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ESTIMATION OF SOLAR RADIATION RECEIPT FROM SUNSHINE DURATION AT WINNIPEG

By H. L. DRIEDGER* and A. J. W. CATCHPOLE†

Summary. Seasonal changes in the relationship between solar radiation receipt and sunshine duration are examined in detail. The seasonal régimes of the linear regression coefficients support the view that this relationship is dependent upon the effects of multiple reflection of solar radiation between snow-covered surfaces and cloud bases.

Introduction. Ångström's pioneer analysis of the empirical relationship between daily solar radiation receipt on a horizontal surface at ground level Q and daily sunshine duration n yielded:

$$Q = Q_0[a' + (1{\cdot}00 - a')\, n/N]$$

where Q_0 = total daily solar radiation receipt on a horizontal surface at ground level on a clear day, N = maximum possible daily duration of sunshine and a' = mean value of Q/Q_0 on completely overcast days.[1]

The major subsequent modifications of this equation have involved:

(i) development of the linear relationship :

$$Q = Q_0\, (a + bn/N)$$

in which a and b are regression coefficients;

(ii) replacement of Q_0 in this relationship by Q_a which evaluates the receipt of solar radiation on a horizontal surface at the top of the atmosphere. This procedure permits the application of the method in areas lacking observations of Q.

These developments have confirmed that there are significant spatial and temporal variations in the magnitudes of these coefficients.

Black *et alii*[2] obtained values of b varying irregularly between 0·29 and 0·63, and values of a varying irregularly between 0·19 and 0·40, among stations distributed over 50 degrees of latitude. In tropical areas the temporal variations of a and b are so irregular as to prohibit the identification of

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seasonal régimes.[3,4] However, in higher latitudes these temporal variations are more regular. In Canada, Mateer identified values of a and b typical of the snow season, of the snow-free season, and of the transitional seasons.[5] Mateer suggested that these seasonal variations are attributable to the effects of either rime deposition on the glass sphere of the sunshine recorder or the multiple reflection of solar radiation between snow-covered ground surfaces and cloud bases.

This paper contributes to the study of seasonal variations in the magnitudes of a and b. The analysis is applied in seven stages, each of which is based upon the sub-division of the year into periods of different and particular duration. The study is applied to data observed at Winnipeg, Canada.

Data. The data were observed during the 18-year period January 1950 to December 1967, at a synoptic meteorological station located at Winnipeg International Airport. The station is situated on the flat prairie surface within the airfield and is relatively free from obstructions to the receipt of solar radiation. The site has remained unchanged during the years under investigation.

Throughout this 18-year period the solar radiation receipt was observed by Eppley 180° pyrheliometers. On receipt of advice from the Canadian Meteorological Branch, the following corrections were applied to the radiation data observed during this period:

(i) The present instrument was installed in July 1956. The calibration factor of its predecessor is thought to have been incorrect by 5 per cent. All data observed prior to 7 July 1956 were therefore reduced by this percentage.

(ii) The data observed prior to January 1958 were corrected for ambient air temperature effects since this correction had not been applied to the published data.

(iii) The data observed between 5 February 1957 and 31 March 1957 were adjusted by factors incorporating corrections both for ambient air temperature and for the change in radiation scale from the Smithsonian Scale (1913) to the International Pyrheliometric Scale (1956).

The sunshine data were derived from a Campbell-Stokes sunshine recorder. This instrument is insensitive to direct solar radiation of intensities less than 0·2 to 0·4 langley/min (1 langley/min = 69·78 mW/cm^2); 1 langley = 1 cal/cm^2. It is considered by the United Kingdom Meteorological Office that this instrument does not record sunshine when the solar elevation is less than 3°.[6] Thus, the apparent length of the day is less than its actual length. In this paper N is defined as the period during which the elevation of the sun above the horizon exceeds 3°.

Method. The pronounced seasonal changes of Q necessitate that the dependent variable in the regression analysis be expressed in relative terms. This can be achieved by expressing Q as a fraction of either Q_0 or Q_a. The advantage of the latter procedure is that Q_a can be evaluated at all locations. In contrast, Q_0 can only be obtained by extrapolation from measured values of Q using a method similar to that employed by Sellers for this purpose.[7]

A preliminary investigation indicated that, at Winnipeg, the relationship between Q/Q_0 and n/N is closer than that between Q/Q_a and n/N.[8] Monthly mean daily sunshine durations and monthly mean daily solar radiation receipts were utilized in a study of the annual linear regression between these variables. It was observed that the annual coefficient of determination r^2 between Q/Q_0 and n/N ($r^2 = 0{\cdot}66$) was substantially greater than that between Q/Q_a and n/N ($r^2 = 0{\cdot}35$). For this reason, Q will be expressed as a fraction of Q_0 in the present analysis.

There are precedents for using a wide range of seasonal sub-divisions of the year for the estimation of Q from n. The monthly sub-division has been used most frequently for this purpose, but the analysis has also been applied to daily data grouped into periods of less than a month.[9] Any choice of period length is arbitrary and, in the interests of objectivity, the analysis is here applied to daily data grouped into periods of 5, 7, 11, 15, 19, 25 and 29 days' duration.

In order to emphasize seasonal trends and suppress the effects of short-term irregularities, overlapping periods were used throughout the analysis. For example, the first of the 5-day periods includes 1–5 January, and the second of these includes 2–6 January. Consequently, 365 daily estimates of a and b are obtained in each of the seven stages of the analysis. The estimated regression coefficients of a particular day are derived from the data observed in the period centred upon that day.

Results. The results are presented in Figure 1, which illustrates the seasonal variations in a and b obtained in each stage of the analysis. Corresponding values of a and b represent the linear prediction equations which describe the relationship between Q/Q_0 and n/N. In all cases the seasonal changes of a are inversely related to those of b, since the former attains its minimum values in summer at which time the latter attains its maximum values. These seasonal régimes can be approximated by the equations :

$$a = 0{\cdot}50187 - 0{\cdot}0020752x + 0{\cdot}00000483x^2$$
$$b = 0{\cdot}35526 + 0{\cdot}0032518x - 0{\cdot}00000796x^2$$

where x = any day of the year from 1 to 365. These equations are based upon the regression coefficients derived from the 5-day periods (Figure 2).

In all cases the seasonal régimes of a and b are disturbed by relatively short-term irregularities which usually decrease in prominence as the duration of the period of analysis increases. The forms of the curves in Figure 1 indicate that pronounced irregularities occur in early spring and late summer. Early spring is characterized by a relatively abrupt divergence between the curves of a and b. In late summer the values of b range between a secondary minimum in mid-August and the primary maximum in mid-September.

The significance of the irregularities detected by the 5-day analysis was tested statistically. These tests indicate that a exceeds its predicted values by an amount significant at the 95 per cent level of confidence during the period 1–21 March (Figure 2). Comparably significant departures of b from its predicted values occur during the periods 13–20 August and 14–26 September. The fitting of a parabolic curve to the observed values of a and b produces a lack of conformity between 31 December and 1 January, but it is considered that the parabolic curve fulfils the limited function of this part of the analysis.

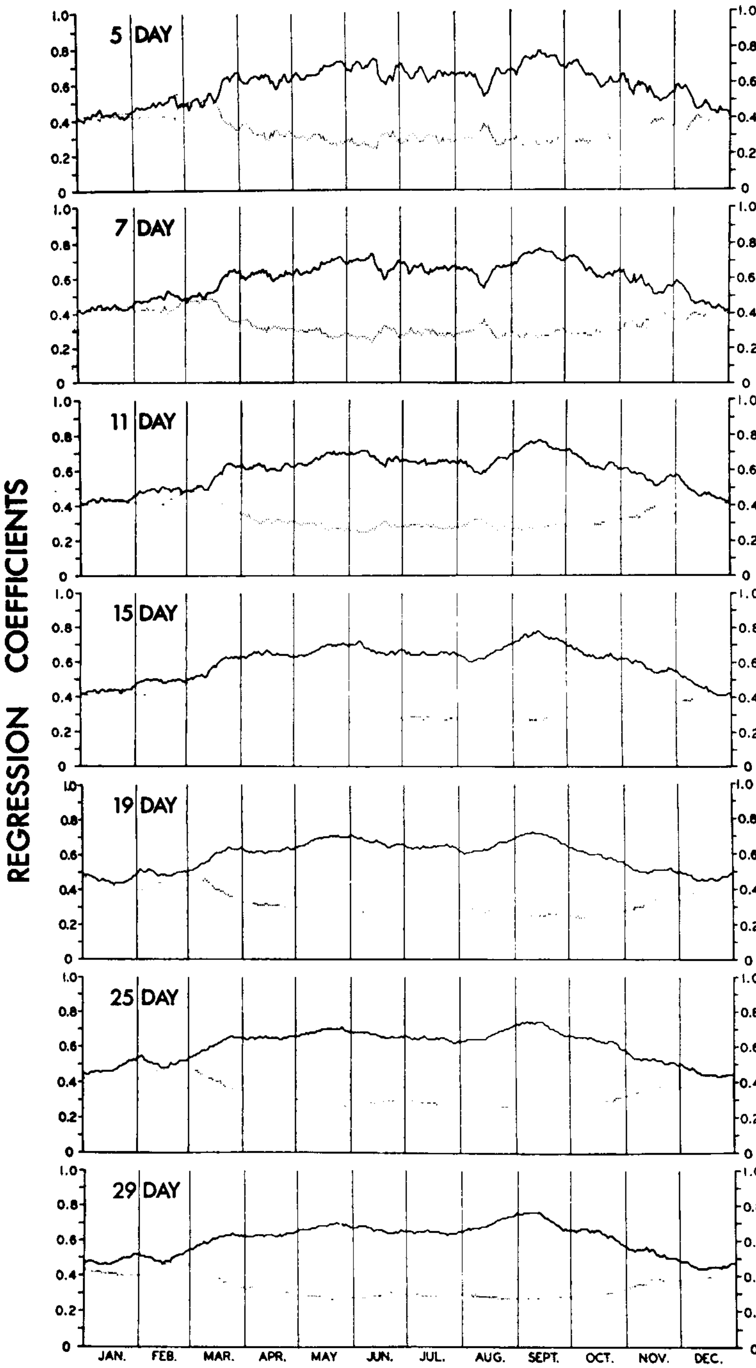

FIGURE I—SEASONAL VARIATIONS OF THE REGRESSION COEFFICIENTS IN THE EQUATION $Q = Q_0\ (a + bn/N)$ DIFFERENTIATED ACCORDING TO PERIOD LENGTH. WINNIPEG INTERNATIONAL AIRPORT 1950–67

