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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.

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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–Bushby[1] 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

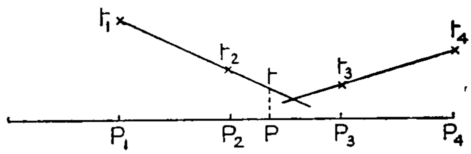


FIGURE I—INTERPOLATION OF TEMPERATURE (t) AT A POINT p

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	*a*	*b*	*c*	*d*	*e*	*a*	*b*	*c*	*d*	*e*
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				
	a	*b*	*c*	*d*	*e*	*a*	*b*	*c*	*d*	*e*
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				
	a	*b*	*c*	*d*	*e*	*a*	*b*	*c*	*d*	*e*
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:

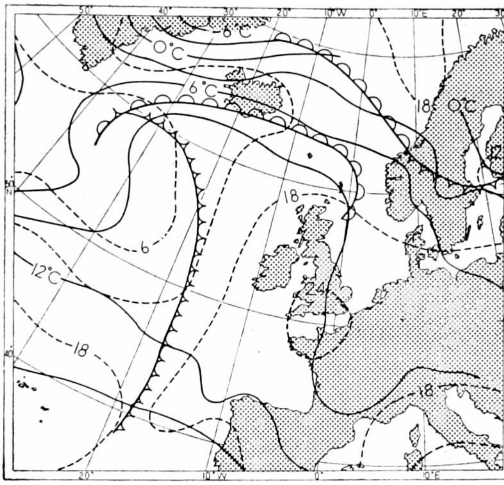
(*a*) initial 1000 mb temperature and contour chart;
(*b*) actual 1000 mb temperature and contour chart 24 hours later;
(*c*) numerically predicted 1000 mb temperature and contour chart at time corresponding to chart (*b*);
(*d*) to (*f*) corresponding temperature charts for 500 mb.

The numerically predicted temperature fields are discussed briefly below.

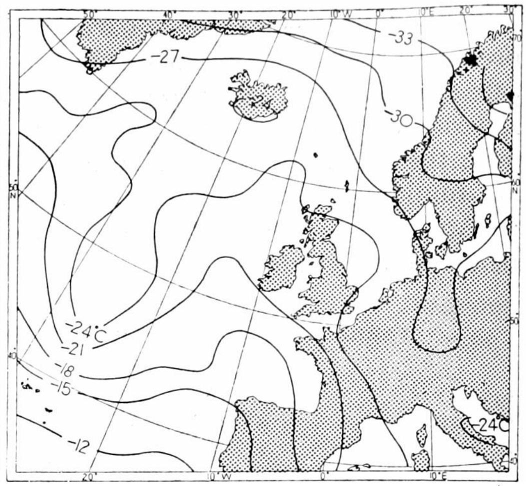
(i) *22 April 1959*—An upper cold trough moved eastwards towards the British Isles, followed by a frontal system on the Atlantic.

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.

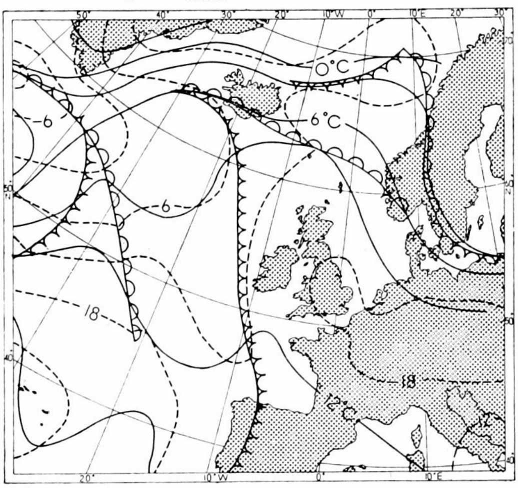
500 mb—The movement of a cold centre over Ireland was well predicted.



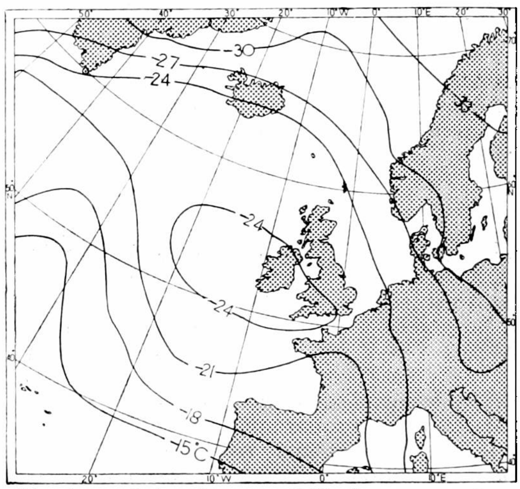
(*a*) Actual isotherms (°C) and contours (decametres) for 1000 mb, 0001 GMT, 22 April 1959



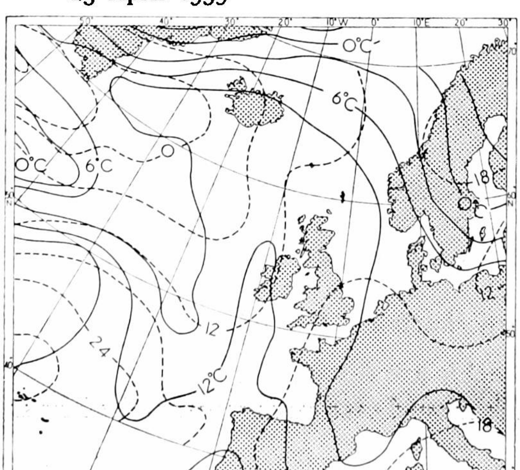
(*d*) Actual isotherms (°C) for 500 mb, 0001 GMT, 22 April 1959



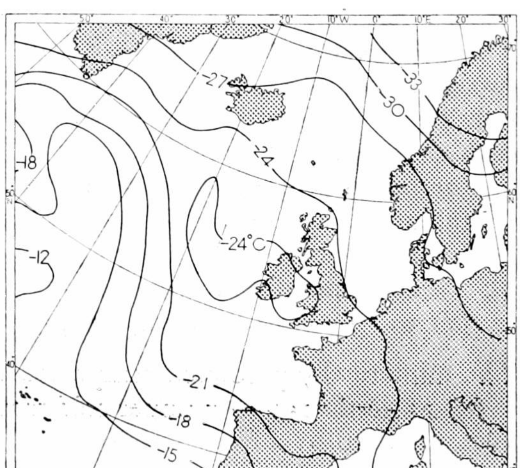
(*b*) Actual isotherms (°C) and contours (decametres) for 1000 mb, 0001 GMT, 23 April 1959



