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WARMING OF THE LOWER TROPOSPHERE BY THE SEA

By R. M. BLACKALL

Summary. From simple assumptions an equation is derived for calculating the effect of a warm sea passage on the surface temperature of cold air. It makes allowance for the duration of passage and for the depth of warming. An equation is also derived which relates the change in surface humidity mixing ratio to the change of surface temperature. A graphical method of using the calculated surface temperature and dew-point to estimate the temperature and dew-point throughout the convective layer is explained.

Introduction. 'It is well known in a general way that the North Sea in winter has a very marked effect upon the cold dry winds from the continent, but at present no theory is available which will enable a quantitative estimate to be given of the effect which is produced upon an air current which has had a sea track of a given length.

In this note a simple rule is given which it is hoped will be of service to forecasters who are faced with these difficulties. The rule applies only when the air is colder than the sea.'

Thus starts the paper by Frost[1] which gives the well-known equations

$$T = T_0 + 0{\cdot}6(T_s - T_0)\,, \qquad \ldots (1)$$

$$X = X_0 + 0{\cdot}6(X_s - X_0)\,, \qquad \ldots (2)$$

where T and X are the final temperature and humidity mixing ratio of air initially at T_0 and X_0 after crossing water at temperature T_s (the saturated humidity mixing ratio at T_s being X_s).

These equations are unsatisfactory because they imply that the duration of warming and depth of convection are irrelevant to the final answer. The factor 0·6 was intended to apply only to North Sea crossings of about 300 nautical miles,* and the theory on which the equations are based ignores the presence of any anticyclonic inversion. Neither gives any indication of conditions other than at the surface and the second equation leads, in some circumstances, to values of X greater than the saturated humidity mixing ratio at T. The purpose of this paper is to present a simple and practical method (using the tephigram) of deriving values of T and X throughout the convective layer which takes into account both the duration of warming and the depth of convection. It has been assumed that the rate of heat transfer from the sea to the air is proportional to the temperature difference between them when the sea is the warmer.

* 1 n.mile ≈ 2 km.

Variation of temperature. In addition to T, T_o and T_s as defined above (and measured at screen level) the following notation is used :

T_d = dew-point
t = time
Q = quantity of heat
h = depth of convection (in units of length)
d = depth of convection (in millibars)
c_p = the specific heat of air at constant pressure
ρ = the density of the air
g = the acceleration due to gravity.

The initial assumption is that over unit area the combined effect of the transfer of heat by convection, conduction and radiation is given by

$$\frac{dQ}{dt} = k(T_s - T) , \qquad \ldots (3)$$

where k is a constant. If the lapse is unchanged, the rate of change of the mean temperature, T_m, of the layer being heated, dT_m/dt, and the rate of change of the surface temperature, dT/dt, will be equal so that

$$\frac{dT_m}{dt} = \frac{1}{hc_p} \cdot \frac{dQ}{dt} = \frac{dT}{dt} . \qquad \ldots (4)$$

Combination of equations (3) and (4) gives

$$\frac{dT}{dt} = \frac{k}{hc_p\rho}(T_s - T) . \qquad \ldots (5)$$

Since it is inconvenient to have to deal with ρ over the depth of convection h, it is eliminated by recourse to the hydrostatic equation $h\rho = d/g$ so that equation (5) becomes

$$\frac{dT}{dt} = \frac{kg}{dc_p}(T_s - T) .$$

Integration between T_o and T, the initial and final temperature over a period t, and rearrangement of the terms gives

$$\frac{T_s - T}{T_s - T_o} = \exp\left(- \frac{kgt}{dc_p}\right) . \qquad \ldots (6)$$

A paper by Craddock[2] deals with the closely related problem of changes in the 1000–700-mb thickness on a warm sea passage. From pairs of soundings he was able to find a value for k of 162 kJ/m^2 h degC. By substitution of 1·01 kJ/kg degC for the value of c_p for dry air and 9·81 m/s^2 for the value of g the exponential becomes $\exp(- 15{\cdot}8\ t/d)$. A trial using this value gave encouraging results but always a little too warm. Errors were minimized when the exponential function was $\exp(- 12\ t/d)$, implying that k should be 120 kJ/m^2 h degC.

Thus the final solution is

$$T = T_s - (T_s - T_o) \exp (- 12\ t/d). \qquad \ldots (7)$$

Table I gives values of $\exp(- 12\ t/d)$ for varying t and d. Equation (7) has two important properties: when $t = 0$ then $T = T_o$, when $t = \infty$ then $T = T_s$.

TABLE I—VALUES OF $\exp(-12\ t/d)$

d	Duration of crossing, t (hours)														Most probable lapse
(*mb*)	1	2	3	4	5	6	7	8	9	12	15	18	21	24	(*degC*
700	0·98	0·97	0·95	0·93	0·92	0·90	0·89	0·87	0·86	0·81	0·77	0·73	0·70	0·66	
600	0·98	0·96	0·94	0·92	0·90	0·89	0·87	0·85	0·84	0·79	0·74	0·70	0·66	0·62	
500	0·98	0·95	0·93	0·91	0·89	0·86	0·84	0·82	0·81	0·75	0·70	0·65	0·60	0·56	40
450	0·98	0·95	0·92	0·89	0·88	0·85	0·83	0·81	0·79	0·73	0·67	0·62	0·57	0·53	35
400	0·97	0·94	0·91	0·89	0·86	0·84	0·81	0·79	0·76	0·70	0·64	0·58	0·53	0·49	31
350	0·97	0·93	0·90	0·87	0·84	0·81	0·79	0·76	0·73	0·64	0·60	0·54	0·49	0·44	26
300	0·96	0·92	0·89	0·85	0·82	0·79	0·76	0·73	0·70	0·62	0·55	0·49	0·43	0·38	22
250	0·95	0·91	0·86	0·83	0·79	0·75	0·71	0·68	0·65	0·57	0·49	0·42	0·36	0·32	17
200	0·94	0·89	0·84	0·79	0·74	0·70	0·66	0·62	0·58	0·49	0·41	0·34	0·28	0·24	14
180	0·94	0·88	0·82	0·77	0·72	0·67	0·63	0·59	0·55	0·45	0·37	0·30	0·25	0·20	13
160	0·93	0·86	0·80	0·74	0·69	0·64	0·59	0·55	0·51	0·41	0·33	0·26	0·21	0·17	12
140	0·92	0·84	0·77	0·71	0·65	0·60	0·55	0·50	0·46	0·36	0·28	0·21	0·17	0·13	10
120	0·90	0·82	0·74	0·67	0·61	0·55	0·50	0·45	0·41	0·30	0·22	0·17	0·12	0·09	9
100	0·89	0·79	0·70	0·62	0·55	0·49	0·43	0·38	0·34	0·24	0·17	0·12	0·08	0·06	8
80	0·86	0·74	0·64	0·55	0·47	0·41	0·35	0·30	0·26	0·17	0·11	0·07	0·04	0·03	6
60	0·82	0·67	0·55	0·45	0·37	0·30	0·25	0·20	0·17	0·09	0·05	0·03	0·01	—	5
50	0·79	0·62	0·49	0·38	0·30	0·24	0·19	0·15	0·12	0·06	0·03	0·01	—	—	4
40	0·74	0·55	0·41	0·30	0·22	0·17	0·12	0·09	0·07	0·03	0·01	—	—	—	4
30	0·67	0·45	0·30	0·20	0·14	0·09	0·06	0·04	0·03	0·01	—	—	—	—	3

Eddy diffusion studies suggest that equation (3) should read

$$\frac{dQ}{dt} = k'\ V(T_s - T)\ ,$$

where V is some wind speed. Because difficulties arise when $V = 0$ a compromise was tried that

$$\frac{dQ}{dt} = (k + k'\ V)\ (T_s - T).$$

This makes equation (7)

$$T = T_s - (T_s - T_o)\ [\exp(-12\ t/d)]\ [\exp(-k'Vgt/dc_p)] \qquad \ldots (8)$$

The influence of the extra term $\exp(-k'Vgt/dc_p)$ was studied by calculation of its apparent value on 24 occasions from equation (8), substituting for T the observed air temperature after the sea crossing. When these values were plotted against the associated values of Vt/d it was found that the extra exponential term, although it scattered about a mean value close to 1 when Vt/d was small, tended to scatter about values a little greater than 1 as Vt/d increased. However the errors arising from the assumption that the value of the extra exponential term was 1 for all values of Vt/d appeared to be small in relation to the general scatter. This suggests that on the synoptic scale equation (7) is a reasonable practical approximation for the range of wind speeds and associated times of sea crossing explored (15 to 50 kt and 30 min to 15 h) (1 kt ≈ 0·5 m/s).

As the air moves out over the sea convection very rapidly causes mixing, setting up a lapse rate represented on a tephigram by a line whose slope lies between the dry and saturated adiabatic lapse rates. The slope is described in Figure 1, which shows the variation of lapse rate with the depth of convection; the data were derived from 45 ascents, from ships or from coastal stations with winds from the sea, and are summarized at the side of Table I (see above). It is assumed that mixing occurs up to that level at which a dry adiabatic from the sea surface temperature and pressure meets the environment curve. This mixing alone can produce large changes in surface temperature and the full expected change has been observed on a short English Channel crossing taking only 40 min.

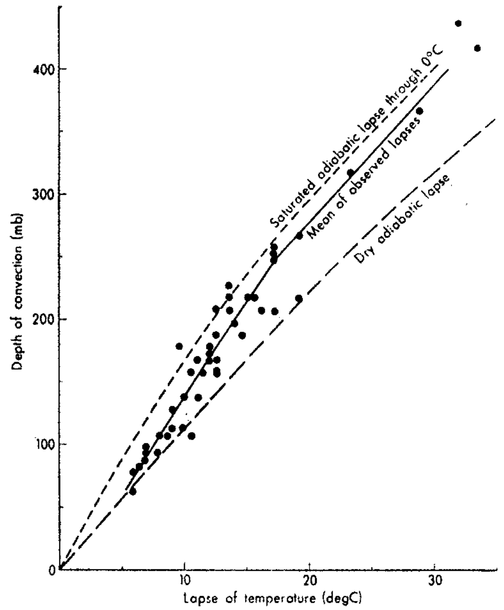

FIGURE 1—VARIATION OF OBSERVED LAPSE RATE OF TEMPERATURE WITH DEPTH OF CONVECTION OVER THE SEA

The plotted points represent data from 45 radiosonde ascents.

Practical forecasting of temperature. The following steps are necessary for the prediction of the final air temperature after a warm sea crossing and are illustrated in Figures 2 and 3.

(a) On the sounding in the air upwind of the sea crossing, draw in the sea level isobar and, if necessary, extend the ascent downwards to meet this isobar at coastal temperatures.

(b) Draw the dry adiabatic through the sea temperature T_s (see (g)). The pressure at which this line meets the environment curve is subtracted from the surface pressure to give the depth of convection d in millibars.

(c) Establish the expected lapse rate: if the air already has a lapse rate implying convection throughout the layer d (see Figure 2) the environment curve should not be changed as any change is unlikely to lead to more-accurate results. If a lapse rate needs to be forecast construct a modified environment curve as follows: draw a line through the layer d, with a lapse appropriate to d (see Figure 1 or side of Table I) such that the environment curve encloses equal areas (A and B in Figure 3) on each side of the line. Where this line meets the surface isobar is T_0. This step represents complete mixing without addition of heat.

(d) Determine the time, t, that the air will spend over the sea from the available wind information for the layer d and the fetch. Note that because of mixing the wind velocity in the convection layer is more or less uniform and great care is required if actual winds are to be used from upwind stations when the soundings from these stations indicate

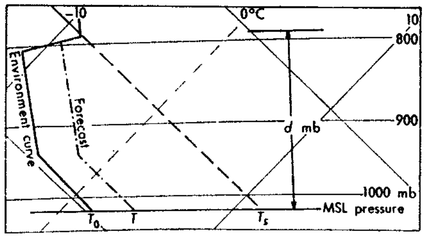

FIGURE 2—STEPS IN THE PREPARATION OF A FORECAST OF TEMPERATURE WHEN THE ENVIRONMENT CURVE NEEDS NO MODIFICATION AND STEP (C) MAY BE OMITTED

See also Figure 5.

