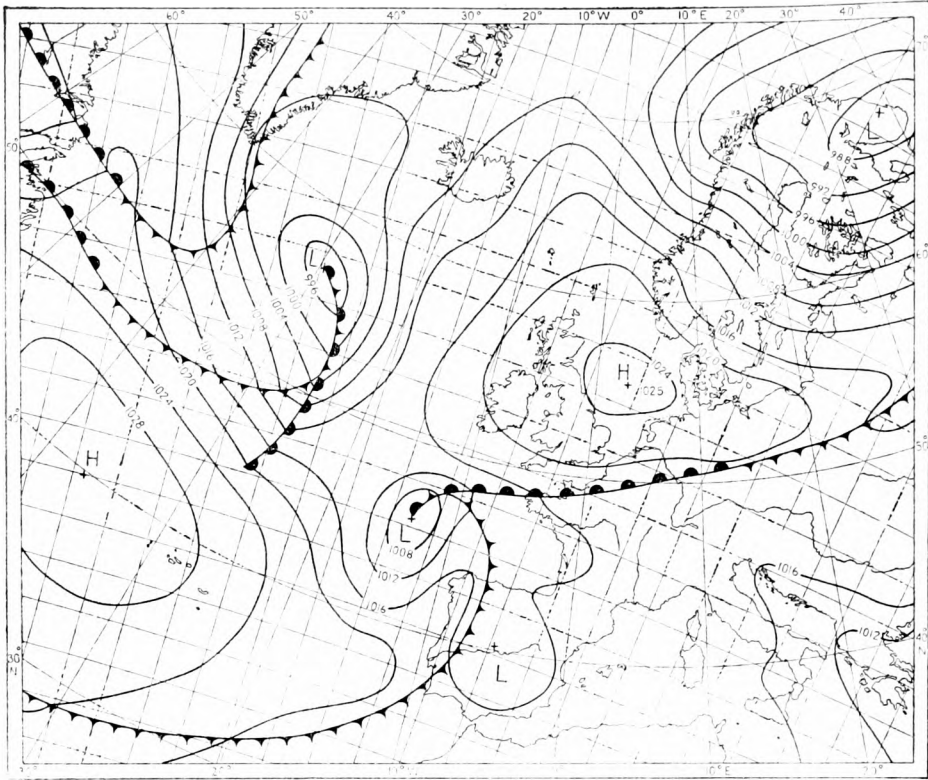


FIGURE 1a—SURFACE CHART FOR 0000 GMT, 14 AUGUST 1962

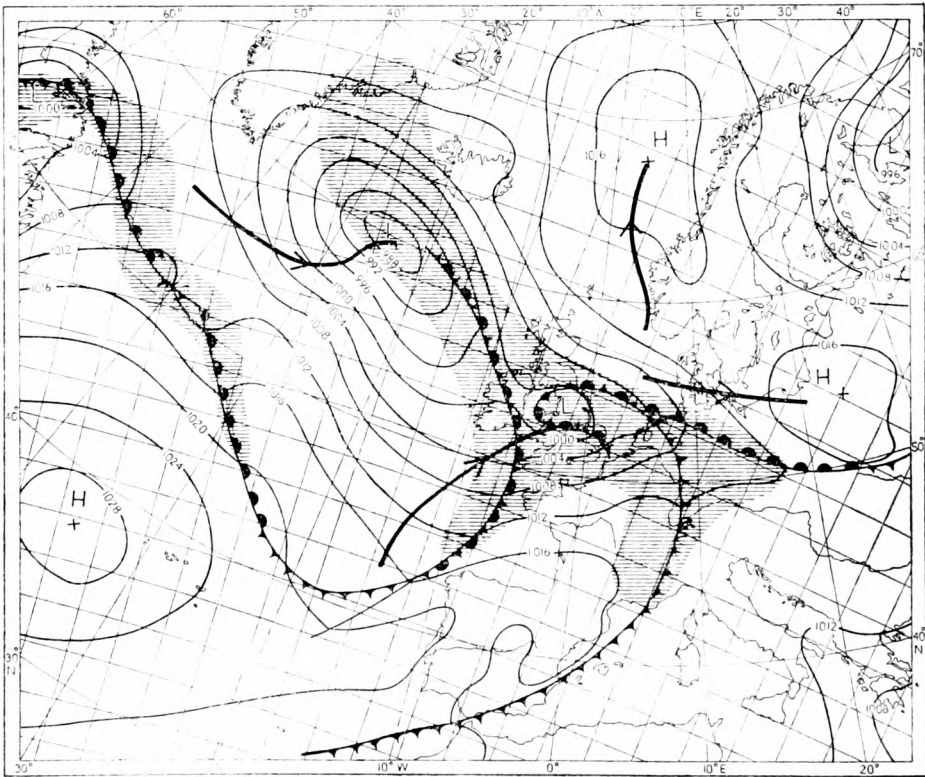


FIGURE 1b—SURFACE CHART FOR 0600 GMT, 15 AUGUST 1962

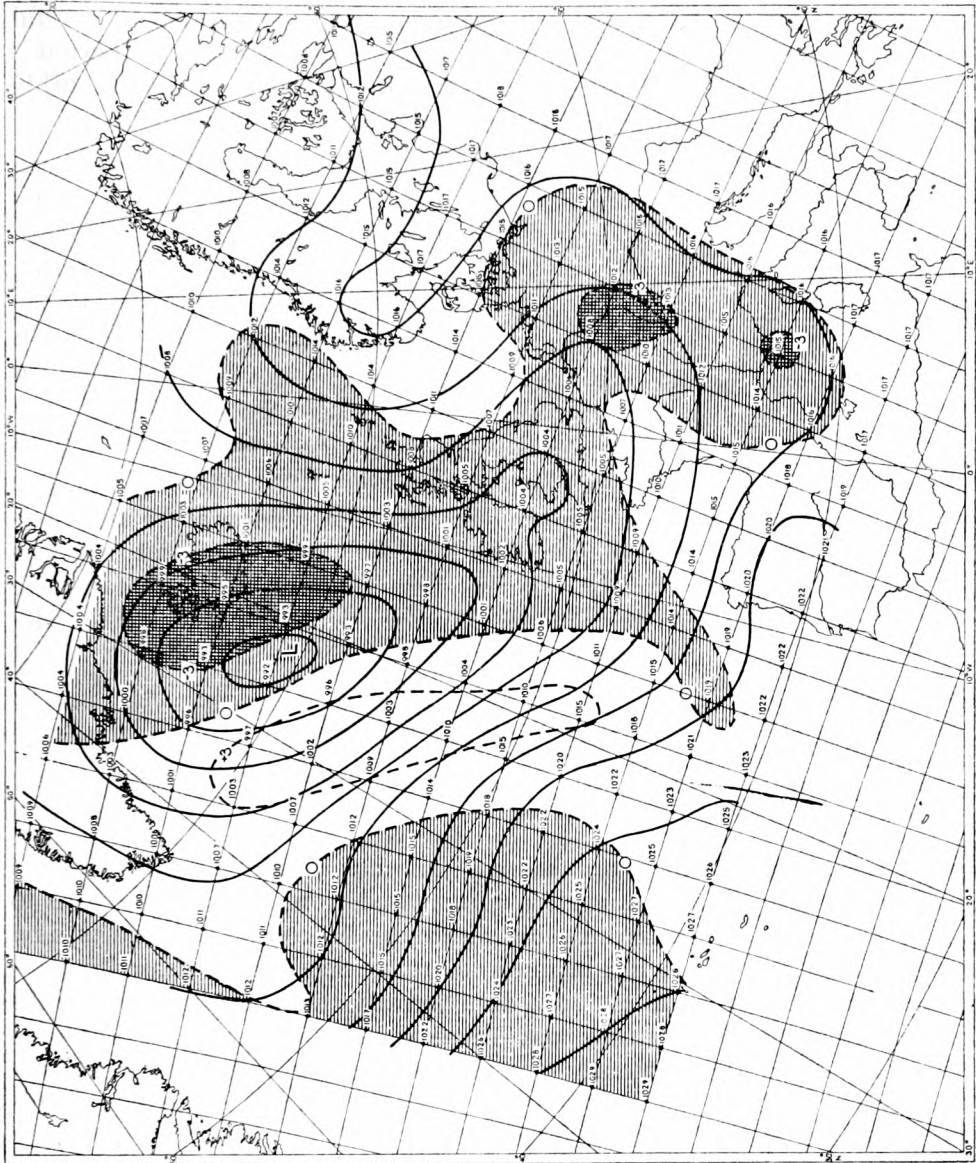


FIGURE 2—NUMERICAL FORECAST FOR 0600 GMT, 15 AUGUST 1962, BASED ON INITIAL CHART FOR 0000 GMT, 14 AUGUST 1962

EXAMPLE OF A NUMERICAL FORECAST

At 0000 GMT on 14 August 1962 the U.K. was under the influence of an anticyclone of 1025 mb whilst there was a depression to the SW and another in mid Atlantic (Figure 1a). By 0600 GMT on 15 August 1962 the anticyclone near the U.K. had been replaced by a depression (Figure 1b) which gave thundery rain over the country. The area of rain and showers or thunderstorms is shaded in Figure 1b. The numerical forecast for 0600 GMT on 15 August 1962 (Figure 2) was computed using a three-level model based on the chart shown in Figure 1a, incorporating some of the effects of topography and surface friction. Computed pressure values at the grid points are given, together with isopleths of mean vertical motion in mb/hr for the layer 1000–600 mb, upward motion being shaded. Most of the important changes are very well predicted in the numerical forecast.

changes was started in the Meteorological Office using appropriate time averages. It was then realised, as has been since amply confirmed in careful work by Craddock,¹¹ that the most significant weather variations have "periods" from about 15 days up to a month or so, and that the readily available monthly mean data are not ideally suited to the study of long-range forecasting.

However, monthly charts of temperature and pressure anomalies have been studied because of their ready availability and a long series of such charts extending back to 1880 for temperature and much earlier for pressure has been built up. Early successes in selecting analogues from the temperature series, and using the analogue year to forecast for the subsequent month, led to the establishment of an experimental series of long-range forecasts. These forecasts have had results only marginally better than those that could be obtained by guessing, and are of little practical utility. Recently the experiment has been broadened, and other bases for a long-range forecast are considered month by month, mainly to build up experience of their practical utility.

Statistical study of the time and space distribution of temperature and pressure anomalies has demonstrated that variations with periods of 10 to 30 days are not the accidental result of shorter-period fluctuations, and one can have reasonable confidence that there are underlying physical factors which broadly determine the character of the longer-scale fluctuations. An important aspect of future research will be to track these down. Since it has been shown that the corresponding anomaly patterns have dimensions on a continental scale, an understanding of the general circulation of the atmosphere and its vagaries is clearly important, and we can look forward to increasing attention to this problem.

Upper winds and their forecasting.— Over the last three decades the normal operational ceiling of aircraft has increased from some 3 km or so to 16 km or more, and their range from a few hundred miles to over 3000 miles. The demand for forecasts of the wind in the free atmosphere has increased correspondingly in range. When the MRC was formed the forecasting of winds in the free atmosphere was a new task—a network of observations was only then becoming available; previously forecasts had been largely made by extrapolation upward from the surface isobars on the basis of a few isolated temperature soundings and pilot-balloon winds.

During the early years of the 1940's, under the pressure of wartime requirements, the techniques of isobaric analysis were firmly established by the Upper Air Unit at Dunstable under the guidance of Dr. S. Petterssen. In later years, as aircraft operated at longer ranges in the upper troposphere and a better upper network of observations became available, interest concentrated on the jet stream and its structure in more detail. A number of synoptic studies were carried out by R. Murray and D. H. Johnson,¹² and special flights were made by aircraft for the purpose.^{13,14} The structure of the tropopause also received attention.

Aircraft speed has also increased with the years and the emphasis on the detailed study of upper wind structure has perhaps passed, although much remains to be learned, particularly at levels above 100 mb where the observations which have become available in recent years have not yet been regularly analysed in this country. The forecasting problem has shifted somewhat to the

prediction of the general upper flow over the Atlantic and other long air-routes—a field in which numerical forecasting methods can be expected to make an increasing contribution and in which they may ultimately provide an objective routine.

Upper air climatology.— From its earliest days the MRC has emphasized the need for a world network of upper air observations upon which an upper air climatology of the world would be established. Largely as a result of the foresight and enthusiasm of Mr. C. S. Durst and Dr. A. H. R. Goldie, the Meteorological Office was the first service to compile an adequate world-wide atlas of the newly accumulating information. The first world pressure charts were published in 1950,¹⁵ and temperature charts in 1958,¹⁶ but revision of the charts has been continuous as new data accumulate.

The preparation of the atlases has been supported by extensive studies of the statistics of upper wind, which have proved of particular value in the planning of air routes; special studies have given additional insight into the general circulation of the atmosphere.

As observations become better organized and more numerous it is becoming possible, and necessary, to concentrate upon the construction of mean upper air charts for specific periods—usually 5 years. This is necessary because the earlier charts combined data from various periods in different parts of the map and the differences associated with any slow changes in climate were apt to distort the picture.

A wealth of upper air observations is now becoming available from all over the world and the mapping and analysis of them bring many fascinating inter-relations to light. The most recent and surprising is perhaps the large-scale alternation between easterly and westerly winds in the equatorial stratosphere with an apparently well defined period of just over two years.¹⁷ We can expect many more interesting studies to be made, thus gradually improving our knowledge of the general circulation of the atmosphere.

Fronts.— Fronts have naturally received the attention of the MRC from its inception. In the early years the emphasis was on techniques of analysis of the surface chart. Later the Committee, Prof. G. M. B. Dobson in particular, stressed the need for observation and study of fronts in space and time. Special flights by the Meteorological Research Flight¹⁸ and other synoptic studies have added much to our knowledge of the frontal and jet-stream systems in the last decade and in many respects the textbook model taken from the early papers of the Norwegian school must be regarded as obsolete.

The greatest need now is for the development of an adequate dynamical treatment of fronts which will explain their existence, persistence and their weather. We are at present only at the beginning of this task but, with the new understanding coming from the work on numerical forecasting, progress may well be rapid in the next decade.

The forecasting of rain.— The need for better methods of forecasting rainfall has been before the attention of the MRC since its inception but although a number of interesting investigations have been carried out it cannot be said that much systematic progress has been made. It is fairly clear that the microphysics of cloud is only important under special circumstances and a physical basis for the prediction of rainfall must involve an understanding of

the upward currents which lead to condensation and the factors which control their magnitude. Adequate understanding which would provide quantitative estimates of rainfall magnitude has so far not been attained, neither have empirical methods improved significantly on the forecaster's current methods of extrapolation and experience.

The problem is difficult because motion on many scales is involved, from the scale of the depression down to that of an individual cloud, and both the field of motion and humidity are "patchy" and not observed in adequate detail by the current synoptic network. The forecasting of rainfall is an intriguing challenge to the dynamical and synoptic meteorologist. We can hope that if enough meteorologists take up the challenge our understanding of the rain-producing systems—fronts, convection storms, orographic lifting, etc.—will slowly improve, but with so many different types of rain-producing system the effect on the standard of forecasting will necessarily be slow.

Local forecasting.—Throughout its life the MRC has had before it the important problems of local forecasting of individual weather elements. Indeed, one of the early studies which it sponsored was that of forecasting fog at the wartime bomber bases carried out by W. C. Swinbank.¹⁹

It is impossible to review all the relevant studies which have been carried out but the recent work by M. H. Freeman²⁰ on the application of statistical methods to short-period forecasting deserves a special mention. The work was aimed to produce purely objective forecasts of visibility at London Airport, but the technique is easily adapted to other weather elements and other places. An electronic computer is used in the development of the prediction formula from a long series of past data, but the arithmetic involved in making an individual forecast is very simple.

With the increase in the library of weather data in a form available for direct input to a computer, the possibility of extending the range and application of such statistical forecasting methods should increase rapidly in the next decade and we can look forward to their practical use on an increasing scale at least as a guide which codifies a much longer experience of local weather than the forecaster can possibly store in his memory.

The preceding paragraphs briefly review only some of the problems which have constantly been under consideration by the MRC. There are others equally important—climatic change, forecast verification and so on. There is also a wide group of activities in applied meteorology, and on the borderlines of other subjects such as hydrology and oceanography, in which the MRC has an important interest. For example, the activities of the agricultural branch of the Meteorological Office under Mr. L. P. Smith have particularly demonstrated how the meteorologist with a wide knowledge of his subject, its resources and techniques, can give practical aid to the agriculturalist and can pose and solve problems which would not have been formulated without the aid of the meteorologically trained mind. By bringing the meteorologist within the Office into contact with outside scientists with different interests, it is to be hoped that the MRC can continue to contribute to the extension of this close interdisciplinary collaboration in the many other fields in which it is possible.

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NOTES BY THE CHAIRMAN OF THE MRC, PROFESSOR P. A. SHEPPARD

I shall always remember the morning in 1941 when Air Ministry approval for the formation of the Meteorological Research Committee (MRC) reached Sir Nelson Johnson, then Director of the Meteorological Office. I was only a war-time bird of passage in the Office, but Sir Nelson called me into his room at Victory House to share his good news and to tell me some of his hopes for research in the Office. Johnson was not given to emotional displays but that morning he was like the proverbial dog with two tails, and I am proud to have been allowed to share his excitement. It was not of course just the formation of the Committee itself that occasioned the happiness but the implication it carried that meteorological research was at last to be a recognized function of the Office, no longer to be left to the insufficient efforts of enthusiastic members of its staff at their postprandial dining tables.

And now, after 21 years, has the record of the MRC justified the hopes of its founders and served well the interests of the Office and the subject in research? Has the MRC in fact been really necessary? I do not know how those actually engaged in research in the Office would answer these questions—perhaps that has emerged in the articles in this number—but it is evident that research could have been prosecuted on a broad front, on problems basic and applied, without the services of the Committee; it could have been judged by performance and in the open forum of the published literature, and found its rectifications internally. That after all is how most non-governmental research institutions proceed, and if those involved are sound and imaginative scientists the internal reactions generally suffice; the existence of a committee is in any case no substitute for them. But I do not think it would be wise to make only a direct, scientific assessment of the record in the stocktaking operation for which this birthday provides the occasion. Meteorology and the Meteorological Office are in a very special case relative to the place of most other pure and applied science in the British community: the science has been most inadequately represented in British universities in relation to the tasks set by the science and the Meteorological Office practically the only employer of meteorologists. This is not the place to discuss all the implications of these special circumstances but they do react on the Committee and the Committee should react on them.

