Met.O.826
METEOROLOGICAL OFFICE

the meteorological magazine

DECEMBER 1970 No 1181 Vol 99
Her Majesty's Stationery Office

METEOROLOGICAL OFFICE Met.O.826

THE METEOROLOGICAL MAGAZINE

Vol. 99, No. 1181, December 1970

551.509.323:625.7

COMPARISON OF METHODS OF FORECASTING NIGHT MINIMUM TEMPERATURES ON CONCRETE ROAD SURFACES

By G. E. PARREY, W. G. RITCHIE and S. E. VIRGO, O.B.E.

Summary. Three methods of forecasting night minimum temperatures at the surfaces of concrete roads were examined and possible improvements considered. A regression-equation method which gives the forecast concrete minimum temperature as a function of the air temperature and dew-point at 12 GMT the previous day was improved by making an adjustment for cloud amount during the night. Satisfactory improvements were not obtained for the other two methods considered which derive the forecast concrete minimum temperature from a combination of a forecast of the air minimum temperature with a forecast of the difference between the air minimum temperature and the concrete minimum temperature. The methods were applied over periods independent of the original data, and successful results were obtained at two independent road surfaces. The mean errors and standard deviations of the errors are given. The methods depending on forecast of air temperature give better results than the direct regression method unless there are large errors in forecasting air temperature.

Introduction. First reports on two experiments concerned with night minimum temperatures at the surfaces of concrete roads have already appeared in this magazine; Parrey[1] has reported on a road at Watnall and Ritchie[2] has reported on one at Wyton. Both experiments are continuing and, as time goes on, more data are accumulating. Since the practical application is to forecasting temperatures of 0°C or below on roads or runways, this paper will be concerned only with the months October to April inclusive.

In both experiments ordinary minimum thermometers are used with their bulbs resting on the surfaces of the roads. Other reports on minimum temperatures at or near concrete surfaces have also been published, for example by Johnson and Davies[3] and by Hay.[4] In these experiments temperatures were measured by other means, but as it is not yet known whether results obtained by the various methods are strictly comparable, this paper will confine itself to a discussion of the Wyton and Watnall results.

There are two ways of attacking the problem of forecasting night minimum temperatures over concrete. One is to forecast the concrete minimum temperature directly by means of a regression equation from observations made in a thermometer screen. The other is to forecast first the air minimum temperature by one of the recognized methods and then as a second step to derive the concrete minimum temperature from it.

The direct regression method. For the first method, the direct method, data from Watnall for the period October 1967–April 1968 were examined and occasions when a front passed between 12 GMT and 06 GMT next morning were rejected. From the remaining 147 cases the following correlation coefficients were obtained :

between M_R and T_{12} 0·75
between M_R and D_{12} 0·81,

where M_R is the minimum temperature at the surface of the concrete road,
T_{12} is the dry-bulb temperature at 12 GMT
and D_{12} is the dew-point temperature at 12 GMT.

These correlation coefficients suggested that a useful regression equation could be set up and the following equation was obtained by the method of least squares[5] :

$$M_R = 0{\cdot}59T_{12} + 0{\cdot}69D_{12} - 4{\cdot}6,$$

where temperatures are in degrees Celsius.

Values derived from this equation were tabulated for Watnall in Table I for ready use. Differences between forecasts obtained from this equation and observed minimum temperatures were calculated and an attempt was made to construct a correction table to make some allowance for the effects of cloud amount and wind speed. There was no apparent relation with wind speed and the residuals were very widely scattered in relation to cloud amount. The best that could be done was to add the small correction table to the main Table I. (Presumably the reason why no relation with wind speed was found is that wind direction is important; if the wind blows along the concrete road, the fetch is over concrete; but if it blows across the road, the fetch is over grass.)

TABLE I—TABLE FOR OBTAINING NIGHT MINIMUM TEMPERATURE AT WATNALL AT THE SURFACE OF CONCRETE FROM AIR TEMPERATURE AND DEW-POINT TEMPERATURE AT 12 GMT ON THE PREVIOUS DAY

Air temperature T_{12}	Dew-point temperature D_{12}(°C) −7	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	
°C	degrees Celsius													
2	−8·3	−7·6	−6·9	−6·2	−5·5	−4·8	−4·1	−3·4	−2·7	−2·0				
3	−7·7	−7·0	−6·3	−5·6	−4·9	−4·2	−3·5	−2·8	−2·1	−1·5	−0·8			
4	−7·1	−6·4	−5·7	−5·0	−4·3	−3·6	−2·9	−2·2	−1·6	−0·9	−0·2	0·5		
5	−6·5	−5·8	−5·1	−4·4	−3·7	−3·0	−2·3	−1·7	−1·0	−0·3	0·4	1·1	1·8	
6	−5·9	−5·2	−4·5	−3·8	−3·1	−2·4	−1·8	−1·1	−0·4	0·3	1·0	1·7	2·4	3·1
7	−5·3	−4·6	−3·9	−3·2	−2·5	−1·9	−1·2	−0·5	0·2	0·9	1·6	2·3	3·0	3·7
8		−4·0	−3·3	−2·6	−2·0	−1·3	−0·6	0·1	0·8	1·5	2·2	2·9	3·6	4.3
9			−2·7	−2·1	−1·4	−0·7	0·0	0·7	1·4	2·1	2·8	3·5	4·2	4·9
10				−1·5	−0·8	−0·1	0·6	1·3	2·0	2·7	3·4	4·1	4·8	5·4
11					−0·2	0·5	1·2	1·9	2·6	3·3	4·0	4·7	5·3	6·0
12						1·1	1·8	2·5	3·2	3·9	4·6	5·2	5·9	6·6
13							2·4	3·1	3·8	4·5	5·1	5·8	6·5	7·2

Correction (δ) to be added for mean cloud amount during the night:

Mean cloud amount (oktas)	0	1	2	3	4	5	6	7	8
δ (degC)	−1·2	−0·7	0·0	0·0	+0·3	+0·6	+0·9	+1·1	+1·3

The next step was to test this equation on samples of data obtained from two separate winters at Watnall and three separate winters at Wyton. In every case the cloud correction produced a marginal improvement in the standard deviation of the errors, but moved the mean a little further from zero; this is not surprising since the basic equation was derived by the method of least squares.

The winter of 1969–70 was one of those for which data from Watnall were used. October 1969 contained many warm days in a range not represented in the data used for deriving the equation, so a recalculation of the data for this winter was carried out by rejecting occasions when D_{12} was greater than 10°C. This was deemed permissible as forecasting temperatures of 0°C or below on roads is unlikely to be a problem for a forecaster in these circumstances, and moreover the regression may not be strictly linear at these extreme values. Table II shows the improvement which resulted.

TABLE II—EFFECT OF REJECTING OCCASIONS WHEN D_{12} WAS GREATER THAN 10°C IN THE APPLICATION OF THE DIRECT REGRESSION METHOD TO WATNALL DATA FOR THE PERIOD OCTOBER 1969–APRIL 1970

		Number of observations	Mean error	Standard deviation
			degrees Celsius	
Without cloud correction :	All cases	110	+0·60	3·54
	Rejecting $D_{12} > 10$°C	96	−0·04	2·83
With cloud correction :	All cases	110	+1·03	3·43
	Rejecting $D_{12} > 10$°C	96	+0·29	2·66

Analysis of variance showed that the three samples of data consisting of errors in forecasts of minimum temperatures at Wyton all came from the same population. Data for all three winters were then lumped together to obtain the best estimates of the mean and standard deviation of this population. Analysis of variance also showed that the data for two winters at Watnall were themselves samples of one population and the mean and standard deviation were calculated for this population. In short, there was no year-to-year variation at either place. Student's *t*-test was now applied to these two resultant populations and it was found that these two populations were themselves samples of a common population. The whole process was then repeated with allowance for cloud cover and this process again yielded resultant populations for Wyton and Watnall which were themselves samples of a common population (though not the same population as the first which contained no correction for cloud cover). The 5 per cent level of significance was used as the criterion and, as stated above, occasions when D_{12} was greater than 10°C were rejected.

It is a noteworthy result that the errors in forecasts of minimum temperatures on two roads over 60 miles apart are samples of the same two populations (with and without cloud cover respectively); but as later work[6] showed that there are differences between the results for other places in the same part of England by this method, this particular result may be no more than a coincidence. Throughout this paper the error is reckoned as the forecast value minus the observed value, and the best estimates of the mean error and standard deviation for each of the two populations are as follows :

	Without cloud correction	With cloud correction
Mean error	−0·14 degC	+0·38 degC
Standard deviation	2·56 degC	2·42 degC

Total number of cases 554.

The reduction in standard deviation is the maximum which can be expected from applying the cloud correction because cloud amounts were assessed from the *Daily register* after the event and are therefore not subject to any forecasting errors.

Because Parrey and Ritchie had shown that the depression of the minimum temperatures at the surface of a concrete road below that of the air in the screen is closely related to the hours of darkness, an attempt was made to introduce a further modification into the direct regression equation to take the duration of darkness into account. It was unsuccessful. Perhaps an equation might have been set up to derive M_R in terms of three quantities instead of two (duration of darkness perhaps being the third) but an equation of this kind cannot be tabulated for ready use on the forecast bench, and the figures given above therefore probably represent the best that can be achieved by direct regression.

Indirect methods. (i) *Parrey's method.* Two methods have been proposed for deriving a forecast of the minimum temperature over a concrete road (M_R) from a forecast of the minimum air temperature (M_A) in the thermometer screen. From data for the winter 1967–68 Parrey[1] derived the linear regression equation :

$$M_A - M_R = 0{\cdot}28t - 2{\cdot}9,$$

where t is the time between sunset and sunrise in hours and temperatures are in degrees Celsius. With the aid of the *Nautical Almanac* this equation can be tabulated for ready use for any given latitude. Table III shows the tabulation for 53°N. This method was not tested on the road at Watnall but it was tested on data for three successive winters at Wyton. As this was done in retrospect, actual values of M_A were used. Analysis of variance showed that data for all three winters could be regarded as samples of the same population and the following results were obtained for all occasions :

number of occasions	618
mean error	− 0·04 degC
standard deviation σ_1	1·02 degC

The errors were normally distributed.