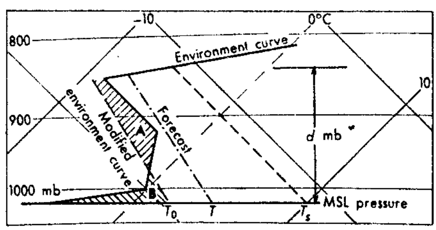

FIGURE 3—STEPS IN THE PREPARATION OF A FORECAST OF TEMPERATURE WHEN A MODIFICATION OF THE ENVIRONMENT CURVE IS NECESSARY

See also Figure 6.

stability over land but instability over the sea. Gradient winds from surface and 850-mb analyses and prognoses should be sufficiently accurate in most cases.

(e) From Table I for the appropriate values of t hours and d millibars find the value of $\exp(-\ 12\ t/d)$ and thence T from equation (7).

(f) From temperature T on the surface isobar, draw a line parallel to the environment curve produced in step (c); this is the predicted environment curve for when the air finishes its crossing.

(g) If the sea temperature is far from uniform a mean value will often give good answers; however, if the changes in T_s will mean changes in d such that $\exp(-\ 12\ t/d)$ alters significantly then it will be necessary to proceed by steps — as will also be necessary when the passage is expected to take more than 24 hours.

The procedure described above does not allow for the presence of fronts and other dynamical means of heating and cooling.

Variation of humidity. In the paper by Craddock cited earlier[2] it was found that over the sea the flux of water vapour, m, was a linear function of the air–sea temperature difference (at the rather low temperatures of the investigation) so that

$$\frac{\mathrm{d}m}{\mathrm{d}t} = A(T_s - T) \qquad \ldots (9)$$

where A was 1·2 mg/cm² h °F, i.e. 21·6 g/m² h K.

Integrating $\int_0^m dm = A\int_0^t (T_s - T)dt$, and

substituting from equation (7)

$$m = A\int_0^t \Big[(T_s - T_o)\exp(-12t/d)\Big]dt,$$

$$m = \frac{Ad}{12}(T_s - T_o)\Big[1 - \exp(-12t/d)\Big].$$

Substituting from equation (7) again gives

$$m = \frac{Ad}{12}(T - T_o),$$

where m is the mass of water in grams evaporated into the layer of air of depth d millibars over an area of one square metre in t hours. This vapour is mixed with M kg of dry air in the same volume where

$$M = h\rho = d/g \times 100, \quad (1 \text{ mb} = 100 \text{ N/m}^2).$$

If the change in the mean humidity mixing ratio for the layer, $\Delta X'$, is measured in grams per kilogram, then

$$\Delta X' = \frac{Ag}{1200}(T - T_o) = 0{\cdot}18(T - T_o). \qquad \ldots (10)$$

Now it is clear from an inspection of tephigrams that the humidity mixing ratio normally decreases rapidly with height and that through a layer affected by convection the dew-point depression is roughly constant: to add $\Delta X'$ throughout the layer of depth, d, would lead to changes in dew-point lapse at variance with observation. At the low temperatures with which this paper is concerned, near 0°C, nearly all the moisture will be in the lowest layers, so that to add $\Delta X'$ to the surface humidity mixing ratio and then allow the dew-point depression to remain constant with height should not be far from the truth.

Practical forecasting of dew-point. The procedure for forecasting dew-point is similar to that described for temperature in sections (a) and (b) and is illustrated in Figure 4. Rearrange the dew-point curve on the ascent

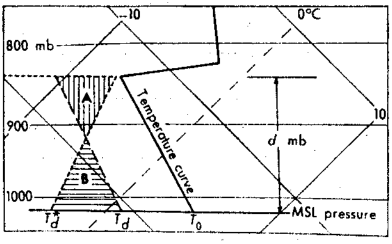

FIGURE 4—STEPS IN THE PREPARATION OF A FORECAST OF DEW-POINT

T_d^* - - - - - - - Initial dew-point curve.
T_d — — — — — Modified dew-point curve.

so that it is parallel to the dry-bulb curve through the layer of depth, *d*, but without any change in the total water content (as a first approximation the original dew-point curve should enclose equal areas on each side of this new line). Note the surface humidity mixing ratio and add to this $0{\cdot}18(T - T_o)$ g/kg; from this new surface humidity mixing ratio draw a line parallel to the forecast temperature curve and this will give a good indication of conditions aloft. Surface dew-points forecast this way were used to compile Tables II and III.

TABLE II—COMPARISON OF ERRORS IN FORECASTING TEMPERATURE AND DEW-POINT ON 24 OCCASIONS

	Method of forecasting temperature		Method of forecasting dew-point	
Range of errors*	Frost's	Present	Frost's	Present
− 6·6 to − 7·5				1
− 5·6 to − 6·5				
− 4·6 to − 5·5				
− 3·6 to − 4·5				2
− 2·6 to − 3·5	1			
− 1·6 to − 2·5	1	2		3
− 0·6 to − 1·5	3	1		4
− 0·5 to + 0·5	3	11	1	6
+ 0·6 to + 1·5	5	7	1	5
+ 1·6 to + 2·5	6	3	2	3
+ 2·6 to + 3·5	2		2	
+ 3·6 to + 4·5			4	
+ 4·6 to + 5·5	2		5	
+ 5·6 to + 6·5	1		5	
+ 6·6 to + 7·5			2	
+ 7·6 to + 8·5			2	

* The error is expressed as (calculated value − observed value).

TABLE III—COMPARISON OF ERRORS OBTAINED WHEN USING FROST'S METHOD AND THE PRESENT METHOD DERIVED FROM THE SAME 24 OCCASIONS AS IN TABLE II

	Frost's method for		Present method for	
	T	T_d	T	T_d
Mean error	2·0	4·6	1·0	1·5
Root-mean-square error	2·75	5·4	1·25	2·4

In practice, since with dew-points in the range 0°C to − 15°C the change of saturation humidity mixing ratio with temperature is near to 0·18 g/kg K, the application of the above technique will often result in an approximately constant dew-point depression during the warming and this can be very useful when surface charts are analysed on which cold air is being warmed over water, as it decreases the temptation to insert extra fronts.

Results. The data used were collected in the winters of 1968–69 and 1969–70 when the track of cold air across the North Sea or eastern North Atlantic could be shown to begin at a place with a radiosonde ascent and finish at a station from which a synoptic report was available. There were 24 occasions when this occurred and the data were readily available; the duration of crossing varied from 40 min to 15 h and the depth of convection from 35 mb to 500 mb. Table II compares the errors obtained on these occasions by the use of both the present method and Frost's method (equations (1) and (2) on page 65). An attempt to gather another independent set of data from earlier winters was largely frustrated by uncertainties of trajectory and timing which required a quite disproportionate amount of effort to resolve.

The new method usually gives better results; if the layer being warmed is deep — as for an Arctic northerly — the results are greatly superior. A count of the errors in temperature showed that Frost's method (equation (1)) gave better results on 8 occasions but the new method gave better results on 13 occasions (there was no difference on the other 3 occasions). A similar count of the errors in dew-point showed that Frost's method (equation (2)) gave better results on only 2 occasions but the new method gave better results on 21 occasions (on 1 occasion there was no difference). The results obtained for the dew-point are particularly good although there are well-known difficulties in getting an accurate dew-point in sub-freezing wet-bulb conditions. Table III, which summarizes the mean errors and the root-mean-square error obtained by the two methods, also shows the superiority of the present method.

Experience shows that in the construction of a modified temperature profile, the conditions in the bottom layers, say within 20 mb of the surface, have very little effect on T because the mixing spreads them through a considerable depth. In other words the diurnal temperature cycle on the continental coast will not normally be apparent after the air has made a sea passage lasting more than about 30 min unless the heating is going to be confined to a shallow layer only.

Figures 5 and 6 are examples of what can happen. In Figure 5 the Arctic maritime air is warmed as it moves from ship 'M' to Lerwick, but there is a problem in deciding a representative temperature and dew-point structure,

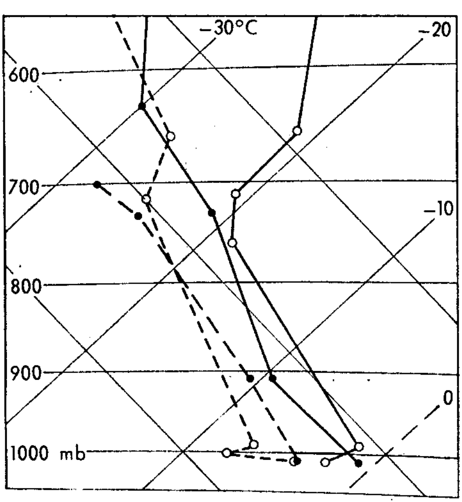

FIGURE 5—EFFECT ON THE SURFACE TEMPERATURE OF COLD AIR OF A WARM SEA PASSAGE FROM OWS 'M' TO LERWICK

●—● OWS 'M', 12 GMT, 10 January 1968; ○—○ Lerwick, 00 GMT, 11 January 1968. Pecked lines denote dew-point.
Distance 370 n. mile, speed 40–50 kt.

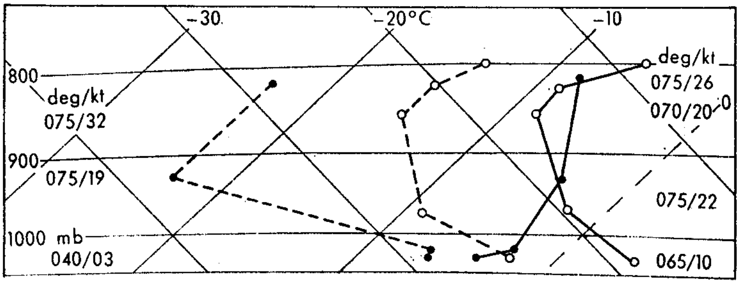

FIGURE 6—EFFECT ON THE SURFACE TEMPERATURE OF COLD AIR OF A SHORT WARM SEA PASSAGE FROM DE BILT TO SHOEBURYNESS, 26 FEBRUARY 1968

●—● De Bilt, 00 GMT; ○—○ Shoeburyness, 12 GMT.
Pecked lines denote dew-point. De Bilt winds on left, Shoeburyness on right.
Distance 90 n. mile.

since either ascent may have been affected by the presence of cumulonimbus, and a short passage over a snow-covered surface has created an inversion in the lowest 20 mb at Lerwick. Figure 6 shows the profound effect of a short sea crossing on air that was cold, stable and dry; particularly worthy of note is that mixing has caused a fall in temperature at 850 mb which was not compensated for by subsequent heating.

Finally it is worth repeating the warning that when fronts, troughs and other means of dynamical heating and cooling affect the passage, or are very close to it, then these cannot be ignored and some allowances should be made even if they cannot be calculated exactly.

Acknowledgements. The author would like to thank all his colleagues who helped collect the raw data for this paper and who offered advice, and especially Mr R. J. Ogden, Mr S. E. Virgo, O.B.E., and Mr N. Thompson for their constructive criticisms.

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RECENT TEMPERATURE CHANGES DUE TO CHANGES IN THE FREQUENCY AND AVERAGE TEMPERATURE OF WEATHER TYPES OVER THE BRITISH ISLES

By A. H. PERRY and R. G. BARRY
University College, Swansea, and University of Colorado, Boulder

Summary. Mean daily maximum and minimum temperatures for the mid-season months of 1925–35 and 1957–67 have been determined for the 'weather type' categories of Lamb at four stations in the British Isles. Evaluation of the changes between the periods due to changes in type frequency and within-type changes of temperature level shows that, apart from January, the latter have a more significant effect on the total change. Problems of explaining these changes are discussed.

Introduction. The temperature fluctuation over the last 30–40 years in the British Isles has been attributed primarily to the decrease in frequency of westerly circulation[1] and the corresponding increase in meridional air-flow types. It has been suggested,[2] however, that temperature changes at Eskdalemuir between 1925–35 and 1957–67 represent the combined effect of changes in the temperature of individual types and changes in type frequency. Only in January, apparently, is the latter effect dominant. This analysis is now extended to three other stations.

Method. The expressions used to determine the contribution of within-type changes of temperature and of changes in airflow-type frequency to the change in monthly mean temperature between two periods are derived as follows :

The average monthly mean temperature during the first time period

$$\overline{T} = \sum_{i=1}^{k} \frac{f_i T_i}{n},$$

where f_i = frequency of type i during the first time period,

T_i = mean temperature of type i during the first time period,

n = total number of days in the first time period,

$\sum_{i=1}^{k}$ = summation over all k types.