Thus, the existence of the Committee has enabled most of the few academic meteorologists of note in this country to become intimately aware of the problems which the Office has to tackle in order to discharge its obligations to the community as well as to advise on research which the Office, by virtue of its special facilities, should be encouraged to undertake. It has also provided an opportunity for scientists outside the Office with skills nearly related to or applicable to meteorology to become more involved with the subject. There may be some disappointment that the involvement has not been greater, but it is not negligible, and the Committee might well regard this as an increasing duty in the future. A healthy Office demands a healthy science, and conversely under the present conditions in this country. Here is a feed-back problem such as we are so used to in the subject itself—there is no one point of “entry” because cause and effect are not the identifiable events of simpler sciences and situations. And the Committee is peculiarly well placed to provide the feed-back if official and non-official sections of the membership realize the need and possess the will. It has already been able to support some research in the universities which might not otherwise have been undertaken and it may well encourage more. Certainly it should miss no opportunity of fanning any lively little academic flame which appears into a real fire, so that the Office will, in due time, feel the warmth of it.

Committees, it is often said nowadays, are a modern disease to which scientists are specially addicted and yet they seem almost to go out of their way to perpetuate the disease. The trouble is that they have discovered no alternative itch, one that will satisfy their promptings to serve society and their subject by a concern for the reactions of one on the other. Moreover, communication is an all-important part of science, provided time remains to produce work worthy of communication, and most scientists thoroughly enjoy the exercise, especially when it can be carried out around a table without great

formality. In my now long association with the MRC, since 1947, I remember many enjoyable scientific discussions and I cannot doubt that those whose research was being discussed gained in their work (and noticed sometimes a lack of appreciation of it in others who might have known better) by having this particular forum to bring it to. If this has indeed been the case then the Committee has surely justified itself, educating witnesses and jury. I hope the Committee will continue to provide opportunity for lively and profitable discussion, to the ultimate benefit of the Office, the science, and the community. The Office has tremendous scope and a tremendous responsibility for improving the public image, particularly the scientific public's image, of meteorology. If the MRC can materially assist in effecting this improvement its past and future will be justified whatever more immediate dividends it may provide. So, on reaching its majority, more strength yet to its elbow.

551.5:06

FOURTEENTH SESSION OF THE EXECUTIVE COMMITTEE OF THE WORLD METEOROLOGICAL ORGANIZATION

By C. W. G. DAKING, B.Sc.

The fourteenth session of the Executive Committee, the last full session before Fourth Congress, took place at the Headquarters of WMO in Geneva from 29 May to 20 June 1962. The President of the Organization, M. A. Viaut, Director of the French National Meteorological Service, in opening the session paid tribute to the memory of Mr. L. J. Dwyer, President of Regional Association V (South-west Pacific), who had died some days before. Mr. Dwyer had been a member of the Executive Committee since 1958. M. Viaut then went on to say that M. J. L. Giovanelli, the Vice-President of Regional Association V would represent that Region at the session. Unfortunately, Dr. Po E and General Giansanti were prevented from coming to the session but they were being represented by alternates. Thus, there was a full attendance of members and alternates (18). In addition, the Committee had the benefit of the presence of the Presidents of the three Technical Commissions which had met since the thirteenth session, namely, Aerology, Instruments and Methods of Observation, and Synoptic Meteorology. Official representatives of UN sister agencies such as UNESCO, International Telecommunications Union and International Atomic Energy Agency were present for items of mutual interest between them and WMO.

As the activities of the WMO steadily develop, the agenda for sessions of the Executive Committee grow larger but the work continues to be completed in three weeks because of the superb facilities at the new Headquarters which permit the Secretariat to produce and distribute documents in English and French with remarkable speed.

The highlight of the session was the discussion on "Uses of satellites in meteorology and international co-operation in the peaceful uses of outer space". In December 1961, the United Nations General Assembly adopted a resolution on outer space which, *inter alia*, called upon WMO to prepare a report for Member Governments and the Economic and Social Council on measures:

- (i) to advance the state of atmospheric science and technology so as to provide greater knowledge of basic physical forces affecting climate and the possibility of large-scale weather modification;

- (ii) to develop existing weather forecasting capabilities and to help Member States make effective use of such capabilities through regional meteorological centres.

A draft report had been prepared by the WMO Secretariat helped by specialists from the U.S.A. (the late Dr. Harry Wexler) and the U.S.S.R. (Prof. V. A. Bugaev) and the Executive Committee Panel of Experts on Artificial Satellites of which Dr. G. D. Robinson of the Meteorological Office is a member. This draft entitled "Advancement of Atmospheric Sciences and their Application in the Light of Developments in Outer Space" was adopted after a number of amendments, mainly on points of detail, had been made. The amended version of the Report was endorsed by the Committee and, in Resolution 27, the Secretary-General was requested to present the Report to the United Nations General Assembly and other interested UN bodies. This resolution also invites support from the United Nations and other organizations and recommends to Congress that high priority be given by WMO to the implementation of the proposals contained in the Report.

One of these proposals was that Congress should set up a WMO Advisory Committee to consider and make recommendations on both the scientific and operational aspects of this question. In the meantime, it was decided in Resolution 28 to establish a Working Group to deal with the scientific aspects, leaving the operational and co-ordinative aspects to the existing Executive Committee Panel of Experts on Artificial Satellites. Dr. R. C. Sutcliffe is a member of this Working Group.

Since Third Congress (1959) the Executive Committee has, on instructions, carried out a review of the Convention of WMO which, having been in force since 23 March 1950, is in need of "modernizing" in the light of experience since that time. Most of the work involved, which has been considerable, has fallen on an Executive Committee Working Group of which the Director-General of the Meteorological Office has been a member, aided by a legal expert of the International Labour Office during its later stages of development. It was only to be expected that at each session of the Executive Committee successive reports of the Working Group would be subjected to criticism and counter-suggestions because the Convention is a treaty between States, and politics must inevitably become involved. However, the proposals of the Executive Committee agreed upon at this session have now been submitted to Members for study, and will be argued, no doubt at length, at Fourth Congress in 1963. The proposals are extensive and virtually present to Members a new text; only some ten Articles out of the thirty-six have neither been amended nor completely recast.

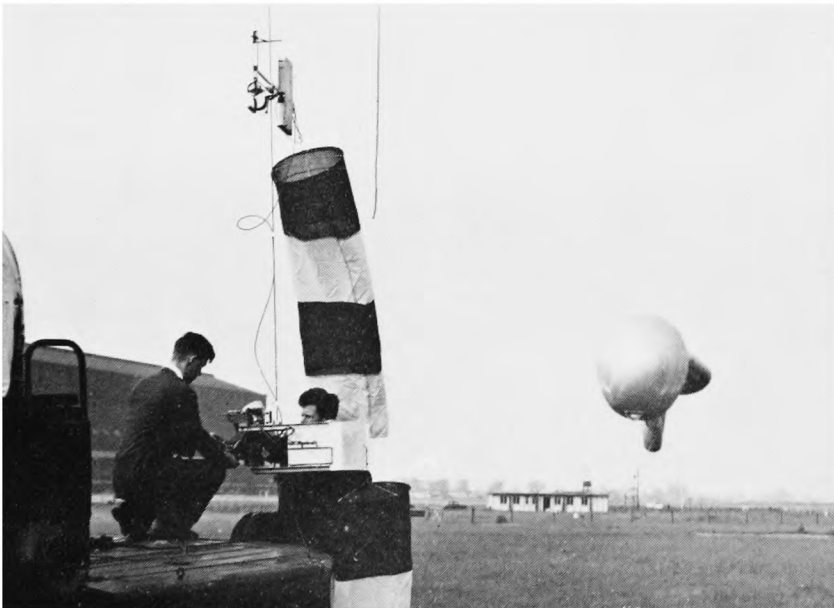
This item, together with financial matters, took up a good deal of the time of the Administrative and Finance Committee, who were confronted with a financial situation which necessitated the production of a supplementary estimate for 1963 in order to meet necessary additional expenditure on important projects during that year, the last of the Third Financial Period (1960-63). This supplementary estimate of some \$100,000 has been submitted to Members for their approval for, although Third Congress foresaw that it might be necessary to incur additional expenditure beyond that which it authorized in 1959, it did not agree that the Organization should be committed without consultation of the Members.



Crown copyright

EQUIPMENT CARRYING FINE-WIRE THERMOCOUPLES FOR RECORDING TEMPERATURE AND HUMIDITY AT TWO LEVELS NEAR THE GROUND.

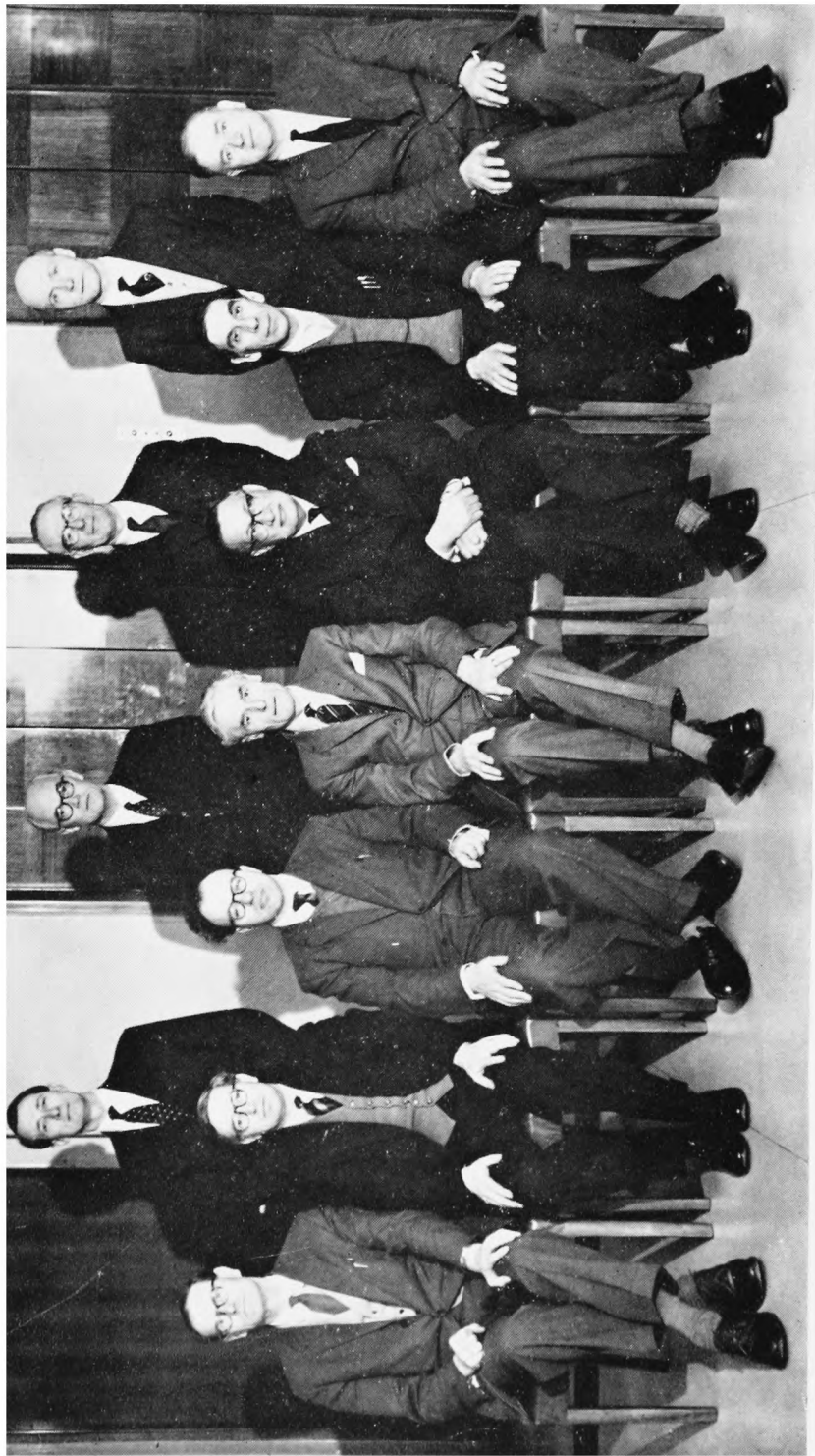
This is used by the unit associated with the School of Agriculture, Cambridge, in studies of the exchange of heat and water vapour between ground and air.



Crown copyright

INVESTIGATION OF ATMOSPHERIC TURBULENCE AND DIFFUSION.

Equipment which telemeters to the ground the speed of the horizontal wind component and the inclination of the wind to the horizontal is fixed to a balloon cable. A drum impactor is being fixed below the anemometer, to sample at intervals the concentration of fluorescent particles which will be released from a source several miles away. In the centre background is the Cardington meteorological laboratory and a second balloon used for experimental purposes.



Crown copyright

PRESENT MEMBERS OF THE METEOROLOGICAL RESEARCH COMMITTEE.

Standing: Dr. E. R. R. Holmberg, Dr. R. C. Sutcliffe, C.B., O.B.E., F.R.S., Dr. A. C. Best, C.B.E., Mr. J. K. Bannon (Secretary).
Sitting: Dr. H. L. Penman, F.R.S., Prof. T. V. Davies, Prof. H. Bondi, F.R.S., Prof. P. A. Sheppard (Chairman), Sir Graham Sutton, C.B.E., F.R.S., Prof. V. C. A. Ferraro, Dr. G. E. R. Deacon, C.B.E., F.R.S.

The following members are not in the photograph: Dr. A. W. Brewer, Inst.-Capt. J. A. Burnetti, Sqd. Ldr. G. P. Lewis, Mr. A. E. Woodward-Nutt, Mr. J. Paton, Prof. Sir Harrie Massey, F.R.S.

Much effort was also devoted to consideration of the budget estimates for the Fourth Financial Period (1964-67). Obviously, it would be inappropriate, to say the least, to disclose details of the Executive Committee's report to Fourth Congress on this subject but one can say that a forward-looking attitude has been taken and that the proposals, if agreed in large measure, will enable WMO to engage in increased activity so that it may fulfil its rôle as laid down in the Convention. It must be obvious to the reader that those concerned in planning activities and budgeting for them for as far ahead as 1966-67 are faced with a difficult task when so many factors can operate to make both these estimates unreal. However, the fact is that the Executive Committee has to make such estimates for a period which ends some $5\frac{1}{2}$ years ahead because of the system of four-year financial periods under which WMO operates.

With the emergence of so many "new" countries, particularly in Africa, the question of meteorological training has become of major importance. WMO asked Prof. J. Van Mieghem, Secretary-General of the International Council for Scientific Unions, to act as a consultant to the Organization and to prepare three reports. These were:

- (i) the problems of the professional training of meteorological personnel of all grades in the less-developed countries;
- (ii) a plan for the development of professional meteorological training in Africa;
- (iii) the establishment of a training section in the WMO Secretariat.

The Committee recognized that two distinct tasks have to be fulfilled by WMO in the field of meteorological training: (a) the establishment of training standards to be recommended by WMO—this includes the preparation of syllabi, scrutiny and recommendation of textbooks and technical arrangements for training seminars; (b) the preparation and carrying out of training projects financed from UN sources. With regard to the proposal for a training section in the WMO Secretariat, such a section was included in the budget estimates for the Fourth Financial Period and it will consequently be considered in detail by Fourth Congress.

The Technical Committee had fifteen items to consider including the reports of sessions of the Commissions for Aerology, Instruments and Methods of Observation, and Synoptic Meteorology. These reports with their resolutions and recommendations (74 of these latter from the Committee for Synoptic Meteorology (CSM)) were all carefully considered and gave rise to no difficulties except for Recommendation 6 of CSM concerning the units to be used for wind speeds in reports exchanged internationally. As might be expected a battle is now in progress between knots and metres per second, and an overwhelming majority of the delegates at CSM-III voted in favour of the latter. The Executive Committee, realizing that the implications of the recommendation affected other bodies external to the WMO as well as the Commissions for Maritime Meteorology and Aeronautical Meteorology, requested the Secretary-General to refer it for examination by other interested bodies and to report to Fourth Congress with their comments.

Reference has already been made to the excellent facilities provided at the WMO Headquarters, a most attractive building made all the more so by the splendid array of gifts provided by Members, which range from the functional

(such as furniture and carpets) to the beautiful (for example, tapestries, vases, wood-cuts, engravings).

Meteorologically, Geneva provided some good extremes of temperature during this visit, day maxima varying from 6°C on 2 June with a strong north-easterly wind to around 26°C on several days later in the month.

REVIEW

The challenge of the atmosphere, by O. G. Sutton. 8½ in. x 5½ in., pp.227, *illus.* Hutchinson and Co. (Publishers) Ltd., 178–202 Great Portland Street, London W.1., 1962. Price: 21s.

This is a most excellent book. It is written in a very elementary way that will strongly appeal to anybody with scientific interests. By starting from the most fundamental points, such as the heat balance, and working through the complicated matters of cloud physics to the more detailed matters of weather production etc., the author follows very much the line of thought of a person interested in the intellectual challenge of the field. There is no rushing to get at results, no suggestion that the only aim of meteorology is to assist forecasting. It is in the highest scientific tradition to treat a subject for its internal merit. It is because we want to know how the atmosphere behaves and what makes it so complicated that a treatment like this is ideal. The fact that it so happens that to a certain extent this is a useful branch of science must not be stressed at the beginning. If scientific investigations undertaken for their own interest lead to results of practical importance, that is good; but if not, it does not matter either.

By thus following through the natural scientific development, Sir Graham Sutton has written a book which the reviewer, at least, finds as difficult to put down as a very good detective story. The clarity of the exposition, the profound understanding of what is important and what is only incidental, put this book into the very highest class of scientific writing for the non-specialist. However, I would be surprised if there were many meteorologists who could not benefit greatly from reading this book, for even in their superiority they will discover a breadth of outlook and understanding that is always refreshing. H. BONDI

PUBLICATIONS RECEIVED

Glass thermometers (Publication No. T/50/2). 11 in. x 8½ in., pp. 59, *illus.*, Negretti & Zambra Ltd., 122 Regent Street, London W.1, 1962.

Mensteel (mercury-in-steel) thermometers (Publication T.40/3). 11 in. x 8½ in., pp. 40, *illus.*, Negretti & Zambra Ltd., 122 Regent Street, London W.1, 1962.

Meteorological instruments, Part 2—Measurement of atmospheric pressure. (Publication No. M4/IP). 11 in. x 8½ in., pp. 28, *illus.*, Negretti & Zambra Ltd., 122 Regent Street, London W.1, 1962.

OBITUARY

Mr. Roger Miles Lane.—It was with deep regret that we learned of the death on 9 September 1962, in a road accident, of Mr. R. M. Lane, Scientific Assistant, at the early age of 28. Mr. Lane joined the Office in August 1957 at Headquarters, Transport Command, serving there until July 1961, when he moved to Headquarters at Bracknell. He served in various branches there and had been moved to the Special Investigations Branch only three weeks before his death.