To obtain the total error it is necessary to take into account the errors in forecasting air minimum temperatures. Steele, Stroud and Virgo[7] have given figures for clear and cloudy nights separately for the period October 1967–March 1968. When compounded the mean error is − 1·10 degC and the standard deviation $\sigma_2 = 2{\cdot}79$ degC. By adding the errors and adding the variances we may obtain an estimate of the errors involved in the whole process. The figures are :

mean error	− 1·14 degC
standard deviation	$\sqrt{(\sigma_1^2 + \sigma_2^2)} = 2{\cdot}97$ degC.

(ii) *Ritchie's method.* Instead of a regression equation Ritchie[2] expressed the quantity $M_A - M_R$ for each day of the year October 1967–September 1968 as a simple sine curve of the form

$$M_A - M_R = 0{\cdot}48 + 1{\cdot}22 \sin(\theta + \varphi),$$

TABLE III—TABULATION OF $(M_A - M_R)$ FOR PARREY'S METHOD

Duration between sunset and sunrise from (h min.)	to (h min.)	$M_A - M_R$ (degC)	Dates	
9 06	9 26	−0·3	26–30 Apr.	
9 27	9 48	−0·2	20–25 Apr.	
9 49	10 09	−0·1	14–19 Apr.	
10 10	10 31	0·0	9–13 Apr.	
10 32	10 53	+0·1	4–8 Apr.	
10 54	11 15	+0·2	29 Mar.–3 Apr.	
11 16	11 37	+0·3	24–28 Mar.	
11 38	11 59	+0·4	19–23 Mar.	
12 00	12 20	+0·5	14–18 Mar.	
12 21	12 40	+0·6	9–13 Mar.	1–5 Oct.
12 41	13 03	+0·7	4–8 Mar.	6–10 Oct.
13 04	13 24	+0·8	27 Feb.–3 Mar.	11–16 Oct.
13 25	13 45	+0·9	21–26 Feb.	17–21 Oct.
13 46	14 06	+1·0	16–20 Feb.	22–26 Oct.
14 07	14 27	+1·1	10–15 Feb.	27–31 Oct.
14 28	14 49	+1·2	4–9 Feb.	1–6 Nov.
14 50	15 10	+1·3	29 Jan.–3 Feb.	7–12 Nov.
15 11	15 32	+1·4	22–28 Jan.	13–19 Nov.
15 33	15 54	+1·5	15–21 Jan.	20–27 Nov.
15 55	16 15	+1·6	8–14 Jan.	28 Nov.–8 Dec.
16 16	16 36	+1·7	9 Dec.–7 Jan.	

The durations on the left-hand side of the table are derived from the equation $M_A - M_R = 0{\cdot}28t - 2{\cdot}9$ where t is duration in hours. The corresponding dates on the right-hand side are appropriate to latitude 53°N. The quantity in the middle column must be subtracted from M_A to obtain M_R.

where θ is the day as an angle (365 days = 360°) and φ is a phase angle. When a harmonic analysis was performed on the data for another year, October 1968–September 1969, it was found that the numerical constants were the same as before to two places of decimals and the only difference was in the phase angle (due presumably to a late spring or early autumn or some such difference between the years). This curve, with the value of the phase angle obtained for the year October 1967–September 1968, was taken as the basis for further study. The actual points for the year October 1967–September 1968 are scattered about this curve and an attempt was made to reduce the scatter by making allowances for wind speed and cloud amount. This was unsuccessful, so the best forecast of the depression of M_R below M_A by this method remains that derived from the curve itself. Values of this quantity were tabulated for 10-day intervals and are given in Table IV.

TABLE IV—TABULATION OF $(M_A - M_R)$ FROM RITCHIE'S CURVE

Days of month	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
				degrees Celsius			
1–10	+0·8	+1·3	+1·7	+1·7	+1·4	+1·1	+0·5
11–20	+1·0	+1·4	+1·7	+1·6	+1·3	+0·9	+0·2
21–31	+1·2	+1·5	+1·7	+1·5	+1·2	+0·7	0·0

This table was then used to obtain values of $M_A - M_R$ for two winters at Watnall and three at Wyton and the errors calculated. They are summarized in Table V. As Student's *t*-test gives strong grounds for believing that the data for the two places are samples of the same population, the averages are also given at the foot of the table. These averages are very similar to the only comparable figures available from the use of Parrey's method, namely

TABLE V—ERRORS IN $(M_A - M_R)$ BY RITCHIE'S METHOD

Place	Number of winters	Total number of occasions	Mean error	S.D.
			degrees Celsius	
Wyton	3	560	−0·09	1·08
Watnall	2	279	+0·08	1·09
Mean			0·00	1·09

those for Wyton (see page 352). When the two sets of figures were compared by means of the *t*-test, a value of $t = 0{\cdot}7$ was obtained. As the critical value of t at the 5 per cent level is 1·96, it may be accepted that both sets of figures refer to samples of the same population. This was to be expected as Parrey's equation and Ritchie's curve are simply different ways of expressing the dependence of $M_A - M_R$ upon the length of the cooling period.

Combined with the data for errors in forecasting M_A given by Steele, Stroud and Virgo (mean error − 1·10 degC, σ_2 2·79 degC) the figures for the whole process for Wyton are :

mean error − 1·09 degC
standard deviation 3·00 degC.

For Watnall for 1969–70 the mean error in forecasting M_A is − 0·21 degC and the standard deviation is 1·99 degC, irrespective of whether occasions when D_{12} was greater than 10°C are included or not. The mean error of $M_A - M_R$ was zero with σ 1·09 degC so that for the whole process for Watnall the figures are :

mean error − 0·21 degC
standard deviation 2·27 degC.

Discussion. To clarify the discussion the essential figures have been gathered together in Tables VI and VII. For Wyton the direct regression

TABLE VI—COMPARISON OF ERRORS IN FORECASTING M_R

Method	Source of observations	Mean error	σ
		degC	
Direct regression with cloud correction and rejecting $D_{12} > 10$°C	Wyton and Watnall combined	+0·38	2·42
Parrey's method	Wyton	− 1·14	2·97
Ritchie's method	Wyton	− 1·09	3·00
Ritchie's method	Watnall	− 0·21	2·27

TABLE VII—COMPARISON OF ERRORS IN FORECASTING $(M_A - M_R)$

Method	Source of observations	Mean error	S.D.
		degC	
Parrey's	Wyton	− 0·04	1·02
Ritchie's	Wyton and Watnall combined	0·00	1·09

method gives better results, possibly because the large errors in forecasting M_A at Wyton are masked to some extent in the direct regression equation. At Watnall, however, where the errors in forecasting M_A are much lower, Parrey's and Ritchie's methods give better results. For forecasting $M_A - M_R$ it is immaterial whether Parrey's or Ritchie's method is used.

The agreement between the results for the two roads over 60 miles apart is remarkable and while it would be unwise to conclude that the tabulations used in these two roads are of widespread application, it may be assumed that these results show the order of accuracy attainable, and it is hoped that other investigators will be encouraged to try similar experiments on roads elsewhere.

REFERENCES

1. PARREY, G. E.; Minimum road temperatures. *Met Mag., London*, **98**, 1969, pp. 286–290.
2. RITCHIE, W. G.; Night minimum temperatures at or near various surfaces. *Met. Mag., London*, **98**, 1969, pp. 297–304.
3. JOHNSON, N. K. and DAVIES, E. L.; Some measurements of temperature near the surface in various kind of soils. *Q. Jnl R. met. Soc., London*, **53**, 1927, pp. 45–59.
4. HAY, J. S.; Some observations of night minimum road temperatures. *Met. Mag., London*, **98**, 1969, pp. 55–59.
5. BROOKS, C. E. P. and CARRUTHERS, N.; Handbook of statistical methods in meteorology. London, HMSO, 1953, p. 245.
6. PARREY, G. E., RITCHIE, W. G. and VIRGO, S. E.; Minimum temperatures at the surfaces of concrete roads and concrete slabs. *Met. Mag., London*, **100**, 1971, in press.
7. STEELE, L. P., STROUD, P. A. J. and VIRGO, S.E.; Accuracy of forecasting night minimum air temperatures by the method due to Saunders. *Met. Mag., London*, **98**, 1969, pp. 107–113.

551.509.323

MAXIMUM TEMPERATURE ON CLEAR DAYS

By G. A. INGLIS

Summary. An account is given of some further developments of Gold's technique for forecasting maximum day temperature. The *isothermal method* is a variation of Johnston's method in which the geometrical work is reduced; in the *oblique method* a set of parallel oblique straight lines is substituted for the isothermals; the *saturated-adiabatic method* makes use of a 'mean' saturated adiabatic instead of a 'mean' isothermal. In the *thickness method* the maximum temperature in summer is obtained from a table of 1000–850-mb thickness values.

The isothermal method. Gold's[1] method of estimating maximum day temperatures was modified by Johnston[2] and this in turn was slightly amended following a suggestion by Jefferson.[3] Johnston made use of assessments (denoted here by p_1) made by Gold of the depth of the layer which is changed from an isothermal to a dry adiabatic by solar heating on clear days (Table I). The term 'depth' is used instead of 'thickness' which is used in a different sense later on. The curve does not really become a dry adiabatic, the lapse rate next to the surface being much steeper in the typical case, but Gold's figures give good results in practice. As in all the tephigram methods the ascent used is that for 00 GMT.

TABLE I—DEPTH OF LAYER (p_1) WHICH IS CHANGED BY HEATING FROM AN ISOTHERMAL TO A DRY ADIABATIC, AND ASSOCIATED RISE IN TEMPERATURE (r_1)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
p_1(mb)	60	80	95	110	120	125	120	110	100	85	60	50
r_1(degC)	5	6·5	8·5	9·5	10·5	11	10·5	10	9	7	5	4·5

In Johnston's method (Figure 1) the isobars p_0 and p_0–p_1 are drawn, corresponding to the pressures at the surface and the top of the layer. The isothermal II′ is drawn to make equal areas between it and the environment curve, IE the boundary of the upper area being a dry adiabatic. The point F where the dry adiabatic meets the surface isobar gives the forecast maximum temperature.