Let $f_i + \Delta f_i$ = frequency of type i during the second time period,

$T_i + \Delta T_i$ = mean temperature of type i during the second time period,

$\overline{T} + \Delta\overline{T}$ = average monthly mean temperature during the second time period.

Then
$$\Delta\overline{T} = \sum_{i=1}^{k} \left\{ \frac{(f_i + \Delta f_i)\ (T_i + \Delta T_i)}{n} - \frac{f_i T_i}{n} \right\}$$

$$= \sum_{i=1}^{k} \left\{ \frac{\Delta f_i\ (T_i + \Delta T_i)}{n} + \frac{f_i \Delta T_i}{n} \right\}. \qquad \ldots (1)$$

The second term on the right hand side in (1), which is independent of any change in frequency, is a component due to within-type changes of temperature. The first term on the right hand side in (1) represents the effect on $\Delta\overline{T}$ of a change in type frequency when a change occurs in the temperature of type i in the second period.

In the previous study[3] the component attributed to changes in type frequency was determined from

$$\sum_{i=1}^{k} \frac{\Delta f_i}{n} \left[(T_i + \Delta T_i) - \overline{T} \right]. \qquad \ldots (2)$$

The additional term in (2), $(\frac{\Delta f_i}{n}\ \overline{T})$, is zero when summed over $i = 1$ to k

and whenever $\Delta f_i = 0$. This expression avoided ambiguity when examining types with a negative Celsius temperature.

In the present analysis the contributions of terms $\Delta f_i\ (T_i + \Delta T_i)/n$ and $f_i \Delta T_i/n$ have been evaluated for mean daily maximum and minimum temperatures for January, April, July and October between 1925–35 and 1957–67 at Buxton, Gorleston and Valentia, and recalculated at Eskdalemuir using the revised catalogue of 'weather types'.[4] Gorleston and Valentia were selected because of their homogeneous record at extreme longitudinal locations in the British Isles, while the results for Buxton should provide some check on those obtained for Eskdalemuir where site changes may have influenced the findings.[5]

Some inaccuracy is present in the data through conversion of units from degrees Fahrenheit in the records of the first period and consequent rounding errors. The computations, which were performed on a desk-top computer, are therefore summarized in Tables III to VI for changes of 0·10 degC or more in the components for individual types. This serves to focus attention on the major changes and is realistic in the light of the significance levels for the observed values of $\Delta \overline{T}$ (Tables III–VI).

Results. Table I gives the type frequency and mean temperatures of the types at the four stations in 1957–67. The change in type frequencies for 1957–67 minus those for 1925–35 and the corresponding changes in the mean daily maximum and minimum temperature for each type at the four stations are shown in Table II. The contributions of the two components of equation (1) to $\Delta \overline{T}$ are tabulated in Tables III–VI.

The results in Tables III–VI reinforce the earlier suggestion[2] that changes in type frequency have contributed significantly to the average temperature change between the two periods only in January. In the other three months the greater part of the total change is due to a component of within-type changes of temperature ($f_i \Delta T_i/n$).

The main features of the tables can be summarized briefly. In January, maximum and minimum temperatures decreased from 1925–35 to 1957–67 at all four stations. Except for minima at Eskdalemuir and Buxton most of this change resulted from the decrease in frequency of W type (Tables I and III). The increased frequencies of N and E types and their generally lower temperatures in 1957–67 (Table II) make only limited contributions to the overall temperature changes (Table III), although further calculations (not included) indicate that $\Sigma \Delta f_i \Delta T_i/n$ accounts for approximately one third of the $\Sigma \Delta f_i\ (T_i + \Delta T_i)/n$ term, primarily due to changes with N and E types. Comparison of the results for Valentia and Eskdalemuir in Table III shows that the use of the expression $\Delta f_i\ (T_i + \Delta T_i)/n$ causes some ambiguity, since minimum temperatures at Eskdalemuir are below 0°C for N, NE and E types. To avoid this problem the component $\Delta f_i\ (T_i + \Delta T_i)/n$ may be computed in kelvins. If this is done in the case of Buxton and Eskdalemuir minima in January, for example, the distinction between W and SW types on the one hand, and N and E types, on the other, is made evident. However, in using kelvins to compare between types, or two stations with the same type, temperature level is subordinated to the change of type frequency so that the results essentially reflect the Δf_i in Table II.

TABLE I—TYPE FREQUENCY $(f_i + \Delta f_i)$ AND MEAN DAILY MAXIMUM AND MINIMUM TEMPERATURE OF TYPES $(T_i + \Delta T_i)$ AT BUXTON, ESKDALEMUIR, GORLESTON AND VALENTIA, 1957–67

		Buxton		Eskdalemuir	$T_i + \Delta T_i$	Gorleston		Valentia	
Type	$(f_i+\Delta f_i)$	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
January				*degrees*	*Celsius*				
NW	16	4·7	0·9	4·4	−0·2	5·4	2·1	8·6	6·3
N	37	1·8	−2·9	2·0	−2·6	3·5	−0·6	6·9	0·8
NE	10	−0·6	−4·5	1·9	−5·0	2·1	−1·2	4·5	0·8
E	37	0·1	−3·3	1·0	−2·3	2·5	0·0	5·6	2·1
SE	9	−0·2	−0 9	1·9	−2·7	3·4	1·4	8·8	6·1
S	32	5·2	0·9	5·3	0·6	6·7	3·4	10·8	7·6
SW	14	6·7	1·6	6·4	3·2	7·0	2·9	10·9	7·4
W	54	6·8	2·0	5·3	0·8	8·0	3·5	10·4	6·2
AW	9	5·8	0·1	6·2	1·7	5·3	1·2	10·6	6·1
CW	20	6·5	2·0	5·0	1·6	8·4	4·0	9·8	5·8
A	60	2·8	−2·8	3·3	−3·4	4·0	0·2	8·4	3·1
C	31	4·2	0·6	3·0	−0·7	6·5	2·8	9·0	4·6
U	12	3·6	−0·4	3·1	−2·0	5·5	3·1	9·1	3·7
Mean		3·8	−0·7	3·8	−1·1	5·4	1·7	8·8	4·1
April				*degrees*	*Celsius*				
NW	21	8·7	3·6	10·1	2·8	11·6	5·5	11·4	7·7
N	33	8·2	2·8	9·8	1·3	9·4	4·3	12·2	5·4
NE	15	7·3	1·8	8·8	1·4	7·3	4·6	12·1	5·3
E	41	6·5	1·2	7·4	0·8	7·2	4·1	11·8	5·5
SE	6	10·2	2·2	10·0	2·0	9·7	6·3	13·2	8·7
S	27	12·1	5·0	10·7	4·1	11·4	6·5	13·2	7·7
SW	10	12·4	6·2	11·7	5·8	12·4	6·8	13·2	8·6
W	50	10·2	3·4	9·9	2·9	12·5	5·3	11·9	7·6
AW	13	11·3	4·6	12·0	3·3	13·1	4·9	13·1	6·8
CW	4	8·2	2·6	8·7	2·2	12·5	4·8	11·2	6·8
A	60	11·1	2·8	13·3	0·7	9·6	5·2	13·9	5·8
C	34	8·9	3·6	8·5	3·0	11·4	6·5	11·7	6·4
U	16	9·0	2·4	9·8	0·8	9·2	4·5	12·0	6·1
Mean		9·7	3·1	10·3	2·1	10·4	5·3	12·4	6·5
July				*degrees*	*Celsius*				
NW	37	14·7	9·0	15·9	8·1	17·9	11·1	16·6	12·0
N	46	14·7	9·1	16·7	7·2	17·0	11·2	17·3	11·5
NE	5	14·2	9·4	16·6	9·2	16·4	13·4	19·8	11·6
E	13	17·2	11·3	17·6	9·3	16·9	13·5	18·5	11·8
SE	2	21·7	8·6	22·0	8·5	18·0	15·0	19·5	13·0
S	12	19·2	10·4	17·0	8·3	18·5	13·3	17·4	13·2
SW	7	20·6	12·6	18·0	11·8	21·0	14·3	18·3	13·3
W	59	17·0	10·7	15·9	8·9	20·6	13·2	16·8	12·7
AW	42	18·7	10·5	17·4	9·1	20·6	13·0	17·8	12·0
CW	8	16·1	10·2	15·0	9·5	19·4	11·4	15·6	11·6
A	52	18·4	9·1	18·5	6·9	18·0	12·5	18·4	10·9
C	63	16·6	10·4	16·3	9·5	19·5	13·1	16·9	12·0
U	13	18·8	10·9	17·8	6·6	19·5	14·1	17·5	11·2
Mean		16·9	10·1	17·0	8·5	19·0	12·7	17·4	12·0
October				*degrees*	*Celsius*				
NW	19	9·5	4·7	10·6	4·0	12·0	6·7	13·1	8·9
N	22	8·1	2·9	9·3	2·1	10·9	6·2	12·2	6·4
NE	3	8·5	5·2	9·6	5·0	11·7	7·7	13·0	6·3
E	18	12·0	7·7	11·7	7·6	14·3	10·5	16·2	9·0
SE	19	13·0	6·1	14·1	4·7	14·5	12·1	16 9	12·0
S	28	13·9	6·4	14·1	6·7	15·7	10·9	15·9	10·8
SW	14	13·0	5·9	11·7	6·1	15·1	8·8	14·4	10·1
W	69	11·9	6·9	11·0	5·2	14·7	8·7	13·9	9·8
AW	20	12·0	4·6	11·6	4·7	14 2	6·3	14·2	9·3
CW	14	12·2	7·2	11·3	6·5	14·9	9·8	13·8	9·8
A	59	11·6	5·3	11·9	4·4	13·9	9·0	14·9	8·5
C	47	10·9	6·2	10·9	5·0	14·3	9·9	13·1	7·6
U	9	11·8	6·2	11·5	3·4	14·4	9·0	14·1	7·6
Mean		11·6	5·9	11·7	5·1	14·1	9·0	14·3	9·4

NW = anticyclonic north-westerly, north-westerly, and cyclonic north-westerly; similarly for the other types except W.

W = westerly type; AW = anticyclonic westerly; CW = cyclonic westerly; A = anticyclonic; C = cyclonic U = unclassifiable days.

In April (Table IV) the changes $\Delta\overline{T}$ are small and mainly non-significant except for increases in minimum temperature at Eskdalemuir and in maximum temperature at Valentia. The within-type component of temperature change

TABLE II—CHANGE IN TYPE FREQUENCY (Δf_i) AND IN MEAN DAILY MAXIMUM AND MINIMUM TEMPERATURE OF TYPES (ΔT_i) AT BUXTON, ESKDALEMUIR, GORLESTON AND VALENTIA, BETWEEN 1925–35 AND 1957–67