(*e*) Actual isotherms (°C) for 500 mb, 0001 GMT, 23 April 1959

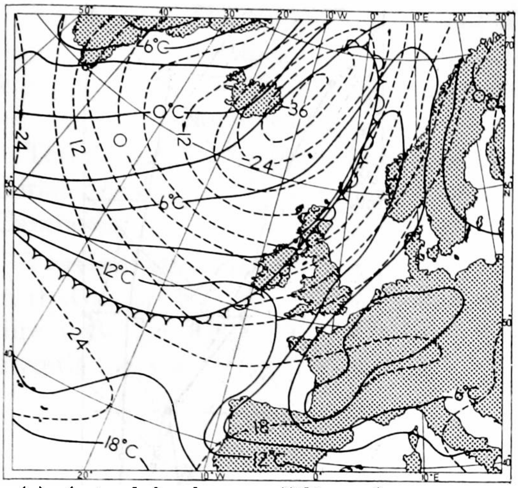


(*c*) Forecast isotherms (°C) and contours (decametres) for 1000 mb, 0001 GMT, 23 April 1959

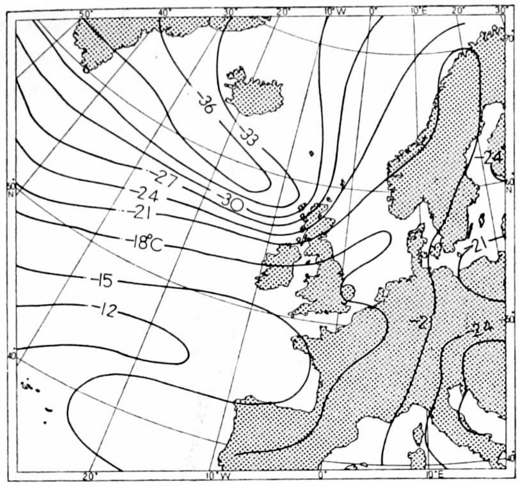


(*f*) Forecast isotherms (°C) for 500 mb, 0001 GMT, 23 April 1959

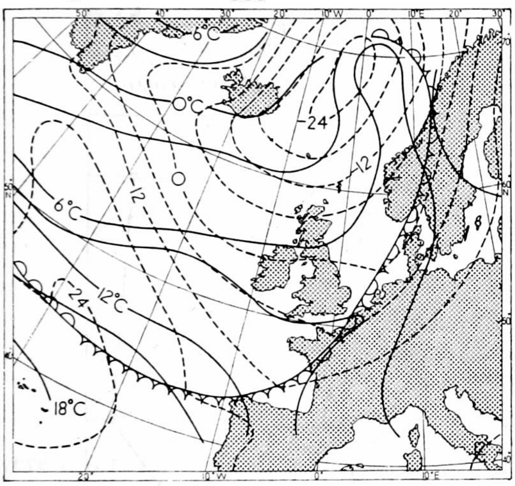
FIGURE 2



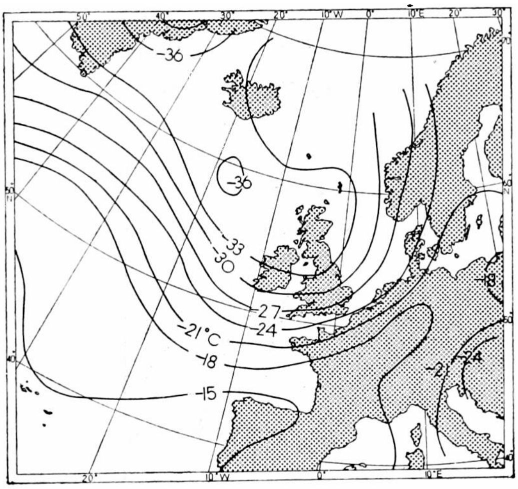
(*a*) Actual isotherms (°C) and contours (decametres) for 1000 mb, 0001 GMT, 9 November 1959



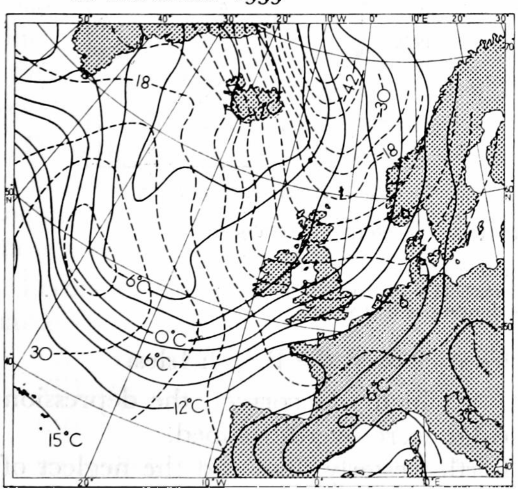
(*d*) Actual isotherms (°C) for 500 mb, 0001 GMT, 9 November 1959



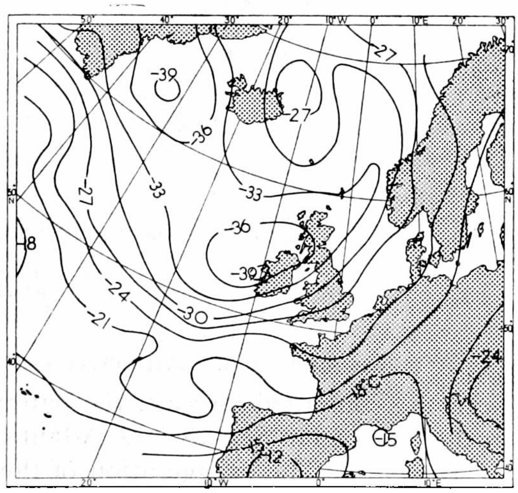
(*b*) Actual isotherms (°C) and contours (decametres) for 1000 mb, 0001 GMT, 10 November 1959