Our deepest sympathy is extended to his parents.

THE METEOROLOGICAL MAGAZINE

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CELLULAR STRUCTURE OF CONVECTIVE STORMS

By K. A. BROWNING
(Imperial College, London*)

Abstract.—Seven convective storm areas crossed south-east England on 9 July 1959; radar data on these are presented to demonstrate a higher degree of organization within the more intense storms.

Introduction.—On 9 July 1959 seven convective storm areas crossed south-east England travelling at about 40 mi hr^{-1} in a north-easterly direction. One of them (storm 1 in the plates and figures accompanying this article) became very severe and produced widespread large hail, especially in the Wokingham area of Berkshire. Detailed radar and ground observations of this particular storm have been analysed in an earlier paper¹ so as to determine the nature of the associated airflow. Throughout its existence the radars showed that this storm consisted of a number of units or cells in various stages of development. Each of them had a lifetime (1–3 hr) which was small compared with the overall life of the storm ($> 8 \text{ hr}$) but still long compared with that of the cells associated with ordinary showers ($< 1 \text{ hr}$). For simplicity overt consideration of this cellular nature was avoided in the above reference. The purpose of the present paper is to expose the characteristic cellular behaviour of this, and another intense storm, and to contrast their organization with the chaotic behaviour of weaker storms occurring during the same day.

General behaviour and intensity of the storms.—For an outline of the synoptic situation on this occasion the reader is referred to section 4 of the paper already mentioned.¹ According to this reference the Wokingham storm developed over Brittany just before 0800 BST:† it subsequently crossed the Channel and travelled within a cold front zone across south-east England, where it came under radar surveillance from East Hill near Dunstable (Bedfordshire). The progress of this and six other individual storm areas was recorded by an AMES type 14/10 cm PPI (plan position indicator) radar and is illustrated by the plates between pages 356 and 357 which include photographs of the full-gain display at 15-minute intervals (apart from a break after 1300 caused by a power failure).

*Now at Weather Radar Field Station, Sudbury, Massachusetts.

†All times in this article are in British Summer Time (BST = GMT + 1).

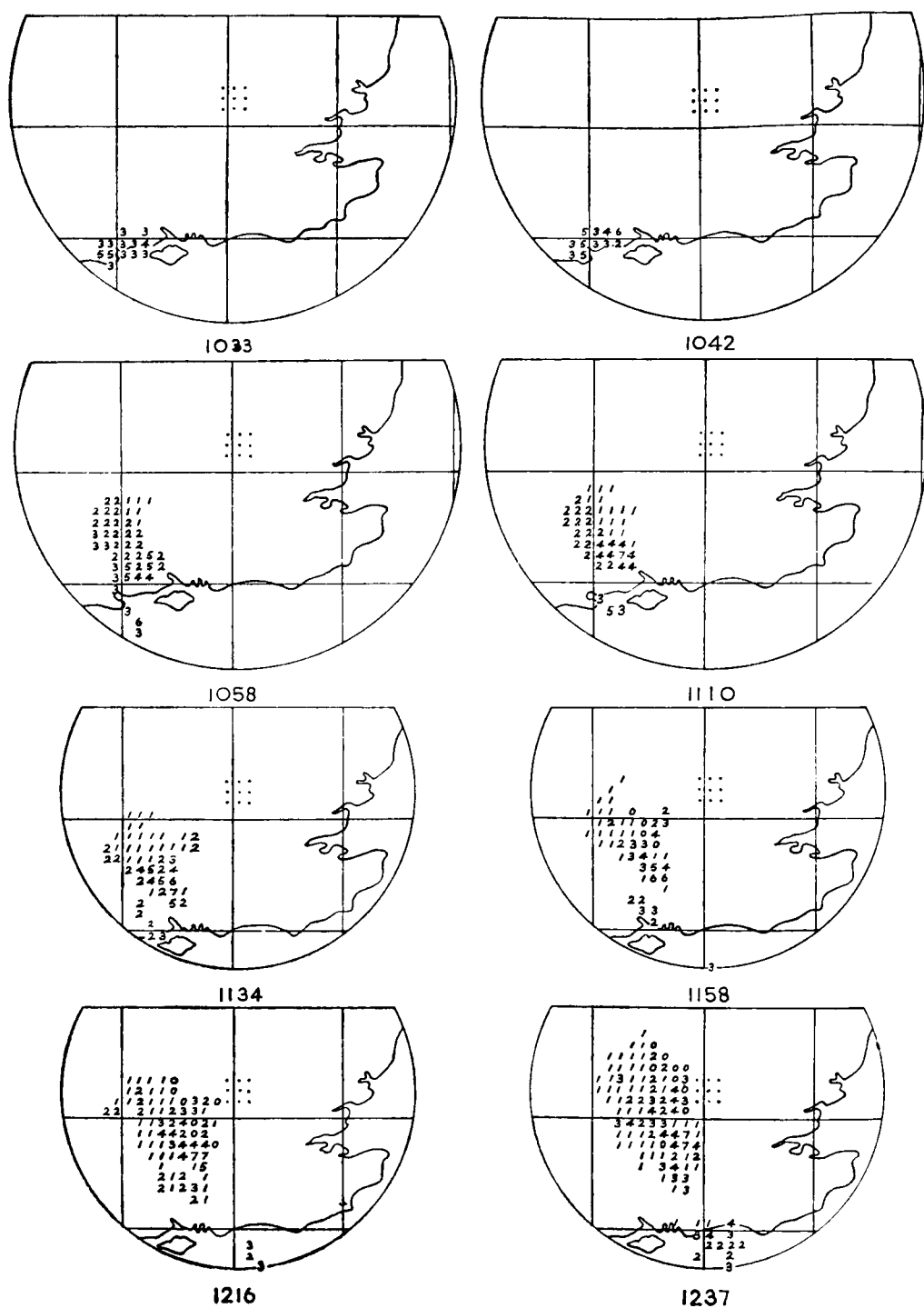
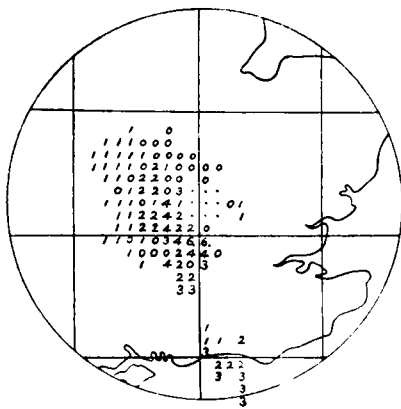
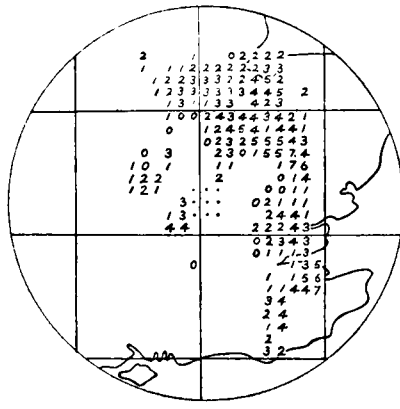


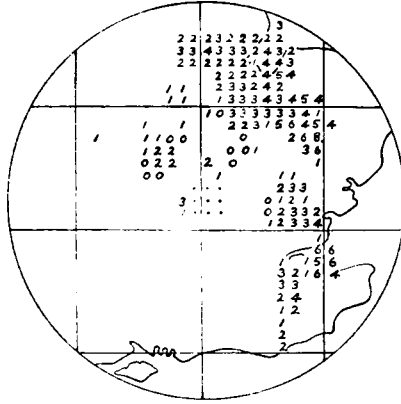
FIGURE 1 — THE HEIGHT-INTEGRATED ECHO-INTENSITY DISTRIBUTION OVER A REGION WITH THE EAST HILL RADAR STATION AS CENTRE, FROM 1033 TO 1646 BST.



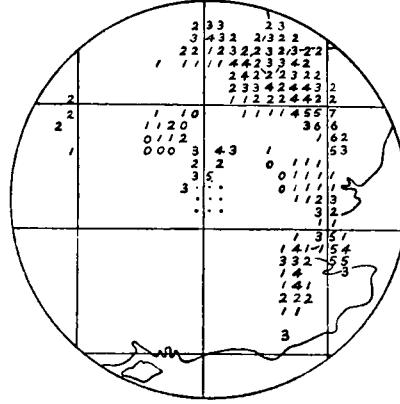
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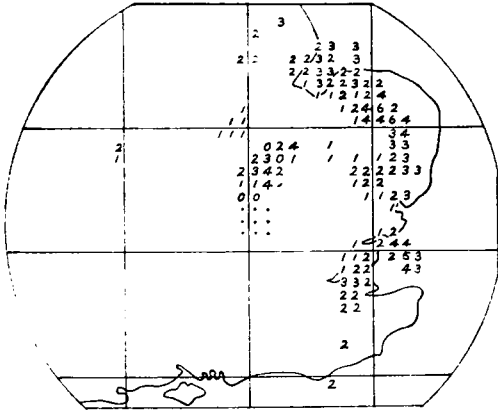
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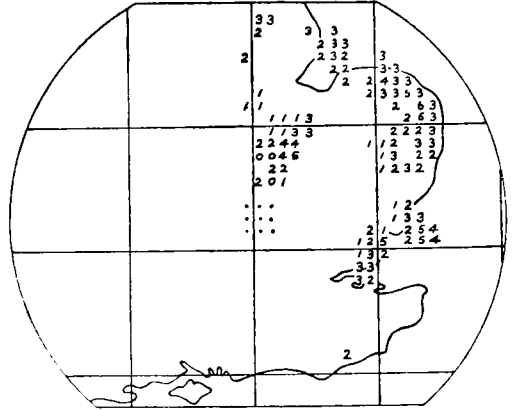
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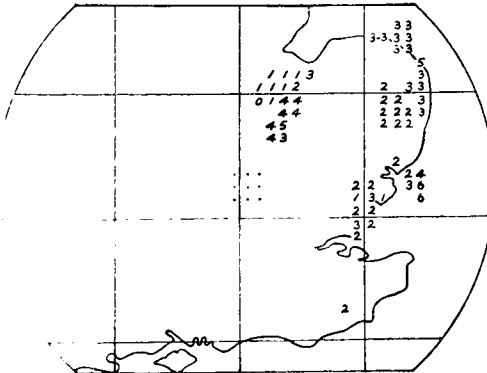
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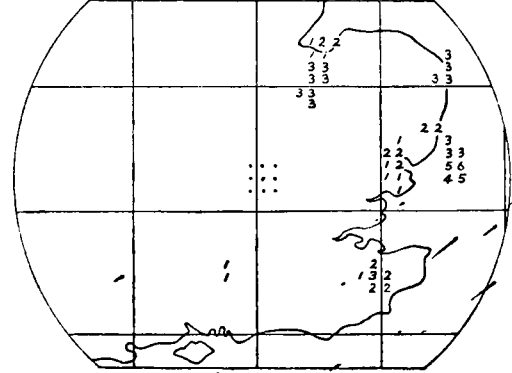
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1528



1540



1559

FIGURE 1 (cont.)

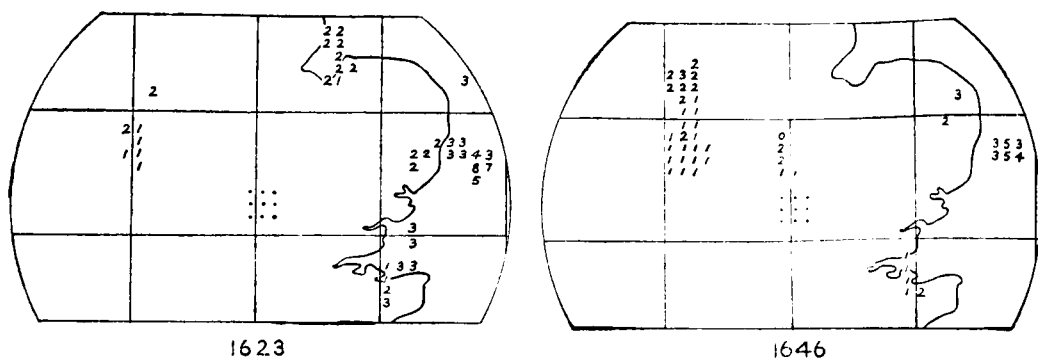


FIGURE 1 (cont.)

The grid lines are those of the National Grid and divide the area into squares of side 100 km. Each of these is subdivided into 100 squares, which contain figures representing the greatest echo intensity present over any area of at least 4 km² according to the following code:

Code figure	$10 \log Z_e^*$	Code figure	$10 \log Z_e^*$
0	≤ 25	5	46-50
1	26-30	6	51-55
2	31-35	7	56-60
3	36-40	8	61-65
4	41-45	9	≥ 66

The nine dots in the centre of each diagram indicate those squares which are at least partly obliterated by echoes from ground objects. (Times are in BST).

A record of the height-integrated intensity distribution within these storms at frequent intervals throughout the day was obtained in the form of series of photographs of the 10 cm PPI display at different gain settings. At this wavelength errors arising from attenuation are negligible and so the only correction necessary was that for the incomplete filling of the beam, which is broad in the vertical. One correction to observed intensities was applied because a part of the beam lay below the radar horizon; another was made on the assumption that strong echo occurred only from the ground up to 30,000 ft, with negligible echo outside these limits. The resulting distributions of height-integrated intensity at various times are displayed in Figure 1 in which the figure in each 10 km square represents the greatest echo intensity present over any area of at least 4 km².†

Figure 2 shows the trend with time of the maximum intensity within each of the storms. (Unfortunately the 10 cm PPI radar tended to drift off-tune and could not readily be set to a standard brightness, so that the absolute values are rather unreliable). Figure 2 illustrates some interesting features; in particular

- (i) storm 1‡ was the most persistently intense as well as the largest storm,
- (ii) there is no obvious relation between intensity and location over land and sea, and
- (iii) storms 3, 5, 6 and 7, and storm 2 while over land had intensities which usually were too low to be associated with the occurrence of thunder:‡ by comparison storms 1 and 4 became very severe.

Figure 3 shows that, whereas storms 1 and 4 respectively produced wide-

* Z_e is the equivalent radar reflectivity in units of mm^6m^{-3} .

† These values may underestimate the maximum intensity by up to 5 decibels.

‡ The Wokingham storm.

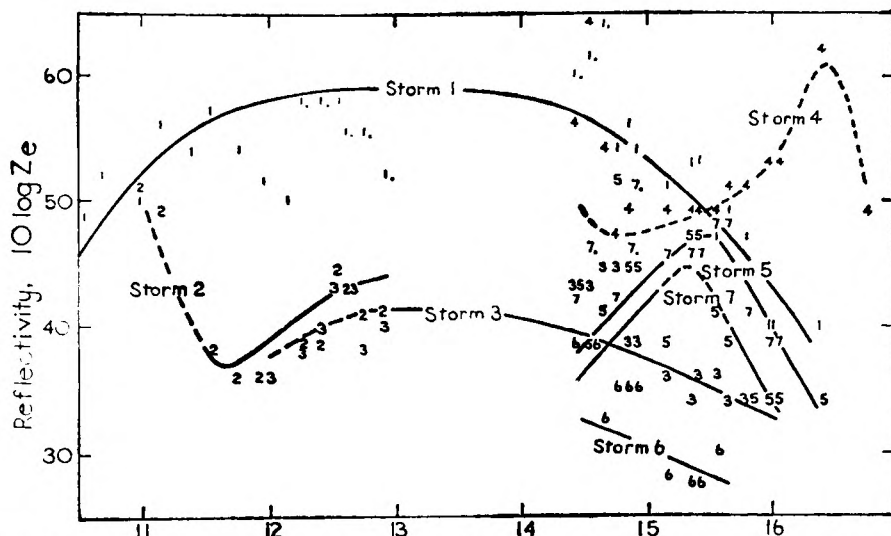


FIGURE 2 — THE TEMPORAL VARIATION OF THE MAXIMUM INTENSITY WITHIN EACH OF THE SEVEN STORMS AS DETERMINED BY THE 10 CM PPI RADAR

The individual measurements have smoothed curves drawn through them, which are dashed during periods when the storms were over the sea. Those values followed by a dot are liable to be under-estimated since they correspond to occasions when it was impossible to reduce gain sufficiently to remove the echo from the display. (Times are in BST.)

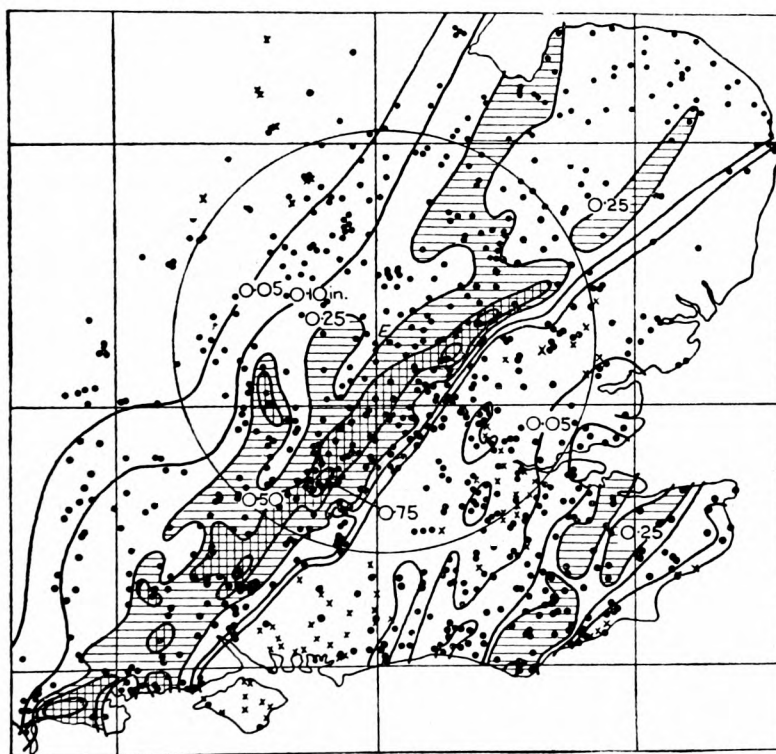


FIGURE 3 — DISTRIBUTION OF RAINFALL IN SOUTH-EAST ENGLAND ON 9 JULY 1959

The positions of 910 observations are indicated as dots or crosses according to whether or not measurable rainfall was reported. *E* denotes the location of the East Hill radar station. The circle marks a radius of 50 miles from East Hill.

spread rainfall totals exceeding 0.5 and 0.25 in., storm 3 produced few totals over 0.05 in. (Storms 2, 5, 6 and 7 probably made comparatively small con-

tributions to these totals). Only storm 1 produced hail overland, giving a 130×5 mile swath roughly in association with the region of highest rainfall (see Figure 2 in Browning and Ludlam's paper¹).