.... *a* ——— *b*

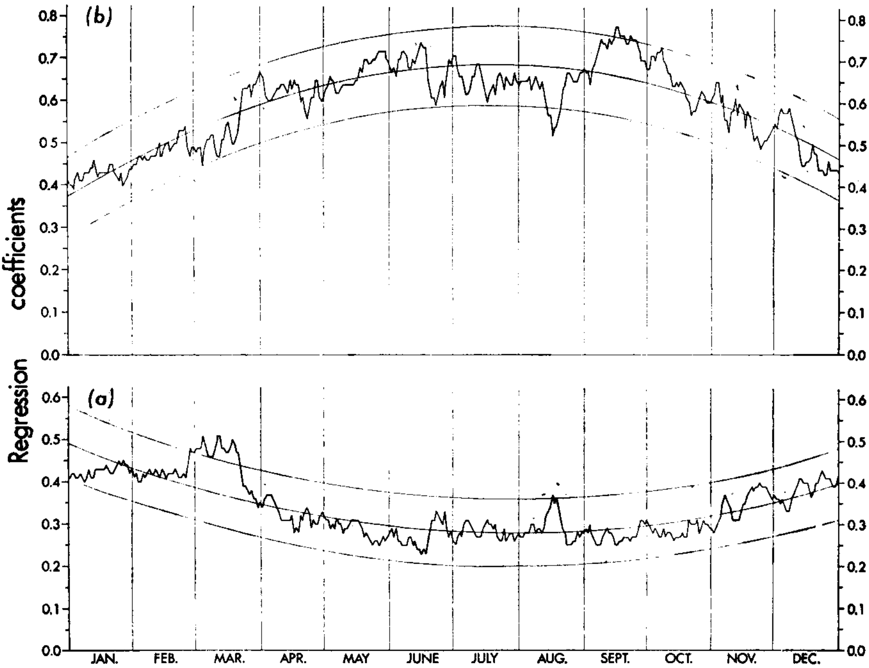

FIGURE 2—SEASONAL VARIATIONS OF THE ACTUAL AND PREDICTED REGRESSION COEFFICIENTS IN THE EQUATION $Q = Q_0\ (a + bn/N)$, DERIVED FROM 5-DAY PERIOD LENGTH. WINNIPEG INTERNATIONAL AIRPORT 1950–67

In the upper diagram *(b)* the irregular curve = actual *b*; the inner smooth curve = predicted *b* obtained by using the equation given in the text; the outer curves = 95 per cent confidence intervals.

In the lower diagram *(a)* the irregular curve = actual *a*; the inner smooth curve = predicted *a* obtained by using the equation given in the text; the outer curves = 95 per cent confidence intervals.

It is noteworthy that the March and August irregularities appear to be most clearly manifest in the short-period analyses, whereas the September irregularity apparently increases in prominence with increasing period length.

Discussion. A comprehensive discussion of these results is prohibited by the complexity of the relationship between solar radiation and sunshine duration. Daily duration of sunshine is a function of cloud conditions, and the attenuation of solar radiation by cloud depends upon a wide range of controls including solar zenith angle, and the amount, form, height, density and distribution of cloud.[10] The result is a relationship between Q/Q_0 and n/N so nebulous that its use is restricted to the prediction of mean solar radiation receipts rather than to the prediction of receipts on particular days.

Similarly, the distinctive seasonal régimes of *a* and *b* cannot with certainty be attributed to the effects of specific factors. In high latitudes particularly, seasonal changes in cloud conditions, concentrations of artificial and natural pollutants, water vapour concentration, midday solar elevation, etc., probably affect the régimes of *a* and *b*. Nevertheless, the general form of these seasonal régimes is consistent with Mateer's view that the periodic development and decay of snow cover may significantly affect the relationship between sunshine duration and solar radiation receipt. The magnitude of each of the regression coefficients might be modified by the effects of multiple reflection between cloud bases and snow-covered surfaces. The coefficient *a* evaluates the receipt of solar radiation on days lacking bright sunshine and it can be approximated to, although not exactly equated with, the solar radiation received on totally overcast days. The multiple reflection process may, therefore, increase the magnitude of *a* in winter. The coefficient *b* evaluates the rate of change in Q/Q_0 per unit change in n/N. Any process which elevates the receipt of solar radiation on sunless days may, in this linear relationship, tend to reduce the magnitude of *b*. In this event, multiple reflection may reduce *b* in winter.

The behaviour of *a* in late winter and spring strongly supports the view that its magnitude is influenced by the multiple reflection process because the period of abrupt decrease of *a* immediately precedes the median date of the spring thaw at Winnipeg. Figure 3 illustrates the duration of snow cover at Winnipeg using data observed between 1950 and 1967. The upper part of this diagram indicates the durations of snow cover during individual winters within this period. Depicted are the periods of discontinuous snow cover of at least a trace (1), the periods of continuous snow cover of at least a trace (2), and the periods of continuous cover of at least 12·5 centimetres (5 inches) of snow (3). The lower part of the figure indicates the median dates of specific events (B), their earliest arrival and latest departure dates (A), and their latest arrival and earliest departure dates (C). Attention is directed to the snow depth of 12·5 centimetres because this has been shown to be critical in terms of the albedo of snow surfaces.[11] With snow depths of less than 12·5 centimetres albedo is a direct function of depth, but albedo remains relatively constant when depths exceed 12·5 centimetres.

The absence of a comparably abrupt change in *a* in association with the median date of snow development may be attributable to the fact that this development occurs near the winter solstice when the absolute receipt of solar radiation is low.

Acknowledgements. The authors acknowledge the assistance of D. H. Gallagher, Director of the Planetarium, Manitoba Museum of Man and Nature, who evaluated the periods of time during which the solar elevation is less than 3° above the horizon at Winnipeg. Financial support for this research was provided by the National Research Council of Canada.

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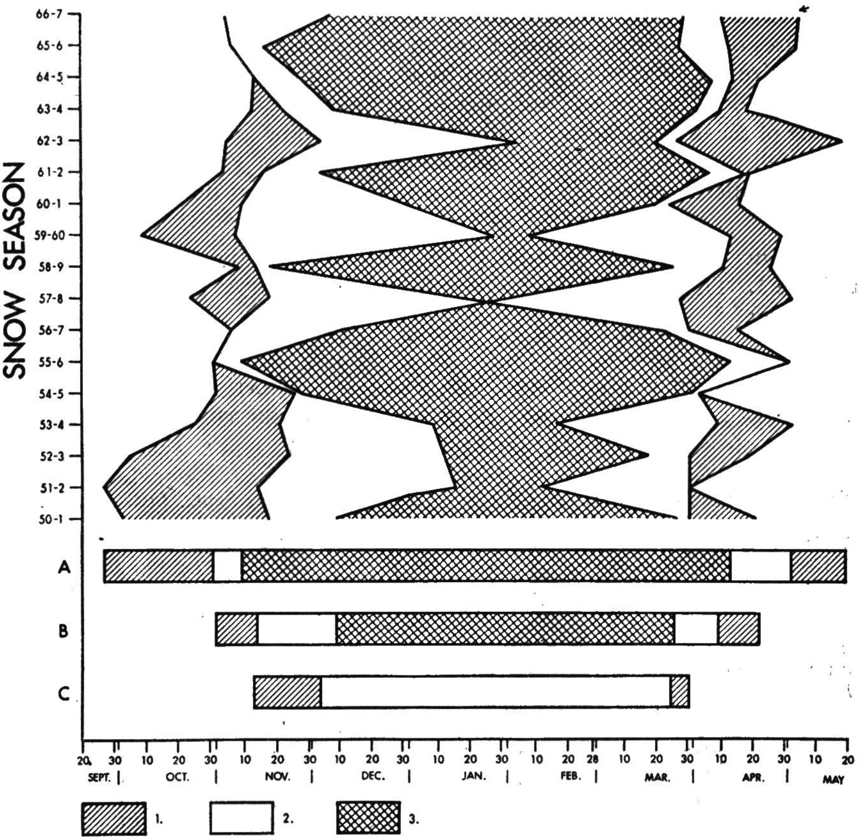

FIGURE 3—DURATION OF SNOW COVER AT WINNIPEG INTERNATIONAL AIRPORT SEPTEMBER 1950 TO MAY 1967

A = Earliest arrival and latest departure dates of specific events.
B = Median dates of specific events.
C = Latest arrival and earliest departure dates of specific events.
Hatched areas (1) = Periods of discontinuous snow cover of at least a trace.
White areas (2) = Periods of continuous snow cover of at least a trace.
Cross-hatched areas (3) = Periods of continuous cover of at least 12·5 cm of snow.
The dates of the snow seasons are abbreviated, e.g. 1966–67 appears as 66–7.
The diagram is taken from CATCHPOLE, A. J. W.; The solar control of diurnal temperature variation at Winnipeg. *Can. Geographer, Toronto*, **13**, 1969, p.p. 255–268.