(*e*) Actual isotherms (°C) for 500 mb, 0001 GMT, 10 November 1959

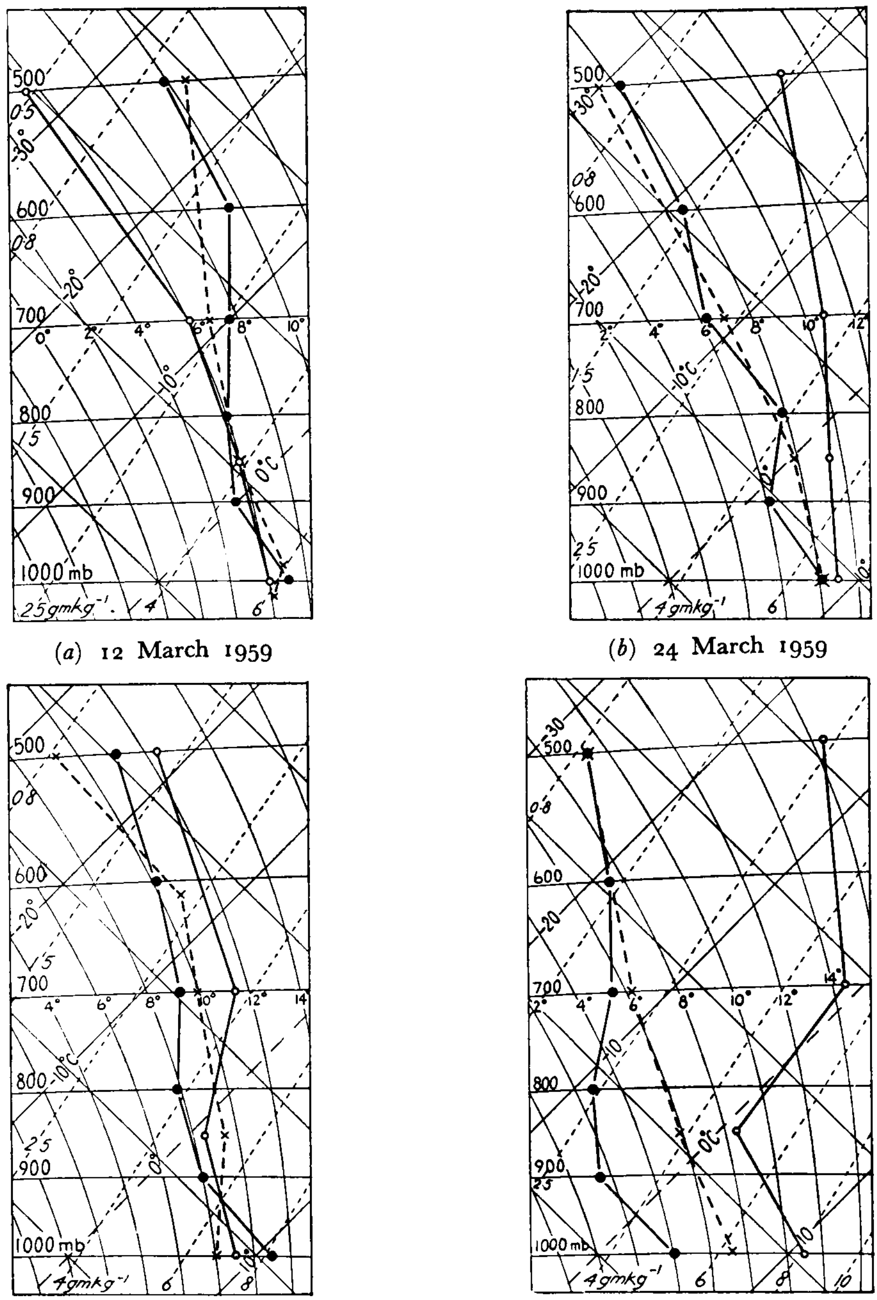


(*c*) Forecast isotherms (°C) and contours (decametres) for 1000 mb, 0001 GMT, 10 November 1959



(*f*) Forecast isotherms (°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

- o———o 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.

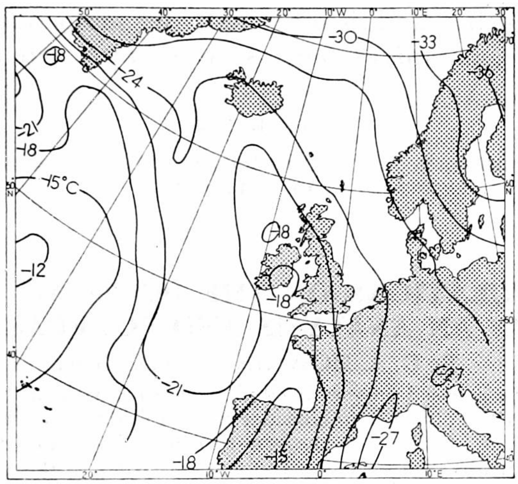
In the computed forecast, the pattern of which was correct, the depression in the Norwegian Sea and the Atlantic ridge were overdeveloped.

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 (°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.

REFERENCE

1. SAWYER, J. S. and BUSHBY, F. H.; A baroclinic model atmosphere suitable for numerical integration. *J. Met., Lancaster, Pa.*, **10**, 1953, p. 54.

551.509.313 551.509.317

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 Forsdyke[1] showed that the local rate of change in thickness at a point is given by:

$$\frac{\partial h}{\partial t} = R\int_{p}^{p_0}\left\{-\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)+\frac{\mathrm{d}p}{\mathrm{d}t}\left(\frac{\gamma}{gp}-\frac{\partial T}{\partial p}\right)+\frac{1}{C_p}\cdot\frac{\mathrm{d}q}{\mathrm{d}t}\right\}\mathrm{d}\log p \quad \ldots (1)$$

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, Murgatroyd[2] 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.—Sutcliffe[3] stated that $\mathrm{d}p/\mathrm{d}t$, 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

$$\frac{\mathrm{d}p_1}{\mathrm{d}t} = -\int_0^{p_1} \mathrm{div}_p\, \mathbf{V}\, \mathrm{d}p \qquad \ldots (2)$$

where p_1 is any pressure level.