The motion of the storm cells.—Regions of radar echo corresponding to each of the seven storm areas portrayed in the plates between pages 356 and 357 are referred to as echo-masses. These varied in size from about 10 to 100 miles across and each comprised a number of distinguishable, but not necessarily completely detached, regions of higher intensity with diameters of the order of a few miles which are referred to as cells.* The velocity of travel of each echo-mass was determined not only by the translational velocity of the individual cells but also by their positions of formation and dissipation. In this respect there is found to be a notable difference between the behaviour of the two intense storms (1 and 4) and that of each of the others, as is now shown.

Storm 3 was the weakest of the seven: it developed off the Sussex coast

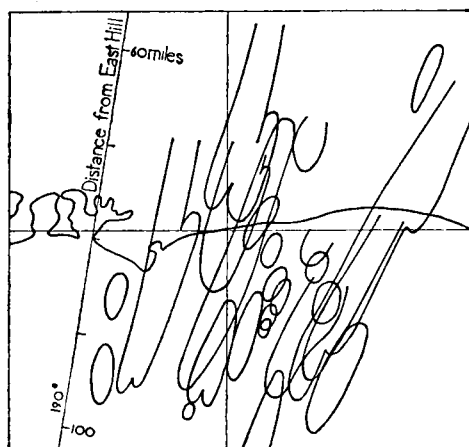


FIGURE 4 — PATHS OF CELLS COMPRISING THE GROUP CLASSIFIED AS STORM 3 DURING THE PERIOD 1150 TO 1300 BST AS THEY CROSSED THE SUSSEX SHORELINE

Note their short duration and lack of organization.

around midday as an irregular cluster of small weak cells. Figure 4 shows that these formed and dissipated in the unsystematic manner which is typical of feeble showers, the majority persisting for short periods only. The motion of the weaker cells (from about 195°) was along the wind direction in the medium levels: the more intense cells moved up to about 10° to the right of this.

The cells comprising storm 2 showed more organization (Figure 5). When the storm first came within range of the East Hill radars it was over the English Channel and consisted of a single intense cell travelling at 40 mi hr^{-1} from 209° : as it approached the south coast it weakened but further cells formed on both flanks, aligned approximately at right angles to their motion (from about 195°). The most intense cells occurred near the right-hand end of the line but none had an intensity within an order of magnitude of that of the first one.

The intense storms 1 and 4 were even more highly organized, the principal new development invariably occurring on the right flank. This is vividly demonstrated by Figure 6, which shows the path of their constituent cells. Like the preceding two diagrams, Figure 6 has been derived from the analysis

*Probably associated with single convective cells.

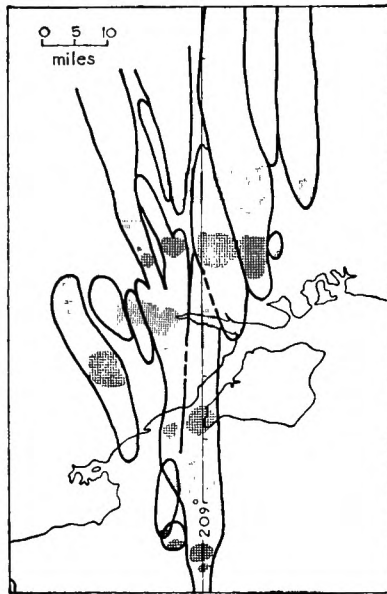


FIGURE 5 — PATHS OF CELLS COMPRISING STORM 2

Positions of the paths are indicated at times 1051, 1109, 1124, 1145, 1203 and 1218 BST (moving northwards).

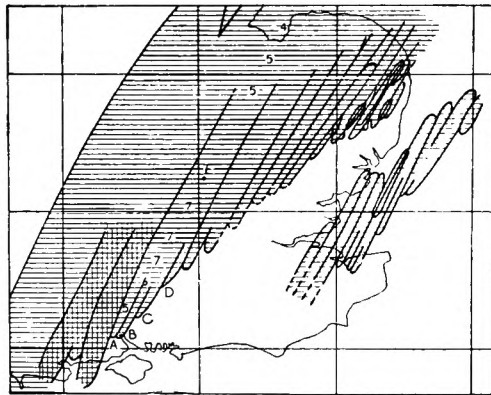


FIGURE 6 — PATHS OF CELLS COMPRISING STORMS 1 AND 4

The paths have been determined largely from the 10 cm PPI records. Boundaries between adjacent cells are terminated as soon as it becomes impossible to resolve them on any of the reduced-gain photographs. Numbers at intervals along the path of the largest cell indicate the trend in its maximum radar intensity according to the code in Figure 1. The two cross-hatched paths are of compact clusters of cells. Note especially the longevity of many of the cells and their systematic formation on the right flank of each echo-mass.

of photographs of the full-gain 10 cm PPI display taken at 3-minute intervals. However, in the case of Figure 6, because most of the cells could only be resolved by the radar at reduced gain, these data had to be supplemented by the frequent series of photographs of the display at different receiver gains. The gap in the 10 cm records caused by the failure of the mains electricity supply was filled in by data obtained using a 4.67 cm MPS-4 radar whose power was supplied by a petrol generator. Unfortunately this radar was operating with a poorer temporal and azimuthal resolution, so that parts of the cell paths

derived therefrom (and drawn dashed in Figure 6) are less reliable.

The orientation of each path in Figure 6 lies within 5° of $210-030^\circ$. This is in good agreement with the wind direction of $214 \pm 6^\circ$ at all heights between 3000 and 30,000 ft recorded at Hemsby at 1200 (150 miles north-east of storm 1), but is veered a little from the wind direction at all medium levels at Crawley and Larkhill at this time. However, this need not necessarily imply a discrepancy between cell motion and the predominant direction of the large-scale geostrophic wind, as the sounding at Crawley and more particularly that at Larkhill were made fairly close to (and therefore may have been modified by) storm 1 during its intense phase. The Crawley sounding shows the wind veering with height throughout the medium levels, suggesting that the motion (from 195°) of the weaker cells comprising storms 2 and 3 was influenced more by the winds at lower levels than were the cells within storms 1 and 4.

The behaviour of cells within the intense storms.—The organization

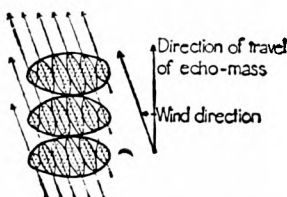


FIGURE 7 — SCHEMATIC DIAGRAM

This illustrates how the formation of new echoes at the right flank of an echo-mass and their eventual decay on the left flank causes the centroid of the echo-mass to travel to the right of the winds.

of storms 1 and 4 is illustrated schematically in Figure 7. It emphasizes the propagation of the centroid of the echo-mass to the right of the winds,* as has been observed by Newton and Katz.³ Each constituent cell eventually became weak and diffuse so as to be indistinguishable from its forerunners on the left flank, its persistence determining the over-all size of the echo-mass.

In Figure 7 the cells are depicted as becoming elongated along the direction of the wind. Elongation along this direction occurred on this occasion because the wind direction was almost invariant with height, so that the shear vector also lay in this direction. This meant that the major component of the convective circulation occurred within a vertical section orientated parallel to the winds. Accordingly the updraught entered the cell at low levels at the downshear end and emerged at high levels at the upshear end before being accelerated downstream. This behaviour is demonstrated in Figure 6 of Browning and Ludlam's paper¹ which shows a series of radar photographs of vertical sections along the axis of a particular cell within storm 1: it portrays a succession of towers (roughly 3 mi in diameter) rising at the upshear end of the cell, each of which becomes the highest echo whilst moving in a downshear direction through the cell before subsiding and decaying at the downshear end. Although the presence of discrete towers implies an updraught which was essentially intermittent, nevertheless it must have been quite persistent, since this cell (and others like it) could be traced

*A similar process can be inferred where this deviation is evident, even though the resolution of the radar is inadequate to distinguish the freshly-formed parts of the echo, as in the case of the most intense cells in storms 2 and 3.

for over an hour, which is longer than the period required for air in a moderate convective updraught to move through the cell or for the precipitation particles formed therein to reach the ground.

Four of these cells (labelled A, B, C and D in Figure 6) became very intense soon after storm 1 came inland and they amalgamated to form a single large cell with horizontal dimensions of the order of 10 mi. This cell has been analysed in particular detail by Browning and Ludlam.¹ They show that it maintained a virtually steady structure throughout a 30-minute period, and employ certain characteristic features of this structure to evolve a three-dimensional model of the associated quasi-steady airflow, a feature of which is the reinforcement of the updraught flux by an inflow from the right flank. During the period prior to the development of new cells on its right flank this "supercell" was reaching the greatest heights and intensities of the day as well as producing the largest and most widespread hail. Although it declined somewhat after the development of new cells to its right, it persisted as a resolvable entity for more than two hours before decreasing in intensity to that of the diffuse decaying echo in which it was embedded.

In contrast with those cells forming during the more intense phases of storm 1, the cells appearing after about 1445 formed quite detached from the main body of the echo-mass, even at full-gain. Thereafter the rate of formation of new cells increased in inverse proportion to their intensity, size and persistence until the storm reached the North Sea, when regeneration ceased altogether.

Conclusions.—Although even small and comparatively weak cells often lasted for an hour, indicating the presence of a persistent (if intermittent) updraught, the larger more intense cells are most notable for their longevity. Indeed, one could still be identified more than three hours after its formation, continuing to be resolvable even after several new cells had developed to its right. This behaviour was responsible for the broad extent of storm 1, the echo-mass of which reached a width of 100 miles at one stage.

The storms which attained high radar intensities and which produced large rainfall totals were not only characterized by long-lived cells; they were also highly organized, propagating systematically to their right. This propagation generally occurred in the form of discrete cells which remained resolvable from their predecessors often for an hour or two. A notable exception occurred during the most intense phase of storm 1 when successive cells amalgamated within 30 minutes of detection to form a large and intense "supercell".

Acknowledgments.—The author is pleased to thank the Director-General of the Meteorological Office for the provision of staff and facilities at the East Hill Radar Station, from which the observations were made, and also for providing British rainfall data. The research on severe storms of which this work has been a part, is also supported by the Geophysics Research Directorate, Air Force Cambridge Research Center of the Air Research and Development Command, United States Air Force. The author is particularly indebted to Dr. F. H. Ludlam for helpful discussions during the course of the analysis.

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551.575.1:551.591.35

FORMATION AND DISPERSAL OF FOG OVER THE FENS

By M. H. FREEMAN, O.B.E., M.Sc.

Introduction.—Forecasters in East Anglia have long been aware that the presence of the fens has an effect on the formation of fog in the area. At Waterbeach, for instance, it was asserted that fogs tend to form earlier and persist longer than in surrounding areas. The extent of the influence of the fens was not known accurately, so a detailed investigation was planned to seek further information on the formation and dispersal of fog over the fens and at the seven meteorological offices (Upwood, Wyton, Oakington, Waterbeach, Mildenhall, Marham and West Raynham) near the borders of the fens.

To this end the co-operation of about 50 voluntary observers (listed in the appendix on pp. 356–7) was obtained. Using the simple forms provided, they undertook to record, whenever practicable, the time at which visibility fell below or improved above the three limits 50, 200 and 1000 yards. Mr. W. B. Painting visited each observer to explain the project and assist in selecting suitable visibility objects and lights. Figure 1 shows a map of the region and indicates the approximate boundary of fen-land. It also shows the locations of the meteorological offices and the voluntary observing stations. The investigation related only to that part of the fens south of the Wash; no reports were obtained from the region to the north-west of Spalding.

The first phase of the investigation took place during the winter October 1959 to March 1960. A detailed analysis of the observations obtained was made by Mr. S. P. Peters, and in the light of his report it was decided to continue the investigation during the following winter 1960–61. A smaller number of strategically placed observers took part in this second phase; their locations are marked by small circles on Figure 1.

Analysis of the observations.—From the two winters 79 periods of fog were examined; a few occasions of patchy short-lived fog were ignored. For each selected period hourly charts on a scale of 1: 253,440 were plotted and lines indicating the boundaries of visibilities less than 50, 200 or 1000 yards were drawn. The standards of reporting achieved by the voluntary observers naturally varied, but it was usually possible to arrive at a coherent analysis of each situation. As would be expected the number of reports between 2300 and 0700 hours was small, and the formation of fog was less well documented than its dispersal. About half the observing stations were at schools, most of which were unable to report during holidays and at week-ends. Week-ends were also less well covered by Meteorological Office stations since Upwood, Oakington and Waterbeach were often closed then. Another, more or less inevitable, difficulty was that voluntary observers could not maintain a continuous watch and their records merely showed the times at which the visibility had been observed to be below a certain limit. Also some occasions of fog were found to be missed so that absence of a fog report could not necessarily be taken as indicating that the visibility was greater than 1000 yards. Nevertheless sufficient reports were usually received to enable a worthwhile analysis to be made. The

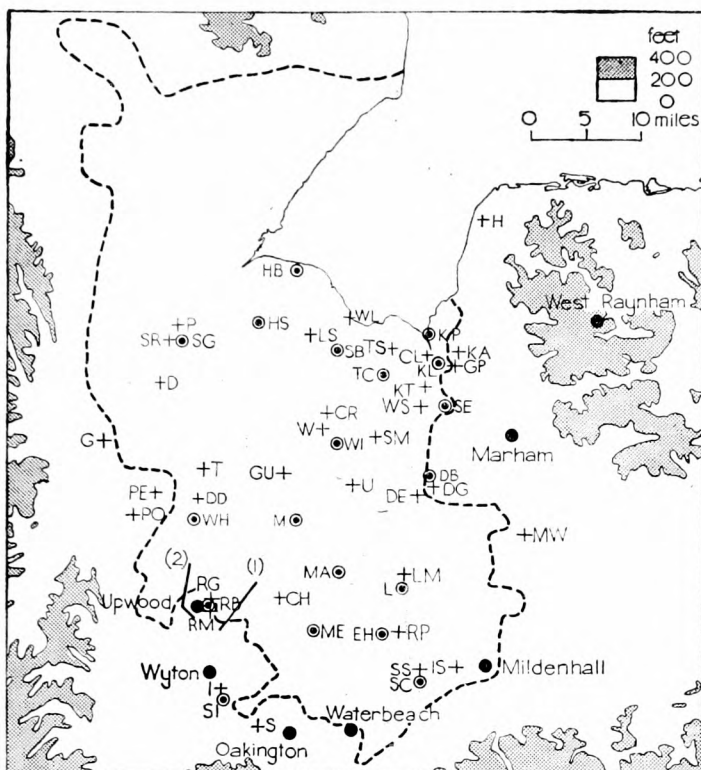


FIGURE 1 — OBSERVING STATIONS FOR THE FEN FOG INVESTIGATION

- Meteorological Office stations
- ⊙ Voluntary observers for two winters
- + Voluntary observers in 1959-60 only.
- Routes of mobile surveys

Names and locations of voluntary observers are listed in the Appendix on p. 356-7. area where uncertainties were greatest was to the north-west of Wisbech, where observers and reports were rather few.

In addition to the limits of the fog, various other data were recorded. For each occasion notes were made of the synoptic situation, the areas of first formation of fog, the clear areas, the areas of dense fog (less than 50 yards) and the area of final clearance. From the daily registers of the Meteorological Office stations details of temperatures, winds and cloud cover were extracted. The following broad picture of the distribution of fog over the fens emerged from an examination of all this material.

Features of fog in the fens.—Most of the fogs examined were associated with synoptic situations which resulted in weak pressure fields. On about 60 per cent of occasions there was a light wind from a southerly point, on 20 per cent of occasions the wind was from some other direction and on the remaining 20 per cent it was predominantly calm. Radiation fogs were the commonest but the sample also included fogs associated with very low cloud or precipitation.

One of the questions to which an answer was sought was whether fog was more likely to form first in one section of the fens than another. Difficulties arose because most of the volunteers did not observe during the night, when

many of the fogs first formed. However, from the known habits of each observer estimates were made of whether or not he was likely to be observing at the time when fog was first reported. For each station the percentage frequency was calculated of occasions when the first appearance of fog occurred at that station. When fog first formed at several stations within a period of one hour all were credited with the first formation. For the voluntary observers the figures are necessarily imprecise, but they probably err on the side of being too low.

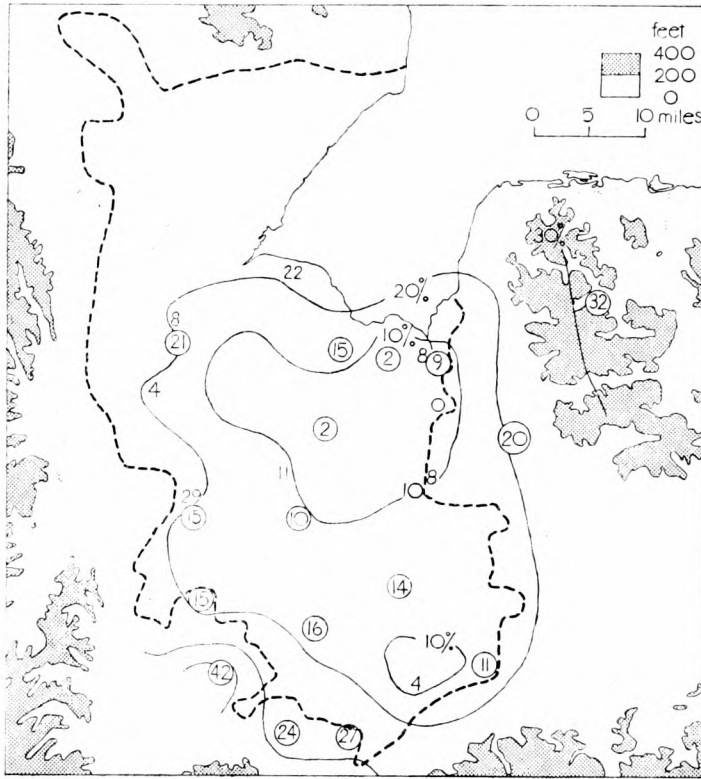


FIGURE 2 — PERCENTAGE FREQUENCY OF FIRST FORMATION OF FOG
Encircled numbers refer to two winters, other numbers to one winter only.

Figure 2 shows the percentage frequency with which fog formed first at each station. Numbers encircled relate to two winters combined, plain numbers to one winter only. Fog is most likely to form first on the borders of the fens, and the area least liable to the initial formation of fog is the interior of the fens, especially the eastern half. The high frequency (42 per cent) with which the first formation of fog was reported at Wyton is noteworthy.