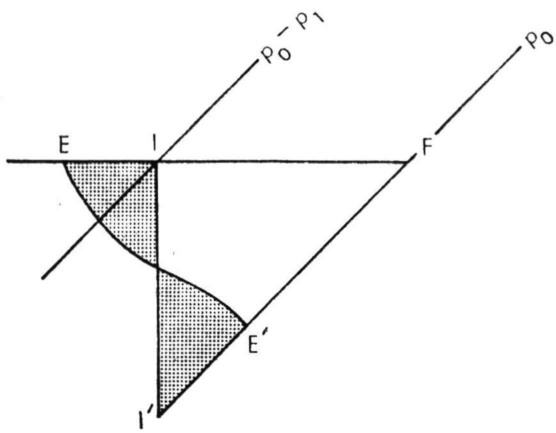


FIGURE 1—JOHNSTON'S METHOD

Gold also made assessments of the rise in temperature (r_1) corresponding to the change from an isothermal to a dry adiabatic; in Table I these have been converted to Celsius to the nearest 0·5 degC. The values of p_1 and r_1, can easily be verified by drawing on the tephigram a set of triangles FII′ for each month.

If we know the value of r_1 it is not necessary to draw IF. If instead we note the temperature at I′ we can add to this the appropriate rise from Table I. This gives an alternative method in which part of the geometry is replaced by arithmetic, and it is considered to be somewhat easier and more accurate.

Procedure. Draw the isobars p_0 and $p_0 - p_1$ (Figure 2). Draw the isothermal II′ to make equal areas between it and the environment curve, IE the boundary of the upper area being a dry adiabatic. To the temperature at I′ add the rise (r_1) from Table I to get the forecast maximum temperature. As in Johnston's method it is helpful to use a transparent scale with two lines at right angles.

Johnston says that the midnight environment curve is to be modified so as to approximate to conditions at dawn. But since modification of the curve is difficult and the change in area is usually insignificant it may be better to leave the curve unaltered.

The oblique method. Johnston's method has two advantages over Gold's; it is independent of the scale of the tephigram and the areas to be estimated are relatively small because the midnight environment curve is often nearly isothermal. But this is not always so; in fact on the average the curve is

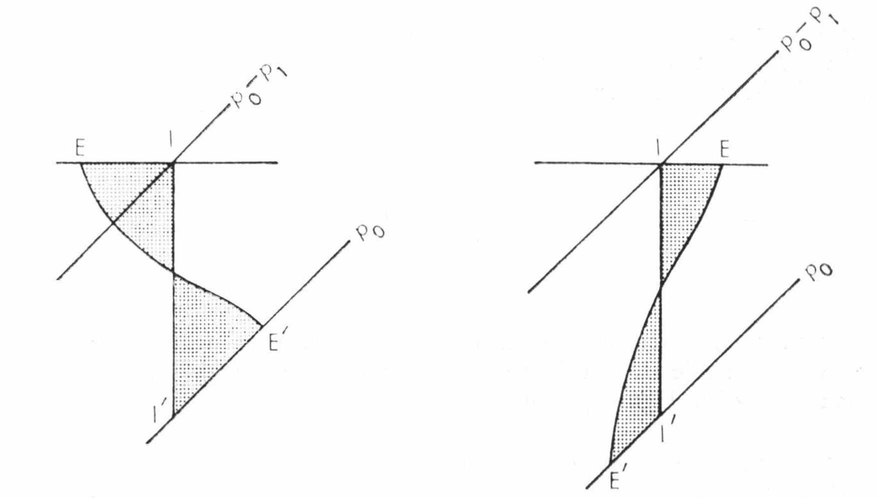


FIGURE 2—THE ISOTHERMAL METHOD

closer to the saturated adiabatic and often nearly coincides with it. It would be useful to have a technique based on estimating a 'mean' saturated adiabatic instead of a 'mean' isothermal. It was found that Johnston's technique for the isothermals can be adapted to any other set of lines; but the saturated adiabatics are not suitable for use with a scale because they vary in slope. (The curvature is negligible.) Therefore another method — the oblique method — was devised which makes use of a set of parallel straight lines inclined at an angle to the isothermals.

It is necessary to make assessments of the depth of the layer which is changed by heating from an oblique to a dry adiabatic and the corresponding rise in temperature. This could be done graphically as in Figure 3. For any month let I′F be the mean surface isobar (say 1020 mb), and let F correspond to the

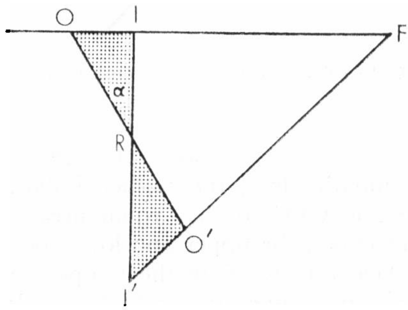


FIGURE 3—GRAPHICAL METHOD OF ASSESSING VALUES OF p_2, r_2, p_3, r_3 AND DIAGRAM FOR OBTAINING FORMULAE FOR p_2 AND r_2

mean daily maximum temperature for, say, southern England. Subtract r_1 from the maximum temperature to get the point I′ and let the isothermal and the dry adiabatic meet at I. Draw the oblique OO′ at the required angle of inclination α so that ORI and O′RI′ are equal in area. Then FO′ will give the rise in temperature r_2, and the difference in pressure between O and the surface will give the depth of the layer p_2.

It is easier however and just as accurate in practice to calculate the values. If the surface isobar is assumed to be a straight line inclined at an angle of 45° to the isothermals then by geometry

$$\frac{r_2}{r_1} = \frac{O'F}{I'F} = \frac{1}{\sqrt{(1 + \tan\alpha)}} \cdot$$

But $r_1p_1 = r_2p_2$ since area II′F = area OO′F, therefore

$$\frac{p_2}{p_1} = \sqrt{(1 + \tan\alpha)} \cdot$$

These formulae were used to calculate, for an angle of inclination α of 45°, the values in Table II, and the values were then used to make the transparent scale illustrated in Figure 4. (not exact).

TABLE II—DEPTH OF LAYER (p_2) WHICH IS CHANGED BY HEATING FROM AN OBLIQUE AT 45° TO A DRY ADIABATIC, AND ASSOCIATED RISE IN TEMPERATURE (r_2)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
p_2(mb)	85	115	135	155	170	175	170	155	140	120	85	70
r_2(degC)	3·5	4·5	6	6·5	7·5	8	7·5	7	6·5	5	3·5	3

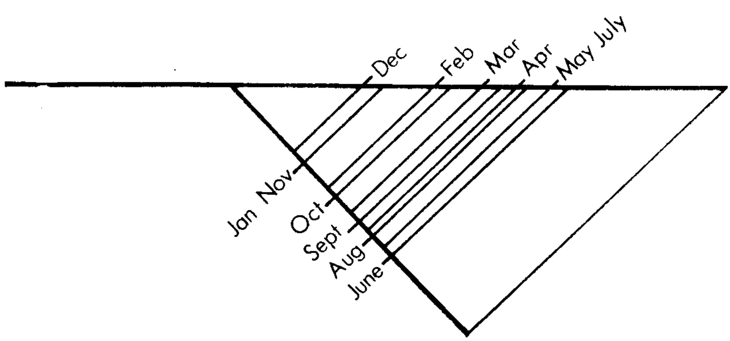


FIGURE 4—SCALE FOR USE IN OBLIQUE METHOD

Procedure. The scale is used as follows (Figure 5). Lay the thin line corresponding to the month along the surface isobar. Adjust the position of the heavy oblique line OO′ so that equal areas are enclosed between it and the environment curve, the upper and lower boundaries being the dry adiabatic and the surface isobar. Note the temperature at O′ and add r_2 to get the forecast maximum temperature, which can also be read at F.

The dimensions of the scale depend on those of the tephigram. Figure 4 is ¾ the scale suitable for the tephigram currently in use, i.e. Metform 2810. Alternatively a scale consisting simply of two lines OO′ and OF inclined at an angle of 45° can be used. The procedure would then be to subtract p_2 from the surface pressure and adjust the position of OO′ so that the point O lies on the isobar $p_0 - p_2$ and OO′ intercepts equal areas between it and the environment curve as above. The temperature at O′ on the surface isobar is then read and the value of r_2 added.

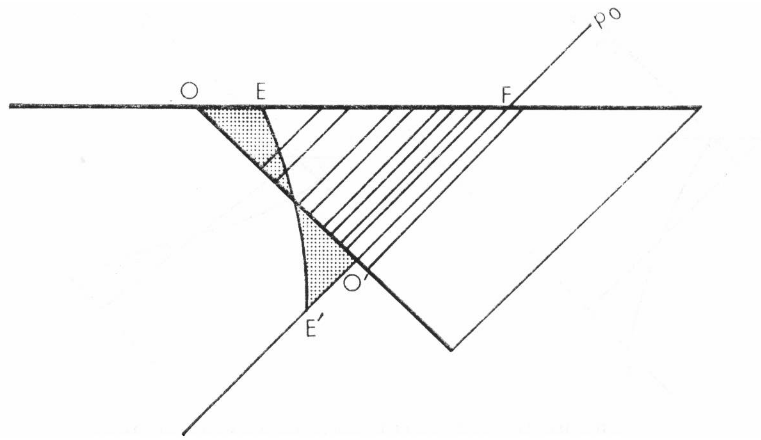


FIGURE 5—METHOD OF USING SCALE

The saturated-adiabatic method. This method is for use without a scale. The necessary table of assessments of values of depth and rise in temperature could be made graphically by a construction similar to that in Figure 3, OO′ being in this case replaced by a saturated adiabatic SS′. But since the curvature of the saturated adiabatics is negligible they can be treated as straight lines, so that the method becomes a modification of the oblique method, in which the slope of the oblique varies from month to month. The values of the angle of slope in Table III were based on mean monthly values of the 1000–850-mb thickness for south-east England but a similar result can be got by drawing on the tephigram a set of saturated adiabatics through the points corresponding to the mean daily surface temperatures. From these values Table IV was calculated using the formulae for the oblique method.