		Buxton		Eskdalemuir	ΔT_i	Gorleston		Valentia	
Type	Δf_i	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
January									
				degrees Celsius					
NW	4	−0·2	0·3	−1·6	−1·2	−0·8	−0·4	−1·2	0·0
N	19	−1·9	−2·5	−1·0	0·3	−1·4	−1·2	−1·1	−3·1
NE	7	−2·8	−3·4	−0·8	−1·5	−4·5	−2·7	−1·7	−2·0
E	29	−1·9	−1·4	−0·8	−1·3	−0·3	−0·1	−1·1	1·0
SE	4	−5·1	−3·1	−1·7	−0·8	−1·5	−0·8	−2·4	−1·6
S	3	−0·1	1·1	−0·5	0·2	0·4	0·2	0·2	0·2
SW	−15	0·6	0·0	−0·3	1·5	−1·0	−1·6	0·6	1·2
W	−68	0·4	0·0	−1·0	−0·4	0·1	−0·1	0·4	−0·3
AW	1	0·9	−1·2	0·3	2·1	−0·2	−0·5	0·4	−0·3
CW	2	0·7	0·8	0·2	1·7	0·4	1·6	1·1	1·1
A	8	−0·1	−1·4	−0·1	−0·1	−1·2	−1·1	0·7	−0·6
C	4	0·1	0·8	−0·2	−0·1	0·3	0·9	0·9	0·7
U	2	−0·5	−0·5	1·0	2·7	0·6	1·5	0·8	1·6
April									
				degrees Celsius					
NW	−7	0·6	1·3	1·0	2·5	0·8	1·6	0·5	0·6
N	−11	0·7	1·6	1·1	1·5	0·6	1·6	1·1	0·5
NE	1	1·3	1·0	1·0	1·3	−0·3	0·4	1·7	1·1
E	5	−2·0	−1·2	−1·0	−0·7	−1·5	−1·3	0·4	0·2
SE	−1	−0·5	−1·1	−0·6	−0·5	0·4	0·6	0·6	1·3
S	3	0·9	0·3	−1·5	−0·1	0·2	−0·9	0·5	−1·2
SW	1	0·8	3·2	2·3	3·1	−0·2	−0·3	0·6	1·2
W	2	−0·2	−0·5	0·1	1·3	0·1	0·2	0·7	0·5
AW	0	0·1	0·3	1·5	−1·1	−1·4	−2·0	0·5	−1·9
CW	−4	−1·9	−1·0	0·5	1·1	0·8	0·4	1·1	0·5
A	25	1·7	1·0	2·3	1·7	−0·7	0·9	1·6	0·6
C	−16	0·3	0·6	−0·1	1·9	0·7	0·7	0·6	0·9
U	2	−1·8	−0·2	−0·7	0·1	−2·1	−0·8	−0·5	0·3
July									
				degrees Celsius					
NW	7	−1·9	−1·5	−1·0	−0·5	−1·5	−0·1	−0·2	−0·7
N	24	−1·0	−0·2	0·2	−0·9	−0·2	0·7	0·6	−0·2
NE	−2	−8·5	−3·0	−0·4	0·5	−3·4	−0·5	0·9	0·6
E	−5	−3·3	0·1	−2·6	−0·7	−2·4	−1·2	−1·3	−1·3
SE	−4	−2·6	−2·6	−2·5	−2·5	0·3	−0·2	−3·7	−1·6
S	−6	−0·8	−1·9	−2·3	−2·6	−2·1	−1·0	−1·1	−0·1
SW	−9	0·9	0·7	0·5	0·5	−1·3	−0·8	0·9	−0·4
W	−15	−0·3	0·0	−0·6	−0·6	−0·4	−0·2	−0·1	−0·5
AW	4	0·4	−0·2	0·9	−0·8	−1·0	−0·8	0·7	−0·8
CW	8	−1·0	−0·8	−1·7	−0·3	−0·9	−1·2	−0·6	−1·0
A	1	−1·8	−1·5	−2·7	−1·1	−0·9	0·2	−1·3	−0·6
C	11	−0·8	−0·8	−0·3	−0·3	−0·4	0·0	0·3	−0·3
U	2	−1·0	0·3	−0·1	−3·2	−0·3	0·1	0·3	−1·3
October									
				degrees Celsius					
NW	−4	−0·2	0·0	0·8	1·4	0·1	2·0	0·8	−0·5
N	−6	−0·6	0·3	1·5	1·6	0·2	2·5	0·6	−0·5
NE	−3	−2·1	0·1	−0·8	3·3	−1·4	−1·6	−0·7	−3·0
E	2	1·1	2·5	1·2	4·2	1·2	0·7	2·6	0·2
SE	16	4·2	2·9	4·0	3·1	1·6	2·1	0·2	0·5
S	13	1·6	−1·0	1·9	−0·9	0·9	0·0	1·0	−0·6
SW	1	−0·1	−2·8	−0·5	−2·0	−1·6	−2·0	−0·3	−1·3
W	−35	0·3	0·8	−0·1	0·8	0·0	0·0	0·2	−0·4
AW	11	−3·1	−4·0	−3·3	−2·4	−1·6	−3·9	−1·4	−2·1
CW	−9	1·1	1·3	1·4	3·4	0·0	1·5	1·0	0·7
A	5	0·5	2·1	0·6	2·8	0·0	2·2	−0·2	0·7
C	12	0·4	0·9	1·3	1·8	0·5	2·6	0·4	−1·0
U	−3	2·9	2·9	3·8	4·9	2·6	4·2	1·5	−0·2

See note below Table I.

accounts for almost all of these increases. The positive contribution at all four stations of the $\Delta f_i\,(T_i + \Delta T_i)/n$ term with Anticyclonic type is cancelled out by negative contributions from Cyclonic, Northerly and North-westerly types (see Δf_i in Table II).

TABLE III—CONTRIBUTION OF COMPONENTS OF CHANGE OF TYPE FREQUENCY AND OF CHANGE OF TEMPERATURE WITHIN TYPE TO THE CHANGES IN MEAN DAILY MAXIMA AND MINIMA AT BUXTON, ESKDALEMUIR, GORLESTON, AND VALENTIA BETWEEN 1925–35 AND 1957–67 IN JANUARY (CHANGES <0·1 degC OMITTED)

	Buxton				Eskdalemuir			
	Maximum		Minimum		Maximum		Minimum	
Type	a*	b	a	b	a	b	a	b
				degrees Celsius				
NW								
N	0·10	−0·10	−0·16	−0·13	0·11		−0·15	
NE							−0·10	
E			−0·28				−0·20	
SE								
S								
SW	−0·29				−0·28		−0·14	0·13
W	−1·35	0·14	−0·40		−1·06	−0·36	−0·16	−0·14
AW								
CW								
A				−0·21				
C								
U								
Total for all types	−1·2	0·0	−1·1	−0·3	−0·8	−0·6	−0·8	0·1
$\Delta\overline{T}$	−1·2		−1·3		−1·3		−0·8	
Significance level (%)	10		8		6		n.s.	

	Gorleston				Valentia			
	Maximum		Minimum		Maximum		Minimum	
Type	a	b	a	b	a	b	a	b
				degrees Celsius				
NW					0·10			
N	0·19				0·38			−0·16
NE								
E	0·21				0·48		0·18	
SE					0·10			
S					0·10			
SW	−0·31		−0·13	−0·14	−0·48		−0·33	0·10
W	−1·60		−0·70		−2·07	0·14	−1·24	−0·11
AW								
CW								
A	0·10	−0·18		−0·17	0·20	0·11		
C					0·11			
U								
Total for all types	−1·0	−0·4	−0·6	−0·3	−0·8	0·3	−1·0	−0·1
$\Delta\overline{T}$	−1·3		−1·0		−0·5		−1·2	
Significance level (%)	8		n.s.		n.s.		3	

See note below Table I.

*a denotes contribution of $\Delta f_i(T_i + \Delta T_i)/n$ to the changes in mean daily maxima and minima at each station.

b denotes contribution of $f_i \Delta T_i/n$ to the changes in mean daily maxima and minima at each station.

In July, the contribution of the temperature decrease with Anticyclonic type (Table II) to $\Delta\overline{T}$ is apparent in the $f_i \Delta T_i/n$ term at Buxton and Eskdalemuir (Table V). This decrease is strengthened by similar temperature changes with other types whereas the $\Delta f_i\ (T_i + \Delta T_i)/n$ contributions again largely cancel out, as in April.

In October, a total temperature increase $\Delta\overline{T}$ occurred at Eskdalemuir and less clearly at Buxton while it was limited to the minimum temperature at Gorleston and the maximum at Valentia (Table VI). Anticyclonic and Westerly types made large contributions to the within-type change of minima

TABLE IV—CONTRIBUTION OF COMPONENTS OF CHANGE OF TYPE FREQUENCY AND OF CHANGE OF TEMPERATURE WITHIN TYPE TO THE CHANGES IN MEAN DAILY MAXIMA AND MINIMA AT BUXTON, ESKDALEMUIR, GORLESTON, AND VALENTIA BETWEEN 1925–35 AND 1957–67 IN APRIL (CHANGES <0·1 degC OMITTED)

	Buxton				Eskdalemuir			
	Maximum		Minimum		Maximum		Minimum	
Type	a	b	a	b	a	b	a	b
				degrees Celsius				
NW	−0·18			0·11	−0·21			0·21
N	−0·26	0·10		0·21	−0·33	0·15		0·20
NE								
E	0·10	−0·22		−0·13	0·11	−0·11		
SE								
S	0·11					−0·11		
SW								
W								0·19
AW								
CW	−0·10				−0·11			
A	0·81	0·18	0·21	0·11	1·01	0·24		0·18
C	−0·42		−0·17		0·41		−0·14	0·29
U								
Total for all types	0·2	0·2	0·0	0·4	0·3	0·4	−0·1	1·1
$\Delta\overline{T}$	0·4		0·4		0·8		0·9	
Significance level (%)	n.s.		n.s.		8		6	

	Gorleston				Valentia			
	Maximum		Minimum		Maximum		Minimum	
Type	a	b	a	b	a	b	a	b
				degrees Celsius				
NW	−0·25		−0·11		−0·24		−0·17	0·14
N	−0·31		−0·14	0·21	−0·41	0·15	−0·18	
NE								
E	0·11	−0·16		−0·14	0·18			
SE								
S	0·10				0·12			
SW								
W						0·10		
AW								
CW	−0·15				−0·14			
A	0·73		0·39	0·10	1·05	0·17	0·44	
C	−0·55	0·11	−0·32	0·11	−0·57		−0·31	0·14
U								
Total for all types	−0·1	−0·1	−0·0	0·3	0·2	0·8	−0·0	0·5
$\Delta\overline{T}$	−0·2		0·3		1·0		0·3	
Significance level (%)	n.s.		n.s.		1		n.s.	

See notes below Tables I and III.

at Buxton and Eskdalemuir. The contribution to $\Delta\overline{T}$ of the decrease in frequency of Westerly type (Table II) in the expression $\Delta f_i\,(T_i + \Delta T_i)/n$ was generally more than offset by the increased frequencies of S, SE and C types.

Discussion. There are several possible reasons for within-type temperature changes. If, for example, there were differences between two periods in the mean airflow trajectories of days recognized as a single type, then a within-type temperature change could result. The Lamb catalogue has recently been revised[4] in order to minimize inconsistencies in type identification and we assume, therefore, that for moderate-sized samples of a given type there will be no bias from this source in the calculated type temperatures for the two periods. It is possible, however, that changes in the spell length of

TABLE V—CONTRIBUTION OF COMPONENTS OF CHANGE OF TYPE FREQUENCY AND OF CHANGE OF TEMPERATURE WITHIN TYPE TO THE CHANGES IN MEAN DAILY MAXIMA AND MINIMA AT BUXTON, ESKDALEMUIR, GORLESTON, AND VALENTIA BETWEEN 1925–35 AND 1957–67 IN JULY (CHANGES <0·1 degC OMITTED)

	Buxton				Eskdalemuir			
	Maximum		Minimum		Maximum		Minimum	
Type	a	b	a	b	a	b	a	b
NW	0·30	−0·17	0·18	−0·13	0·33		0·17	
N	1·03		0·64		1·17		0·51	
NE		−0·17			−0·10			
E	−0·25	−0·17	−0·16		−0·26	−0·14	−0·14	
SE	−0·25		−0·10		−0·33		−0·10	
S	−0·34		−0·18	−0·10	−0·30	−0·12	−0·15	−0·14
SW	−0·54		−0·33		−0·48		−0·31	
W	−0·75		−0·47		−0·70	−0·14	−0·39	−0·13
AW	0·22		0·12		0·20		0·11	
CW	−0·38		−0·24		−0·35		−0·22	
A		−0·27		−0·22		−0·40		−0·16
C	0·54	−0·12	0·34	−0·12	0·53		0·31	
U	0·11				0·10			−0·10
Total for all types	−0·3	−1·1	−0·2	−0·6	−0·1	−1·0	−0·2	−0·8
$\Delta\bar{T}$	−1·4		−0·7		−0·9		−0·9	
Significance level (%)	6		5		n.s.		3	

	Gorleston				Valentia			
	Maximum		Minimum		Maximum		Minimum	
Type	a	b	a	b	a	b	a	b
NW	0·37	−0·13	0·23		0·34		0·25	
N	1·24		0·79		1·22		0·81	
NE	−0·10				−0·12			
E	−0·25	−0·13	−0·20		−0·27		−0·17	
SE	−0·21		−0·18		−0·23		−0·15	
S	−0·33	−0·11	−0·23		−0·31		−0·23	
SW	−0·55		−0·38		−0·48		−0·35	−0·11
W	−0·90		−0·58		−0·74		−0·56	
AW	0·24		0·15		0·21		0·14	
CW	−0·46		−0·27		−0·37		−0·27	
A		−0·13				−0·19		
C	0·63		0·42		0·54		0·39	
U	0·11				0·10			
Total for all types	−0·2	−0·9	−0·3	−0·2	−0·1	−0·3	−0·1	−0·6
$\Delta\bar{T}$	−1·0		−0·4		−0·3		−0·8	
Significance level (%)	5		n.s.		n.s.		5	

See notes below Tables I and III.

certain types[5] may be of some significance in this respect. This aspect of the problem merits further study. Differences in the wind speed on days of a specified type in the two periods may be another contributory factor to within-type temperature change. However, to evaluate this, one would require type averages of wind speed at each station and along the airflow trajectory, which poses the problems of data unavailability and involved synoptic analysis of uncertain reliability. Lawrence[6] has drawn attention to the possible effects of pollution at Eskdalemuir, but this factor can be ruled out in the case of Valentia, at least, where with the exception of October the overall and within-type temperature changes are similar to those at the other three stations.