Fog covered all, or almost all, the area on about two-thirds of the occasions considered, so that if fog is reported at any station it is likely that the whole area will be (or already is) affected. However, it should be remembered that short periods of patchy fog were specifically excluded from the investigation. When fog was not widespread a note was made of the clear areas. The south-west of the fens was least often clear and the eastern side the most often clear. Fog appeared to be rather less frequent also in the Holbeach-Spalding area.

The incidence of dense fog is a matter of importance in connection with road transport. The number of periods during which selected stations reported

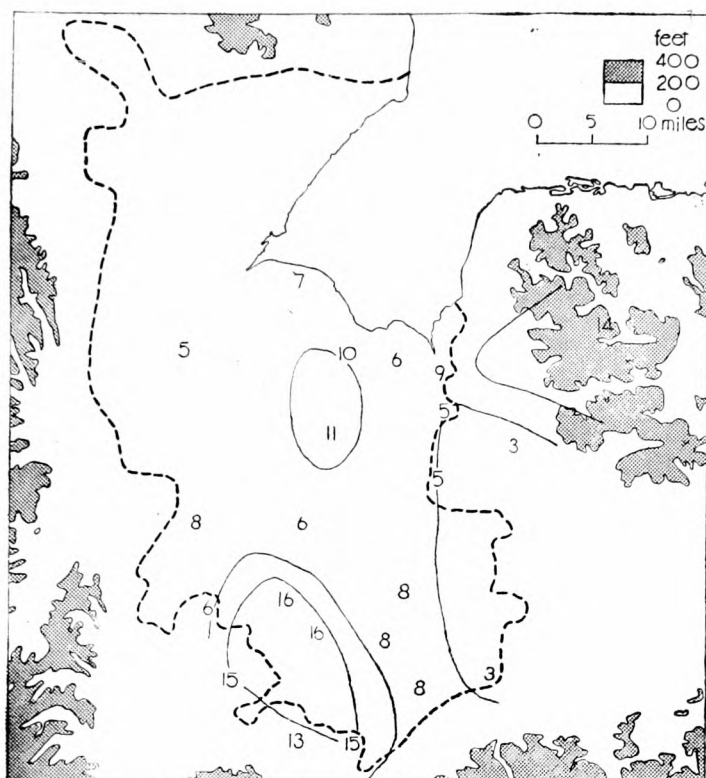


FIGURE 3 — NUMBER OF REPORTS OF DENSE FOG (< 50 YD) OUT OF 79 FOG SITUATIONS

visibilities of less than 50 yards are shown in Figure 3. The relatively high frequency over the south-west of the fens, and adjacent borders, and the low frequencies near the eastern borders are noteworthy. Since most stations were not observing all the time the individual figures are not strictly comparable. However, significant differences are shown between the four Meteorological Office stations which reported 24 hours per day, namely Wyton (15 dense fogs), Mildenhall (3), Marham (3) and West Raynham (14).

The irregularity of observing times can be partially overcome by considering the incidence of fog at 0900 hours, a time when most stations were usually reporting and fairly reliable estimates could be made for the few missing reports. In the two winters there were 73 occasions when fog existed somewhere in the fens at 0900 hours and Figure 4 shows the number of times each station had, or probably had, fog at this time. Fog was least frequent in the south-east, where it was present on a little more than one-third of occasions, and most frequent in the west, where it occurred on two-thirds of occasions.

Although reports of first formation of fog were rather few, the final dispersal of fog was well documented. A striking result was that on only five out of 79 occasions was the last report of fog at a station in the interior of the fens. Almost always the fog persisted longest at a place near the borders of the fens, and on two-thirds of occasions the last dispersal of fog was at the downwind edge. It appears that clearance of fog on the borders is often delayed by the drift of fog from the interior. When fog has dispersed at a downwind meteorological office on the borders, it is most likely that the fog has already cleared from the interior of the fens.

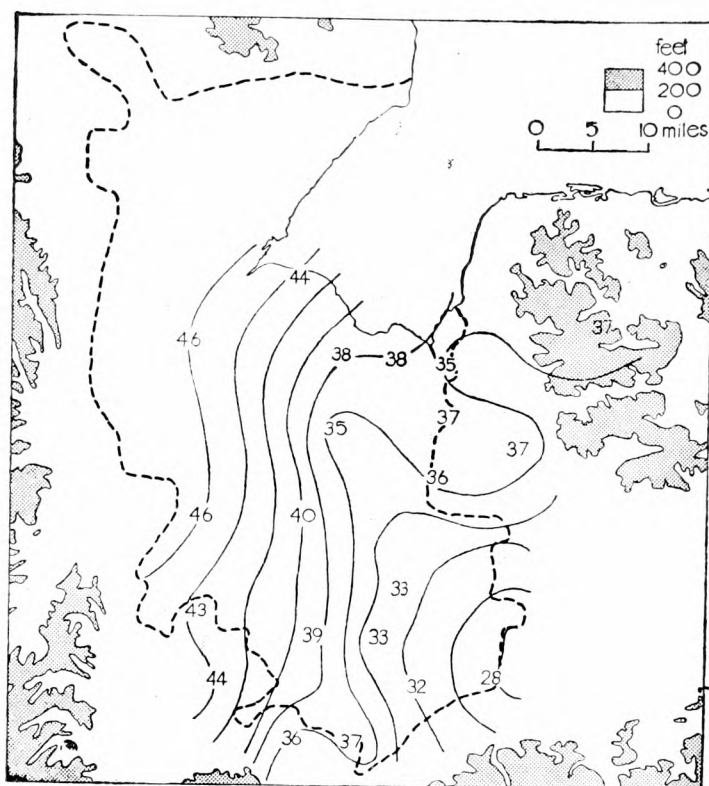


FIGURE 4 — FREQUENCY OF OCCURRENCE OF FOG AT 0900 GMT IN TWO WINTERS (OUT OF 73 OCCASIONS)

Persistence of fog with fairly strong winds was noted quite often. On nearly half the occasions at least one of the Meteorological Office stations reported fog with a surface wind of 10 knots or more, the extreme being 22 knots at West Raynham. The phenomenon was commonest at West Raynham (26 times out of 64) and Wyton (20 out of 73); these are the two highest stations (263 and 128 feet above sea level respectively).

The high frequency with which fog formed first at Wyton has already been noted. Examination of the fog-points, as defined by the temperatures at which fog actually formed, showed that Wyton had a fog-point which was as high or higher than all other Meteorological Office stations on 34 out of 73 occasions. The station which most often had the lowest fog-point was Marham (26 occasions). Differences between the greatest and least fog-points as high as 5°C were noted, and the average difference was 2.2°C. The existence of such differences over a small area highlights the difficulties of accurately forecasting fog-points. Part of Wyton's liability to high fog-points may be attributed to the fact that fog formed with a relative humidity less than 95 per cent on eight occasions, twice as often as at any other station.

Mobile surveys of temperature.—In order that a direct comparison might be made between temperatures over the fens and the surrounding higher ground four mobile surveys were made by Mr. R. Bojdys. His car was fitted with a strut thermometer, and observations were made at short intervals over two four-mile stretches of road. On each occasion conditions were suitable for the formation of radiation fog, with clear skies and light winds. The routes

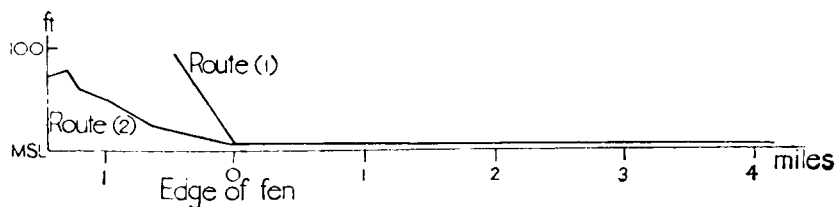


FIGURE 5 — GROUND PROFILES OF ROUTES OF MOBILE SURVEYS

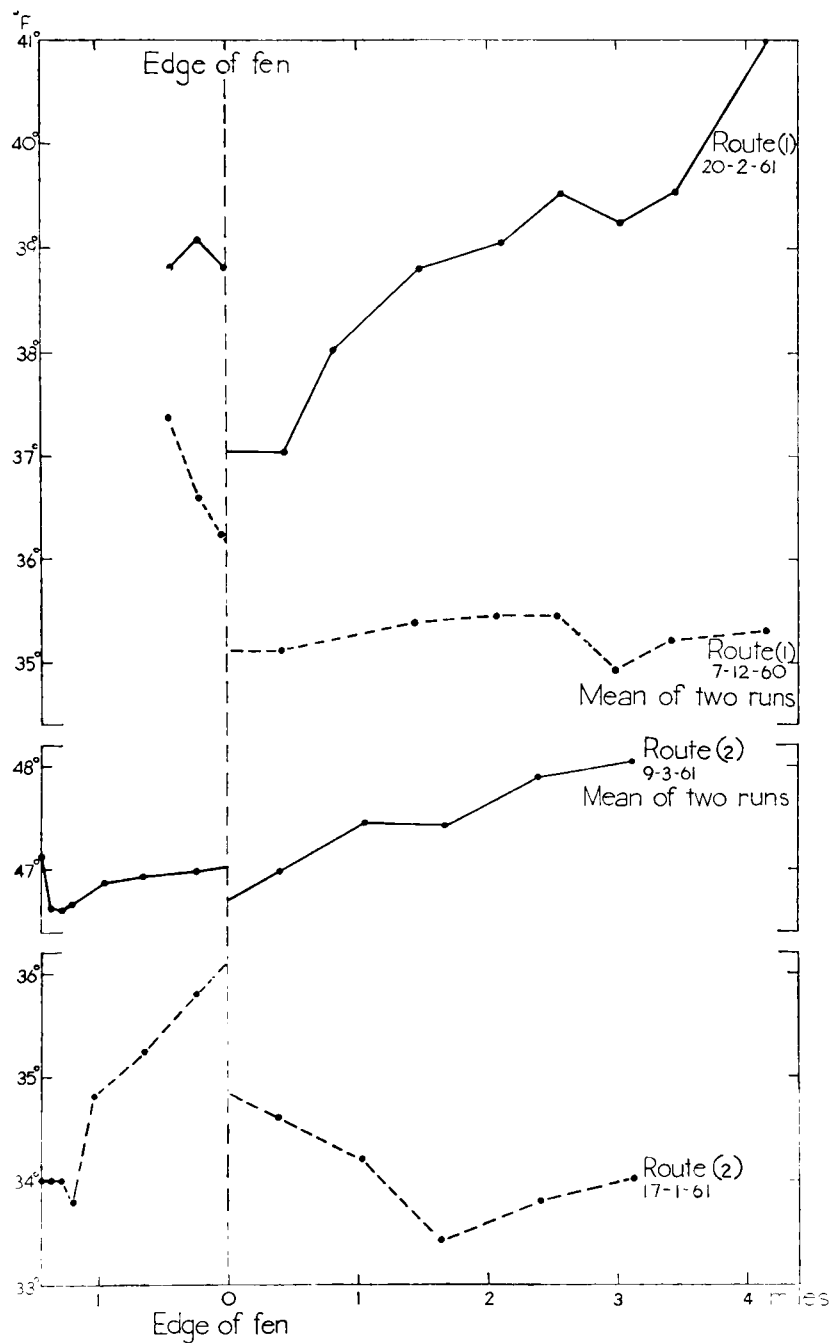


FIGURE 6 — TEMPERATURES ON RADIATION NIGHTS OVER PEAT FEN AND HIGHER CLAY GROUND

chosen, Warboys to Forty Foot Drain and Upwood to Ramsey St. Marys, were partly over flat fen-land and partly over slightly higher ground. The profiles are shown in Figure 5.

The most interesting aspect of the readings was that on crossing from the clay "hills" to the peat fen there appeared to be a drop in temperature of about 1°F. This was well marked on 7 December 1960, 17 January and 20 February 1961, but was only barely evident on 9 March 1961. Figure 6 has been drawn to accentuate this effect by depicting a discontinuity in the horizontal temperature profile at the boundary of the fen. On all occasions there appeared to be different trends on either side of the boundary. The evidence from these four radiation nights in winter indicates that the fen soil (dark peat) cools more rapidly than nearby clay soil.

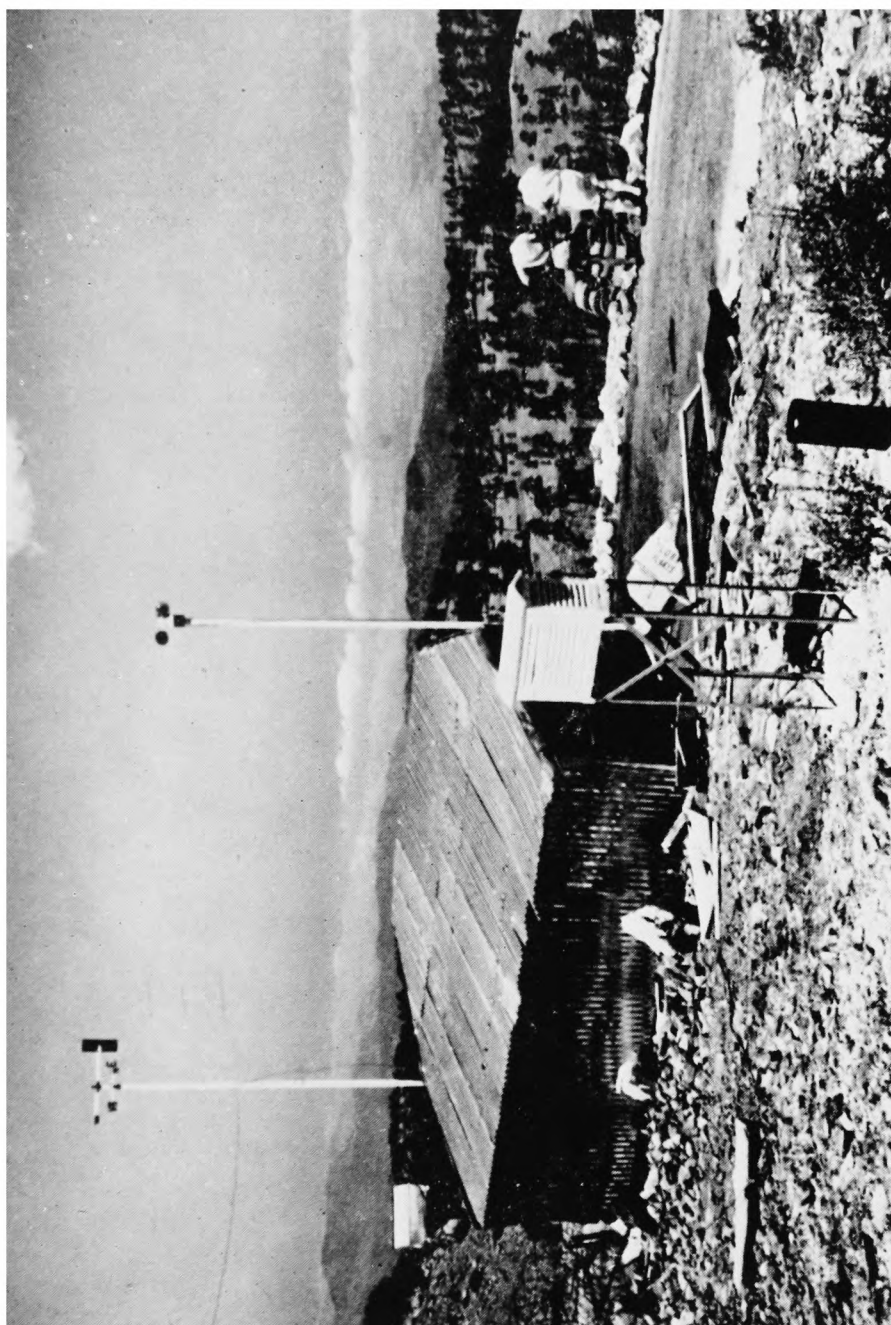
Conclusion.—The main features of interest disclosed by this investigation are that fog more often first formed near the borders than in the centre of the fens and that the final clearance was almost always on the borders, and was usually on the downwind edge. The south-west of the area was least often clear of fog and most often had dense fog, the opposite being true of the east of the fens.