TABLE III—MEAN INCLINATION TO THE ISOTHERMAL OF THE SATURATED ADIABATICS IN THE 'HEATED LAYER'

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
					angular degrees						
58	58	57	55	51	47	45	45	49	51	55	57

TABLE IV—DEPTH OF LAYER (p_3) WHICH IS CHANGED BY HEATING FROM A SATURATED ADIABATIC TO A DRY ADIABATIC, AND ASSOCIATED RISE IN TEMPERATURE (r_3)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
p_3(mb)	100	130	150	170	180	180	170	155	145	125	95	80
r_3(degC)	3	4	5	6	7	7·5	7·5	7	6	5	3	3

Procedure. Draw the surface isobar p_0 and the upper isobar $p_0 - p_3$ (Figure 6). Draw a saturated adiabatic SS′ making equal intercepts with the environment curve, SE the boundary of the upper area being a dry adiabatic. To the temperature at S′ add r_3 to get the forecast maximum temperature. The latter can also be read at the intersection of the dry adiabatic and surface isobar. In drawing the saturated adiabatic the curvature can be disregarded.

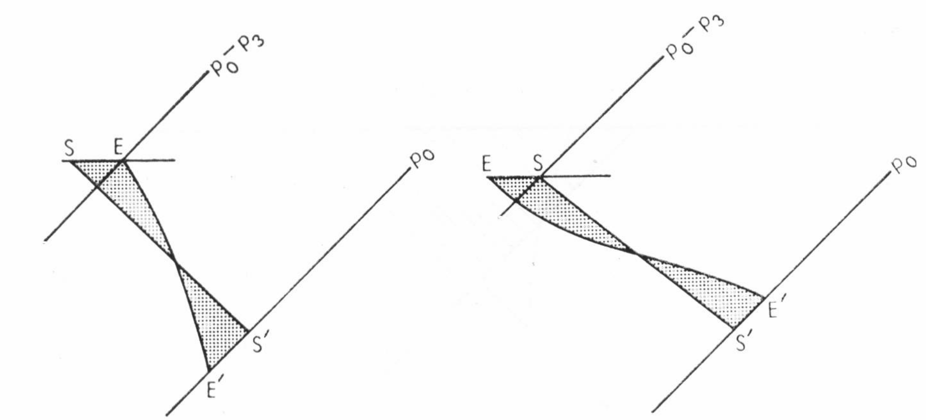


FIGURE 6—THE SATURATED ADIABATIC METHOD

The 1000–850-mb thickness method. In the methods described above we see that the maximum temperature can be regarded as consisting of two parts — the 'mean' temperature in a layer of the atmosphere next to the surface, which is a characteristic of the air mass, plus a constant which depends on the month. But the mean temperature of the layer between two pressure levels can also be measured by its thickness in geopotential metres, and in the summer months it happens that the layer examined to find the Gold maximum is very nearly the same as the 1000–850-mb layer at 00 GMT.

The areas equated in the isothermal method are not exactly the same as those equated in calculating the 1000–850-mb thickness; if they were the same then the thickness value, from a suitable table, would give the Gold maximum exactly. Actually two curves with different profiles but with the same thickness and same surface pressure have Gold maxima which differ by an amount which is usually less than 1 degC. If, in order to make a suitable table, we assume an average value of the lapse rate then the thickness value can be used to give an estimate of maximum temperature very close to the Gold maximum.

The average value of the lapse rate was assumed to be three-quarters of the saturated adiabatic and from the Radio Sounding Diagram (Metform 2813A) Table V was prepared, an allowance being made for an assumed mean relative

TABLE V—VALUES OF 1000–850-mb THICKNESS AND ASSOCIATED SURFACE TEMPERATURE (AT 1020 mb) ASSUMING THREE-QUARTERS OF SATURATED ADIABATIC LAPSE RATE AND 75 PER CENT RELATIVE HUMIDITY

Thickness (gpm)	1280	1290	1300	1310	1320	1330	1340	1350	1360	1370	1380	1390
Temperature (°C)	−0·5	1·4	3·3	5·2	7·1	9·0	10·9	12·7	14·5	16·3	18·2	20·0

humidity of 75 per cent. (The tephigram is not suitable for calculating values of the 1000–850-mb thickness.) Table VI was then prepared by proportional parts from Tables I and IV, and Tables V and VI were combined in Table VII. To avoid the need for interpolation the maximum temperatures corresponding to each geopotential metre have been worked out for August in Table VIII, which can also be used for the other months if a small correction is applied.

TABLE VI—RISE IN TEMPERATURE ASSOCIATED WITH CHANGE BY HEATING FROM A CURVE WITH THREE-QUARTERS OF THE SATURATED ADIABATIC LAPSE RATE TO A DRY ADIABATIC

	April	May	June	July	August	September
Rise (degC)	6·9	8·0	8·5	8·3	7·8	6·8

TABLE VII—VALUES OF GOLD MAXIMA FROM 1000–850-mb THICKNESS, ASSUMING THREE-QUARTERS OF SATURATED ADIABATIC LAPSE RATE AND 75 PER CENT RELATIVE HUMIDITY

Thickness	April	May	June	July	August	September
gpm			*degrees Celsius*			
1280	6·4	7·5	8·0	7·8	7·3	6·3
1290	8·3	9·4	9·9	9·7	9·2	8·2
1300	10·2	11·3	11·8	11·6	11·1	10·1
1310	12·1	13·2	13·7	13·5	13·0	12·0
1320	14·0	15·1	15·6	15·4	14·9	13·9
1330	15·9	17·0	17·5	17·3	16·8	15·8
1340	17·8	18·9	19·4	19·2	18·7	17·7
1350	19·6	20·7	21·2	21·0	20·5	19·5
1360	21·4	22·5	23·0	22·8	22·3	21·3
1370	23·2	24·3	24·8	24·6	24·1	23·1
1380	25·1	26·2	26·7	26·5	26·0	25·0
1390	26·9	28·0	28·5	28·3	27·8	26·8

TABLE VIII—1000–850-mb THICKNESS VALUES AND CORRESPONDING GOLD MAXIMA FOR AUGUST

Thickness	0	1	2	3	4	5	6	7	8	9
gpm					*degrees Celsius*					
1280	7·3	7·5	7·7	7·9	8·1	8·3	8·4	8·6	8·8	9·0
1290	9·2	9·4	9·6	9·8	10·0	10·1	10·3	10·5	10·7	10·9
1300	11·1	11·3	11·5	11·7	11·9	12·1	12·2	12·4	12·6	12·8
1310	13·0	13·2	13·4	13·6	13·8	13·9	14·1	14·3	14·5	14·7
1320	14·9	15·1	15·3	15·5	15·7	15·9	16·0	16·2	16·4	16·6
1330	16·8	17·0	17·2	17·4	17·6	17·7	17·9	18·1	18·3	18·5
1340	18·7	18·9	19·1	19·2	19·4	19·6	19·8	20·0	20·1	20·3
1350	20·5	20·7	20·9	21·0	21·2	21·4	21·6	21·8	21·9	22·1
1360	22·3	22·5	22·7	22·8	23·0	23·2	23·4	23·6	23·7	23·9
1370	24·1	24·3	24·5	24·7	24·9	25·1	25·2	25·4	25·6	25·8
1380	26·0	26·2	26·4	26·5	26·7	26·9	27·1	27·3	27·4	27·6
1390	27·8	28·0	28·2	28·3	28·5	28·7	28·9	29·1	29·2	29·4

	April	May	June	July	September
Correction (degC)	−0·9	+0·2	+0·7	+0·5	−1·0

The meaning of Table VIII is that, for example, in the month of August a curve with a thickness of 1335 gpm, a surface pressure of 1020 mb, a relative humidity of 75 per cent and a lapse rate three-quarters of the saturated adiabatic will have a Gold maximum of 17·7°C exactly. If with the same surface pressure and relative humidity the lapse rate is really isothermal, then Table VIII will overestimate the Gold maximum by an amount between 0·7 and 1·0 degC. If the lapse rate is really a saturated adiabatic then the table will underestimate the Gold maximum by about 0·2 degC.

Differences also arise from variations in surface pressure; 1020 mb was taken as the mean surface pressure on sunny days (i.e. slightly higher than the mean pressure for all days), and strictly speaking, a correction of about 0·1 degC should be added or subtracted for every 2 mb above or below 1020 mb; but this correction is usually small and was disregarded in the test. Other differences may arise from variations in humidity and from irregularities in the shape of the curve near 850 mb.

Test. A test of the method was carried out using data for the months April to September 1966–69. Days with 40 per cent or more of possible sunshine and no precipitation between 09 and 15 GMT were selected. The upper air ascent for 00 GMT at Aughton was used to forecast the maximum temperature by (i) one of the tephigram methods and (ii) the thickness method. (Aughton was used because plotted ascents from southern England were not available.) The forecast maxima were compared with the reported maxima at one or more of the stations Ringway (334), Shawbury (414), Birmingham (534) and Watnall (354). If more than one of these qualified as 'sunny' the mean was taken.

TABLE IX—COMPARISON OF TEPHIGRAM AND 1000–500-mb THICKNESS METHODS AS PREDICTORS OF MAXIMUM TEMPERATURE USING DATA FOR AUGHTON 1966–69

	Number of observations	Root-mean-square error Tephigram method	Thickness method
		degC	*degC*
April	32	1·67	1·56
May	29	1·39	1·44
June	43	1·65	1·66
July	45	1·94	1·82
August	28	1·55	1·68
September	27	1·13	1·10
Apr.–Sept.	204	1·62	1·59

The results are shown in Table IX. It will be observed that there is no difference in accuracy between the two methods and hence in the summer months the thickness method could be used instead of the tephigram methods with equally good results. Although the method was fully tested only for the six summer months it is thought that it may be useful for some other months such as March and October. All that is necessary is to add these months to the list of corrections in Table VIII.