In a subsequent paper, Sutcliffe and Forsdyke[1] 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

$$\int_0^{p_0} \mathrm{div}\, \mathbf{V} \mathrm{d}p = \int_0^{p_0} \mathrm{div}\, \mathbf{V}_0\, \mathrm{d}p + \int_0^{p_0} \mathrm{div}\, \mathbf{V}'\, \mathrm{d}p \qquad \ldots (3)$$

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 $\int_0^{p_0} \mathrm{div}\, \mathbf{V}\, \mathrm{d}p$ must be approximately zero and hence

$$\int_0^{p_0} \mathrm{div}\, \mathbf{V}_0\, \mathrm{d}p = p_0\, \mathrm{div}\, \mathbf{V}_0 \simeq -\int_0^{p_0} \mathrm{div}\, \mathbf{V}'\, \mathrm{d}p\, . \qquad \ldots (4)$$

Turning now to the 100–200 mb layer, Probert-Jones[4] demonstrated that the 100 mb field is for all practical purposes non-divergent and, since

$$\mathrm{div}\, \mathbf{V}_{100} = \mathrm{div}\, \mathbf{V}_{200} + \mathrm{div}\, \mathbf{V}'_{100\text{-}200} \qquad \ldots (5)$$

it follows that

$$\text{div}\,\mathbf{V}_{200} = -\,\text{div}\,\mathbf{V}_{100\text{-}200}\,. \qquad \ldots (6)$$

In other words, the development at 200 mb should be uniquely determined by the development in the 100–200 mb thickness field. Sutcliffe[3] goes on from equation (2) by a series of carefully considered approximations to derive the relationship

$$\text{div}_p\,\mathbf{V} - \text{div}_p\,\mathbf{V}_0 = -\frac{1}{l}\,V'\,\frac{\partial}{\partial s}\,(l + \zeta + \zeta_0) \qquad \ldots (7)$$

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 div $\mathbf{V}_{100} \simeq 0$, we have:

$$-\,\text{div}\,\mathbf{V}_{200} = -\frac{1}{l}\,V'_{100\text{-}200}\,\frac{\partial}{\partial s}\,(\zeta_{200} + \zeta_{100} + l) \qquad \ldots (8)$$

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

$$\therefore\ \text{div}\,\mathbf{V}_{200} = \frac{1}{l}\,V'_{100\text{-}200}\,\frac{\partial}{\partial s}\,(2\zeta_{100} - \zeta'_{100\text{-}200} + l) \qquad \ldots (9)$$

where the term containing ζ_{100} is the movement term, the term containing $\zeta'_{100\text{-}200}$ 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 Gold[1] 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 Shaw[2] (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 Stagg[3] 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 Stagg[3]. For our present purposes it is sufficiently accurate to use the diagram[4] 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 Daily insolation outside atmosphere at 35°N	2 Mean period sunrise to 1400h LMT	3 Direct insolation at MSL, sunrise to 1400h	4 Diffuse short-wave radiation, sunrise to 1400h	5 Total insolation reflected at surface	6 Effective mean radiating temp of earth	7 Long-wave radiation from earth, sunrise to 1400h	8 Daily evaporation	9 Heat to evaporate 50 per cent of col. 8	10 Heat available for warming air	11 Equiv. depth of isothermal-to-adiabatic change
	gm cal cm^{-2}	*hr*	*gm cal gm*$^{-2}$	*gm cal cm*$^{-2}$	*gm cal gm*$^{-2}$	°*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 Myers[5] and Ashbel[6]. 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.
						gm cal cm^{-2}						
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 Mather[7]. 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.)