Appendix

List of observers in the fen-land fog investigation

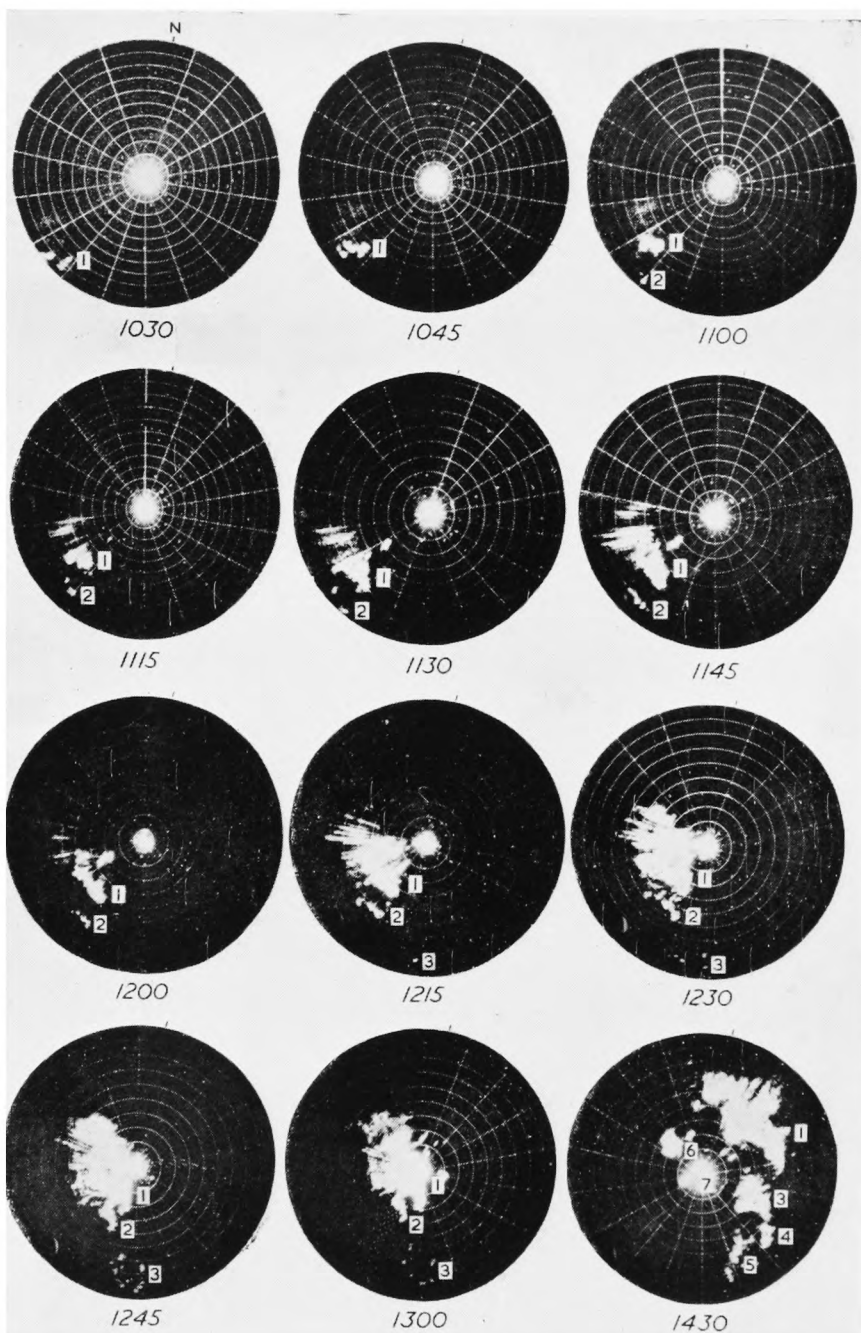
CH	Chatteris	Rev. J. C. Hawthorne
CL	Clenchwarton	Mr. S. Brown
CR	Crabmarsh	Mr. H. Crowe
D	Deeping St. Nicholas	Mr. J. A. Pick
DB	Downham Street	Mr. G. Rich
DD	Whittlesey	Mr. A. J. Foster
DE	Downham Market	Mr. J. O. Vince
DG	Downham Market	Miss E. J. Tebbutt
EH	Ely	Miss E. Langton
G	Glington	Mr. R. Booker
GP	King's Lynn	Mr. C. Guy
GU	Guyhirn	Mr. J. H. Cox
H	Hunstanton	Mr. G. A. Timothy
HB	Holbeach	Royal Air Force
HS	Holbeach	Mr. P. A. Moxon
I	St. Ives	Mr. H. King
IS	Isleham	Mr. H. W. Woodward
KA	King's Lynn	Mr. A. Chadwick
KL	King's Lynn	Mr. W. J. R. Baxter
KP	King's Lynn	Mr. W. Marshall
L	Littleport	Mr. J. H. Martin
LM	Littleport	Mr. C. R. Browning
LS	Long Sutton	Mr. F. A. Noon
M	March	Mr. C. E. M. Fyson
MA	Manea	Mr. R. Loose
ME	Mepal	Royal Air Force
MW	Methwold	Mr. R. S. Ashwell
P	Pinchbeck	Mr. E. Bain
PE	Peterborough	Miss B. Bennett
PO	Peterborough	Mr. G. Buffham
RB	Ramsey	Mr. R. Bojdys
RC	Ramsey	Mr. A. M. Rees
RP	Ely	Mr. Jones
RM	Ramsey	Mr. F. J. Burton
S	Swavesey	Mr. J. F. Gale

(cont. on p. 357)



Photograph by D. McFarlane

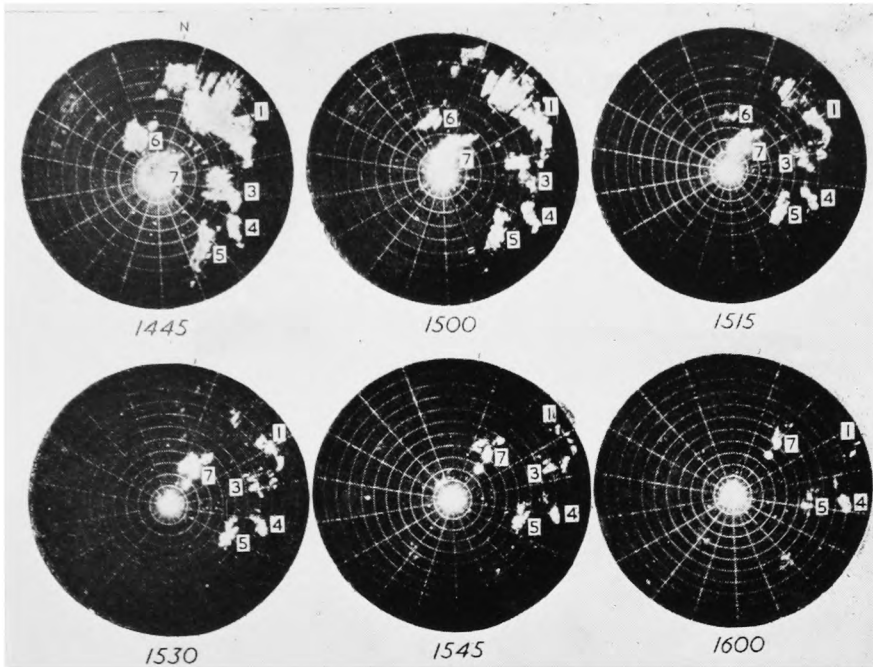
THE AUXILIARY REPORTING STATION ON THE SUMMIT OF MOUNT OLYMPUS (6403
FEET) IN THE SUMMER



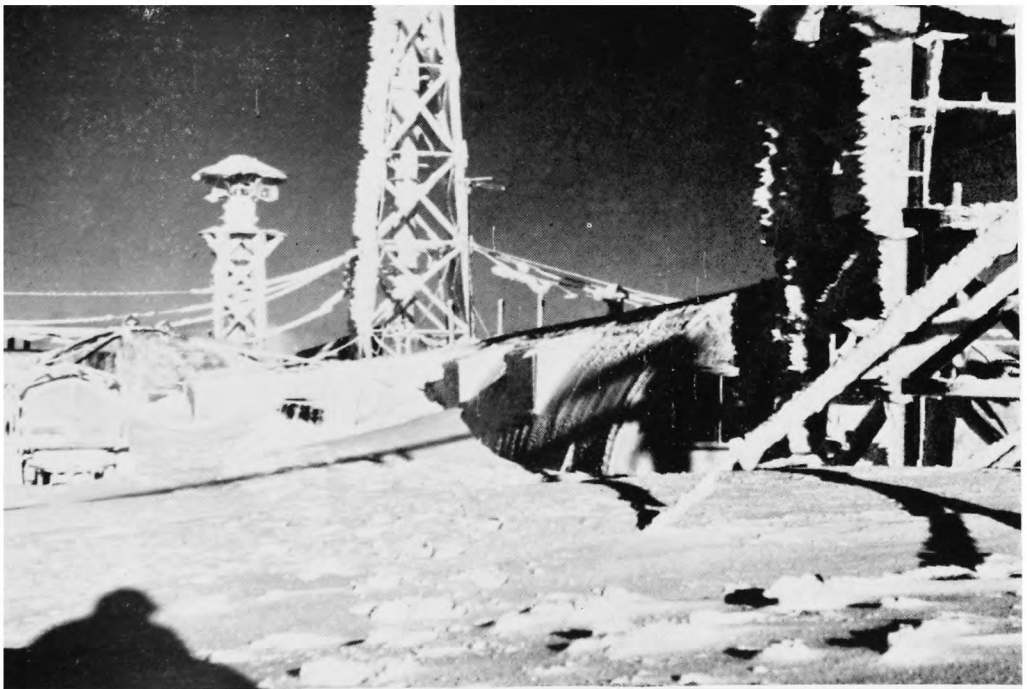
PHOTOGRAPHS OF THE 10 CM PPI RADAR BASED AT EAST HILL, SHOWING THE
PASSAGE OF SEVEN SEPARATE STORM AREAS ACROSS SOUTH-EAST ENGLAND ON
9 JULY 1959

(cont. on next art page)

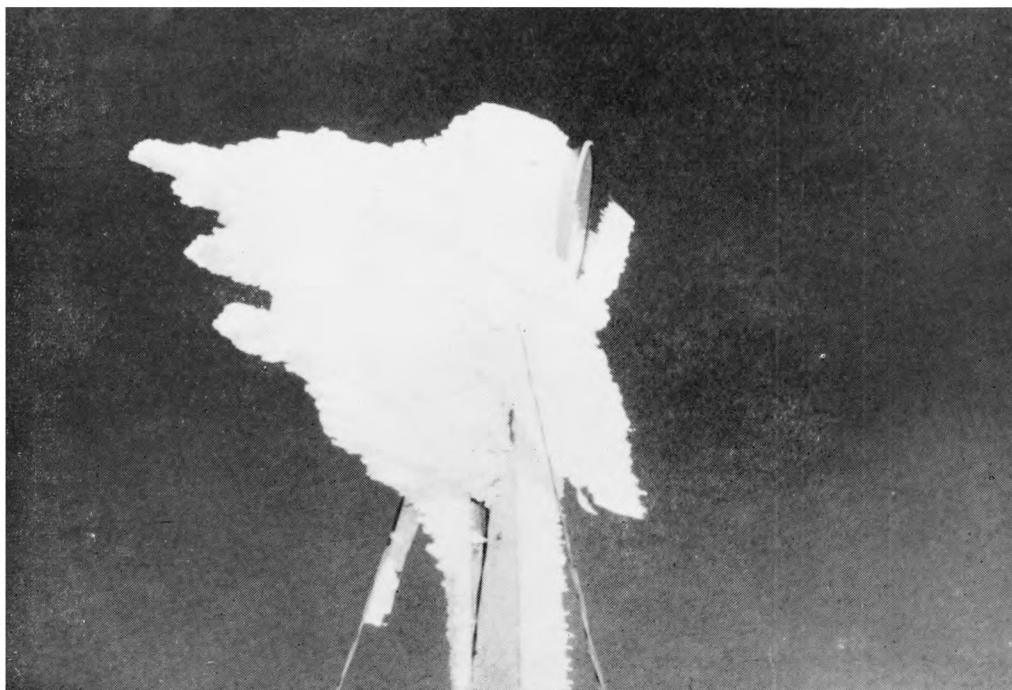
The range markers are at intervals of 10 miles and the azimuth markers are at 20° intervals from 010° (true).



(cont. from previous art page)



SUMMIT OF MT. OLYMPUS AFTER HEAVY SNOWFALL
(See also the following two photographs.)



Photograph by Cpl. R. Hacker, Royal Corps of Signals



Photograph by S.Ldr. E. R. Lacey, R.A.F.

SUMMIT OF MT. OLYMPUS AFTER HEAVY SNOWFALL

The conditions depicted in these photographs are not exceptional. The great deposits of rime become dangerous when strong winds carry off the more recent formations.

List of observers in the fen-land fog investigation (cont.)

SB	Sutton Bridge	Mrs. A. Noble
SC	Soham	Mr. G. W. J. Leach
SE	Setch	Mr. W. J. Hoff
SG	Spalding	Miss P. Wheatley
SI	St. Ives	Mr. J. R. O. Sandison
SM	Smeech	Mr. J. Frost
SR	Spalding	Mr. Renfall
SS	Soham	Mr. G. D. Watts
T	Thorney	Mr. T. Glover
TC	Terrington St. Clement	Mr. A. C. Owers
TS	Terrington St. Clement	Mr. H. S. Kenyon
U	Upwell	Mr. J. R. Frost
W	Wisbech	Mr. D. E. C. Morgan
WH	Whittlesey	Mr. R. Shadrake
WI	Wisbech	Mr. A. F. R. Fisher
WL	Sutton Bridge	Mr. J. Thompson
WS	Wiggenhall St. Germans	Mr. J. W. P. Rees

The indicator letters are those marked on the map at Figure 1 (p.351).

551.524.3:551.576.11:551.589.5

NORTH SEA STRATUS OVER THE FENS

By M. H. FREEMAN, O.B.E., M.Sc.

Introduction.—An investigation of the effect of the fens on the formation and dispersal of fog has been reported elsewhere.¹ For this purpose the co-operation of numerous voluntary observers had been obtained and a selection of them agreed to report also the times of formation or dispersal of low cloud when there was a north-easterly wind. Most observers realized that they would have difficulty in recognizing the required conditions, so arrangements were made for the meteorological office at Mildenhall to issue warnings by telegram of occasions when there was a possibility of stratus forming. As spring and early summer is the time of year when North Sea stratus is commonest, the investigation was mounted for the periods April to July 1960 and 1961, immediately following the previous winter's fog investigation.

In order to find out how frequently North Sea stratus could be expected, a statistical analysis was carried out on observations at Mildenhall for 24 hours per day for the ten years 1949–1958. Table 1 shows the average number of hours per month when the surface wind was in the sector 340 to 070 degrees inclusive, the average number of hours when there was also $\frac{5}{8}$ or more cloud at 1000 feet or below, occasions of precipitation other than drizzle being excluded, and the percentage frequency of low stratus in north-easterly winds for each month.

The figures in Table 1 for April are interesting. North-easterly winds are commoner in April than in any other month but their chances of being associated with cloud at 1000 ft or below are less than at any other time of the year. Even in May, June and July, the peak period for North Sea stratus, the frequency of its occurrence is low, and in the years 1960 and 1961 opportunities for investigating the phenomenon were also few.

Analysis of the observations.—In 1960 stratus occurred extensively in only two periods, 16 to 21 May and 24 to 27 June. The voluntary observers had not been alerted for the formation of stratus on 16 May and its dispersal on the 17th. Stratus re-formed during the night of 17th/18th after the volunteers had ceased observing, and the low cloud then persisted for four days. Wide-

TABLE 1—AVERAGE MONTHLY FREQUENCY OF NORTH-EASTERLY WINDS
AND LOW CLOUD AT MILDENHALL, 1949-1958

Month	No. of hours with surface wind 340°- 070°	No. of hours with ½ or more cloud at 1000 ft or below	Percentage frequency of low cloud with north-east winds
Jan.	95	9	10%
Feb.	122	12	10%
Mar.	150	22	15%
Apr.	198	8	4%
May	191	25	13%
June	150	29	19%
July	122	21	17%
Aug.	84	9	11%
Sept.	85	6	7%
Oct.	80	5	7%
Nov.	87	12	13%
Dec.	58	8	14%
Year	1422	166	12%

spread thunderstorms on the night of 23/24 June formed cloud below 1000 feet over the fens and this persisted until early on the 25th. Very few reports relating to these periods were made, but useful information was obtained from the voluntary observers concerning the formation of stratus on the evenings of 25 and 26 June; these occasions are discussed below. In 1961 warnings of the possibility of stratus formation were issued on six occasions, but on five of them no more than a few patches of stratus occurred and the last was associated with precipitation. In the two years therefore, useful results were obtained for only two occasions.

On 25 June 1960 there was a light north-easterly air flow over England between a shallow depression near Switzerland and a belt of high pressure from Norway to O.W.S. "J"*. During the afternoon temperatures inland over East Anglia rose to 75-80°F. Nearer the coast and over the fens the maxima were in the lower 70's, while on the coast the maximum was 64-65°F. The sea temperature in the Wash was 63°F. Isotherms of maximum temperature are shown in Figure 1. By evening, reports from ships indicated that there was no cloud over the southern North Sea. No stratus formed over the eastern part of Norfolk and Suffolk or over northern Lincolnshire. Elsewhere stratus formed when the temperature had fallen to about 58°F and the dew-point to near 56°F. This happened first near the coast, where only a small drop in temperature was needed. Isochrones of stratus formation are shown in Figure 2. Times given in brackets are for offices which had closed for the weekend; these times were estimated from thermograms, which usually had a marked change of slope which could be associated with the arrival of stratus. To some extent the isochrones reflect the shape of the coastline, but they also show a bulge southwards over the fens, where lower maximum temperatures had been recorded. Slightly lighter winds may have been the reason for the eastern half of East Anglia remaining clear. At some of the meteorological offices near the fens the cloud dispersed again during the night when the surface wind speed dropped; at other places the clearance occurred with rising temperatures soon after dawn.

On 26 June 1960 there was little cloud over land during the day and the

*Ocean Weather Station "J" is at 52½°N, 20°W

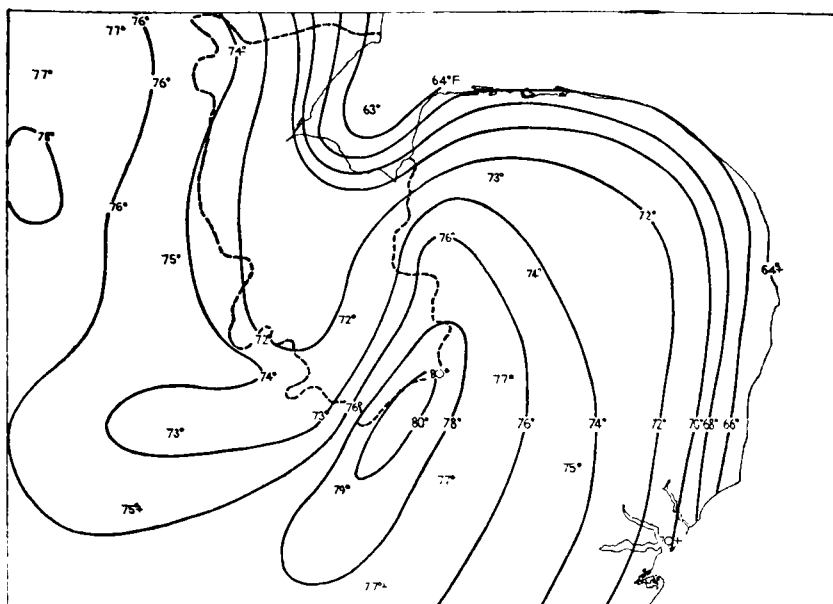


FIGURE 1 — MAXIMUM TEMPERATURES (°F) ON 25 JUNE 1960
The pecked line indicates the boundary of the fens