The thickness method has several advantages. Firstly, there is no need to plot and examine the tephigram; secondly, a central office can obtain a forecast very quickly for a large area, e.g. north-west Europe, by plotting the thickness values on a chart; thirdly, the method can be used by inexperienced staff as it simply involves a subtraction followed by reference to a table.

Regression technique. The direct way to establish a relationship between thickness and maximum temperature would be by means of a regression equation, using the same type of data as in the test above. It would have to be done separately for each month, except that the midsummer months could be grouped together. The result would be entirely independent of Gold's figures and might be the best method if sufficiently large samples were taken.

Comments. During the past two years the tephigram methods described above have been found to be easy and accurate. The curve is usually nearer to the saturated adiabatic than to the isothermal and is often so close to it that the areas involved are almost nil in which case the estimation can be done by eye alone. The reduction in geometrical work makes the methods more suitable for use with FAX copies of the tephigram than the older methods. The thickness method provides a quick and accurate estimate of the maximum temperature without reference to the tephigram.

REFERENCES

1. GOLD, E.; Maximum day temperatures and the tephigram. *Prof. Notes met. Off., London*, No. 63, 1933.
2. JOHNSTON, D. W.; The estimation of maximum day temperatures from the tephigram. *Met. Mag., London*, **87**, 1958, pp. 265–266.
3. JEFFERSON, G. J.; The estimation of maximum day temperature from the tephigram. *Met. Mag., London*, **88**, 1959, pp. 151–152.

551.509.324.2:551.557

DEW-POINT TEMPERATURE AS A SNOW PREDICTOR

By B. J. BOOTH

Summary. Winter observations made at Upavon were analysed to see if there is any correlation between the dew-point temperature and the type of precipitation occurring at the time of the observation, which might allow the dew-point to be used as a snow predictor. A relationship was found and an empirical formula is suggested for use by the practising forecaster.

Introduction. Many, if not all, of the snow predictors now in use resort to the use of upper air data. The various methods have been summarized by Boyden.[1]

The use of upper air data creates three basic problems:

(i) Which ascent or ascents are applicable to a particular area?

(ii) The ascents are only available at 12-hourly intervals, and may substantially change in any 12-hour period.

(iii) Most of the radiosonde stations are close to the sea, and in the lower levels may not be representative of a particular air mass.

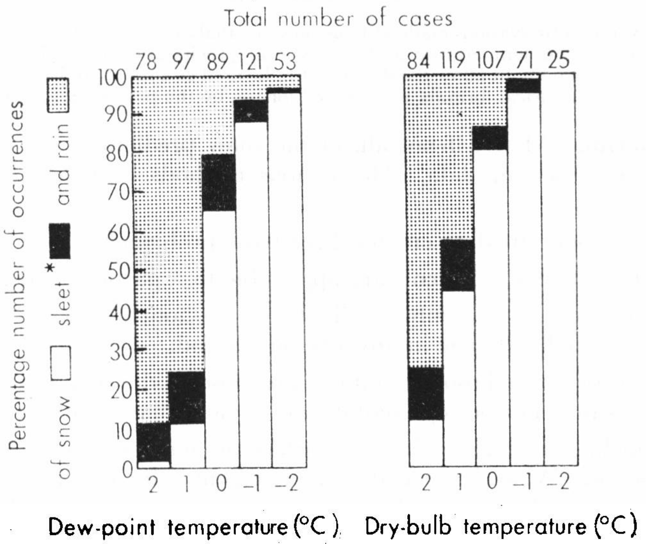
Boyden in his paper finds that the surface air temperature is an unreliable snow predictor. What is needed is an element which is readily available hour by hour, easily measured, and reasonably conservative. With this in mind an analysis was made of the full synoptic observations at Upavon, to see if it would be feasible to use the dew-point temperature as a snow predictor. Upavon is an exposed station some 580 ft (177 m) above mean sea level, and about 35 nautical miles (65 km) from the south coast. Full synoptic observations are made at 09, 12, 15 and 21 GMT. Temperature observations are not available in the form of a continuous record.

The data. The dry-bulb temperature, dew-point temperature and type of precipitation were extracted from the Upavon observations on all occasions when precipitation was occurring at the time of the observation, or had occurred during the previous hour, for the winter months of the years 1950 to 1969 inclusive. No note was made of the intensity or duration of the precipitation. Winter in this case was defined as the months December, January and February.

Results. An analysis was made of the dry-bulb temperature and associated precipitation so that a comparison could be made of the methods of forecasting snow using dry-bulb temperature and dew-point temperature. Scatter diagrams were then prepared, in which the type of precipitation was plotted against (i) the dew-point temperature and (ii) the dry-bulb temperature.

It was noted that snow never fell with a dew-point $\geqslant 3°C$ and rain never occurred with a dew-point $\leqslant -3°C$.

In the dew-point diagram the type of precipitation showed a marked change from rain to snow at about 0°C. Boundaries were then marked on the diagram such that 2°C embraced values between 2·4°C and 1·6°C inclusive, 1°C embraced 1·5°C to 0·5°C, etc., i.e. the approximations used when coding synoptic reports. The percentage numbers of occasions on which snow fell for each temperature were then calculated. Snow was classified as all types of freezing precipitation (excluding hail and sleet*). Occasions of sleet were also noted and are shown in the histograms, Figures 1*(a)*, 1*(b)*, 2*(a)*, 2*(b)*. Freezing rain or drizzle was also included as snow, but this only occurred on 9 occasions in the 20 years.



(a) **With varying dew-point temperature.** *(b)* **With varying dry-bulb temperature.**

FIGURE 1—HISTOGRAMS SHOWING THE FREQUENCY OF OCCURRENCE OF DIFFERENT TYPES OF NON-SHOWERY PRECIPITATION

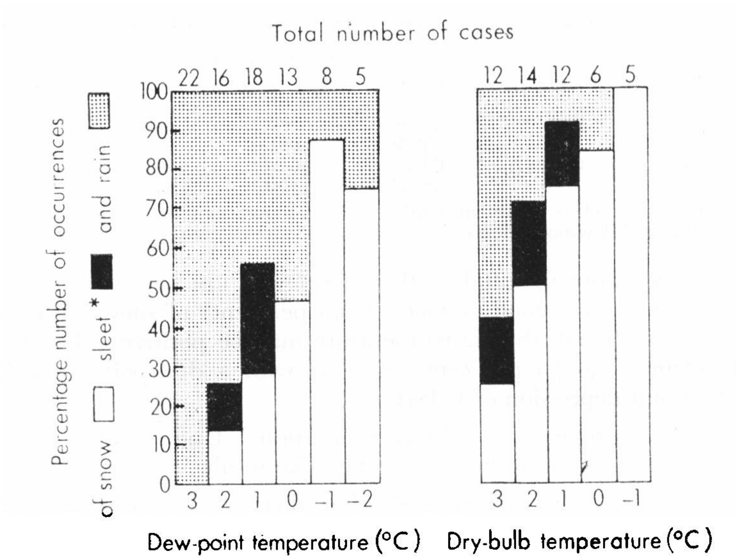
* Sleet : see footnote.

The histogram in Figure 1*(a)* shows a marked increase in the frequency of snow when the dew-point changes from 1°C to 0°C. The solid black area of each column shows the percentage number of occurrences of sleet. The total number of occasions examined was 438.

An analysis of the dry-bulb temperatures and type of precipitation gave the histogram in Figure 1*(b)*. The increase of frequency of snow occurrences is a much steadier process. Total number of cases examined was 406.

Separate diagrams were produced for occasions when showers occurred. Although the size of the sample was small, the results, as shown by the histograms, Figures 2*(a)* and 2*(b)*, show a similar pattern to the results previously noted. Here however the increased frequency of snow showers occurs with a dew-point of minus 1°C. Smith,[2] in a recent paper, also noted that a dew-point of 0°C was the critical value for the change from rain to snow.

* In the United Kingdom the term sleet is used to denote precipitation of snow and rain (or drizzle) together or of snow melting as it falls, but it has no agreed international meaning.



(a) With varying dew-point temperature. *(b)* With varying dry-bulb temperature.

FIGURE 2—HISTOGRAMS SHOWING THE FREQUENCY OF OCCURRENCE OF DIFFERENT TYPES OF SHOWERY PRECIPITATION

* Sleet : see footnote on page 364.

As there seemed to be a marked increase in the frequency of non-showery snow with a dew-point of 0°C a further analysis was made to see if a more accurate forecast of snow or rain/drizzle could be made, taking into account the dew-point depression. A scatter diagram was made with the dew-point as the abscissa and the air temperature as the ordinate. The type of precipitation was plotted at the intersection of each value of dew-point and air temperature. The results are summarized in Tables I, II and III.

TABLE I—SLEET* : FREQUENCY OF OCCURRENCES

Dew-point depression	Dew-point in degrees Celsius				
	−2	−1	0	1	2
degC			*per cent*		
3	0	16			
2	0	4	40		
1	0	4	25	15	
0	—	3	5	13	10

* Sleet : see footnote on page 364.

TABLE II—RAIN : FREQUENCY OF OCCURRENCES

Dew-point depression	Dew-point in degrees Celsius				
	−2	−1	0	1	2
degC			*per cent*		
3	0	33			
2	12	11	20		
1	0	8	29	77	
0	—	0	18	72	87

TABLE III—SNOW : FREQUENCY OF OCCURRENCES

Dew-point depression *degC*	Dew-point in degrees Celsius −2	−1	0	1	2
			per cent		
3	100(18)	51(6)			
2	88(8)	85(26)	40(5)		
1	100(24)	88(47)	46(28)	8(26)	
0	—	97(38)	77(56)	15(54)	3(30)

Numbers in brackets represent total number of occasions examined for each dew-point and dew-point depression.

It can be seen from these tables that (i) snow is unlikely with a dew-point $\geqslant 1°C$; (ii) there is a good chance ($>$ 50 per cent) of snow with negative dew-points even though the air temperature may be positive; (iii) there is a moderate chance (30–50 per cent) of snow with a dew-point of 0°C even with a dew-point depression of 1 degC.

The process was repeated for showery situations. Unfortunately the sample was not large enough to produce any conclusive results.