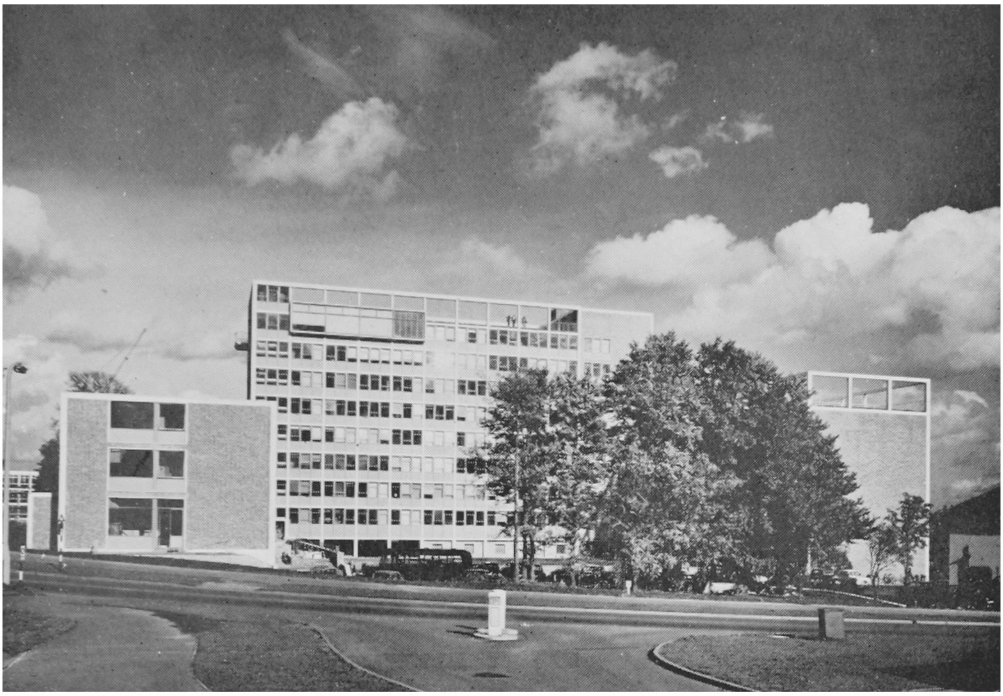

PLATE I—VIEW OF THE METEOROLOGICAL OFFICE, BRACKNELL, FROM THE SOUTH-WEST

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

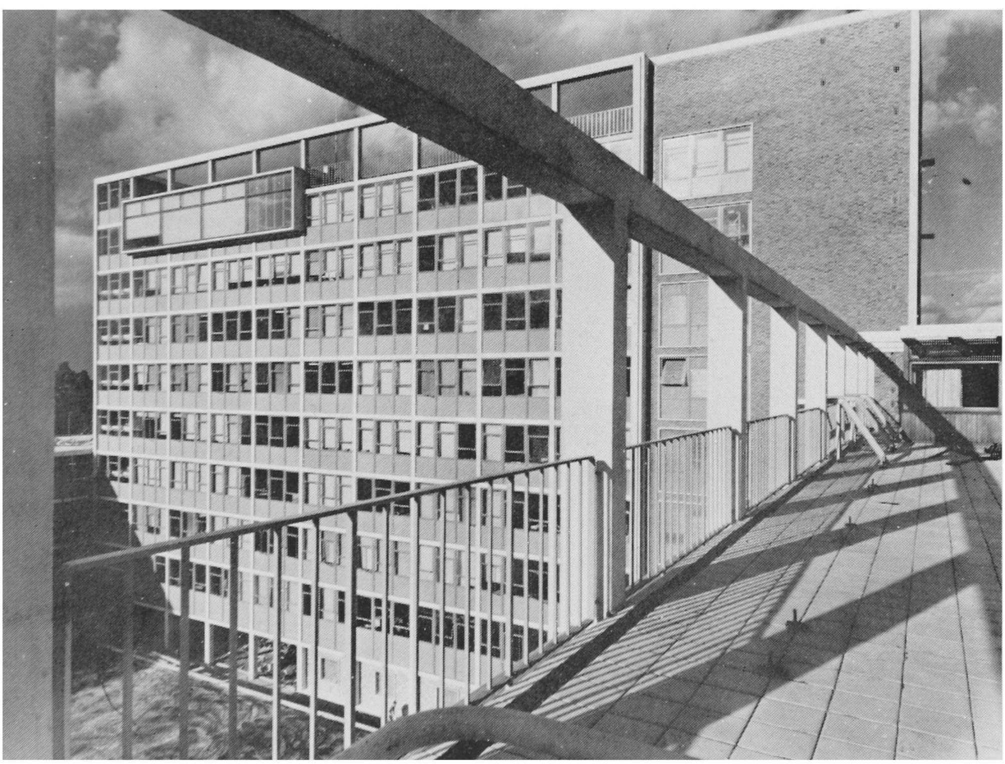

PLATE II—VIEW OF THE NAPIER SHAW BUILDING FROM THE ROOF OF THE FITZROY WING

(see p. 1)

Crown copyright

PLATE III—FORECAST ROOM

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PLATE IV—TELEPRINTER ROOM

(see p. 1)

PLATE V—FACSIMILE ROOM

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. (Myers[5] 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 discussion[1] 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 cm^2, 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 cm^2 = 17 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 Johnson[8] 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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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	Driffield	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. Spreen[2] 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!