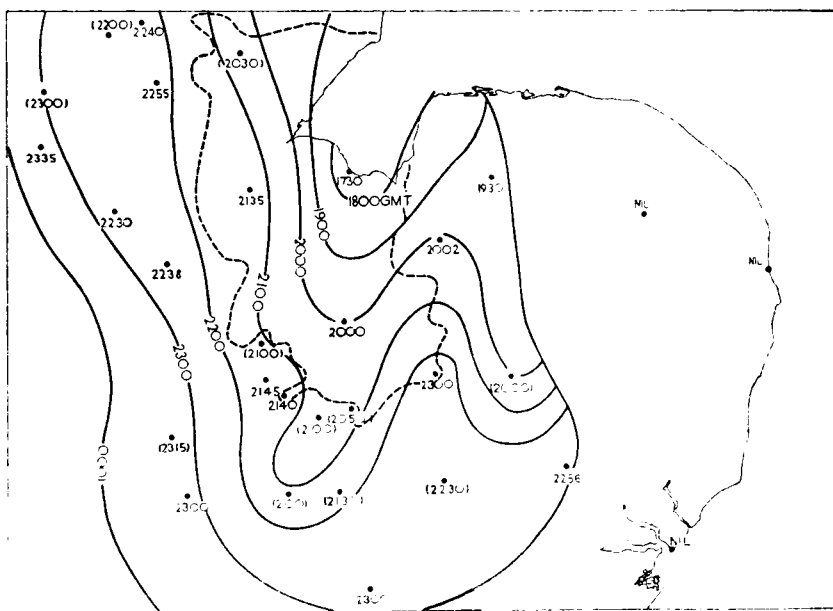


FIGURE 2 — TIMES OF FORMATION OF STRATUS ON 25 JUNE 1960

temperature rose to a maximum of 72–77°F, the distribution being very similar to that of the previous day; the lower values over the fens were again noteworthy. Little change in the isobaric pattern occurred in the 24 hours but, over the North Sea, stratus had spread southwards and by late afternoon was near the Norfolk coast. Stratus spread southwards across East Anglia fairly quickly during the evening. The earliest report was from Sutton Bridge at 1600 GMT. The lower maximum temperatures over the fens resulted in

stratus spreading in more quickly in this area. Isochrones of cloud arrival are shown in Figure 3. The temperature at which cloud appeared was about

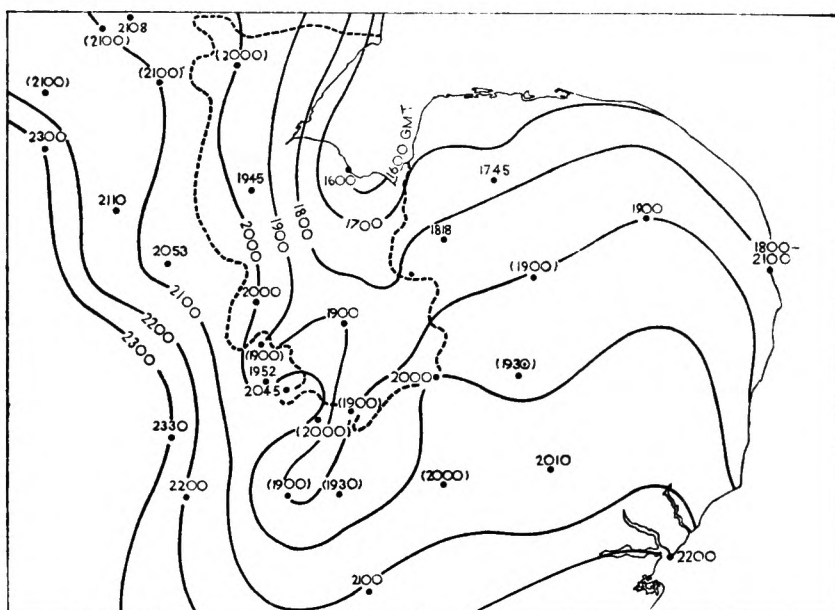


FIGURE 3 — TIMES OF FORMATION OF STRATUS ON 26 JUNE 1960

the same as on the previous evening. There was no clear-cut dispersal of the stratus next day; the cloud base gradually lifted and breaks occurred in the afternoon.

Recording thermometers had been installed at Manea, in the fens, and at Waterbeach, on the borders, and comparisons were made of the daily maximum and minimum temperatures. In the period May–July 1960, on the average Manea had a maximum 1°F higher and a minimum 2°F lower than Waterbeach. In June there were only five days when Manea had the lower maximum temperature, and the two largest differences (4° and 5°F) occurred on the 25th and 26th, two occasions when stratus formed. It is possible that the lower temperatures on these days had been caused by a sea breeze.

Conclusions.—The two occasions which were all that could be analyzed are insufficient to provide generalizations. They gave similar patterns of maximum temperature, both having relatively lower values over the fens. On one night stratus formed over land and on the other it spread in from the sea, but on both occasions cloud appeared over the fens and to the south of fenland earlier than in neighbouring areas. Analysis of the thermograms from Manea and Waterbeach suggested that the tendency for lower maximum temperatures over the fens was not a persistent feature.

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1. FREEMAN, M. H.; The formation and dispersal of fog over the fens. *Met. Mag., London*, **91**, 1962, p. 350.

THE SPREAD OF LOW STRATUS FROM THE NORTH SEA ACROSS EAST ANGLIA

By W. R. SPARKS

Introduction.—The problem of the rate at which low stratus over the North Sea spreads over East Anglia with north-east winds is of concern to many forecasters in the area. For the investigation of this problem a dense network of reporting stations was needed, so a war-time period, namely 31 July to 7 August 1944, was selected for study, and daily registers from 123 stations within 100 miles of the Wash were examined. Throughout the period pressure was high over the North Sea and low over Germany, giving a gradient wind direction between north and east. There was stratus over the North Sea the whole time and the investigation was confined to a study of when and how the stratus moved inland.

Analysis of the data.—Charts of surface wind and M.S.L. pressure were plotted for 1800 GMT each day. An attempt was made to measure the gradient wind on each chart, but it was found on all occasions that a balance was not possible between the forces due to the pressure gradient, the curvature of the isobars and the earth's rotation. The air was therefore being accelerated and it was impossible to make a reliable estimate of the 2000 ft wind from the isobars. For example, on the six days when the point at which balanced flow became impossible was east of Downham Market, the mean angle of backing of the measured 2000 ft wind from the direction of the isobars at Downham Market was 60° . The range of the angle of backing was 29° – 100° . On the one occasion during the period when balanced flow was possible at, and to the east of, Downham Market the angle of backing of the measured 2000 ft wind from the direction of the isobars was 15° . Figure 1 is the isobaric chart for 1800 GMT on 4 August 1944. The inability of the air to follow the isobars round the ridge is seen in the marked backing of the surface wind from the direction of the isobars on the western side of the ridge.

Since it proved impossible to estimate the wind at stratus level from the pressure pattern, reported winds had to be used. Surface winds from all stations were plotted on large-scale charts (10 miles to the inch) and stream lines were drawn from an isogonal analysis. Figure 2 shows an example corresponding to the isobaric chart at Figure 1. The streamline analysis proved very interesting and from an examination of this one series of charts the following points emerged:

- (i) On every occasion there was diffluence from the region of the Wash.
- (ii) There was a tendency for surface winds to be stronger at stations bordering the fens than at other stations to the east and north.
- (iii) The surface streamlines were a good approximation to the direction of advection of the stratus sheet.
- (iv) To the south-west of the Wash the speed of advection of the stratus was approximately the speed of the surface wind at 1800 GMT
- (v) To the south-east of the Wash the speed of stratus advection was much less consistent but the average speed was always slower than the surface wind speed at 1800 GMT.

- (vi) A change of surface wind direction during the night seemed to have an effect on stratus advection but a decrease in the surface wind did not.
- (vii) Lines of shear in the surface wind field were almost certainly important in the advection of stratus sheets but, even when streamline charts were drawn hourly using the very dense network of stations available for this investigation, it was difficult to place shear lines accurately and usually impossible to be sure of their exact form.

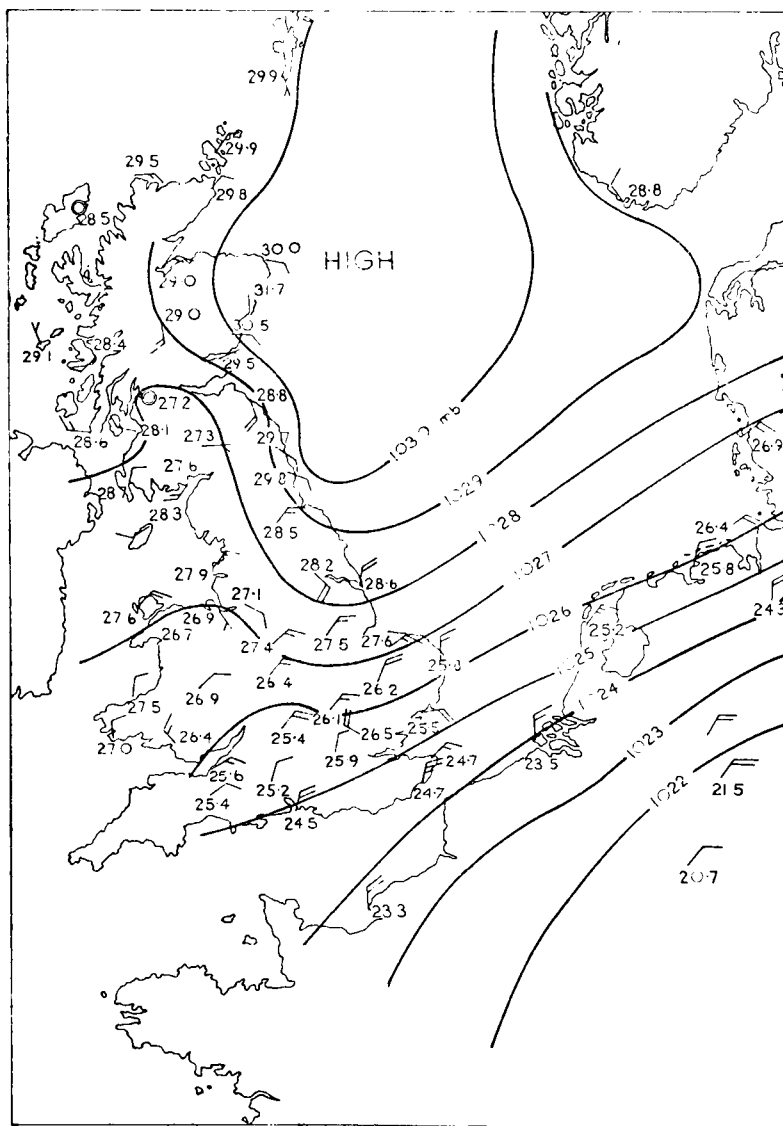


FIGURE 1 — SURFACE SYNOPTIC SITUATION FOR 1800 GMT, 4 AUGUST 1944
The figures beside the plots indicate pressure (millibars and tenths)

Charts of stratus advection were drawn and on most occasions it proved sufficient to plot a chart showing the time of the first report of stratus and to draw isochrones of the position of the leading edge of the stratus sheet. Figure 3 is the chart for 4–5 August 1944. It was not possible to use this method on two occasions when stratocumulus had persisted over land during the day and

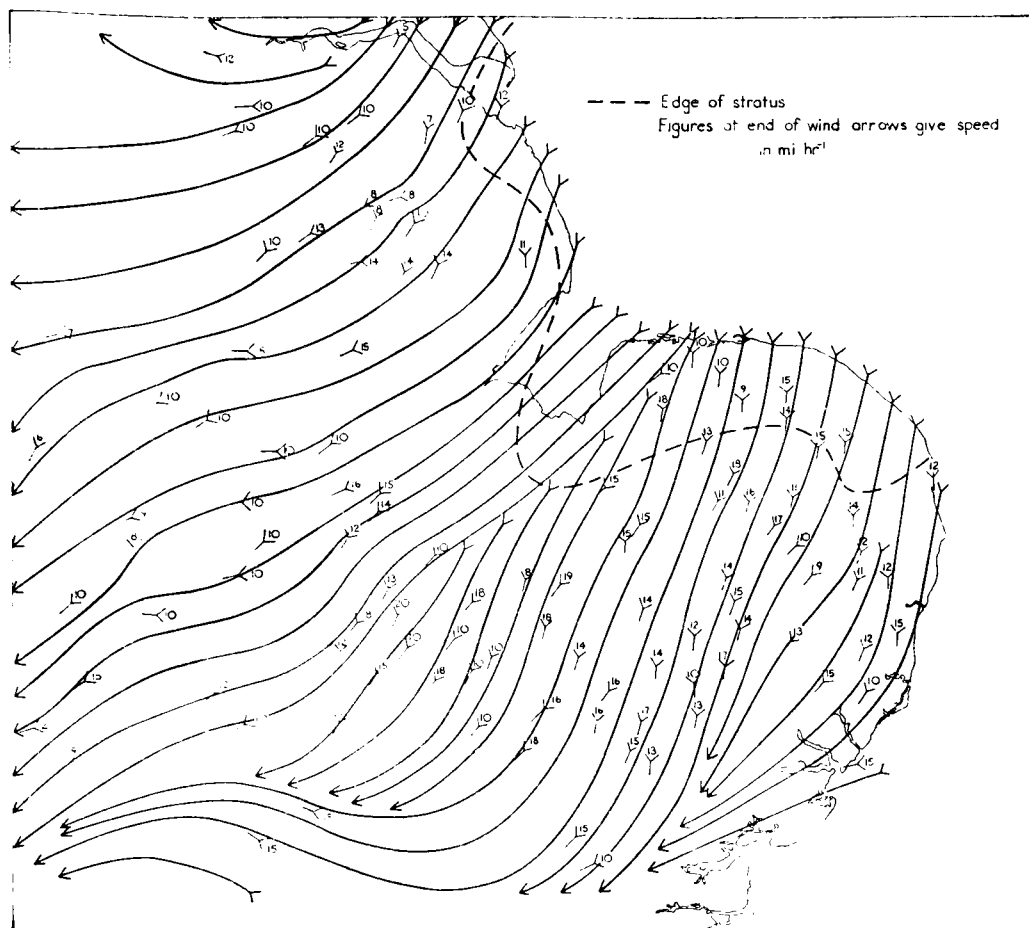


FIGURE 2 — SURFACE WINDS AND STREAMLINES AT 1800 GMT, 4 AUGUST 1944

gradually lowered to stratus during the night.

Time cross-sections showing isotherms in the layer from the surface to 900 mb were plotted for the whole period for Downham Market (radiosonde observations) and Bircham Newton (aircraft observations). These cross-sections showed that, although no fronts passed either station during the period, the air stream was far from homogeneous. Warm and cold closed centres appeared on the cross-sections, usually near the inversion base, and although they were modified by diurnal heating, this cannot account for them (for example, at Downham Market the temperature at 970 mb rose from 56°F at 1200 GMT to 66°F at 2359 GMT on 3 August 1944). Similar results were found by Findlater.¹

A chart was plotted for 5 August 1944, showing the temperature at which the stratus cleared. The clearance temperature was almost constant over the chart (62°F in the north, gradually becoming 63°F in the south-east). On other days a chart was not plotted but a glance through about 20 selected registers was sufficient to show the clearance temperature for the day. Charts showing the temperature when stratus reached each station were also plotted. The main features shown by these charts were:

- (i) Stratus affected coastal stations as soon as their temperature fell below the clearance temperature of the stratus sheet.

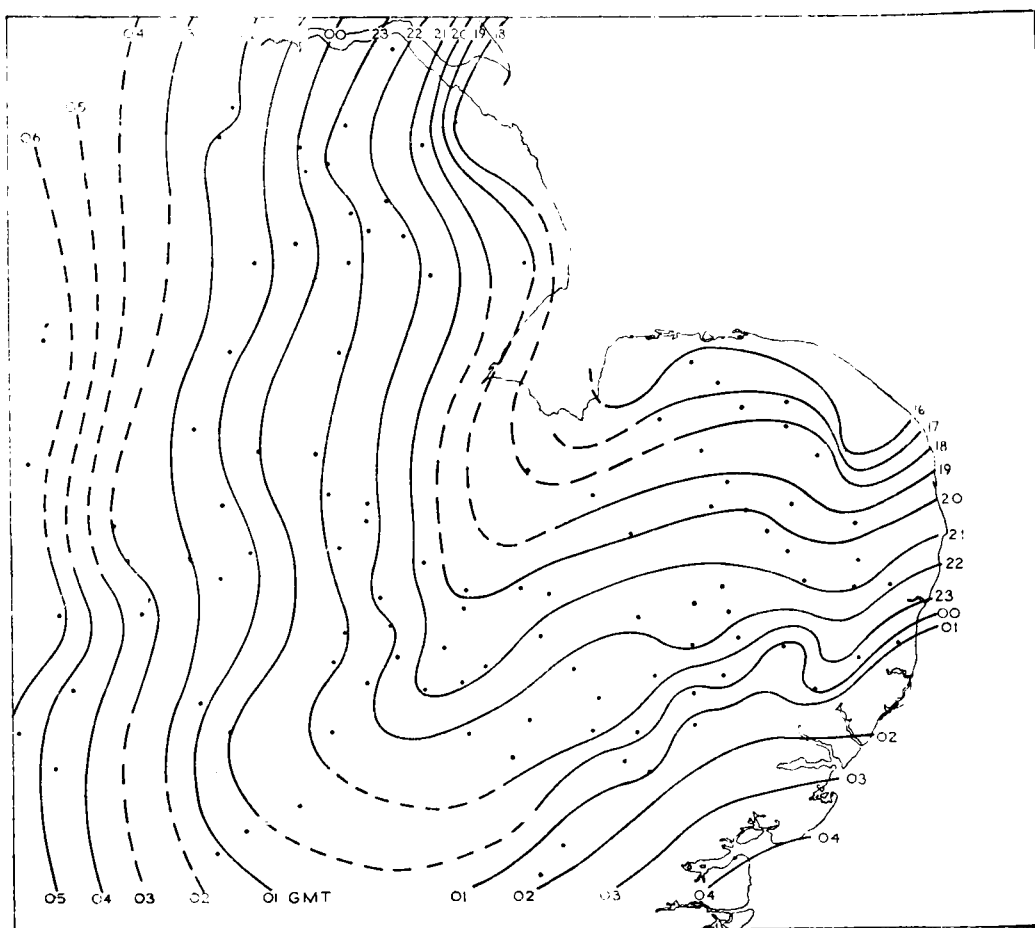


FIGURE 3 — ISOCHRONES OF STRATUS EDGE, 4-5 AUGUST 1944

The dots show the positions of stations which provided data

- (ii) Stratus did not affect an inland station until its temperature was below the clearance temperature and sometimes the temperature fell considerably below the clearance temperature before the station was affected.

Conclusions.—The following simple model is suggested by this analysis of the data for one particular stratus situation. When a stratus sheet is present over the North Sea during the day it is presumably in dynamic equilibrium, with continual formation over the sea and continual evaporation of the leading edge of the sheet as it advects over land. When the temperature at coastal stations falls below the clearance temperature of the stratus sheet the leading edge is no longer evaporated and the stratus will then move inland. The leading edge of the stratus moves inland at the speed of the wind at its own level, provided the temperature at inland stations has fallen below the clearance temperature. This simple picture is complicated by the heterogeneous temperature structure of the air stream. The advection of a warm area to replace a cold area at about 950 mb causes a change in the inversion height and a change in the clearance temperature of the stratus sheet.

The spread of stratus inland was mainly due to advection, but on two

occasions there was evidence of stratus forming over high ground ahead of the main sheet.

In the absence of a suitable temperature sounding through the stratus, the temperature at which stratus cleared in the morning provided the best estimate of the temperature at which it started to move inland in the evening.