551.524.36

A NOTE ON CENTRAL ENGLAND TEMPERATURES IN QUINTILES

By R. MURRAY

Summary. Monthly and seasonal mean temperatures for central England for the period 1873–1968 were assigned to quintiles by ranking (A) departures from 25-year moving averages and (B) actual temperatures. The quintiles to which the temperatures were assigned by the two methods were found to differ by not more than one quintile on over 99 and 97 per cent of occasions for monthly temperatures and seasonal temperatures respectively. Larger differences, of two quintiles, occurred mostly in October for monthly means and in autumn and spring for seasonal means.

In several papers (e.g. Murray[1]) the quintiles of mean temperature over central England[2] for months or seasons have been based on the ranking of the departures of mean temperature from 25-year moving averages, in an attempt to minimize the effect of long-period trends of temperature. For some purposes it may be desirable to use quintiles of temperature derived from the simple ranking of mean temperatures without trying to allow for long-period changes. Let us call the two methods 'A' and 'B' respectively. Then it is of interest to see what differences result in the allocation of quintiles derived in these two ways.

For convenience, the quintile boundaries used in the 'B' case are given in Table I. The method of obtaining quintiles in the 'A' case has been given by Murray.[1,3]

TABLE I—QUINTILE BOUNDARIES OF MEAN TEMPERATURES OVER CENTRAL ENGLAND FOR *(a)* MONTHS AND *(b)* SEASONS, BASED ON THE PERIOD DECEMBER 1873 TO NOVEMBER 1963

(a) Months

Quintile	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						degrees	*Celsius*					
5/4>	5·3	5·8	6·8	9·0	12·2	15·2	17·1	16·4	14·4	10·6	7·4	5·8
4/3>	4·3	4·8	6·1	8·3	11·5	14·5	16·2	15·8	13·7	10·1	6·7	4·9
3/2>	3·6	3·8	5·2	7·7	10·9	14·1	15·5	15·3	13·0	9·5	6·1	4·0
2/1>	2·3	2·7	4·2	7·1	10·3	13·6	15·1	14·6	12·5	8·8	5·3	2·9
Mean temperature	3·6	4·0	5·5	8·0	11·2	14·2	15·9	15·5	13·4	9·7	6·3	4·3

(b) Seasons

Quintile	Winter	Spring	Summer	Autumn
		degrees	*Celsius*	
5/4>	5·2	8·9	15·8	10·5
4/3>	4·5	8·4	15·5	10·1
3/2>	4·0	8·1	15·1	9·7
2/1>	3·0	7·5	14·6	9·1
Mean temperature	4·0	8·2	15·2	9·8

Note. In January quintile 4 refers to mean monthly temperatures > 4·3° and < 5·3°C.

The frequencies of the difference between the 'A' and 'B' quintiles each month for the period from December 1873 to November 1968, based on quintile boundaries derived from 1873 to 1963, are presented in Table II.

Table II shows that the same quintile number was allocated by 'A' and 'B' on about 72 per cent of the months and that the two methods differed by not more than one quintile on 99·6 per cent of occasions. Exact correspondence

TABLE II—OCCASIONS WITH SPECIFIED DIFFERENCES IN QUINTILES DERIVED BY 'A' AND 'B' METHODS EACH MONTH

	Differences A–B (quintiles)						
	−3	−2	−1	0	1	2	3
December	0	0	12	69	13	1	0
January	0	0	13	67	15	0	0
February	0	0	11	72	12	0	0
March	0	0	8	73	14	0	0
April	0	0	21	60	14	0	0
May	0	0	16	66	13	0	0
June	0	0	8	74	13	0	0
July	0	0	12	76	7	0	0
August	0	0	15	67	13	0	0
September	0	0	11	75	9	0	0
October	0	2	25	57	10	1	0
November	0	0	15	67	13	0	0
Total	0	2	167	823	146	2	0

was least in October (57 cases) and April (60 cases). However, it may be said that serious discrepancies between the quintile specification of months according to the 'A' and 'B' procedures are generally very small. Three of the four biggest differences (± 2) occurred in October.

Examination of the basic data shows clearly that the incidence of positive or negative differences between 'A' and 'B' is markedly concentrated in different epochs. This is not surprising because of the well-known long-period temperature variations, which are not in phase each month. For instance, the mean January temperature was at a maximum in the 1920s and 1930s but a cooling trend began around 1940. In July the mean temperature was lower in the 1920s than in the 1940s but a cooling trend has set in since about 1960. In April the mean temperature was lower by about 1 degC in the first 25 years of this century compared with the following 25 years, and now a cooling trend appears to have set in during the 1960s. On the other hand, in October the mean temperature was at its lowest in the 1880s and in the most recent decade it has steadily risen. Such long-period changes inevitably affect the sign of the differences between the 'A' and 'B' quintiles. In January positive differences (i.e. A − B positive) occurred mostly before 1920 and after 1952, in April entirely between 1901 and 1939, in July between 1897 and 1942 (mainly in the 1920s and 1930s) and in October mostly between 1888 and 1912.

The seasonal quintiles have also been examined for the two methods 'A' and 'B' and the results are presented in Table III.

TABLE III—OCCASIONS WITH SPECIFIED DIFFERENCES IN QUINTILES DERIVED BY 'A' AND 'B' METHODS EACH SEASON

	Differences A–B (quintiles)						
	−3	−2	−1	0	1	2	3
Winter	0	0	9	63	23	0	0
Spring	0	4	15	67	9	0	0
Summer	0	0	10	70	15	0	0
Autumn	0	6	20	56	13	0	0
Total	0	10	54	256	60	0	0

From Table III it is seen that the same quintiles (i.e. $A - B = O$) applied on 67 per cent of the seasons. No cases with $|A - B| > 1$ occurred in winter and summer; however, in spring and autumn there were 10 cases where the

'A' procedure specified quintiles which were two less than those indicated by the 'B' method. Thus the two methods differed by not more than one quintile on 97·4 per cent of occasions. It appears that serious discrepancies between quintiles specified by the two methods are likely at times in autumn and spring.

The positive and negative differences are not randomly scattered throughout the period but differences of the same sign tend to be concentrated in certain epochs. The differences were all positive before 1920(17) and after 1950(6) in winter, all positive before 1911(9) in spring, mostly positive before 1933 in summer, and mostly positive before 1936 in autumn. Except in winter as just mentioned, all differences were negative after 1935. The largest negative difference of − 2 occurred after 1952 in spring (namely in 1953, 1963, 1966 and 1967) and autumn (namely in 1954, 1955, 1960, 1961, 1963 and 1964).

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551.511.32:517.9

AN ALGORITHM DEPENDING ON THE PHYSICAL INTERPRETATION OF THE LAPLACIAN

By R. DIXON

Summary. An algorithm is presented which has its genesis in Maxwell's physical interpretation of the Laplacian. Two examples illustrating different applications of the algorithm are given: (i) the removal of a gross irregularity from a height field, and (ii) the intensification of the contour pattern of a height field.

Kirk[1] has recently recalled the physical interpretation given to the Laplacian by Maxwell,[2] who showed that the value of the Laplacian of a function at a point is a measure of the difference between the value of the function at the point and the average value of the function over a small surrounding neighbourhood. In fact

$$\frac{d^2}{24}\,(\nabla^2\varphi) = \varphi_m - \varphi_0, \qquad \ldots (1)$$

where φ is a scalar function, d is a small measure of distance, and the suffix o indicates the value taken at the point in question.

Now the Laplacian is itself a scalar, and equation (1) remains true if $\varphi = \nabla^2 F$ where F is some other scalar. We then have

$$\frac{d^2}{24}\,(\nabla^4 F)_0 = (\nabla^2 F)_m - (\nabla^2 F)_0\,. \qquad \ldots (2)$$

Thus the Laplacian of the Laplacian, known as the biharmonic, is a measure of the difference between the value of the Laplacian at a point and its average value over a small surrounding neighbourhood. The form (2) is given a particular significance for meteorologists by virtue of the fact that the geostrophic vorticity is, save for a factor, given by the Laplacian of the geopotential height field.

This gives rise to the possibility of achieving certain desired adjustments to a geopotential height field by a process having a prescribed effect upon the vorticity field. If the grid points in the neighbourhood of a given grid point o are locally numbered in traditional fashion

		10		
	6	2	5	
11	3	0	1	9
	7	4	8	
		12		

and the height at each grid point h_0 is replaced in turn by a new height h_0' such that

$$h_0' = a(h_1 + h_2 + h_3 + h_4) + bh_0, \qquad \ldots (3)$$

where a and b are constants, then it may be shown that the new geostrophic vorticity field ζ_0' is related to the old geostrophic vorticity field ζ_0 by

$$\zeta_0' = [1 + (4a + b - 1)]\zeta_0 + ad^2(\bigtriangledown^4 h)_0, \qquad \ldots (4)$$

where $\bigtriangledown^4 h$ is a finite-difference analogue of the biharmonic $\nabla^4 h$. Thus the modified vorticity is a multiple of the original vorticity plus an adjustment depending on the local anomaly of the vorticity relative to its average value over the immediate neighbourhood.