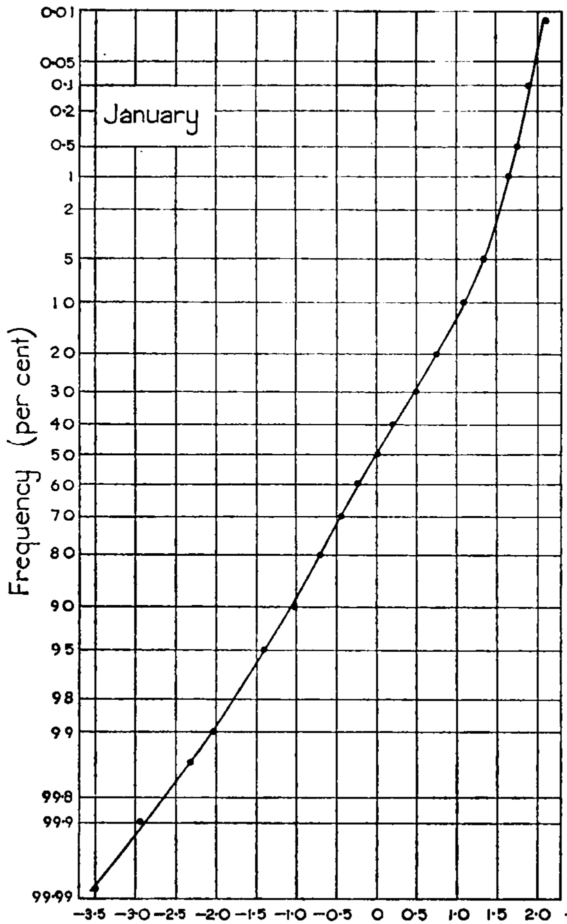

FIGURE 1

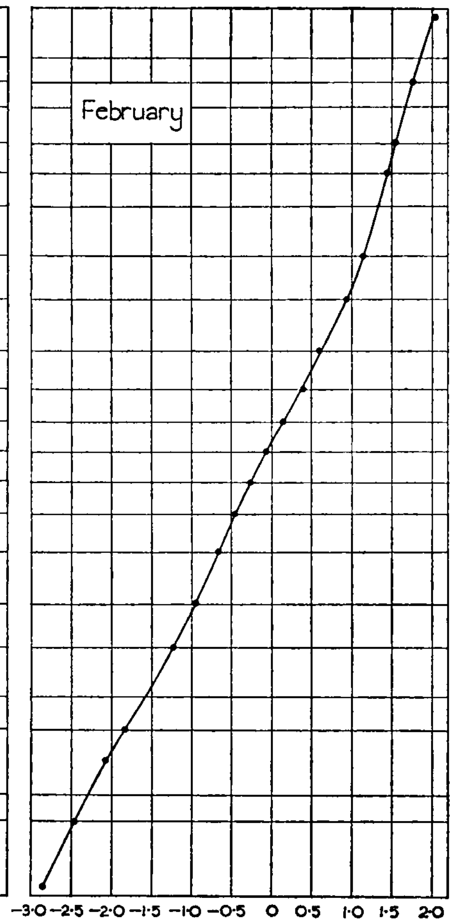

FIGURE 2

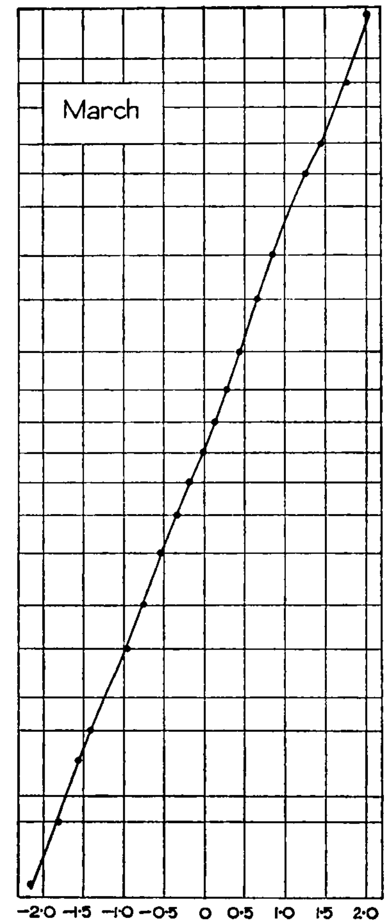

FIGURE 3

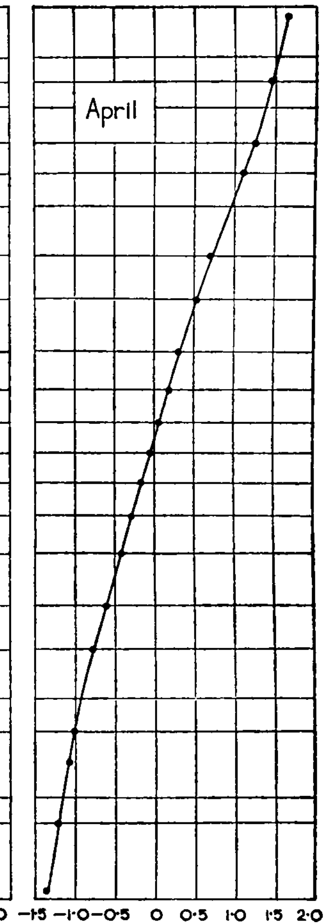

FIGURE 4

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

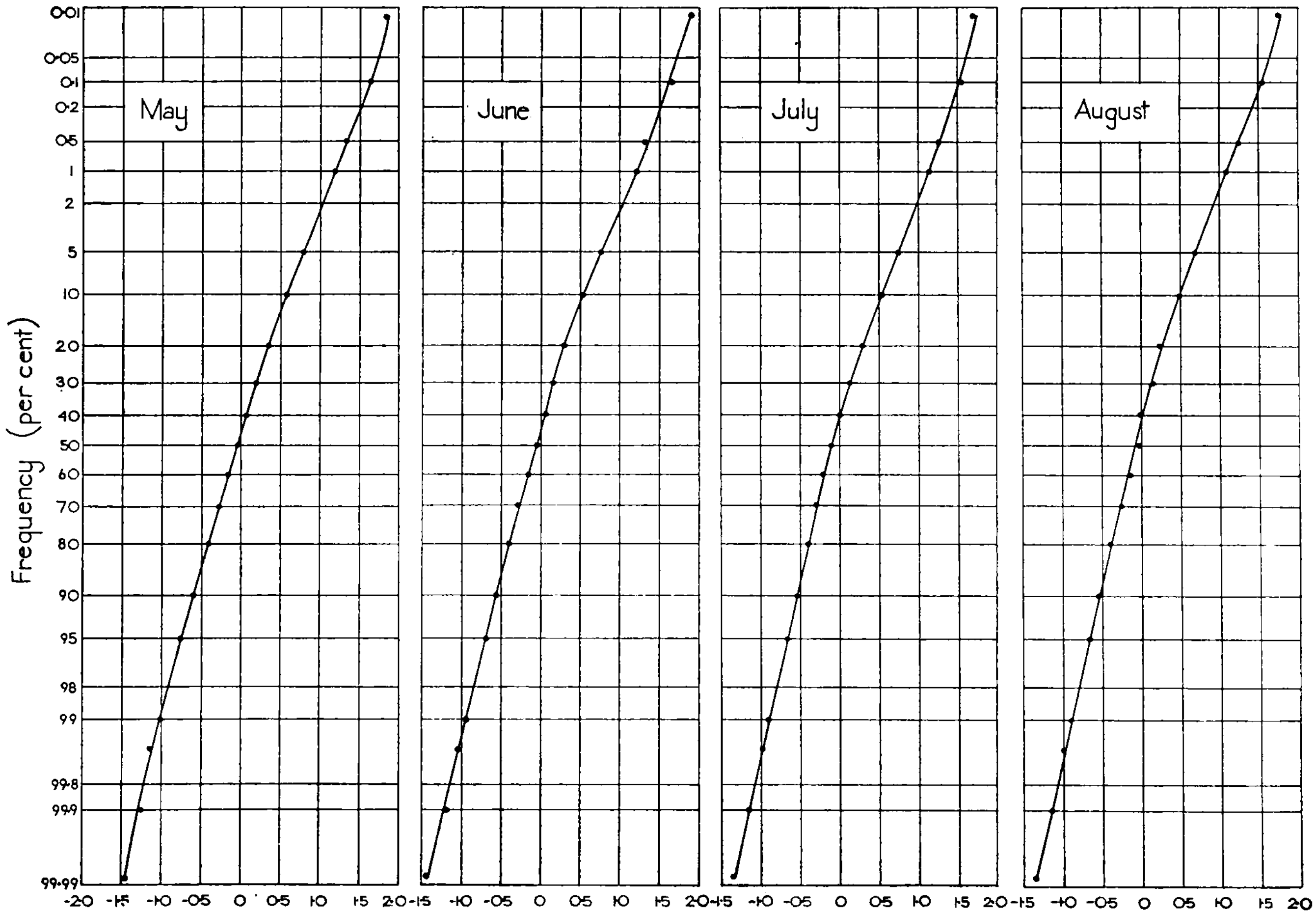

FIGURE 5 FIGURE 6 FIGURE 7 FIGURE 8

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

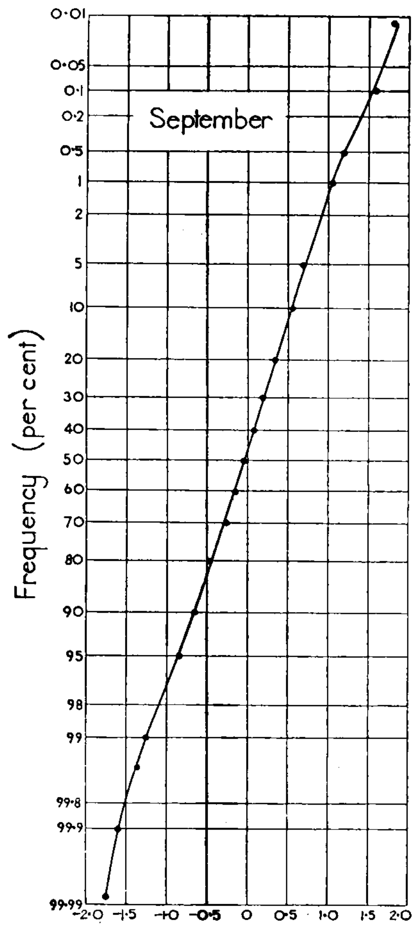

FIGURE 9

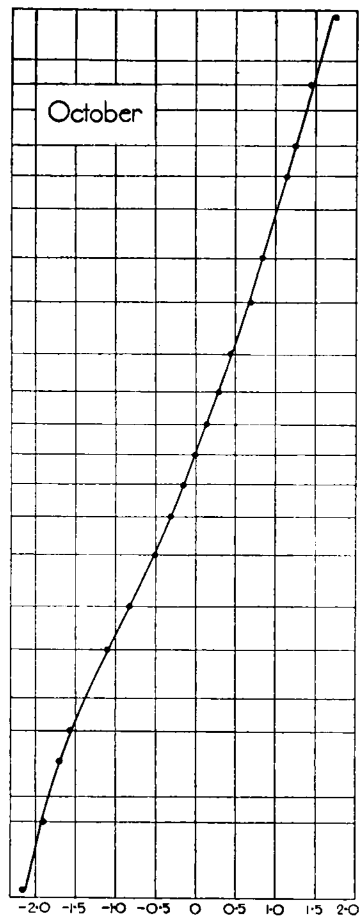

FIGURE 10

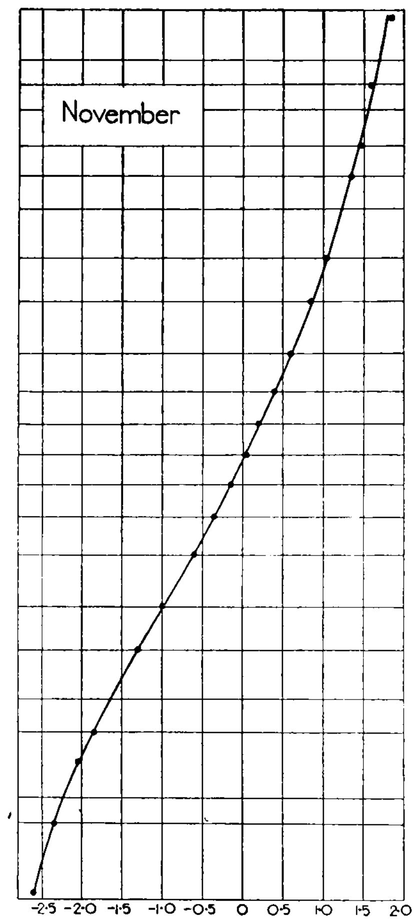

FIGURE 11

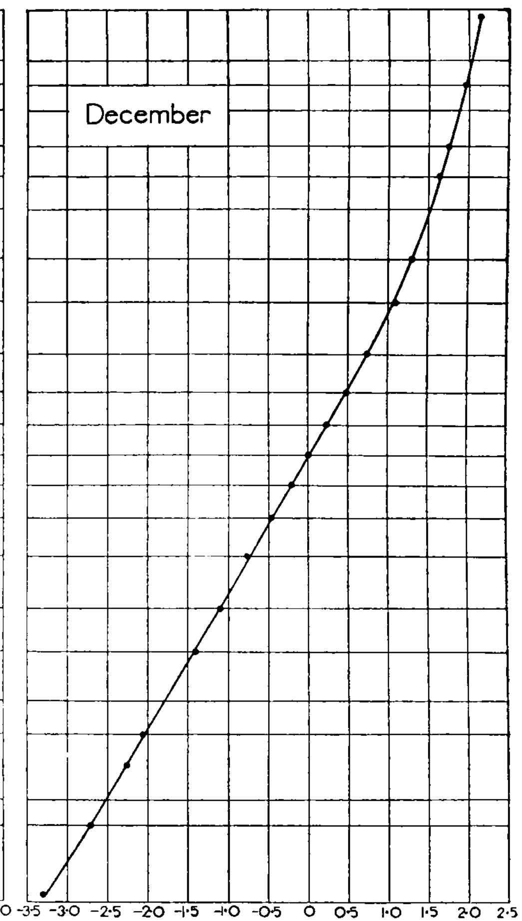

FIGURE 12

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

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

January																			
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
Croydon	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
Lympne	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	−2·1	−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	−1·1	−1·5	−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																			
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
Croydon	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
Lympne	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	−0·8	−1·0	−1·1	−1·2	−1·3
Boscombe Down	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	−0·6	−0·7	−0·9	−1·0	−1·1	−1·2
Renfrew	1·5	1·2	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	−1·4