Examination of Table III suggests that there is a relationship between dew-points $\leqslant 0°C$ (DP) and dew-point depressions (DPD) which gives the boundary between snow and precipitation other than snow. This is :

$$\text{DPD} = [(-2 \times \text{DP}) + 1] \text{ degC},$$

i.e. if DPD $\leqslant [(-2 \times \text{DP}) + 1]$ degC, then there is a good ($>$ 50 per cent) chance of snow.

Table IV gives the values of dew-point and dew-point depression required for $>$ 50 per cent chance of snow using the above relationship. These values are easily obtainable from hourly synoptic reports.

TABLE IV—VALUES OF DEW-POINT AND DEW-POINT DEPRESSION FOR PROBABILITY OF SNOW > 50 PER CENT

Dew-point in degrees Celsius	0	−1	−2	−3	−4
Dew-point depression in degrees Celsius equal to or less than	1	3	5	7	9

Result of check on independent data. Using Table IV and adding the rider 'no snow with dew-points 0°C', the method was tested on independent data for March 1950–69. Although the frequency of snow and sleet is declining in March, it is still, at Upavon, as high as in December. The results are summarized in Table V*(a)*.

TABLE V*(a)*—NON-SHOWERY PRECIPITATION

Forecasts of rain	Correct forecasts	Forecasts of snow	Correct forecasts
49	37(76 per cent)	46	41(89 per cent)

5 of the incorrect forecasts were due to sleet. 1 of the incorrect forecasts was due to sleet.

TABLE V*(b)*—SHOWERY PRECIPITATION

Forecasts of rain	Correct forecasts	Forecasts of snow	Correct forecasts
18	14(78 per cent)	25	23(92 per cent)

Table V*(b)* gives the results for showery precipitation. Here, however, the criterion used was simply a forecast of snow with a dew-point $\leqslant -1°C$. This cruder criterion was used mainly because of the lack of conclusive data as previously mentioned.

Discussion. As the analysis of dew-points and dew-point depressions was made without reference to the intensity or duration of precipitation, no conclusion could be made about the rate of increase or decrease of the dew-point during precipitation. One would expect a change of dew-point with the approach of a different air mass, and it is possible to follow the change of dew-points and dew-point depressions on a normal working chart. It is then possible to decide, particularly in the case of an approaching warm front in winter, when precipitation falling as snow will turn to rain.

Lumb[3] states that snow can extend down to the 1·5°C wet-bulb level; unfortunately surface wet-bulb temperatures are not plotted on synoptic charts. If the figures in Table IV are plotted on a tephigram and the wet-bulb temperatures calculated, it will be seen that they lie between 0·5°C and 1·5°C. Thus by using the criteria in Table IV we now have a method of estimating, hour by hour, from the synoptic charts the change in wet-bulb temperature at the surface. Lumb[4] shows how prolonged moderate or heavy precipitation can also cause a change of dew-point.

The figures in Table IV were calculated for occasions when precipitation was occurring. It is felt, however, that in situations where precipitation is expected to occur, if the conditions of Table IV are fulfilled, then it would be reasonable to forecast the precipitation as snow.

Table VI gives the 2 × 2 contingency table comparing forecasts of rain or snow with the actual occurrences of rain and snow for the test forecasts on the March data. The chi-square value (with Yates's correction) is also shown.

TABLE VI—NUMBER OF FORECASTS OF SNOW OR RAIN AT UPAVON COMPARED WITH THE TYPE OF PRECIPITATION THAT ACTUALLY OCCURRED

	Rain forecast	Snow forecast	Totals
Rain occurred	37	5	42
Snow occurred	12	41	53
Totals	49	46	95

The chi-square value is 37·6, which is significant at the 0·1 per cent level.

The results of the test, Table V, are encouraging; however it would be interesting to see if similar results would be obtained from a low-level inland site, and a coastal site.

The object of this paper was to see if there was a correlation between the type of precipitation and dew-point temperature; this would seem to be the case with the dew-point of 0°C being the critical value for non-showery precipitation and − 1°C for showery precipitation.

REFERENCES

1. BOYDEN, C. J.; A comparison of snow predictors. *Met. Mag., London,* **93**, 1964, pp. 353–365.
2. SMITH, M. F.; Winter precipitation over East Anglia. *Met. Mag., London,* **99**, 1970, pp. 20–27.
3. LUMB, F. E.; The problem of forecasting the downward penetration of snow. *Met. Mag., London,* **90**, 1961, pp. 310–319.
4. LUMB, F. E.; Downward penetration of snow in relation to intensity of precipitation. *Met. Mag., London,* **92**, 1963, pp. 1–14.

551.558.21

MOUNTAIN LEE WAVES IN THE VALE OF YORK

By G. F. RUDDOCK

Following publication of Casswell's simplified method of forecasting lee-wave conditions,[1] a number of aircraft reports were received at Linton-on-Ouse during frequent westerly spells in the period June 1966 to December 1967. These westerly spells frequently produce wave conditions over the Vale of York, because of flow over the Pennines.

Examination of the reports, together with ground observations of wave-type clouds, suggested that, broadly speaking, Casswell's method worked fairly well in regard to maximum vertical velocities. However, the investigation drew attention to two important variations from Casswell's findings :

(i) Casswell quoted 20 kt* as the likely lower limit of wind speed at the mountain crest for wave formation. In this area the incidence of wave clouds, or of waves reported by aircraft, is quite common with wind speeds down to about 15 kt. This is in agreement with the statement in WMO *Technical Note* No. 34, page 119, that the minimum speed for wave formation is about 7 m/s for small mountains.

(ii) Casswell's method involves smoothing the environment temperature curve between 1000 and 700 mb, and between 700 and 300 mb. This has the disadvantage of smoothing through inversions, which may be major discontinuities. Theory strongly points to the height of maximum vertical velocity being at the inversion level (see for example Corby,[2] para. 19). The examination of aircraft reports leads to the same conclusion. It follows that the height of the maximum vertical velocity, as deduced by Casswell's method, is open to doubt if it differs widely from the base of the stable layer.

A comparison was made for 57 occasions (all suitable for mountain waves) between the height of maximum vertical velocity as deduced from Casswell and the height of the base of the isothermal or inversion layer, as taken from the representative tephigram.

This gave the following results :

Number of occasions with base of stable layer below 10 000 ft*	49
Number of occasions when Casswell method gave height of maximum vertical velocity within 1000 ft of the base of the stable layer	14 (28·6 per cent)
Number of occasions when Casswell method gave height of maximum vertical velocity more than 1000 ft above the base of the stable layer	32 (65·3 per cent)
Number of occasions when Casswell method gave height of maximum vertical velocity more than 1000 ft below the base of the stable layer	3 (6·1 per cent)

If the maximum vertical velocity occurs at the base of the stable layer then the Casswell method will give too high a level on a substantial number of occasions presumably because of the smoothing used in the procedure. Thus the height of inversion, or of base of isothermal, should be used to forecast the height of maximum vertical velocity, rather than the theoretical value. In practice, the nearer the stable layer to the mountain top, the more important this becomes. Light aircraft with maximum power lift of 1000 to

* 1kt ≈ 0·5 m/s; 1000 ft ≈ 300 m; 1000 ft/min ≈ 5 m/s.

1500 ft/min have insufficient power to overcome downdraughts of 1200 to 1500 ft/min and these are not uncommon in waves due to the Pennines.

REFERENCES

1. CASSWELL, S. A.; A simplified calculation of maximum vertical velocities in mountain lee waves. *Met. Mag., London,* **95**, 1966, pp. 66–80.
2. CORBY, G. A.; Air flow over mountains. Notes for forecasters and pilots. *Met. Rep., London,* No. 18, 1957.

REVIEWS

Atmospheric tides, by Sydney Chapman and Richard S. Lindzen. 240 mm × 165 mm, pp. ix + 200, *illus.*, D. Reidel Publishing Company, 419–421 Singel, PO Box 17, Dordrecht, Holland, 1970. Price : Dfl. 38.

This monograph must be one of the last of the great contributions made by Professor Sydney Chapman to our knowledge of the upper atmosphere. It was with deep regret that the members of a Symposium of the American Meteorological Society on 'The Dynamics of the Mesosphere and Lower Thermosphere' at Boulder, Colorado (*Bull. Amer. met. Soc., Lancaster, Pa,* **51**, 1970, pp. 377–387), learned that because of illness he would not be able to be Chairman of one of the sessions and later that he had died. He was 82. The first of his papers quoted in the references was dated 1913 and the last in 1969 and there were several in each decade between. As all interested in atmospheric physics will know, his contributions were not restricted to the tides. Other subjects such as the ionosphere, the earth's magnetism, ozone photochemistry, solar radiation, the theory of non-uniform gases, etc., etc., have equally benefited from his great insight. His co-author Professor Lindzen of the University of Chicago some 50 years his junior has already established himself as a world authority on tidal and other wave motions in the upper atmosphere. Their joint review of the present state of knowledge of this complicated subject is authoritative and must become a standard reference book for many years.

Attempts to explain theoretically the magnitudes and phases of the observed tides in the ocean and in the atmosphere have been made by outstanding physicists and mathematicians for almost the last three centuries and a short discussion of the contributions due to such scientists as Newton, Laplace, Kelvin, Rayleigh, Lamb, Taylor and many others are included in the introductory first chapter which also gives a clear account of the fundamental concepts and outstanding problems. It is known that the gravitational pull of the moon is greater than that of the sun and hence in the ocean the lunar tides are greater than the solar. In the atmosphere, however, the lunar tide measured by barometers is comparatively small and hence it appears that the thermal drive due to the sun must play a dominant role. Observations show also that the semidiurnal barometric solar tide is unexpectedly great compared with the diurnal component although the thermal forcing for the latter is clearly the greater. Earlier explanations in terms of a natural resonance of the atmosphere have now been rejected in favour of increased efficiency of coupling between the semidiurnal forcing terms and their induced motions.