If it is not intended to alter the general level of the h field, then the condition

$$4a + b - 1 = 0 \qquad \ldots (5)$$

must be observed. Putting

$$a = \frac{1 - k}{4} \quad \text{and} \quad b = k$$

equation (4) becomes

$$\zeta_0' = \zeta_0 + \tfrac{1}{4}(1 - k)d^2(\bigtriangledown^4 h)_0 \qquad \ldots (6)$$

and it is seen that putting $k < 1$ will decrease the local vorticity anomaly and effect a smoothing of the h field, whilst putting $k > 1$ will enhance the local vorticity anomaly and thereby intensify the h field pattern.

Example 1. Figure 1 shows a section of the 200-mb operational analysis at 00 GMT on 23 March 1967. The obviously wrong grid-point values were adjusted by a recursive application of equation (3), with a and b determined by $k = 0$, to give the result shown in Figure 2. It is seen that, using this technique, the computer arrived at an adjusted h field which is very close to the one which would be obtained by a subjective adjustment.

It is not, of course, being argued that this is the only way to deal with this particular problem. A Shuman type filter with suitable parameter values would doubtless accomplish a similar result as far as the h field is concerned. The point here is simply that the adjustment depends directly on equation (1) for its effectiveness.

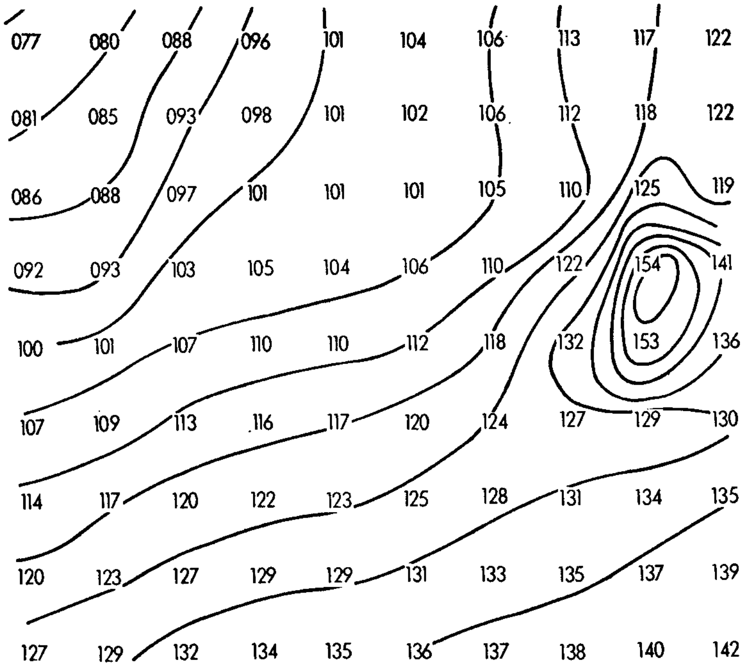

FIGURE 1—SECTION OF THE OPERATIONAL 200-mb ANALYSIS FOR 00 GMT, 23 MARCH 1967

Grid-point and isopleth values in geopotential decametres.

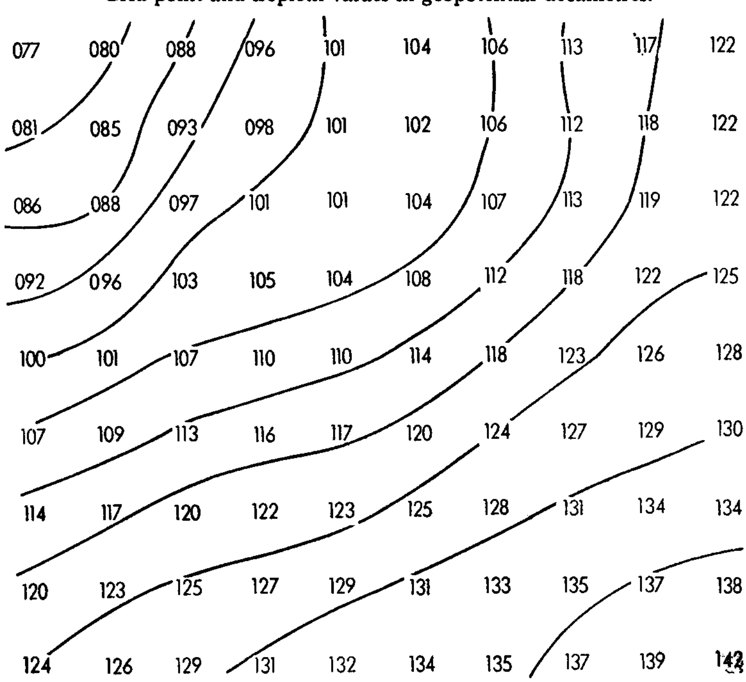

FIGURE 2—THE 200-mb ANALYSIS FOR 00 GMT, 23 MARCH 1967 AS ADJUSTED BY THE ALGORITHM

Example 2. When a set of grid-point geopotential height values are produced by some analysis process depending on smoothing scans or polynomial approximation there is an inevitable loss of intensity in the pattern of the field. Again, if an analysed field is subjected to a numerical forecasting process which is dependent on finite-difference technology a similar loss of intensity will occur. It seems intuitively obvious that this loss effect will be greatest in those regions where the departure of the intensity of the field from linearity is greatest. This being the case an application of equation (3) with a and b determined by a $k > 1$ can be expected to restore the lost intensity.

Figure 3 shows the 200-mb analysis for 00 GMT on 24 June 1969 together with the geostrophic isotachs. Figures 4 and 5 show the result of applying equation (3) with a and b determined by $k = 2$, and $k = 3$ respectively. The progressive intensification of the contour pattern is clearly discernible to the eye and is confirmed by the isotachs.

Finally, it may be noticed that although what has been done in these two examples is essentially the adjustment (equation (4)) of the vorticity field, in fact only equation (3) was used in the computations. Neither the old and new vorticities nor the biharmonic were calculated. This illustrates what has become a commonplace of numerical analysis, namely that a computer algorithm need bear little resemblance to the algebra it is effecting.

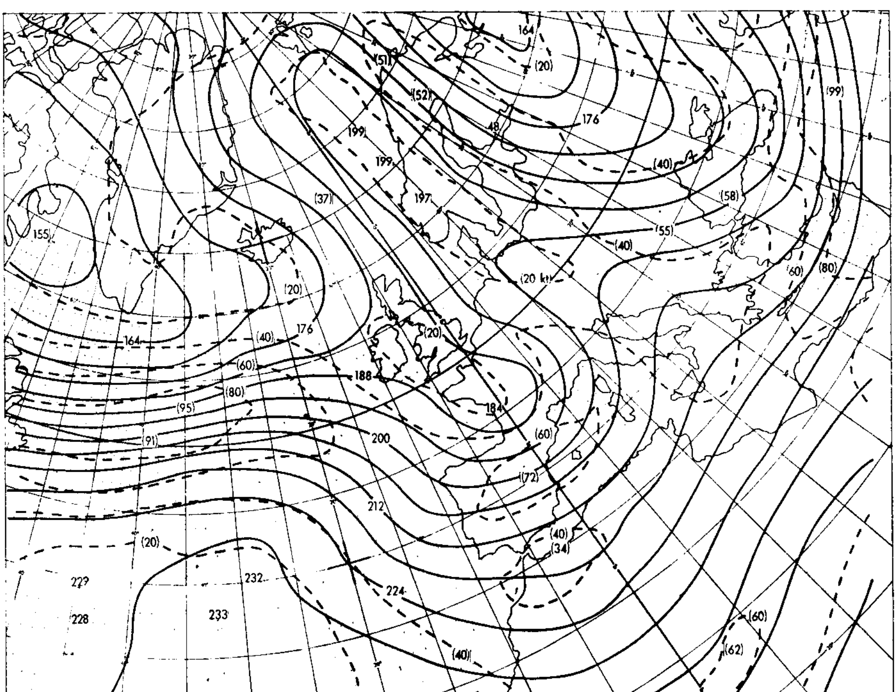

FIGURE 3—200-mb CONTOURS FOR 00 GMT, 24 JUNE 1969 AS OBTAINED BY THE OPERATIONAL ANALYSIS SYSTEM. GEOSTROPHIC ISOTACHS ARE ALSO SHOWN

——— Contours at intervals of 6 geopotential decametres.

– – – Isotachs at intervals of 20 knots (isotach values in brackets).

Wind speeds are given in knots in accordance with WMO recommendations (1 knot$\approx$0·5 m/s).