Changes in sea surface temperature in the eastern North Atlantic between the two periods are another likely source of within-type temperature change

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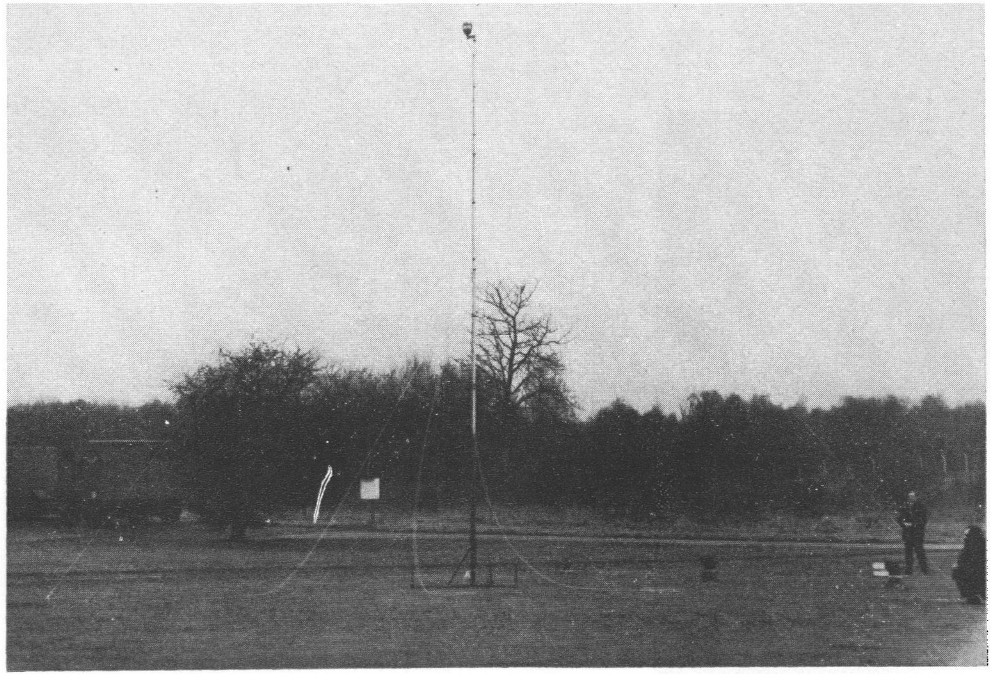
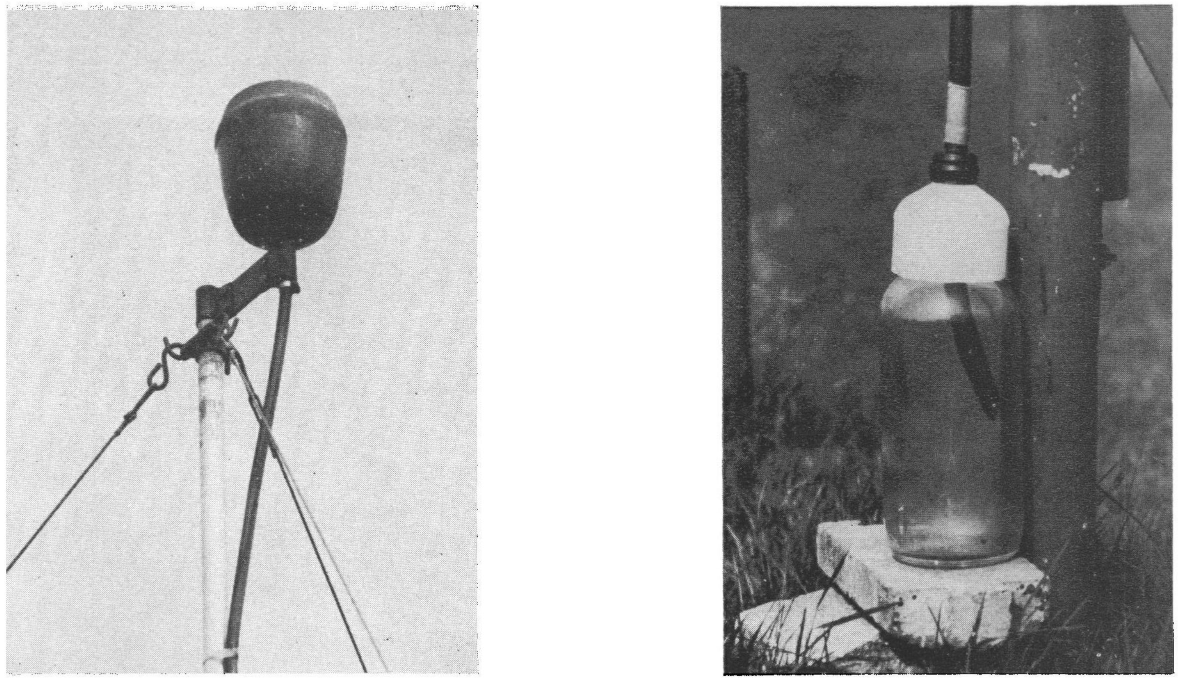


PLATE I—MAST-TOP RAIN-GAUGE AT BEAUFORT PARK, EASTHAMPSTEAD

See page 83.



(a) Collecting funnel

(b) Collecting bottle

PLATE II—MAST-TOP RAIN-GAUGE AT BEAUFORT PARK, EASTHAMPSTEAD

See page 83.

PLATE III—MAJOR K. G. GROVES WITH MR P. R. ROWNTREE, WINNER OF THE MEMORIAL PRIZE FOR METEOROLOGY

See page 93.

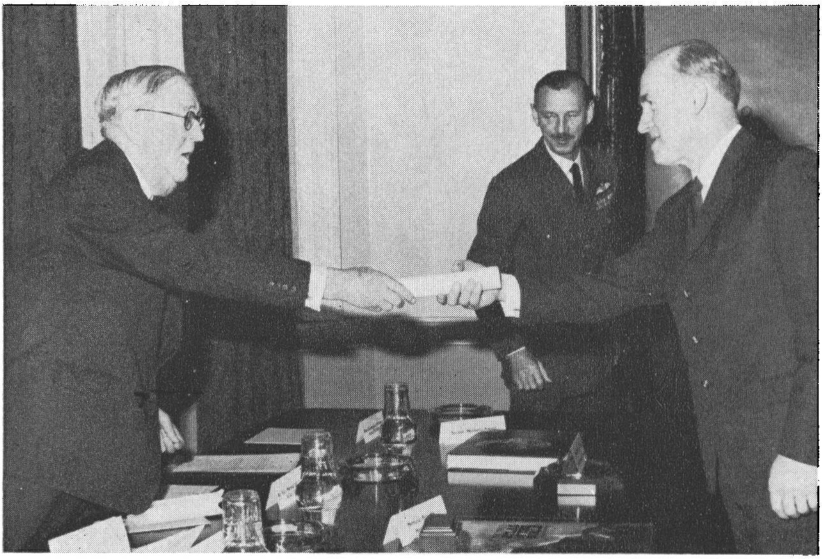


PLATE IV—MAJOR K. G. GROVES WITH MR J. I. P. JONES, WINNER OF THE SECOND MEMORIAL AWARD

See page 93.

PLATE V—MAJOR AND MRS K. G. GROVES WITH MASTER ELECTRONICS OPERATOR M. B. DANE, M.B.E., WINNER OF THE AIRCRAFT SAFETY PRIZE

See page 92.

TABLE VI—CONTRIBUTION OF COMPONENTS OF CHANGE OF TYPE FREQUENCY AND OF CHANGE OF TEMPERATURE WITHIN TYPE TO THE CHANGES IN MEAN DAILY MAXIMA AND MINIMA AT BUXTON, ESKDALEMUIR, GORLESTON, AND VALENTIA BETWEEN 1925–35 AND 1957–67 IN OCTOBER (CHANGES <0·1 degC OMITTED)

	Buxton				Eskdalemuir			
	Maximum		Minimum		Maximum		Minimum	
Type	a	b	a	b	a	b	a	b
NW	−0·11				−0·12			
N	−0·14				−0·16	0·12		0·13
NE								
E				0·12				
SE	0·61		0·29		0·66		0·22	
S	0·53		0·24		0·54		0·26	
SW				−0·11				
W	−1·22		−0·71	0·25	−1·13		−0·53	0·24
AW	0·39		0·15	−0·11	0·37		0·15	
CW	−0·32		−0·19		−0·30		−0·17	0·23
A	0·17			0·33	0·17			0·44
C	0·38		0·22		0·38	0·13	0·18	0·18
U	−0·10			0·10	−0·10	0·13		0·17
Total for all types	0·2	0·4	−0·1	0·8	0·4	0·6	0·1	1·5
$\Delta\overline{T}$	0·7		0·8		1·1		1·7	
Significance level (%)	n.s.		9		2		1	

	Gorleston				Valentia			
	Maximum		Minimum		Maximum		Minimum	
Type	a	b	a	b	a	b	a	b
NW	−0·16			0·14	−0·15		−0·10	
N	−0·19		−0·11	0·21	−0·21		−0·11	
NE	−0·10				−0·11			
E					0·10	0·12		
SE	0·68		0·57		0·79		0·56	
S	0·60		0·41		0·61		0·41	
SW								
W	−1·51		−0·89		−1·42		−1·00	−0·12
AW	0·46		0·20	−0·10	0·46		0·30	
CW	−0·39		−0·26	0·10	−0·36		−0·26	
A	0·20		0·13	0·35	0·22		0·12	0·11
C	0·50		0·35	0·27	0·46		0·27	−0·10
U	−0·13			0·15	−0·12			
Total for all types	0·1	0·1	0·3	1·0	0·3	0·4	0·1	−0·3
$\Delta\overline{T}$	0·2		1·3		0·9		−0·2	
Significance level (%)	n.s.		2		4		n.s.	

See notes below Tables I and III.

through the mechanism of air-mass modification. However, the limited availability of sea surface temperature data makes it doubtful whether adequate resolution can be obtained to examine this question in view of the small temperature changes observed and the fact that feedback processes undoubtedly make the air–sea interaction very complex. For example, temperatures were higher in the second period with NW and N types in April (Table II) although in view of the recent expansion of polar pack-ice this change would not have been expected. The frequencies of particular airflow directions are correlated with sea surface temperature anomalies, as is evident from the associations established by Ratcliffe and Murray[7] between such anomalies in areas of the western North Atlantic and the subsequent month's pressure anomaly pattern over the British Isles. Nevertheless, preliminary examination of Ratcliffe's catalogue of monthly sea surface temperature anomaly patterns[8] indicates no evident relationship with the changes of within-type temperature.

The present authors' findings confirm Goedecke's[9] conclusion that the pattern of temperature change over the British Isles between two periods is complex, highly variable from month to month, and a result of many factors, both atmospheric and terrestrial. In order to isolate the causes of the within-type changes considerable detailed analysis will be required. Goedecke's study, which only recently came to the authors' notice, in fact provides useful information on which to base the selection of other stations for analysis since he maps changes of mean seasonal temperature between 1901–30 and 1921–50. Additional spatial coverage seems necessary in view of the complex response of the four stations to within-type temperature changes shown in Tables II and V. It would be valuable also to extend the analysis to a number of consecutive decadal periods. This would determine to what extent, if any, the changes between 1925–35 and 1957–67 constitute a trend. The temporal and spatial complexity of the changes of type temperatures between these two periods illustrates the problems of interpreting inferred temperature changes in the historical (and earlier) periods in terms of simplified models of the regional atmospheric circulation.

Acknowledgements. The authors wish to thank Professor H. H. Lamb for kindly making available his then unpublished catalogue of weather types.