The second and third chapters (labelled 2S and 2L) deal respectively with the solar and the lunar daily atmospheric oscillations as revealed by meteorological data. Near the surface the details are not easy to extract. The necessary harmonic analyses require careful statistical techniques and the detailed results are described at some length. At higher levels the tidal components become successively larger until above 100 km they dominate the general circulation of the atmosphere. The rapidity of the wind changes and their magnitudes and phases at different times and locations raise severe practical problems as regards methods of measurement and theoretical questions regarding wave propagation, forcing functions and dissipation mechanisms.

The final chapter (3) sets out in detail the present position on the quantitative theory of tides. The basis as in all dynamical studies of atmospheric motions rests on the equations of motion and the continuity and thermodynamic equations and the analytical solutions of their linearized forms with the tidal constraints are given in full. The subject, however, is complex and the Hough functions which arise in the solutions have in practice to be evaluated numerically using electronic computers. Recent computations are presented in some detail, compared with observations and outstanding problems discussed.

The division of labour between the two authors was broadly that Professor Chapman wrote most of Chapters 1, 2S and 2L except the sections dealing specifically with recent upper atmosphere observations and modern theoretical calculations while Chapter 3 was written by Professor Lindzen. Even if it had not been stated in the Preface this could have been deduced directly. In his section Chapman sets out his procedures in great detail while Lindzen prefers to assume that his readers do not need quite so much guidance. This may be a disadvantage as many students may be deterred by the difficulty of the theoretical aspects in some sections, leaving these to the specialists. In particular it might have been preferable to include more detailed explanations in Chapter 3 possibly with the inclusion of examples of the procedures involved.

The subject is still moving rapidly due, to a large extent, to further work by Lindzen himself and no doubt in a few years a second edition will be called for. The sections covered by Chapman, however, will need little revision and until that time this edition will remain the major basic text and statement of all that was known about this subject in early 1970. The book is attractively set out and clearly illustrated but a few minor errors were noted presumably due to insufficient proof reading.

R. J. MURGATROYD, O.B.E.

Statistische Auswertung geophysikalischer und meteorologischer Daten, by J. Taubenheim. 230 mm × 165 mm, pp. 386, *illus.* Geest & Portig K.-G., Sternwartenstrasse 8, Leipzig, 1969, Price : DM 61.

The application of statistical methods to geophysical data has been surprisingly unsystematic, considering the number, variety and quality of the data and there is a need for an authoritative and comprehensive account of the tools of the statistician's trade which is sympathetic to the geophysical medium. Professor Taubenheim's book goes a long way towards satisfying this need by providing a well-balanced and well-illustrated account, first of the standard statistical concepts and methods and then of subjects such as time series analysis, power spectrum analysis and filtering which are relatively more important in geophysical work than they are elsewhere. The illustrations are nearly all drawn from meteorology or other geophysical sciences and the depth of the theoretical treatment is enough to serve the needs of most professional meteorologists without being violently excessive. The treatment does not generally extend to the statistical aspects of methods, such as principal component analysis or stepwise multiple regression, which can only be exploited by computer, nor to subjects such as the statistical control of errors in data, which have become increasingly important in the era of computerized research.

Some statistical tests such as Kolnogoroff's and Wilcoxon's are included which are not usually found in comparable accounts, and the general impression is of clarity and thoroughness, and of the collection in one place of material which is hard to find elsewhere. The bibliography is good and the index excellent. Altogether a book to be recommended, and this reviewer at any rate hopes that it will appear before long in English translation.

J. M. CRADDOCK

Meteorological data catalogue. International Indian Ocean Expedition Meteorological Monographs, Number 3, by James R. Nicholson. 210 mm × 280 mm, pp. 59, *illus.*, East-West Center Press, Honolulu, Hawaii, 1969. Price: $7.50.

This monograph is the third in a series covering the meteorological work of the International Indian Ocean Expedition (IIOE) between 1959 and 1965. The author, an Environmental Science Services Administration (ESSA) Weather Bureau research meteorologist assigned to the IIOE, spent the years 1963 and 1964 at the International Meteorological Centre, Bombay, followed by three years at the University of Hawaii where he supervised data handling for this series of monographs, and so can write on the subject with some authority. As implied by its title the monograph is primarily intended to serve as a reference catalogue of data collected in the course of the meteorological and oceanographic research programmes of this expedition, and the reader will soon appreciate how well this purpose has been achieved. In the field of meteorological telecommunications there is material concerned with organization and operational experience, which could have a bearing upon planning for similar large-scale projects in the future within the World Weather Watch. Problems met with in the recording, collection and processing of data are next briefly described, followed by an account of methods of archiving which includes tables giving full details of sorties and observations made by research aircraft over the Indian Ocean, together with a description of instrumentation available on the aircraft and time-lapse films taken on these flights. Another table, summarizing all computer programmes (title, language, purpose, etc.) already written in connection with processing numerous categories of data collected during the IIOE, could be a valuable aid to research workers in these fields.

The monograph concludes with a brief discussion and, arising from experience gained by the author and his colleagues during the IIOE, some suggestions for future procedures for data collection and handling during World Weather Watch. While some valid points are made relating to quality control of data and modification of codes, it seems doubtful whether difficulties involved in revising codes at the international level have been fully appreciated by the writer of this book.

The monograph is lavishly produced and contains a useful set of up-to-date references. Not surprisingly it is rather expensive in relation to its slim dimensions.

R. F. M. HAY

Numerical analysis — the mathematics of computing, Volume 1, by W. A. Watson, T. Philipson and P. J. Oates. 227 mm × 149 mm, pp. xi+224, *illus.*, Edward Arnold (Publishers) Ltd, Woodlands Park Avenue, Woodlands Park, Maidenhead, Berks., 1969. Price: 25*s.* (limp edition).

Those of us who have learned something of numerical analysis as and when it became necessary will welcome the publication of this book. Although designed primarily as a textbook for the special G.C.E. A-level course in numerical analysis, this book will be useful also in other sixth-form courses and in courses of further education. It provides a basic introduction to numerical methods of solving mathematical problems, such as must surely now be regarded as an essential feature of scientific education in schools. An increasing use of books such as this in science sixth forms will do much, I think, to eliminate confusion and apprehension from attitudes to the use of computers in scientific work.

The first three chapters of the book prepare the ground for the remaining six by introducing the reader to hand calculating machines, flow charts, and the sketching of simple functions respectively. I found that the emphasis on hand calculating machines in the opening chapter gave the book a rather dull beginning. The rather tedious details of register setting and crank rotating might perhaps have been better placed in an appendix to the book. By contrast, I felt that the second and third chapters provided clear and attractive introductions to their respective topics.

The rest of the book deals with a series of basic numerical techniques which include iterative methods for the solution of equations, differences, linear interpolation, and numerical integration up to Simpson's rule. Chapter six, dealing with the solution of linear simultaneous equations, is especially useful, I think, introducing as it does such topics as the method of relaxation in a painless way.

Throughout the book clear indication is given of the limitations of the techniques described and of the rounding and other errors involved in various operations. Profitable use is made of worked examples to explain the numerical methods, and a good selection of examples for the student (with answers) is included. Taken as a whole, there is no doubt that this is a useful introductory textbook on numerical analysis, and I look forward to the publication of Volume 2 in due course.

A. J. GADD

Numerical analysis — the mathematics of computing, Volume 2, by W. A. Watson, T. Philipson and P. J. Oates. 227 mm×149 mm, pp. x+166, *illus.*, Edward Arnold (Publishers) Ltd, Woodlands Park Avenue, Woodlands Park, Maidenhead, Berks., 1969. Price: 28*s.* (limp edition).

The first volume of this work gave a useful introduction to some basic concepts of numerical analysis and encouraged one to look forward to the publication of this second volume. In the event, however, I found the second volume rather disappointing. In general one would not quarrel very much with the presentation of individual techniques; the disappointment stems rather from the suspicion that the student who follows through these two volumes may be left with the impression that numerical analysis is a tedious and confusing subject.

Admittedly the authors had no easy task of presentation in this second volume. They are concerned in part with extending and generalizing the material of Volume 1 and in doing so they inevitably become involved with more complex techniques which lack both mathematical elegance and obvious usefulness. Even so, I feel that a more attractive presentation could have been achieved if an overall direction of development of the subject were more apparent. Volume 2 ends with a short chapter on the summation of slowly convergent series which is a complete anticlimax. One is tempted to believe that the fact that the book has three authors may have contributed to a certain lack of coherence from one chapter to another.

More than half of the pages of this second volume are devoted to material which in earlier books on numerical analysis has generally appeared in the chapter headed 'interpolation'. I find it difficult to judge whether or not such an emphasis is justified, but certainly a rather sustained effort is required to remain interested in the various details presented.

As the authors admit, the inclusion of an introductory chapter on the numerical solution of differential equations has the difficulty that the readers of the book in schools may not be in a position to cope with the methods of solution which are most widely used. Some simpler methods are therefore presented, in the hope that an enthusiasm for further study will be stimulated. The authors deal mainly with first-order equations, despite the fact that the simplest numerical process is that for a second-order equation with the first derivative absent. The description given of Fox and Goodwin's method for first-order equations is, I think, unnecessarily daunting, and would have been better introduced by way of the trapezium rule for integration.

One feature of the layout of the printed material deserves comment. The tables, formulae, and numerical examples are printed so boldly that they overshadow the explanatory text and tend to obscure the continuity of the development. I liked the occasional historical references and thought that they could have been usefully extended to give more perspective to the place of numerical analysis in the general pattern of mathematics and physics.

I remain grateful that the attempt has been made to provide an attractive introduction to numerical analysis at sixth-form level, but I feel that there is scope for an improved presentation in the near future.

A. J. GADD

Field guide to snow crystals, by E R. LaChapelle. 210 mm × 150 mm, pp. v + 101, *illus.*, University of Washington Press, Seattle and London, c/o American Universities Publishers Group, 27–29 Whitfield St, London, W1. 1970. Price : 62*s*.