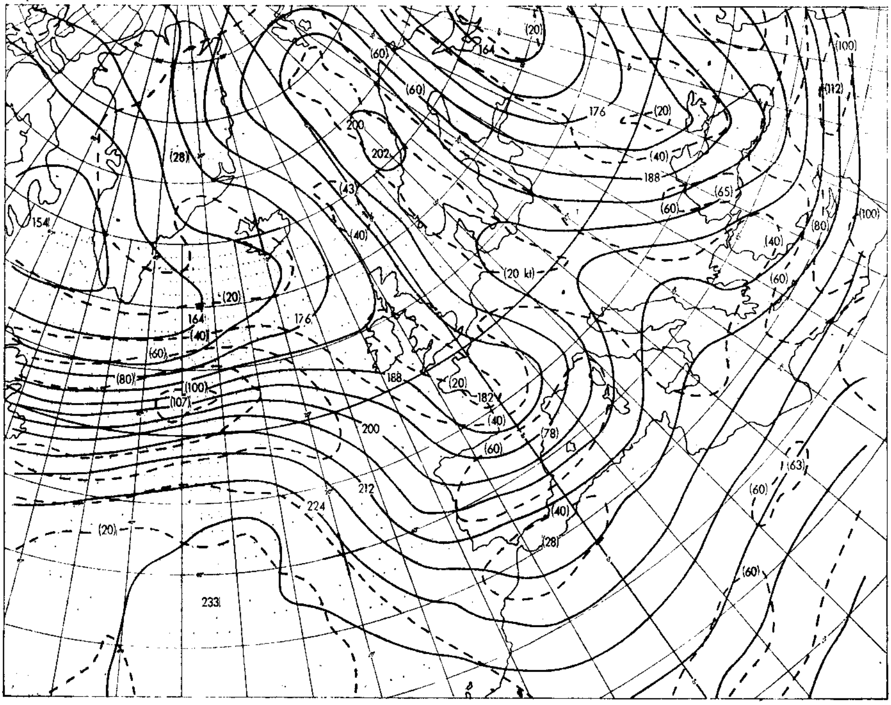

FIGURE 4—200-mb CONTOURS FOR 00 GMT, 24 JUNE 1969 WITH THE PATTERN INTENSIFIED BY APPLICATION OF THE ALGORITHM WITH $k = 2$

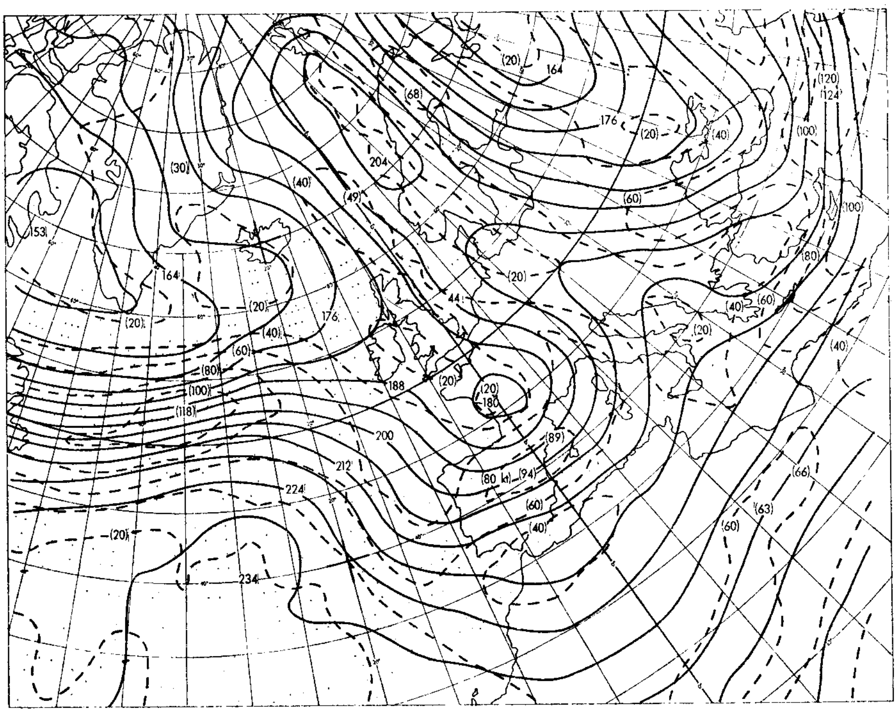

FIGURE 5—200-mb CONTOURS FOR 00 GMT, 24 JUNE 1969 WITH THE PATTERN INTENSIFIED BY APPLICATION OF THE ALGORITHM WITH $k = 3$

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1. KIRK, T. H.; The Laplacian and its relevance for analysis. *Met Mag., London*, **99**, 1970, pp. 151–152.
2. MAXWELL, J. C.; Scientific papers. New York, Dover, 1952.

551.578.45:625.1

A RAILWAY PROBLEM DURING THE HEAVY SNOWFALL OF 4 MARCH 1970

By G. E. PARREY

Summary. On 4 March 1970 a small depression moved south-east across the country and brought a heavy snowfall to the Midlands and south-east England. Train services on the electrified main line into London (Euston) were disrupted because the weight of snow and ice brought down the locomotive pantographs and prevented contact with the overhead line. As this was the first time the difficulty had been encountered in five years of operation since electrification, the prevailing meteorological conditions were investigated in order that both forecasters and British Railways might be alive to the problem in future. A possible explanation of the difficulty experienced is proposed.

On 4 March 1970 a small depression moved south-east across England and heavy falls of snow occurred, chiefly on the north-eastern side of the track of the depression. At 06 GMT the depression was centred just south of Chester, at 09 GMT a little north of Reading and by 12 GMT the centre was over mid-Channel south of Beachy Head (see Figure 1 for place names and Figures 2 and 3 for synoptic situation). Heavy delay was caused to trains on the electrified route into London (Euston) from the Midlands by the pantographs on the electric locomotives failing to make contact with the overhead line equipment. The pantographs thrust upwards with considerable force but the weight of snow and ice was sufficient to overcome this upward thrust and to prevent contact being made. A feature of the occurrence was that, although moderate or heavy snow was falling over some part or other of the line between Crewe and Euston from about 03 GMT to 15 GMT, the difficulty with the pantographs was only experienced between about 0930 and 1300 GMT when successive southbound trains were brought to a standstill between Bletchley and Euston. Little or no pantograph trouble was experienced in other sections of the line, or with northbound trains in the same section. Plate I shows a pantograph.

Hourly weather and temperatures at four Meteorological Office stations are given, for relevant times, in Table I. The stations : Shawbury (Shropshire), 235 feet (72 m) above MSL; Birmingham Airport, 319 feet (97 m); Cardington (Bedfordshire), 93 feet (28 m) and Northolt (Middlesex), 108 feet (33 m), were chosen as being the nearest hourly-reporting stations to the main line. The recorded temperatures are taken at 4 feet (1·2 m) above ground level in standard thermometer screens. On this particular occasion there was no inversion of temperature near the ground and ambient temperatures at pantograph level would be only a fraction of a degree lower than those in the screen.

TABLE I—WEATHER AND TEMPERATURES AT SHAWBURY, BIRMINGHAM AIRPORT, CARDINGTON AND NORTHOLT ON 4 MARCH 1970

Time GMT	Shawbury		Birmingham Airport		Cardington		Northolt	
	Weather	Air temp. °C	Weather	Air temp. °C	Weather	Air temp. °C	Weather	Air temp. °C
00	s_0s_0	0·4	c	0·1				
01	s_0s_0	0·5	s_0	−0·2				
02	s_0s_0	0·3	s_0s_0	−0·2				
03	ss	0·4	s_0s_0	−0·1	Stations closed overnight			
04	ss	0·4	ss	0·0				
05	ss	0·4	ss	−0·1				
06	ss	0·4	SS	0·0				
07	ss	0·4	SS	0·0	ss	−0·5	s_0s_0	0·0
08	c	0·3	ss	−0·3	ss	−0·5	ss	0·4
09	s_0	0·4	s_0s_0	−0·4	SS	−0·3	ss	0·5
10	c	0·0	ss	−0·4	ss	0·0	s_0s_0	0·4
11	c	−0·3	ss	−0·7	ss	0·3	rs	1·0
12			s_0s_0	−0·5	ss	0·4	rd	1·6
13			s_0s_0	−0·4	ss	0·3	rs	1·4
14			c	−0·1	ss	0·3	ss	0·9
15					ss	0·1	SS	0·1
16					s_0s_0	0·0	s_0s_0	0·3

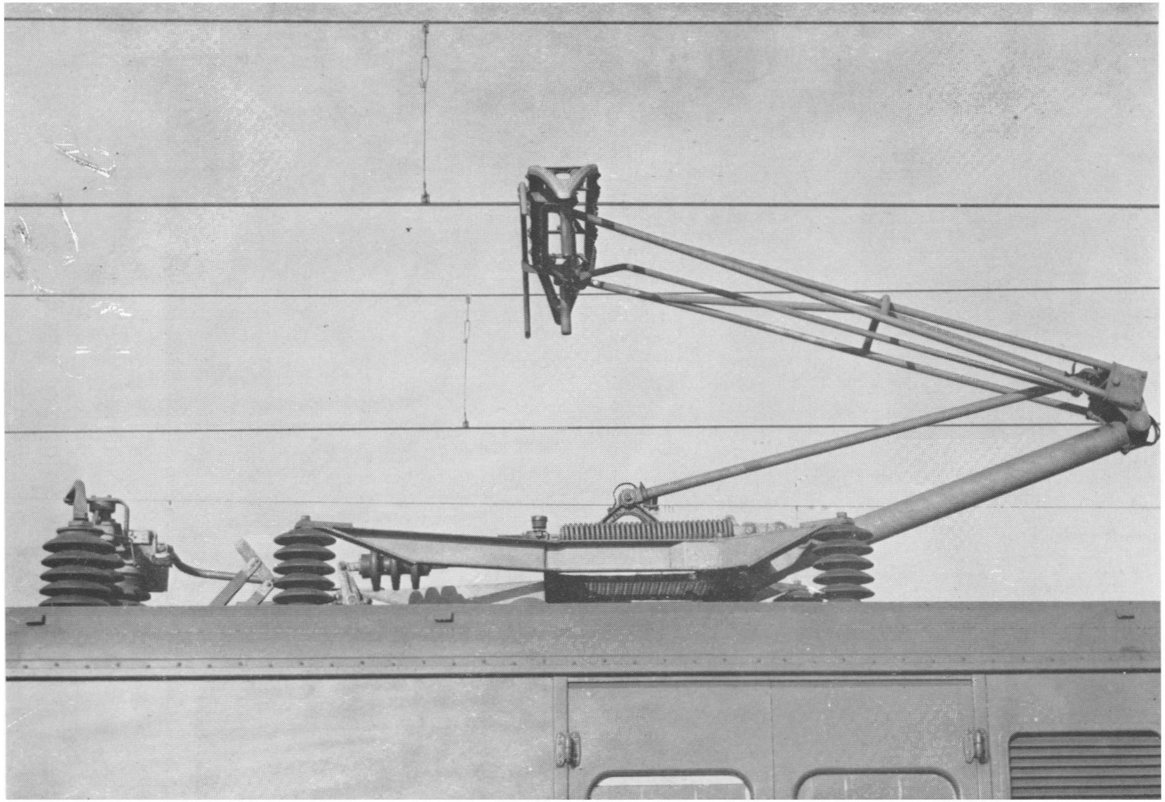
For an explanation of the Beaufort letters used in this table see *Observer's handbook*, third edition, London, HMSO, 1969, pp. 67–71.