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THE PERFORMANCE OF A MAST-TOP RAIN-GAUGE IN THE FIELD

By L. S. CLARKSON

Summary. A tulip-shaped rain-gauge funnel mounted on top of a 10-m mast was found to have collected, over two years, 98·4 per cent of the rainfall collected in a standard Mk 2 rain-gauge nearby. Random differences of rainfall rarely exceeded $\pm$ 0·75 mm for daily values or $\pm$ 2 mm for monthly totals. By applying a small correction to allow for evaporation the random variations of the mast-top gauge were reduced and its overall deficiency in catch was eliminated.

The mast-top rain-gauge. The base and rim-flange of a 150-cm² Mk 4 glass-fibre rain-gauge were cut away and the resulting simple tulip-shaped collecting funnel was mounted on top of a slender mast 10 m above the ground (see Plates I and II(a)) at Beaufort Park, Easthampstead, adacent to the array of rain-gauges used in the trials previously reported on.[1]

Rain-water caught by the mast-top funnel was led down ½-inch* polythene tubing into a collecting bottle at the foot of the mast (Plate II(b)). The entry of the tubing into the bottle was carefully shielded to prevent any rain-water that might run down the outside of the tube from entering the bottle. The bottle was sheltered from direct sunshine and its contents were measured daily in a standard rain measure.

The mast was kept vertical — and the rim of the collecting funnel horizontal — by staying with six guy ropes: three attached to the top of the mast and three to a point about half-way up it. These last three had been found necessary in a preliminary experiment; without them the slender mast tended to bow slightly in a strong wind, resulting in the orifice of the collecting funnel tilting into the wind.

After the first rainfall, many small droplets of rain-water could be seen clinging to the interior walls of the polythene tube. However, it was noticed that these were very slow to evaporate, the tube rarely becoming dry before the onset of the next period of rain.

Field trial results and discussion. In the two-year period from 22 May 1970 to 31 May 1972, 169 measurements were made of daily rainfall of amounts ≥1 mm which did not fall as snow.

Designating the daily amount in millimetres collected by the mast-top gauge as M, and by the Mk 2 gauge used as a standard in previous rain-gauge trials as S, the overall ratio $\Sigma M/\Sigma S$ was 98·4 per cent, and the regression equation of M on S was

$$M = 1{\cdot}003S - 0{\cdot}13 \pm 0{\cdot}75 \text{ (95 per cent confidence limits).}$$

Table I compares the results of the field trial with results from an adjacent Mk 2 rain-gauge S_2 for the period 25 June 1969 to 30 June 1970.[1]

TABLE I—COMPARISON OF RESULTS OF FIELD TRIAL WITH THOSE OF AN ADJACENT MARK 2 RAIN-GAUGE

Period	n	$\sum M$ *mm*	$\sum S$ *mm*	Ratio *per cent*	Regression ±95 per cent confidence limits
22/5/70–31/5/72	169	1179·5	1198·5	98·4	$M = 1{\cdot}003S - 0{\cdot}13 \pm 0{\cdot}75$
		$\sum S_2$ *mm*	$\sum S$ *mm*		
25/6/69–30/6/70	89	491·8	494·7	99·4	$S_2 = 0{\cdot}997S - 0{\cdot}02 \pm 0{\cdot}29$

n = number of occasions of 24-hour rainfall ≥1 mm.

In a comparison of the two regression equations, it is seen that a negligible addition of 0·02 mm to the daily catch in the S_2 gauge will cause it on average to register virtually the same (within 0·3 per cent) as the standard rain-gauge, with random differences not exceeding 0·29 mm on 95 per cent of rain days. For the mast-top gauge, however, the addition to its daily catch required to cause it on average to read the same (within 0·3 per cent) as the standard

* 1 in = 25·4 mm.

gauge is 0·13 mm, six and a half times greater, and the random differences are considerably larger, not exceeding 0·75 mm on 95 per cent of rain days.

Despite the danger of reading a physical significance into a purely statistical relationship, the regression equation does imply that, relative to the standard rain-gauge, the mast-top gauge systematically loses on average 0·13 mm, and randomly differs by $\pm$ 0·75 mm per rain day, the loss being practically independent of the amount of daily rain. Reasons for the systematic relative loss could be that additional turbulence at the mast-top level diverts raindrops out of the funnel, and/or that there is a loss by evaporation of droplets on the interior walls of the polythene tube between rainfall events. The confidence limits of the regression equation indicate that occasionally. i.e. on about 2·5 per cent of rain days, the mast-top gauge can be expected to collect over 0·62 mm *more* than the standard rain-gauge. The only plausible explanation for such an over-collection is that on these rather rare occasions droplets clinging to the inner wall of the polythene tube are shaken down into the collecting bottle by the vibration of the tube in strong winds.

It is likely that effects due to the polythene tube leading from the funnel to the collecting bottle are the main source of the overall deficit and the day-to-day additional variability of the catch in the mast-top gauge relative to that in the standard rain-gauge.

If evaporation from the tube is the main cause of the deficit, then the mast-top gauge deficit should be larger than average for rain days preceded by several dry days, and below average for rain days which followed rain days. In the daily data there were 16 rain days prior to which there had been no precipitation at all during the previous 5 days. For these, $\sum S$ was 120.5 mm. and $\sum M$ was 115·5 mm, giving a deficit per rain day preceded by 5 dry days of 5/16 mm, or 0·313 mm. From the data another 16 rain days were found at around the same dates as the previously considered 16, but for each of which rain had fallen the day before. For these, $\sum S$ was 180·9 mm, and $\sum M$ was 180·3 mm, giving a deficit of only 0·6 mm, or 0·038 mm per rain day. (Over the whole two years, the average deficit per rain day was 19/169 mm, or 0·11 mm.)

The figures quoted above support the contention that the main difference in performance between the mast-top and the surface rain-gauges may be ascribed to evaporation from the polythene tube on occasions when a rain day was not preceded by a day with precipitation.

In Table II the rain days are aggregated into 23 approximately monthly periods. Applying a 'correction' of + 0·11 mm per rain day to the mast-top gauge readings results in $M_1 = S \pm 2{\cdot}0$ mm (95 per cent confidence limits) for monthly totals, while correcting by the addition of 0·23 mm on only those occasions when the previous day was dry gives $M_2 = S \pm 1{\cdot}6$ mm (95 per cent confidence limits). The latter method can be expected to yield the more consistent results if the loss is really due mainly to evaporation, and this is in fact what is found. By either method, monthly totals obtained from the standard and the (corrected) mast-top rain-gauges are seen to differ very rarely by as much as 2 mm.

Conclusions. Some general conclusions which follow from this field trial are :

(a) When no 'corrections' are applied, the mast-top rain-gauge over two

TABLE II—PERFORMANCE OF MAST-TOP RAIN-GAUGE COMPARED WITH THAT OF A STANDARD MARK 2 RAIN-GAUGE NEARBY

Period	$\sum S$	$\sum M$	n	M_1	$S-M_1$	n'	M_2	$S-M_2$
	mm			mm			mm	
22/5–23/6/70	25·7	25·0	4	25·4	0·3	3	25·7	0·0
24/6–11/8/70	104·4	102·0	16	103·8	0·6	9	104·1	0·3
12/8–7/10/70	78·9	78·2	13	79·6	−0·7	5	79·3	−0·4
8/10–6/11/70	28·4	28·5	6	29·2	−0·8	3	29·2	−0·8
7/11–2/12/70	129·6	130·1	13	131·5	−1·9	3	130·8	−1·2
3/12/70–16/1/71	17·5	16·9	4	17·3	0·2	2	17·4	0·1
17/1–15/2/71	99·5	98·4	13	99·8	−0·3	2	98·9	0·6
16/2–28/2/71	8·3	7·5	4	7·9	0·4	1	7·7	0·6
1/3–31/3/71	45·8	45·0	3	45·3	0·5	3	45·7	0·1
1/4–30/4/71	57·8	54·8	4	55·2	2·6	4	55·7	2·1
1/5–31/5/71	45·4	45·4	6	46·1	−0·7	4	46·3	0·9
1/6–30/6/71	121·7	122·8	6	123·5	−1·8	2	123·3	−1·6
1/7–31/7/71	12·3	11·3	5	11·9	0·4	3	12·0	0·3
1/8–31/8/71	65·5	64·6	16	66·4	−0·9	3	65·3	0·2
1/9–31/9/71	10·8	10·4	2	10·6	0·2	1	10·6	0·2
1/10–31/10/71	62·2	62·5	5	63·1	−0·9	3	63·2	−1·0
1/11–31/11/71	30·1	29·5	4	29·9	0·2	3	30·4	−0·3
1/12–31/12/71	18·5	18·0	3	18·3	0·2	3	18·7	−0·2
1/1–31/1/72	52·3	5·07	11	51·9	0·4	6	52·1	0·2
1/2–29/2/72	63·4	62·0	9	63·0	0·4	5	63·1	0·3
1/3–31/3/72	47·5	46·4	5	47·0	0·5	4	47·3	0·2
1/4–30/4/72	33·3	32·7	7	33·5	−0·2	5	33·8	−0·5
1/5–31/5/72	39·6	36·7	10	37·8	1·8	7	38·3	1·3
22/5/70–31/5/72	1198·5	1179·5	169	1198·0	0·5	84	1198·9	−0·4
Standard deviations of differences (mm)					1·00			0·81

n = number of rain days, i.e. rainfall $\geqslant 1$ mm.
n' = number of rain days each preceded by a day with not more than a trace of precipitation.

$$M_1 = \sum M + 0{\cdot}11\, n.$$

$$M_2 = \sum M + 0{\cdot}23\, n'.$$

years under-read compared with the standard gauge by less than 2 per cent, and for daily rainfalls was relatively no more variable than were the tipping-bucket rain-gauges at Glasgow Airport and Bristol/Filton investigated previously.[1]

(b) After a correction of + 0·23 mm was applied to each daily rainfall of 1 mm or more measured on the mast-top rain-gauge provided the previous day was dry, this gauge over two years collected the same amount of rain as was collected in the standard Mk 2 rain-gauge; monthly totals very rarely differed by as much as 2 mm, and daily totals by as much as 1 mm.

(c) The under-reading and additional variability, if primarily due to the 10-m length of polythene tube, could possibly be obviated by arranging for automatic metering of the rain-water by a suitable mechanism mounted on the mast, just below the collecting funnel.

(d) The mast-top rain-gauge appears potentially suitable for operational use in situations where it is impracticable properly to site and expose a standard rain-gauge at ground level, for example over shallow water, on ground liable to flooding and on rocky terrain.

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551.513:551.547.3

SEASONAL VARIATIONS IN THE 500-mb MONTHLY OSCILLATION OVER THE NORTHERN HEMISPHERE

By M. G. COLGATE and R. J. HEWS

Summary. An analysis of six years of daily 500-mb data filtered for retention of oscillations of about a month over a grid network which covered most of the northern hemisphere revealed some interesting seasonal variations in the location of large monthly oscillations. A comparison between time-series oscillations obtained by use of the monthly filter, and also a filter designed to retain short-period oscillations, illustrates the significant contribution that monthly oscillations make to the 500-mb fluctuations.

Introduction. Several papers have been written describing methods of using filters to detect the presence of oscillations in time series of meteorological data. In particular, a paper by Sawyer[1] described how 500-mb, 1000–500-mb thickness, and surface pressure data over the northern hemisphere were filtered to retain only those oscillations with a period of about a month. Although the results of his paper indicated that these were prominent fluctuations on a monthly time-scale, the yearly time series that were analysed merged together any seasonal variations that might be present. This paper describes a similar analysis on a seasonal time series of 500-mb data only. Besides monthly oscillations, short-period oscillations were also analysed for comparison.

Data and filters. Six years of daily 500-mb data starting from 1949 onwards were analysed for a grid network of 112 points shown in Figure 1. The four seasons were each defined as a three-calendar-month period with spring starting on 1 March.

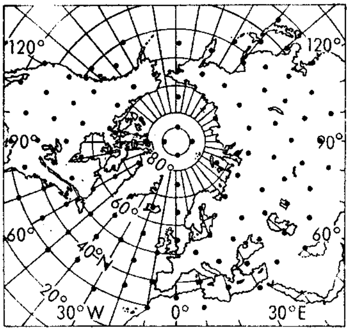

FIGURE 1—112-POINT GRID USED FOR THE TIME-SERIES ANALYSIS

Three filters of order 15 (i.e. 31 terms) were used. They were designed to retain the following fluctuations :

(a) those with a time period of about a month,
(b) those with time periods of 10 days or less, and
(c) those with a time period of about a week.