Stornoway	1·6	1·3	1·1	0·9	0·7	0·5	0·4	0·3	0·1	0	−0·1	−0·2	−0·4	−0·7	−0·9	−1·1	−1·2	−1·5	−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																			
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
Croydon	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
Lympne	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	−0·6	−0·7	−0·9	−1·0	−1·1	−1·2
Boscombe Down	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
Renfrew	1·7	1·5	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	−1·5
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	−0·6	−0·7	−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																			
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
Croydon	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
Lympne	1·9	1·5	1·3	1·2	0·9	0·7	0·5	0·3	0·1	0	−0·2	−0·3	−0·6	−0·9	−1·1	−1·5	−1·7	−1·8	−1·9
Boscombe Down	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
Renfrew	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	−0·8	−1·2	−1·7	−1·8	−2·0	−2·1
Stornoway	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
Aldergrove	1·9	1·5	1·3	1·2	0·9	0·7	0·4	0·3	0·1	0	−0·2	−0·3	−0·5	−0·8	−1·1	−1·6	−1·7	−1·9	−2·4
Manchester	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
Driffield	1·5	1·3	1·1	1·0	0·7	0·6	0·4	0·3	0·1	0	−0·1	−0·3	−0·5	−0·7	−1·0	−1·4	−1·5	−1·7	−1·9