Associated with the depression was a tongue of slightly milder air which had the effect of bringing temperatures near the ground up to a little above freezing-point and so increasing the liquid water content of the falling snow. The temporary rise of temperature as the depression passed each of the four stations is well illustrated in the table. At Shawbury the maximum temperature was probably reached at about 05 GMT, at Birmingham between 06 and 07 and at Cardington and Northolt between 11 and 13 GMT. The Northolt reports also show a temporary change from snow to rain. Other factors complicating the distribution of above-zero and below-zero temperatures were (i) the normal tendency for temperatures to rise during the day and, possibly, (ii) the subtle effect of altitude over the Northamptonshire uplands and the Chiltern Hills.

The suggested sequence of events which led to the halting of the trains is as follows :

Between 08 and 13 GMT screen temperatures in the Birmingham area were 0·3 degC or more below freezing-point. Pantograph temperatures on south-bound trains travelling towards Bletchley at this time would be a degree or two below freezing-point. Snowflakes containing little or no liquid water would be blown clear by the rush of air. South of Bletchley, however, after 09 GMT air temperatures were beginning to rise a little above freezing-point and in consequence snowflakes would contain an increasing proportion of liquid water. From the Northolt reports of rain and drizzle one may also deduce that somewhere on the London side of Bletchley separate water droplets began to fall with the snow. This water and wet snow would freeze on contact with the still sub-zero pantographs until eventually the weight of accretion brought the equipment down from contact with the overhead line. The fact that temperatures south of Bletchley were only a little above

To face page 300



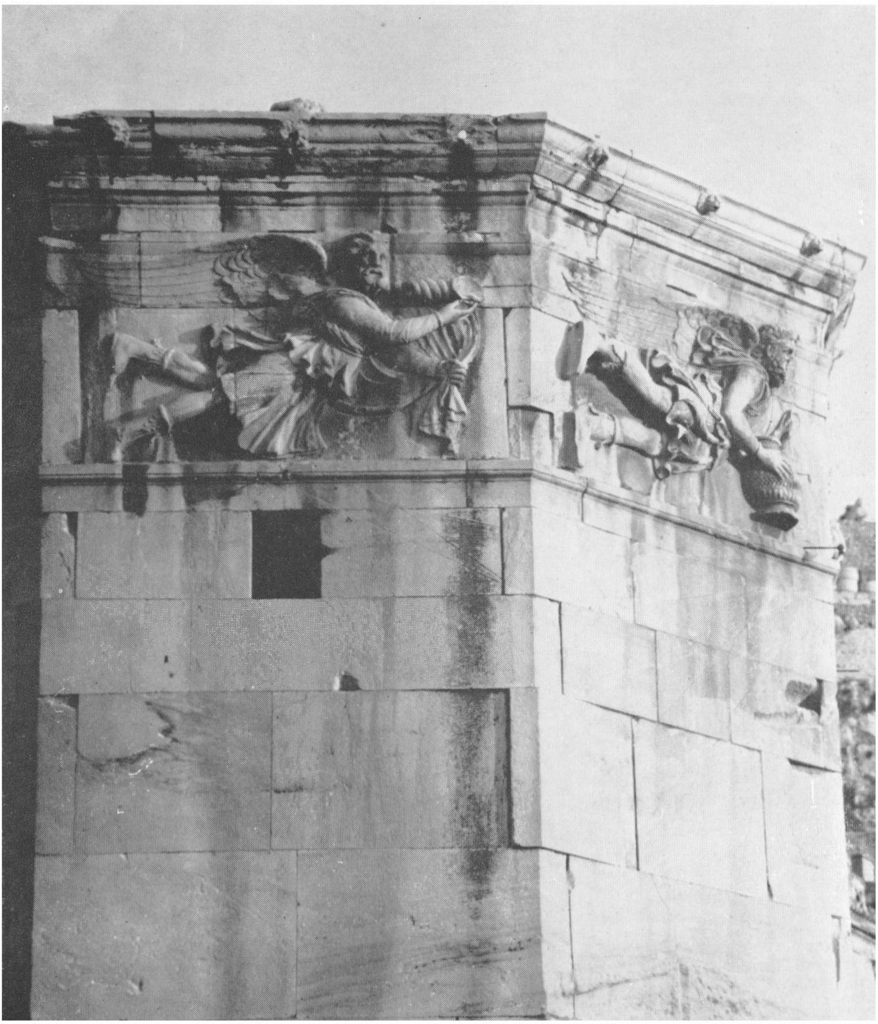
Reproduced by courtesy of British Railways

PLATE I—PANTOGRAPH AND OVERHEAD CONDUCTORS
(See page 299).

Photograph by R. K. Pilsbury

PLATE II—THE TOWER OF THE WINDS IN ATHENS

The tower, which was built in about the second century BC, carries on its sides the names of the winds associated with the eight compass points and also symbolic figures which represent the character of the winds.

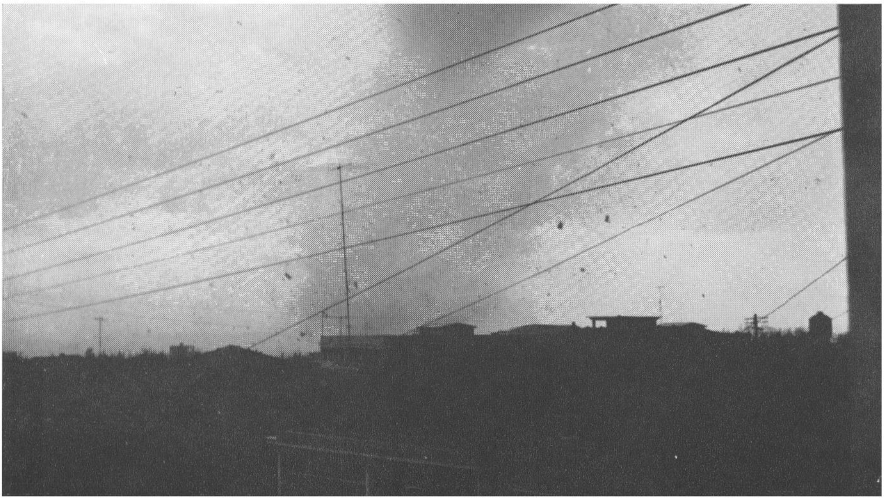


Photograph by R. K. Pilsbury

PLATE III—DETAILED VIEW OF TWO OF THE SYMBOLIC FIGURES ON THE TOWER OF THE WINDS IN ATHENS

The left-hand figure is Boreas (north or north-north-east)—an old man very warmly clothed holding a conch shell. The right-hand figure is Skiron (north-west) — an old man holding a large inverted jar, which may be a brazen fire pot. (See SHAW, SIR NAPIER; Manual of Meteorology, Volume I. London Cambridge University Press, 1932, p. 80.)

PLATE IV—WATERSPOUTS APPROACHING LIMASSOL ON THE AFTERNOON OF 22 DECEMBER 1969



Photographs by courtesy of Sgt. Pownall, RAF

PLATE V—PASSAGE OVER LAND OF TORNADO OVER LIMASSOL ORIGINATING FROM A WATERSPOUT SHOWN ON PLATE IV

Note dust and flying debris which indicate the persistence of the system over land.