When a balanced gradient wind was impossible the surface winds gave a much better approximation to the direction of stratus advection than the direction of the isobars.

The speed of the surface wind, at a time when convection and turbulence were still operative in the lowest layers (say 1800 GMT in August), gave a fair approximation to the speed of stratus advection.

REFERENCE

1. FINDLATER, J.; Thermal structure in the lower layers of anticyclones. *Quart. J.R. met. Soc., London*, **87**, 1961, p. 513.

551.510.42:551.515.8:551.521.16

A CONTRIBUTION TO THE PROBLEM OF DAY-DARKNESS OVER LONDON

By P. B. GILDERSLEEVES

Introduction.—This report describes and examines the factors contributing to the formation of a belt of extreme day-darkness which crossed the London area during the morning of 1 December 1961. Comparisons are made with the report of another occasion by Helliwell and Blackwell¹ and some suggestions are made which may assist in forecasting this phenomenon.

The synoptic situation.—Figure 1 shows the synoptic situation at 0600 GMT on 1 December. Pressure was low over Scandinavia and high to the west of the

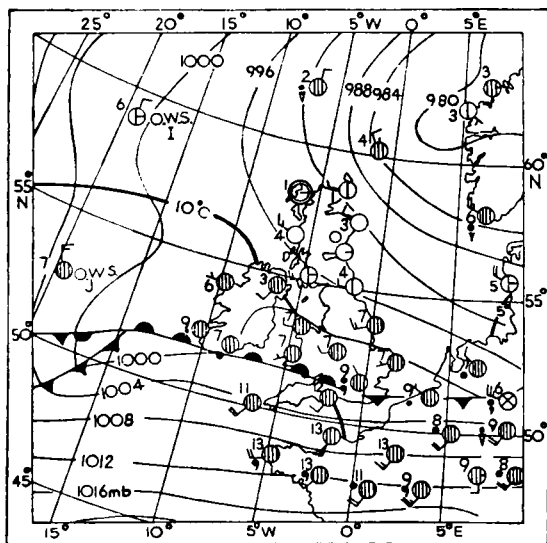


FIGURE 1 — SURFACE SYNOPTIC SITUATION AT 0600 GMT, 1 DECEMBER 1961
The isotherms are of mean sea temperature (10°C)

Iberian Peninsula. A cold front which had been moving quickly south over the United Kingdom since 1800 GMT on 30 November became quasi-stationary over southern England during the morning of the 1st.

In the London area the front remained almost stationary between Bovington and London Airport from 0200 to 0330 GMT, eventually passing through London Airport just after 0330 when the temperature and dew-point fell from 12° and 10°C to 8° and 7°C respectively and the wind veered from 250° to 310°. This temperature contrast across the front is comparable to that reported by Helliwell and Blackwell.¹

Analysis.—A streamline analysis was carried out for the period 0100 to 1200 GMT on 1 December using hourly surface wind reports from 12 synoptic stations and 10 auxiliary climatological stations (Table 1) in south-east England.

TABLE 1 — STATIONS WHOSE WIND RECORDS WERE USED TO PRODUCE STREAMLINE CHARTS

Meteorological Office stations	Auxiliary climatological stations
Benson	Amersham (Radio Chemical Centre)
Bovington	Coryton
Kew	Garston (Building Research Station)
London (Gatwick) Airport	Gravesend (Thames Ferry Station)
London (Heathrow) Airport	Hampden
London Weather Centre (Kingsway)	Isle of Grain
Northolt	Rothamsted (Lawes Agricultural Trust)
Shoeburyness	Sheerness
South Farnborough	Stanstead Abbots
Stanstead	Woolwich (Thames Ferry Station)
West Malling	
White Waltham	

Surface air trajectories were computed using these streamlines. An example of the streamline analysis is shown in Figure 2.

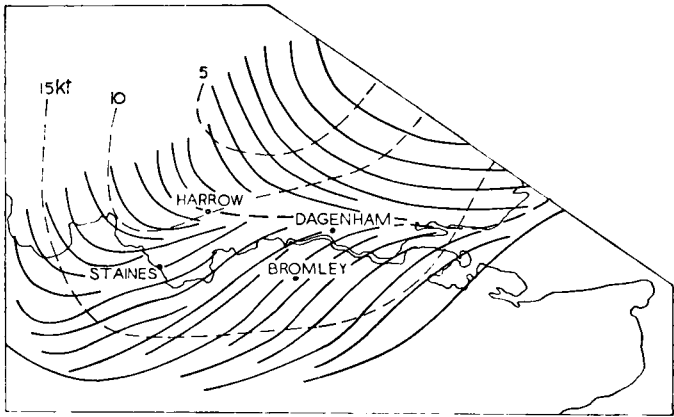


FIGURE 2 — STREAMLINES FOR THE HOUR ENDED 0300 GMT (THE FLOW IS FROM LEFT TO RIGHT), AND ISOTACHS (PECKED LINES), 1 DECEMBER 1961

Four trajectories were computed, the starting points being in the form of a square, the sides of which enclosed an area of 1600 square miles. Figure 3 shows the trajectories of the surface air starting at 0001 GMT on 1 December, from the corners of a square just to the west of London. These were found to converge on central London by 1000 GMT. This compares with an observation of smoke-pall to the south-west made by the London Weather Centre at 0900 GMT.

The positions of the end points of the four trajectories at 1000 GMT formed a quadrilateral of area 490 square miles, a reduction of 69 per cent in the original area, an indication of convergence processes operating with consequent vertical

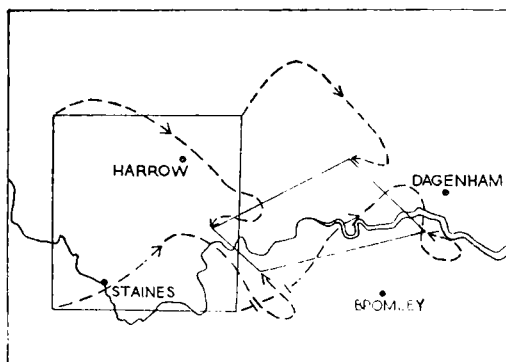


FIGURE 3 — TRAJECTORIES, 0001-1000 GMT, 1 DECEMBER 1961

motion. This quadrilateral was positioned almost symmetrically about the Thames with an orientation ENE-WSW.

Upper air analysis.—The ascents made on 1 December from Hemsby at 0001 GMT, and from Crawley at 1200 GMT, are shown in Figure 4.

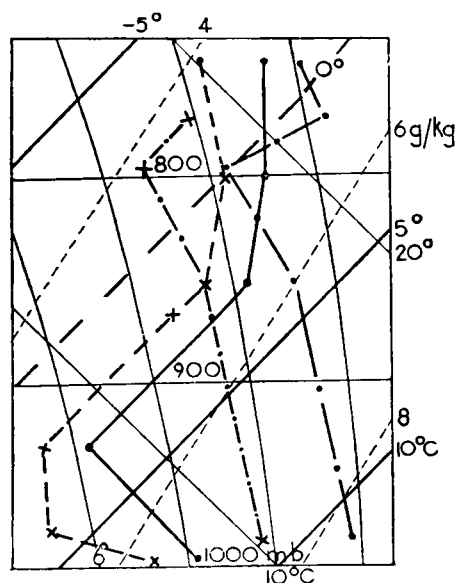


FIGURE 4 — TEPHIGRAM SHOWING ASCENTS FROM HEMSBY AT 0001 GMT AND CRAWLEY AT 1200 GMT, 1 DECEMBER 1961

Hemsby ——— Dry bulb Crawley ——— · ——— · Dry bulb
 ——— ——— Wet bulb ——— · ——— · Wet bulb

The Hemsby ascent can be seen to be somewhat complex, consisting of three distinct layers. In the lowest layer, that is below 550 m, one can see the moist cold air behind the front whilst above 1500 m the moist warm air is ahead of it. This air was very moist and from humidities reported dense cloud can be inferred to at least 5000 m. Between these two layers was a very moist transition zone characterized by a marked increase in wet-bulb potential temperature, from 6°C at 550 m to 10°C at 1500 m.

The 1200 GMT ascent for Crawley (Figure 4) shows the structure of the moist tropical air south of the front with temperatures from the surface to 850 mb following closely the saturated adiabatic line for 12°C.

Illumination in the dark belt.—The daylight illumination records and total radiation records for Kew and the London Weather Centre were examined to provide some quantitative data on illumination in the dark belt. Figure 5

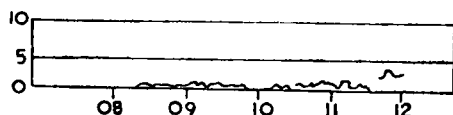


FIGURE 5 — DAYLIGHT ILLUMINATION RECORD FOR LONDON WEATHER CENTRE ON 1 DECEMBER 1961 (IN KILOLUX)

shows the daylight illumination record for the London Weather Centre on 1 December. It is immediately apparent from the record that the combined effect of the dense frontal cloud and smoke had the effect of delaying the dawn until 1140 GMT.

The illumination at London Weather Centre from 0815 when the record started, until 1010 GMT, was less than 0.1 kilolux,* and during this period the illumination fell twice to a value almost indistinguishable from zero, namely at 0900 GMT, when an observation of day-darkness was recorded in the daily register, and again at 1000 GMT. This second minimum in the illumination lasted for some 12 minutes compared with 6 minutes for the first one. A tentative explanation for this is that a secondary smoke-pall had formed and drifted northwards in the light south-easterly drift. There is no corroboration of this hypothesis by way of observations; there was, however, a marked confluence in the surface wind field just to the north-west of the Weather Centre at 1000 GMT. A rough mean value for the illumination at the Weather Centre using all the available data (3 years) has been calculated for 0900 GMT in December for those occasions on which there was more than 7/8 of cloud, with the base of the lowest layer less than 1000 feet, or less than 1500 feet if it was raining continuously. This value, 2.03 kilolux, may be used to obtain an estimate of the contribution made by the smoke alone in reducing the illumination, on the assumption that under dense cloud illumination is reduced to 2.03 kilolux; if, following Helliwell and Blackwell,¹ a value of 0.03 kilolux is taken as the intensity of illumination at the time when the smoke-pall crossed the area, then the reduction in illumination due to the smoke alone was about 2 kilolux. This compares with a value of just under 7 kilolux adduced by Helliwell and Blackwell for 1300–1400 GMT in January and quoted in their report.¹ Also in this report they offer a hypothesis to account for this reduction in illumination; the mechanism they suggest may well be operative in the present case as essential details are similar.

Conclusions.—Although it is not possible at present to assess the frequency of occurrence of the phenomena the following seem to be the most important factors contributing to day-darkness. (Hence they may be taken as examples of the type of element which forecasters should look for when deciding to issue a day-darkness warning.)

Helliwell and Blackwell stressed the importance of the first two.

- (i) A very active front with a marked temperature contrast and dense cloud.

*1 kilolux = 1000 lumens m⁻².

- (ii) Marked convergence on the front.
- (iii) A long period of stagnation with a slow-moving front, enabling smoke to be entrained in the lowest layers of cloud.
- (iv) Low-level inversion or stable layer, reducing the dissipation of smoke upwards, thus enabling the lower layers of the atmosphere to become heavily polluted. (The importance of this is brought out in DSIR's report on *Investigation into Atmospheric Pollution*²).
- (v) Confluent wind field across the front with light winds moving the polluted air into the convergent frontal zone.

REFERENCES

1. HELLIWELL, N. C. and BLACKWELL, M. J.; Day-time darkness over London on January 16, 1955. *Met. Mag., London*, **84**, 1955, p. 342.
2. London, Department of Scientific and Industrial Research; The investigation of atmospheric pollution, research and observations in the year ending 31st March, 1958. London, HMSO, 1960.

551.5:06.045:63

WORLD METEOROLOGICAL ORGANIZATION, COMMISSION FOR AGRICULTURAL METEOROLOGY

Representatives of 31 nations attended the third meeting of the Commission for Agricultural Meteorology held at the University of Toronto, Ontario, Canada from 9-27 July 1962 under the presidency of P. M. Austin Bourke of Eire. A feature of the session was the excellent series of reports submitted by the Working Groups which had been set up by the previous meeting at Warsaw. The reports on apple scab, frost protection, shelter, forest fires, the storage of fruit, and agricultural aviation were outstandingly good and will provide material for valuable additions to the series of Technical Notes published by WMO.

Further working groups were planned to deal with other important subjects, namely, wheat rust, the oriental fruit moth and codling moth, air pollution and crop yields, local climatological influences, the storage of cereals, soil moisture problems, lucerne, animal experiments, and instruction syllabi in agricultural meteorology.

Three scientific sessions were held including one sponsored jointly with the Royal Meteorological Society's Canadian Branch under the chairmanship of Dr. Andrew Thomson, O.B.E., at which a number of interesting papers were read.

Visits were also arranged to the Canadian Meteorological Service and to research stations in the neighbourhood, including one to the hydro-electric installations at Niagara Falls.

The undoubted success of the meeting was greatly helped by the extremely efficient organization for which the Canadian Meteorological Service was largely responsible.

Mr. L. P. Smith (United Kingdom) was elected President of the Commission.

REVIEW

Über die Fruchtgrößenveränderung einiger Apfelsorten und ihre Abhängigkeit von atmosphärischen Umweltbedingungen, by S. Stenz. 9 in. x 6 in. pp.60, *illus.*, Akademische Verlagsgesellschaft, Geest & Portig K.-G. Leipzig C1, 1962. Price: D.M.6.50.

This publication from the Institute of Agrometeorology in Leipzig describes experimental work on the variation in fruit size of certain apple varieties in relation to weather. The author has developed an instrument for providing a continuous record of the growth of an apple still on the tree and the records from such instruments are compared with standard meteorological data, including global radiation. The investigation is based on records from one site in East Germany in 1955 and four sites in 1956.

The growth records show that a diurnal variation in fruit size is superposed on the normal increase in size which occurs during the growing season. The maximum size occurs at about 0800h and then follows a decrease in size until early afternoon, which may amount to 2 per cent. of volume. By late afternoon the pre-shrinking size is regained and during the night there is a net increase. The diurnal shrinkage varies directly as radiation, sunshine and maximum air temperature, and inversely as minimum daily relative humidity. These are not unexpected results, but it appears that the most important factor is relative humidity. This suggests to the reviewer that two fundamental factors are involved, radiation and air mass.

Seasonal fruit growth is estimated from the 0400h values and the relationship with weather is much less definite than for the diurnal variation. In fact, correlation coefficients between growth over a period of a month or two and the meteorological elements are not consistent in sign when different years and locations are considered, and more extensive investigations over wide areas are necessary to clarify these results.

A section of this paper deals with variations in fruit size from a physiological point of view and is of somewhat less interest to the meteorologist. Fruit shrinkage is shown to be due to the insufficient capacity of the capillary vessels at times of high transpiration, or to insufficient water uptake by the roots. In general, soil moisture appears to exert less influence on fruit development than those weather elements which lead to a high transpiration rate, with the associated moisture stress phenomena in the tree. A study of fruit-fall, and of the June drop in particular, suggests that this is a complex problem; it is probably related to water losses, but these are to some extent affected by available nitrogen. These ideas are quite consistent with those now current in general farming, that water and nitrogen are to some extent interchangeable.

W. H. HOGG

PUBLICATION RECEIVED

The Weather: fronts (in the series "Physics-astronomy and space exploration"). 30 in. x 40 in., Wallchart (C.851) in three colours, Educational Productions Ltd., East Ardsley, Wakefield, Yorkshire, 1962. Price 10s.

OFFICIAL PUBLICATION

The following publication has recently been issued: *Cloud types for observers*, London, HMSO, 1962. Price: 8s. Details are given on p. 372.

AWARDS

R.A.F.V.R. awards.—We are pleased to note that the undermentioned officers in the Meteorological Section of the R.A.F.V.R. have been granted the Air Efficiency Award.

Flt.-Lt. J. M. Mulvey.

Flt.-Lt. G. M. Smith.

METEOROLOGICAL OFFICE NEWS

Retirements.—The Director-General records his appreciation of the services of:

Mr. P. Powell, Senior Experimental Officer, who retired on 3 September 1962 after 43 years' service. Mr. Powell joined the Office as a Boy Clerk in March 1919 and served at various stations in south-east England as a Clerk Grade III and Technical Assistant III and II until he was mobilized into the Royal Air Force Reserve on the outbreak of war and sent to France. He returned to the U.K. early in 1940 and was demobilized in 1941. After service at No. 1 Group and No. 2 Group Headquarters he was attached to the 21st Weather Squadron, U.S.A.F., in 1943, and for his work there was awarded a Certificate of Merit by the squadron. In 1943 he was commissioned in the Royal Air Force and served with the Bomber Wing of 2nd T.A.F. until demobilization in 1945. In the post-war reconstruction he was assimilated as an Experimental Officer and served at High Wycombe until he went to Germany in 1947, where he stayed for five years, being promoted to Senior Experimental Officer in 1949. On his return to the U.K. in 1952 he went to Mildenhall, and stayed there for the remainder of his career.

Mr. A. Lee, Experimental Officer, who retired on 2 September after 33 years' service. Mr. Lee joined the Office as a Grade III Clerk in June 1926 at Calshot. After a year he was transferred to Sealand and later to Calshot where he became an Assistant III. In 1939 he was posted to Thorney Island, where he remained until 1941 when he moved to Headquarters. During three years' service at Prestwick between 1942 and 1945 he was mobilized into the Royal Air Force in the rank of Flying Officer. On demobilization in 1946 he was assimilated as an Experimental Officer and after a year's service at London (Heathrow) was transferred to the radio-sonde station at Fazakerley where he became officer-in-charge. He was responsible for the move of the unit to Aughton and remained there until he retired.

CORRIGENDUM

In the equation halfway down p. 323 of the November 1962 *Meteorological Magazine*, $R(t)1=-\frac{1}{2} \dots$ should read $R(t)=1-\frac{1}{2} \dots$

CLOUD TYPES FOR OBSERVERS

This publication has been prepared in the Meteorological Office, and is attractively produced on stout card of convenient size, being designed for outdoor as well as indoor use. It contains 37 photographs with descriptive notes which will help the observer to identify the main types of cloud. Additional notes, diagrams and coding instructions are also included to enable the observer to classify the state of the sky in accordance with the codes approved by the World Meteorological Organization.

This album replaces the earlier publications *Cloud forms* and *Cloud card for observers*, which are now obsolete because of changes in cloud classification introduced by the World Meteorological Organization.

9½in. x 7¼in. 30 pp. 8s. (post 9d.)

Obtainable from
HER MAJESTY'S STATIONERY OFFICE
or through any bookseller