This slim volume consists principally of a collection of 65 very beautiful photographs of snow crystals, each of which is accompanied by a short commentary describing the situation in which the crystals were found and the important physical mechanisms involved in their formation. The photographs have been carefully selected, not so much for their symmetry and beauty, but rather to illustrate clearly the various forms which snow crystals *on the ground* can assume. In this respect the new book differs significantly from the classic collections obtained by Bentley and Humphreys and by Nakaya, who were primarily concerned with the forms of snow crystals as they first fall from the sky.

In the opening chapter, LaChapelle describes very clearly the processes which lead to changes in the structure of precipitated snow when it is lying on the ground. He also gives an account of a new system for classifying snow on the ground which has been proposed by R. A. Sommerfeld and himself. In this scheme three major processes leading to changes in the structure of snow are recognized—equitemperature (destructive) metamorphism, temperature-gradient (constructive) metamorphism and firnification (the process by which snow changes into glacier ice).

The book contains a short section explaining how best to observe and photograph snow crystals with fairly simple equipment, so that the interested reader can experiment for himself.

In short, this book fully lives up to the claim made in its title to be a *field guide* to snow crystals and it will make a handsome addition to the libraries of all who are interested in the fascinating forms of snow crystals.

J. T. BARTLETT

Tropical Indian Ocean clouds, International Indian Ocean Expedition Meteorological Monographs No. 4, by Andrew F. Bunker and Margaret Chaffee. 282 mm × 222 mm, pp. 194, *illus.*, East-West Center Press, Honolulu, Hawaii, 1970. Price: $10.00.

This monograph, the fourth in the series reporting data-gathering activities during the International Indian Ocean Expedition, presents schematic cloud patterns deduced from flights over the Indian Ocean during 1963 and 1964. Cloud data were derived from time-lapse film frames exposed from aircraft at intervals ranging from 2 to 10 seconds. A vast number of photographs were taken but only one frame in every hundred was used in this analysis. The photogrammetric technique employed to determine the distances of cloud from the aircraft, and the heights of bases and tops, is described. The volume is not, however, a collection of cloud photographs as the title might suggest.

Two main sections deal with the south-west and north-east monsoons separately and each section is liberally illustrated with diagrams. There are only 20 pages of text compared with 165 pages of diagrams. There is the surprising total of 346 figures, nearly all of them line drawings; only 23 show actual cloud photographs and of these only 4 were taken from aircraft, the remaining 19 being from satellites. All photographs are of rather poor quality.

The schematic cloud distributions along flight paths are presented in cross-section or map form with the minimum of discussion, and are supported by daily wind maps showing streamline and isotach analyses for the surface and 700-mb levels. These maps, 210 of them, are very much smoothed and do not show the wind data upon which they were based. In some cases the analyses are significantly different from others for the same days published in *Monograph No.* 1 of this series. For example, Figure 125 should be compared with Figure 21 of *Monograph No.* 1, where basic data are reproduced on all the maps and small-scale distortions in the wind field are shown to exist. Such small-scale variations may be more closely related to cloud formations than the broad-scale flow itself, but the authors do not attempt any detailed interpretation of cloud patterns in relation to the wind field.

No legend to the symbols used in depicting clouds appears with the diagrams. The reviewer found it a little distracting to refer back continually to the description of the method of representation given on page 8, and even then some of the schematic forms remained difficult to interpret. Some radiation and temperature measurements are discussed briefly and presented as composite — not daily — data. In particular the temperature data are of little help in studies of the daily cloud structures.

The volume is presented in the same attractive way as the others of the series. The reviewer would have preferred the daily wind-field maps to be adjacent to the appropriate cloud charts instead of being gathered together at the end of each section — but this is a minor criticism. The book is likely to have little general appeal because it is really intended for the research worker interested in the weather of the Indian Ocean, and to him it presents a wealth of information for study and digestion.

J. FINDLATER

HONOUR

The following honour was announced in the Queen's Birthday Honours List 1970 :

B.E.M.

Mr V. Efstathiou, Communications Superintendent, Main Meteorological Office, Episkopi.

AWARDS

WMO Research Prize

We note with pleasure the decision of the Executive Committee of the World Meteorological Organization to award the WMO Prize for 1970 to the following young research workers : Mr F. B. A. Giwa (Nigeria), Mr M. Yamasaki (Japan), Mr P. E. Merilees (Canada) and Mr F. Bretherton (United Kingdom), for research work in various fields of meteorology.

Fifteenth IMO Prize

This prize, which is awarded each year as a token of remembrance of the International Meteorological Organization, which was the non-governmental body preceding WMO, was awarded posthumously to Professor R. Scherhag, Berlin, who died on 31 August 1970.

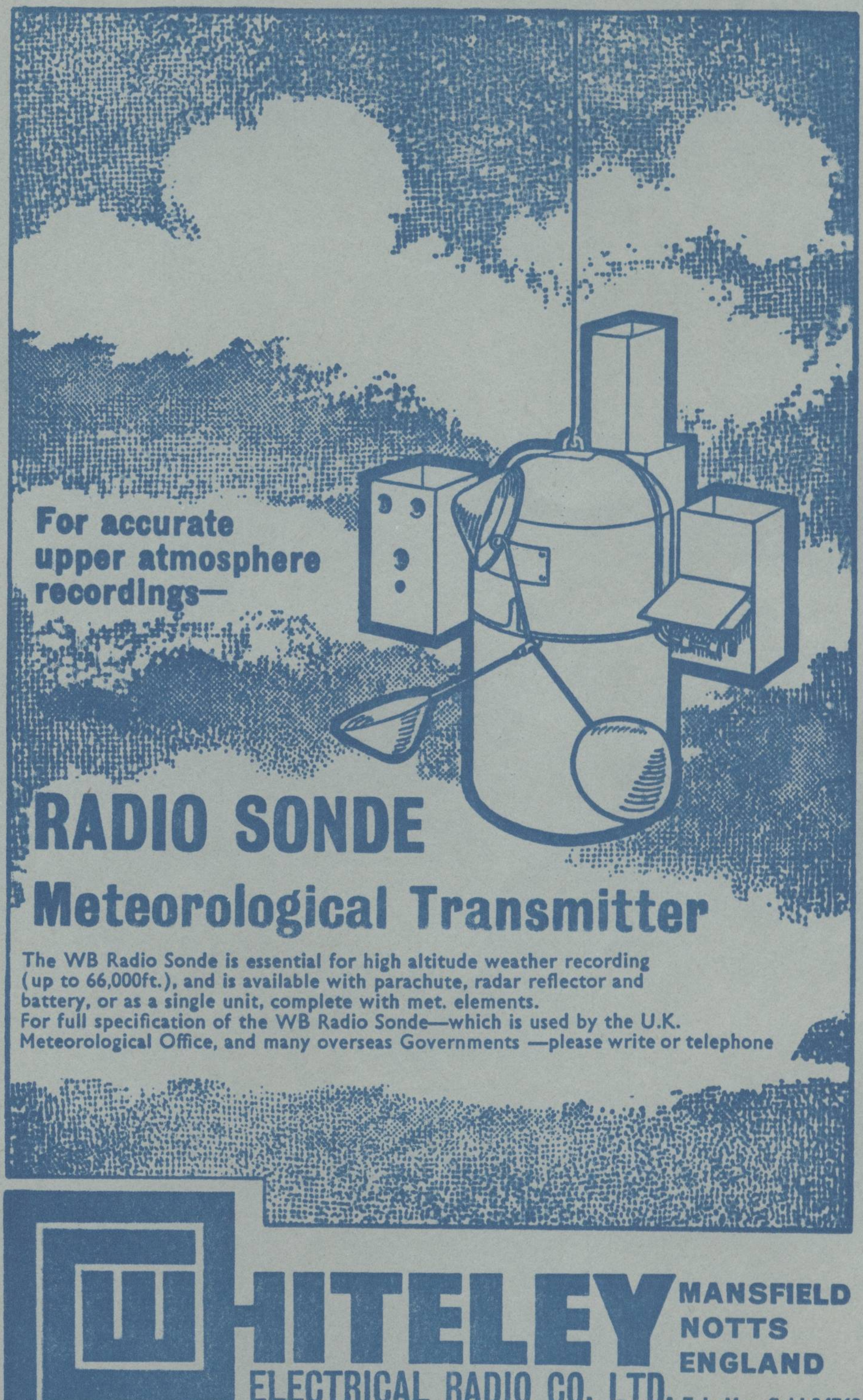
NOTES AND NEWS

Meteorological Magazine : price increase

As from January 1971, the price of an issue of the Meteorological Magazine will be 4*s*. [20 p] and the annual subscription will be £2 14*s*. [£2.70] including postage.

CORRECTION

Meteorological Magazine, September 1970, p. 270. In the second line of the summary and the fourth line of the main text of the article on a heated anemometer, for 'Mount Olympus, Greece, *read* 'Mount Olympus, Cyprus'.


For accurate upper atmosphere recordings—
RADIO SONDE
Meteorological Transmitter
The WB Radio Sonde is essential for high altitude weather recording (up to 66,000ft.), and is available with parachute, radar reflector and battery, or as a single unit, complete with met. elements.
For full specification of the WB Radio Sonde—which is used by the U.K. Meteorological Office, and many overseas Governments —please write or telephone
WHITELEY
ELECTRICAL RADIO CO. LTD.
MANSFIELD
NOTTS
ENGLAND
Tel: Mansfield 24762

THE METEOROLOGICAL MAGAZINE

VOL. 99 NO. 1181 DECEMBER 1970

CONTENTS

NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire, RG12 2SZ, and marked 'for Meteorological Magazine.'

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

All inquiries relating to the insertion of advertisements in the Meteorological Magazine should be addressed to the Director of Publications, H.M. Stationery Office, Atlantic House, Holborn Viaduct, London E.C.1. (Telephone: 01-248 9876, extn 6098).

The Government accepts no responsibility for any of the statements in the advertisements appearing in this publication, and the inclusion of any particular advertisement is no guarantee that the goods advertised therein have received official approval.

Printed in England by The Bourne Press, Bournemouth, Hants.

and published by

HER MAJESTY'S STATIONERY OFFICE

3s. 6d. [17½p] monthly Annual subscription £2 7s. [£2·35] including postage

Dd. 500145 K16 12/70 SBN 11 400081 6