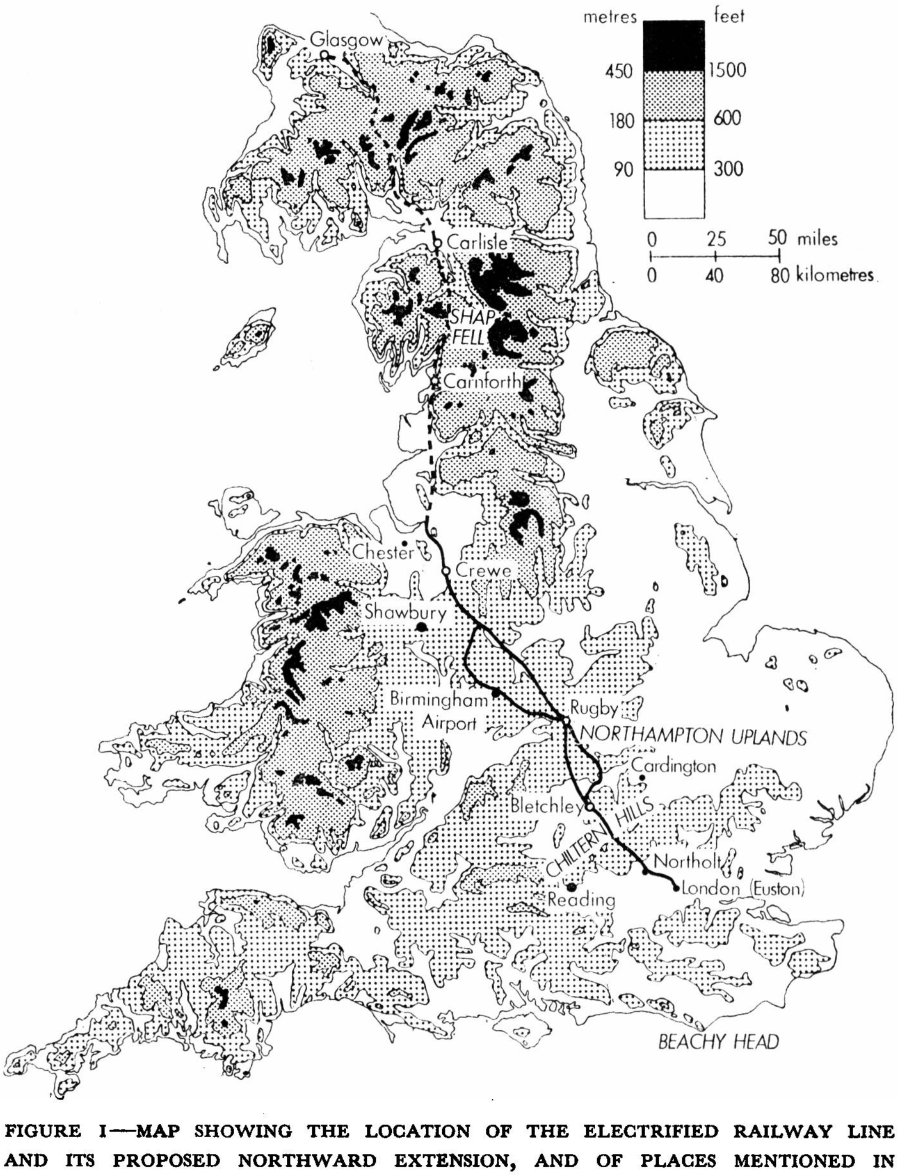


FIGURE I—MAP SHOWING THE LOCATION OF THE ELECTRIFIED RAILWAY LINE AND ITS PROPOSED NORTHWARD EXTENSION, AND OF PLACES MENTIONED IN THE TEXT

freezing-point is significant; if they had been higher, the pantographs would have been more likely to acquire above-zero temperatures before a large ice accretion had collected. Points in support of this theory are as follows :

(i) Trouble did not occur prior to 09 GMT when temperatures at Cardington were below freezing-point.

(ii) Trouble did not affect northbound trains in the Euston–Bletchley area because they were running from higher towards lower temperatures.

(iii) Trouble did not affect northbound trains between Birmingham and Crewe because at the times when temperatures were favourable for accretion (between 01 and 03 and between 08 and 10 GMT), the snow was only slight during the first period and had become intermittent in the second period, and was dry during both periods.

Two awkward questions remain :

(i) Why were southbound trains not similarly affected between 07 and 09 GMT in the London area where temperatures were just beginning to rise above freezing-point while a little further north they were below zero?

(ii) The possible effect of altitude on air temperature near the ground has already been mentioned; is there any evidence to show what this was and is it justifiable to use temperatures at Cardington in the argument when this station is some 100 to 300 feet (30 to 100 m) below the general level of the line?

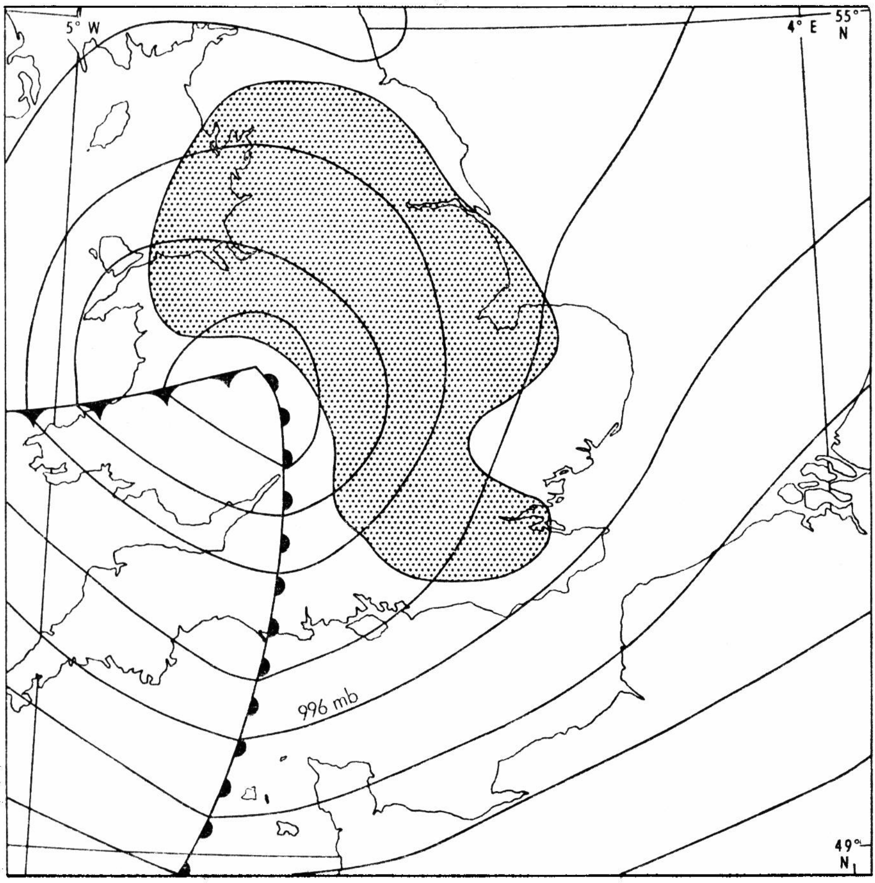


FIGURE 2—SYNOPTIC SITUATION AT 06 GMT ON 4 MARCH 1970

Isobars are at intervals of 2 millibars. The stippled area shows the extensive belt of snow. Some drizzle or sleet occurred near the edge of the snow belt.

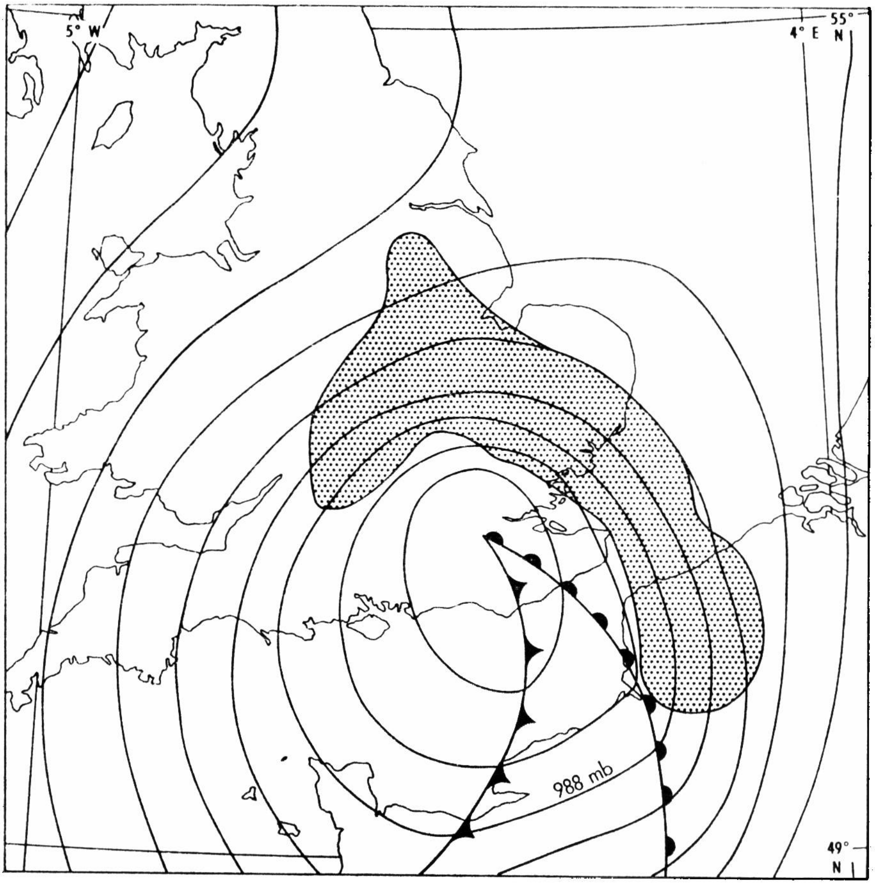


FIGURE 3—SYNOPTIC SITUATION AT 12 GMT ON 4 MARCH 1970

Isobars are at intervals of 2 millibars. The stippled area shows the extensive belt of snow. Some drizzle or sleet occurred near the edge of the snow belt.