Graphs of the magnification factor of the amplitude against the period of oscillations for the three filters are shown in Figure 2. The inclusion of a filter to retain all periods of 10 days or less was chosen because this passed all the high frequencies that were not passed by the monthly filter. Thus filters (a) and (b) pass mutually exclusive and complementary wavebands which will provide useful comparison.

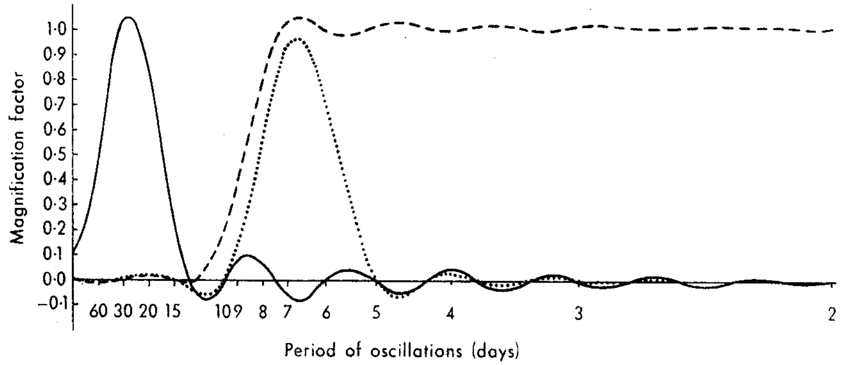

FIGURE 2—GRAPH OF MAGNIFICATION FACTOR AGAINST PERIOD FOR DIFFERENT FILTERS

——— Filter for periods of about a month
– – – Filter for periods of less than 10 days
. . . . . . Filter for periods of about a week

Analysis of hemispheric data. The results reproduced here are those formed by using the monthly filter only. Four seasonal charts of the root mean square (r.m.s.) of the filtered time series for each of the points were drawn for each year. The six charts corresponding to each season were then combined, and the results are shown in Figures 3–6.

During spring Alaska has the highest fluctuation of monthly oscillations. This feature is prominent in all six years. Two other important areas of high monthly fluctuations during spring were over the Atlantic, and over the Gulf of Ob. The centre of high r.m.s. values over the Atlantic tended to wander from this position for three of the years, moving to a position over south Greenland or the west Atlantic. The centres of low fluctuation were generally over and around the North Pole, south of 50°N and over most of North America.

Summer monthly oscillations (Figure 4) are generally of smaller magnitude than those for the other seasons, which is to be expected since fluctuations of unfiltered 500-mb data are lowest during summer. The summer centres of high r.m.s. values over the Atlantic are generally in the same regions as those that occur during spring although the spring high cell over Alaska has moved south-westwards over the Bering Sea, and the Gulf of Ob high centre is less prominent. The high r.m.s. values over north-west Greenland are a special feature of the summer season.

As in the spring and summer, autumn cells of high r.m.s. values are mainly over the north-east Atlantic, Gulf of Ob and Gulf of Alaska. One prominent area which is different during autumn is over the Great Lakes. This region had a high cell during two of the years whilst none was present during any of the other seasons.

Although the winter season possessed the largest monthly oscillations, it was the least consistent for the recurrence from year to year of high r.m.s. values. Moreover the latitudinal extent for the presence of high cells increases during winter with centres in some years occurring as far south as 45°N over

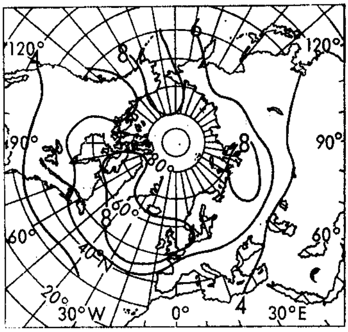

FIGURE 3—SPRING r.m.s. OF DAILY 500-mb HEIGHTS FILTERED TO RETAIN MONTHLY OSCILLATIONS ONLY

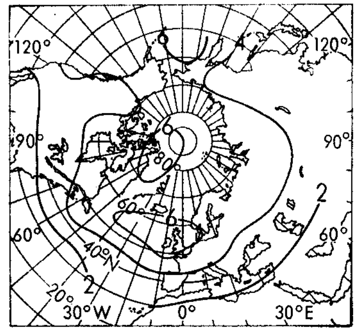

FIGURE 4—SUMMER r.m.s. OF DAILY 500-mb HEIGHTS FILTERED TO RETAIN MONTHLY OSCILLATIONS ONLY

Units are geopotential decametres.

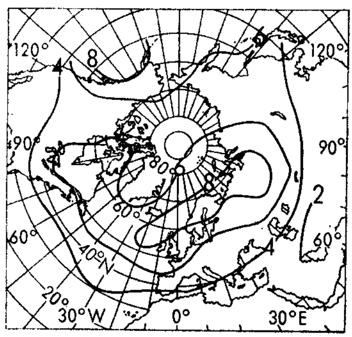

FIGURE 5—AUTUMN r.m.s. OF DAILY 500-mb HEIGHTS FILTERED TO RETAIN MONTHLY OSCILLATIONS ONLY

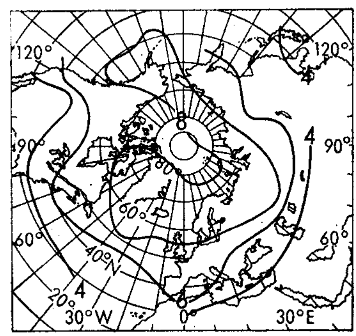

FIGURE 6—WINTER r.m.s. OF DAILY 500-mb HEIGHTS FILTERED TO RETAIN MONTHLY OSCILLATIONS ONLY

Units are geopotential decametres.

southern France, and as far north as 75°N over the Laptev Seas. Nevertheless, the combined winter r.m.s. chart for the six years shows strong similarity to those of the other seasons.

Thus the results for the four seasons can be summarized as indicating that the main areas for high monthly fluctuations lie in middle latitudes with preferred areas over the northern North Atlantic, Gulf of Ob and the Alaskan region.

Analysis of time series at selected points. In order to reduce computational effort, only four points were selected from the grid network for the purpose of illustrating the effect of filtering 500-mb time-series data. The points chosen were: along the Greenwich meridian at 55°N, 65°N 20°E, 65°N 160°W and 45°N 60°W.

Figure 7 displays the effect of filtering a four-month time series starting from 1 May 1952 at 55°N, 0°. It can be clearly seen how the monthly filtered time series reflects all the large-amplitude fluctuations in the original time series. Also shown is the distinctly large amplitude of monthly oscillations

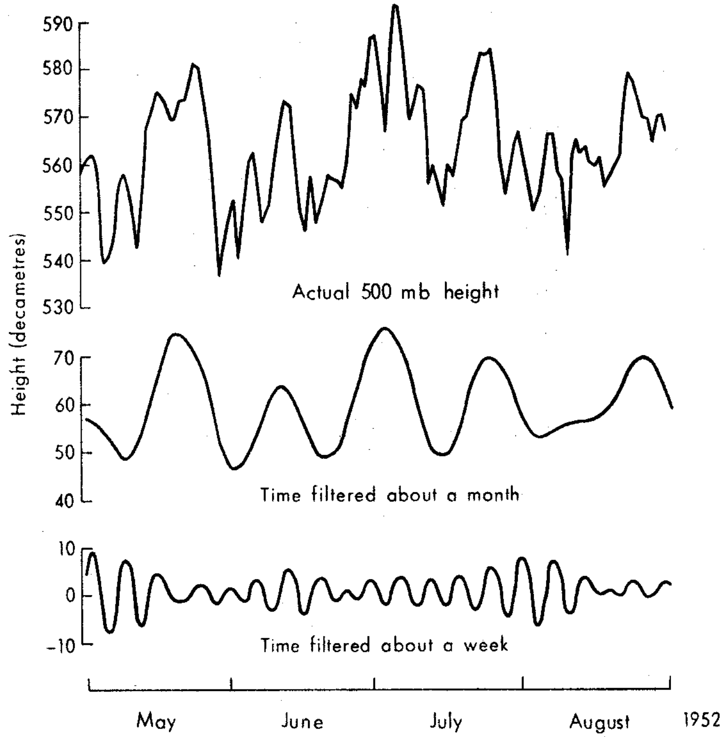

FIGURE 7—TIME-FILTERED AND ORIGINAL 500-mb HEIGHT SERIES OFF NORTH-EAST ENGLAND AT 55°N, 0°

relative to the oscillations of the time series filtered for periods of about a week. These large-amplitude oscillations in the monthly filtered time series are consistent with the commonly observed association between quasi-stationary blocking types and large-magnitude 500-mb anomalies. Similarly the small-amplitude oscillations present in the weekly filtered time series are probably associated with fast-moving, small-amplitude waves in the 500-mb flow.

An objective method for testing the significance of monthly oscillations was carried out as follows. The variance of a filtered time series can be used to estimate the variance of the original time series by dividing the filtered time-series variance by the 'power' of the filter (see Craddock[2,3]). If two such estimates are made from filters passing waves whose periods lie in non-overlapping wavebands then Fisher's variance ratio test ('F' test) can be used to compare the variance of the waves retained within the respective wavebands. By choosing a filter which passes all periods of 10 days or less, it is possible to test the significance of monthly oscillations. Table I shows the 'F' ratio for each of the four points, and for each of the seasons between summer 1949 and winter 1952. The 0·1-per-cent level of significance for the 'F' ratio is 4·10, which is exceeded in all the instances listed in Table I except on two occasions. Clearly, the results are highly significant.

TABLE I—RATIO OF VARIANCE OF THE ESTIMATES OF THE ORIGINAL VARIANCE FROM THE MONTHLY FILTERED SERIES AND THE SERIES FILTERED FOR PERIODS OF TEN DAYS OR LESS (DEGREES OF FREEDOM 7 AND 70)

		55°N 0°	65°N 20°E	65°N 160°W	45°N 60°W
1949	Summer	11·52	17·01	12·28	12·88
	Autumn	12·70	30·03	13·24	4·01
	Winter	8·01	41·27	28·15	4·74
1950	Spring	21·78	22·50	27·25	4·18
	Summer	8·27	8·90	64·86	5·44
	Autumn	5·12	29·68	19·28	6·01
	Winter	11·99	27·30	24·15	7·08
1951	Spring	12·43	24·58	45·47	12·19
	Summer	12·33	15·93	15·77	11·83
	Autumn	12·13	14·94	5·41	5·21
	Winter	9·34	14·94	25·53	6·34
1952	Spring	20·21	10·65	11·04	4·30
	Summer	21·01	28·75	16·60	9·98
	Autumn	10·74	35·94	11·05	7·10
	Winter	20·46	7·68	28·76	2·38

Conclusions. The comparison of monthly oscillation with short-period oscillations has demonstrated the importance of monthly oscillations in 500-mb fields. Most of the high fluctuations lie between 50°N and 65°N. For all seasons the regions with the highest monthly fluctuations can be summarized as being over the northern North Atlantic, Gulf of Ob and the Alaskan region. Nevertheless, there are distinct variations from season to season with regard to the position of high fluctuations over the Alaskan region; being over Alaska/Bering Strait during winter and spring, over the Bering Sea during summer and over the Gulf of Alaska during autumn. Other differences in the seasons can be noted, but generally they are not consistent from year to year.

In middle latitudes the most consistent area for low monthly oscillations was over the Rockies.

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NOTES AND NEWS

Retirement of Mr J. H. Brazell

On 2 January 1973 John Brazell retired from the Meteorological Office in which, for the past two years, he held the post of Assistant Director, Observational Requirements and Practices.

He joined the Office in 1936 and for much of his career was concerned with the provision or organization of forecasts for aviation or the general public. He served in the Central Forecasting Office before the War and at several RAF stations until he was mobilized in the Royal Air Force Volunteer Reserve in 1940 and sent to Iceland. He was in Malta for 18 months in the most active part of the siege until 1943 when he was posted to Habbaniya and later to Cairo. On demobilization in 1946 he became Senior Meteorological Officer at Uxbridge (Air Traffic Control Centre) and in 1950 moved to the newly formed RAF Flying College at Manby. In 1956 he was lent to the East African High Commission to become Director of the East African Meteorological Service for three years. On his return from Nairobi in 1959 he helped to set up the London Weather Centre where he was Senior Meteorological Officer until 1967; it was largely due to his efforts that this office developed into the important and effective Centre that we now know, with its varied service to the Press, television, radio and the general public and its specialized service for oil and gas drilling in the North Sea. In 1967 he was promoted Senior Principal Scientific Officer and took charge of the Climatological Services Branch at Bracknell; later he was Chief Meteorological Officer at London/Heathrow Airport before returning to Headquarters.