Elmdon	2·0	1·5	1·3	1·1	0·9	0·7	0·5	0·3	0·2	0	−0·1	−0·3	−0·4	−0·7	−1·0	−1·5	−1·7	−1·8	−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 Actual	January Estimated	March Actual	March Estimated	June Actual	June Estimated	August Actual	August Estimated
			percentage frequency (hours)					
−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 Actual*	January Estimated	April Actual*	April Estimated	July Actual*	July Estimated	October Actual*	October Estimated
			percentage frequency (hours)					
−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°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. $8\frac{1}{2}$ in. $\times 5\frac{3}{4}$ in., pp. 608, *illus.*, Oxford University Press, Amen House, London, E.C.4, 1961. Price: 55*s.*

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. $8\frac{1}{2}$ in. × $5\frac{1}{2}$ in., pp. vii+122, *illus.*, The Maritime Press Limited, 30 Fleet Street, London, E.C.4, 1961. Price: 10*s.* 6*d.*

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.

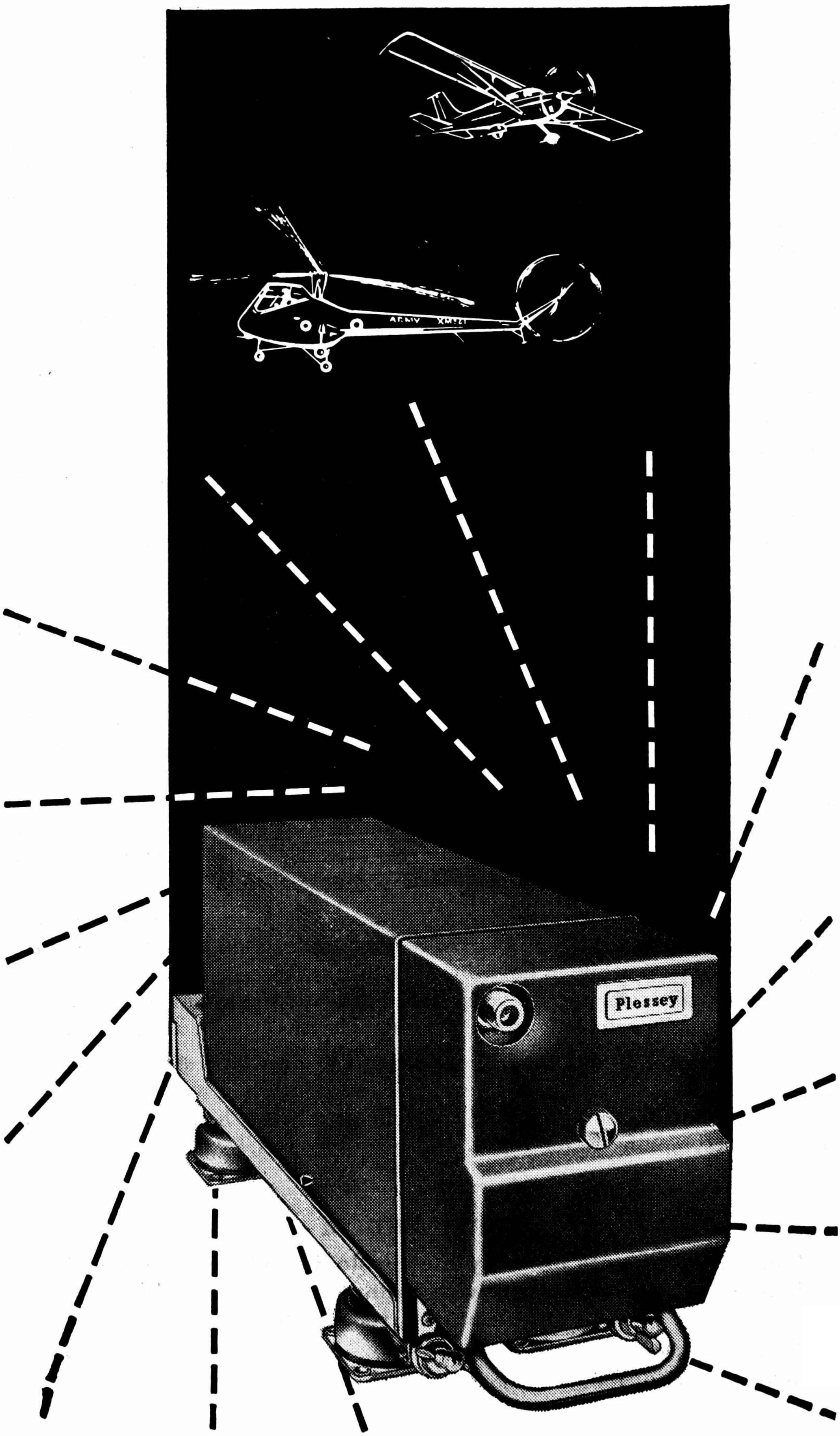
He was commissioned in the R.A.F.V.R. as a Flight Lieutenant in 1943 and served with R.A.F. formations both at home and in Iceland. After demobilization he served for a while in Gibraltar and then returned again to East Anglia, where he remained for several years before undertaking a tour of duty at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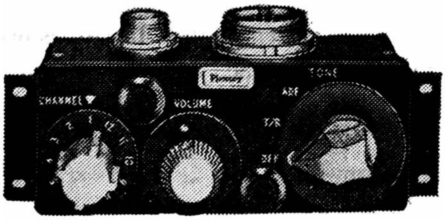

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