John Brazell was an authority on the weather of London. He wrote papers on air pollution, the effects of weather on the building industry and other topics and was the author of *London weather* (HMSO, 1968).

John has now returned to his native valley in south Wales, within easy reach of the sports grounds of Llanelli, Swansea and Cardiff, where he can once again enjoy some of the best rugby-football there is. We wish him many happy years of retirement.

J. K. BANNON

NASA launch satellite carrying Heriot-Watt University experiment

A rocket was launched from NASA's Western Test Range in California on 11 December 1972 which placed into polar orbit the weather satellite NIMBUS-E.

Aboard the satellite is a scientific experiment (developed jointly by Heriot-Watt University, Edinburgh, and the University of Oxford) which has already revolutionized the technique of measuring the temperature of the earth's atmosphere by providing one of the earliest quantitative global surveys — at a fraction of the cost per measurement by conventional methods (radiosonde balloons).

This was achieved by the similar experiment currently orbiting aboard the NIMBUS-4 weather satellite which has been in orbit since April 1970. (From this experiment some 10 million readings have been obtained at a cost of £250 000 — i.e. 2½p per measurement.)

The experiment results from the invention and development by Professor Desmond Smith at Heriot-Watt University and Dr John Houghton at the University of Oxford of an instrument called a Selective Chopper Radiometer which from the orbiting satellite continuously monitors the temperature of the earth's atmosphere at various levels. From the data it produces, scientists at Heriot-Watt University using a computer in their research laboratory at

Riccarton can produce, twice daily, an accurate vertical temperature profile of the earth's atmosphere up to a height of 50 kilometres and provide information, vital to meteorologists, on its water vapour content and cloud cover.

The Selective Chopper Radiometer works by measuring the infra-red radiation emitted by carbon dioxide in the earth's atmosphere. From this information the vertical temperature profile can be built up.

So successful was the NIMBUS-4 experiment that, in the face of stiff competition from no less than 36 major research laboratories in the U.S.A., the British experiment developed (with the financial support of the Science Research Council) by research teams at Heriot-Watt and Oxford Universities was chosen for the NIMBUS-E project.

The Selective Chopper Radiometer on NIMBUS-E is an improved version of the NIMBUS-4 experiment. This new radiometer provides 16 readings every 4 seconds. From these readings temperatures at 8 heights and information on cloud cover and water vapour content can be deduced to provide twice daily a complete global picture. Every temperature measurement made from the satellite, which orbits at about 1100 kilometres ($\approx$600 nautical miles) above the earth, is accurate to within 2 degrees Celsius.

The data are relayed directly from the satellite to Riccarton for analysis via the data receiving station at Fairbanks in Alaska, the Goddard Space Flight Centre in Washington and the Oxford research unit.

AWARDS

L. G. Groves Memorial Prizes and Awards

The 26th award of prizes was made on Friday, 8 December 1972, at the Ministry of Defence, Whitehall, by Major and Mrs K. G. Groves. The Assistant Chief of the Air Staff (Operations), Air Vice Marshal D. G. Evans, C.B.E., presided and the ceremony was attended by the Director-General of the Meteorological Office. (See Plates III — V.)

The 1972 Aircraft Safety Prize has been awarded to Master Air Electronics Operator M. B. Dane, M.B.E., formerly of Royal Air Force Akrotiri, with the following citation :

> 'Master Air Electronics Operator M. B. Dane has been employed on Search and Rescue duties, a role in which he has had considerable experience. Apart from the requirements of his normal duties, however, Mr Dane has consistently taken an active interest in all aspects of flight safety, and his personal enthusiasm, industry and imagination have led him to put forward many practical ideas. Over a period of time, his suggestions have embraced matters such as helicopter cliff rescue, illuminating flares, the recovery of injured survivors into single seat dinghies and the concept of Crash Rescue Quick Reference Cards.
>
> The Quick Reference Cards provide, for rescue teams, vital and quickly assimilated information on access points for a range of aircraft, and could be instrumental in saving time and lives in the event of a crash. These Cards have been adopted by the Ministry of Defence and they typify Mr Dane's involvement with safety.

Overall, the number of constructive and practical schemes devised by Mr Dane, has made an invaluable contribution to flight safety.'

The 1972 Meteorology Prize has been awarded to Mr P. R. Rowntree, Principal Scientific Officer, Meteorological Office, with the following citation :

'Mr P. R. Rowntree has studied over several years the effects which variation of the ocean temperatures in the equatorial Pacific may have on the large scale circulation of air over the Northern Hemisphere. It had earlier been surmised by Professor J. Bjerknes that sea temperatures in the Pacific exert a significant control over long term weather regimes over wide areas. In a paper published in the last year Mr Rowntree has calculated quantitatively the effects to be expected, and has shown that they are similar to those observed. This is the first time that quantitative numerical methods have been applied successfully to explain long-period weather variations.'

The Meteorological Observer's Award has been awarded to Mr J. Findlater, Senior Scientific Officer, Meteorological Office, with the following citation :

'Mr J. Findlater has carried out a unique series of observations through a band of exceptionally strong winds (a low-level jet stream) which he had earlier located from meteorological observations over East Africa as a regular summer occurrence. The observations were made from a light aircraft and were planned by Mr Findlater to disclose the cloud structure and wind circulation associated with the phenomenon.'

The Second Memorial Award for 1972 has been awarded to Mr J. I. P. Jones, Senior Scientific Officer, Meteorological Research Division, CDE, Porton Down, with the following citation :

'Mr J. I. P. Jones has over many years contributed a wide variety of ingenious ideas to the design of the mechanism and electronics of wind vanes and anemometers. Without his contributions the instrumentation now in use in the study of atmospheric turbulence would not have achieved its present high degree of accuracy and sensitivity.'

Owing to Mr J. Findlater's further service with the East Africa Meteorological Department, his award was collected on his behalf by Mr J. Crabtree.

REVIEWS

Foundations of climatology, by E. T. Stringer. 260 mm × 190 mm, pp. xiii + 586, *illus.*, W. H. Freeman and Company, 58 Kings Road, Reading, RG1 3AA, 1972. Price: $17·50.

Techniques of climatology, by E. T. Stringer. 260 mm × 190 mm, pp. xiii + 539, *illus.*, W. H. Freeman and Company, 58 Kings Road, Reading, RG1 3AA, 1972. Price: $17·50.

The first of these two volumes, *Foundations of climatology*, is a text written from the view point of classical physics for the serious student of climatology, who needs more than the purely descriptive treatment of atmospheric phenomena found in most books on climatology. It is a stimulus and a challenge to a newcomer to the subject of climatology when he is made to realize, as here, that for proper understanding of the subject he needs to know a great deal about physical, dynamical and synoptic meteorology as well as geography, and to be able to apply statistical methods to summarize and analyse data meaningfully.

It is not possible for anyone to know all there is to know about the topics dealt with by Dr Stringer under the six chapter headings: 1. The Atmosphere; 2. Atmospheric Properties and Processes; 3. Atmospheric Turbulence and Diffusion; 4. The General Circulation of the Atmosphere; 5. Scientific Inference in Climatology; 6. The Synoptic Method; but certainly anyone who has mastered this book and followed up the excellent set of references will be able to hold his own in good meteorological company.

The second volume, *Techniques of climatology*, is a manual for those who have mastered the first volume and wish to apply the techniques of the meteorologist, the mathematical statistician and the geographer to the solution of specialist problems in a great variety of disciplines, e.g. engineering, medicine, agriculture, physical and biological sciences, etc. The first three chapters discuss the making of climatological observations, instrumentation and required networks; the interpretation and statistical analysis of data; and physical and mathematical models of phenomena of weather and climate. The remaining five chapters discuss the applications of these basic techniques to radiation climatology, temperature, clouds and climate, visual climate and optical climatology, and geographical climatology.

Anyone reading *Techniques of climatology* and following up the references will know how to tackle the most difficult problem of all for climatologists: how to assemble, analyse and interpret climatic data.

These two volumes make a very valuable addition to climatological literature, and I am sure that most climatologists and those in other professions who have to tackle or understand climatological problems would wish to have them within easy reach.

A. F. JENKINSON

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LETTER TO THE EDITOR

Rule for reading the rain measure

Since observers in the British Rainfall Organization have been making their returns of rainfall in millimetres, they have used taper measures graduated in tenths as far as 10·0 mm. When there is more water in the rain-gauge than can be measured by one filling of the measure, they follow the advice given in section 7 of *Rules for rainfall observers* (Met O Leaflet No. 6). The metric equivalent of this rule is that the glass should be filled nearly to the 10·0 mark and the reading noted. The contents are emptied into a jug and the glass is filled again as often as is necessary; the reading is noted each time. The individual amounts are added together to give a total measurement, e.g. 9·7 + 9·5 + 9·9 + 5·1 = 34·2.

I submit that the measuring procedure would be facilitated if the graduations on the measure were extended as far as 11·0 or even 12·0, and the advice on measuring large quantities of rain modified to read: 'the glass should be filled to just beyond the 10·0 mark . . .'. In this way the foregoing fall of rain might be measured as follows: 10·2 + 10·1 + 10·4 + 3·5 = 34·2.

Not only would the summation be easier but often fewer fillings of the measure would be required.

Artetech International
Botley, Oxford
G. T. MEADEN

Reply by the Meteorological Office:

There are several factors which influence the most cost-effective size of rain measures: a 10-mm glass measure was standardized as a reasonable compromise between one too long and therefore expensive, inconvenient and fragile, and one so short as to require many fillings to measure the average amount of rain-water collected in the rain-gauge.

It does appear possible, however, that the graduations could be extended above the 10-mm mark, and this point will be examined at the time when further rain measures are ordered.

M. J. BLACKWELL AND L. S. CLARKSON

HONOURS

The following honours were announced in the New Year's Honours List, 1973:

C.B.

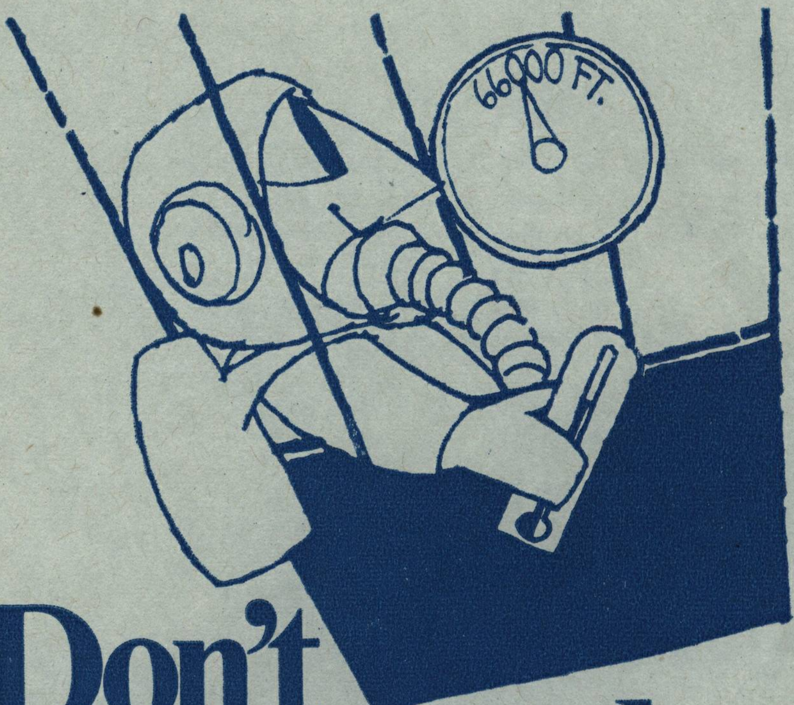
Dr B. J. Mason, F.R.S., the Director-General of the Meteorological Office.

I.S.O.

Mr R. K. Pilsbury, F.R.P.S., formerly of the Telecommunications Branch, Meteorological Office, Bracknell.

OBITUARY

It is with regret that we have to record the death of Mr R. P. Johnson, Higher Scientific Officer, Met O 2, on 30 November 1972.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