A possible clue to question (i) lies in the change from snow to sleet* and then to rain and drizzle at Northolt between 10 and 13 before snow returned by 14 GMT. This clearly indicates a temporary increase in the liquid water content of the precipitation south of Cardington — probably due to slight warming aloft as well as near the ground — at precisely the period when serious accretion occurred. Presumably the liquid content between 07 and 09 GMT was insufficient to give trouble. With regard to question (ii), simultaneous temperature readings at a much larger network of stations in the area have been inspected and differences that can be attributed to altitude are less than 1 degC.

Discussion. The foregoing demonstrates how finely balanced the weather and, particularly, the temperature distribution was on this occasion, and, by implication, how rare the recurrence of similar situations in this part of the

* 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.

country might be. Information from British Railways indicates that this is the first time this particular trouble has occurred to any serious extent during the five years since electrification of this line. To predict the same combination of circumstances would be extremely difficult. However, electrification from north of Crewe to Glasgow, using the same overhead system, has now been sanctioned and it may well be that a similar icing problem will be encountered more frequently in north-west England and southern Scotland. High-speed trains, after encountering snow and below-freezing temperatures over Shap Fell (about 900 ft (275 m) above MSL) for example may, on a number of occasions each winter, run into wet snow, sleet or rain at lower levels on the route to Carnforth or Carlisle, both of which are near sea level. If air temperatures at the lower levels are only a degree or so above freezing-point, the cold pantographs may well rapidly acquire an accretion of ice before the equipment has time to attain a temperature above freezing-point. Similar situations could also be expected after crossing the Scottish hills.

551.510.52:551.515.5:551.524.73

STRUCTURE OF THE TROPOSPHERE OVER GAN

By D. W. DENT and B. H. PREEDY

Summary. Analysis of upper air data from Gan and other tropical stations shows that mean monthly temperature variations are very small throughout the troposphere in the areas considered.

Measurement of stability by means of indices reveals no useful relationship between instability and rainfall, though humidity is the most sensitive element in differentiating between wet and dry days.

Introduction. Despite the fact that most rain in the tropics falls from large cumulonimbus clouds, forecasters have found that upper air temperature soundings provide little or no useful aid for solving the problem of forecasting showers or thunderstorms.

The purpose of this report is :

(i) to present mean tropical soundings and their seasonal variability in the temperature structure, and

(ii) to examine the relationship between stability and rainfall or thunderstorms.

Source of data. This type of investigation has been carried out for various parts of the tropics by several authors, including Harris and Ho[1] who studied convective activity and stability for continental south-east Asia. However, the Indian Ocean region appears to have received little attention in this context. Because of its equatorial position and of its being a small island more than 500 miles (800 km) from the nearest land mass, Gan(0° 41′S, 73° 09′E) was chosen for a detailed analysis. The data are therefore considered representative of the atmosphere over the equatorial Indian Ocean.

Processing of data. Upper air data for a number of stations are stored on magnetic tape at Bracknell. Temperature, humidity mixing ratio, wind speed and wind direction are recorded for a number of standard levels. Calculations were performed for a five-year period (1960–64), for each month of the year for Gan. One radiosonde temperature and humidity sounding made at 12 GMT (17 local zone time) was available for each day.

It was necessary to classify each day as either 'wet' (rainfall at Gan being at least 1 mm in 24 hours) or 'non-wet', less accurately 'dry' (rainfall at Gan being less than 1 mm). The use of this definition is unsatisfactory in that the data from one rain-gauge is being used to represent conditions in an area around the station. The Harris and Ho method of using a radar index to define convective days is more representative of the local environment, but could not be applied to Gan as radar pictures were not available for a long period.

The following were calculated :

(i) Mean monthly ascents for all standard pressure levels up to 100 mb.

(ii) Mean ascents for wet days and dry days for January, April, July and October.

(iii) Mean ascents for days on which thunder was reported and for days on which thunder was not reported at Gan.

(iv) the instability of each temperature sounding as measured by the following instability indices :

(a) Boyden's[2] index (I) is given by

$$I = Z - T_{700} - 200$$

where Z = 1000 – 700-mb thickness (decametres)

T_{700} = 700-mb temperature (°C);

(b) Rackliff's[3] index (ΔT) is given by

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

where θ_{w900} = 900-mb wet-bulb potential temperature (°C)

T_{500} = 500-mb temperature (°C);

(c) Jefferson's[4] index (T) is given by

$$T = 1{\cdot}6\,\theta_{w900} - T_{500} - \tfrac{1}{2}Td_{700} - 8$$

where Td_{700} = 700-mb dew-point depression (degC).

These indices were designed for temperate latitude environments and no attempt is made to justify the suitability of their use in the tropics. They were selected so that variations in stability could be investigated.

(v) A moisture-deficit index for each sounding as defined by

$$M = \tfrac{1}{2}d_{500} + d_{600} + d_{700} + \tfrac{3}{4}d_{800} + \tfrac{1}{2}d_{850} + \tfrac{1}{4}d_{900}$$

where $d_{500} = x_{s500} - x_{500}$ etc.,

where x_{s500} = saturated humidity mixing ratio at 500 mb (g/kg)

x_{500} = humidity mixing ratio at 500 mb (g/kg).

This index represents the dryness of the troposphere from 900 mb to 500 mb by integrating the moisture deficit between these levels, as suggested by Johnson and Mörth.[5]

Results.

(i) *Variations of mean monthly temperature.* These are remarkably small (see Figure 1) showing variations not greater than 1 degC in the lower troposphere (900 mb to 500 mb) and not exceeding 2 degC throughout the entire troposphere. In May and June there is a temperature fall of 0·5 degC in the lower troposphere increasing to 2 degC at 200 mb. This coincides with the onset of the south-east monsoon at Gan. However, at 100 mb there is a large temperature rise of 6·6 degC between April and August preceding a corresponding fall during the following three months. These changes are closely linked with the height of the tropopause and the position of the thermal

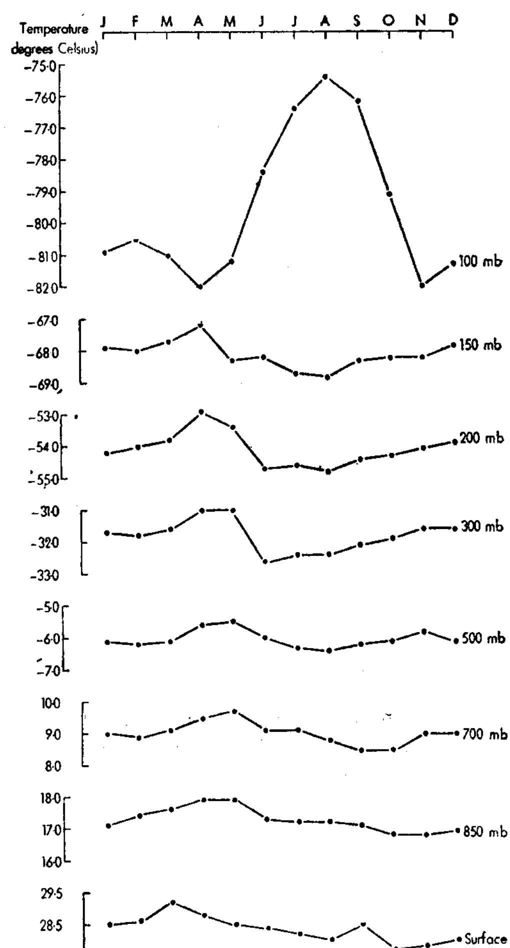


FIGURE 1—MEAN MONTHLY TEMPERATURES AT GAN (1960–64)

equator. The mean ascents, of which October (see Figure 2) is a typical example, show conditional instability from the surface to 500 mb and a near saturated-adiabatic lapse rate above.

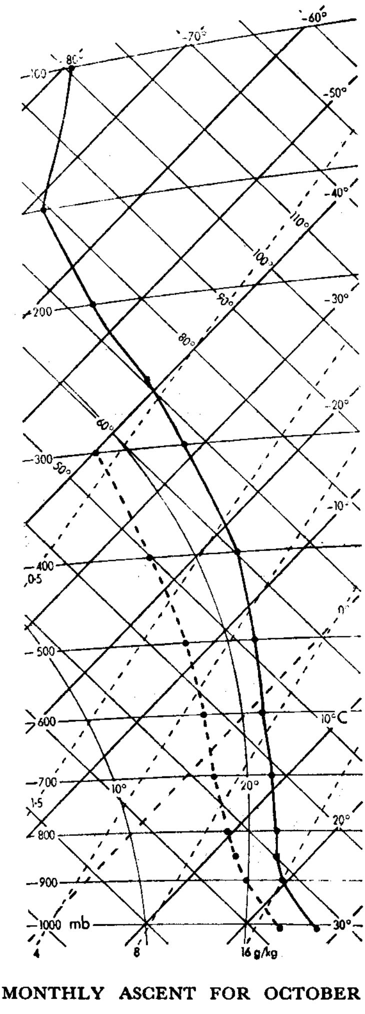


FIGURE 2—MEAN MONTHLY ASCENT FOR OCTOBER AT GAN (1960–64)
·——— · Dry-bulb temperature ·- - - - · Dew-point temperature

(ii) *Variations of temperature within each month.* Standard deviations of temperature for the levels from 900 mb to 500 mb are less than 1·25 degC (see Figure 3). There is a minimum value of standard deviation in all months at 900 mb with an absolute minimum of 0·66 degC in January at this level. These values are consistently smaller than those indicated by Goldie, Moore and Austin[6] for this region.

(iii) *Mean stability indices.* The mean monthly values of Boyden's index are not less than 95·9 in all months. This contrasts with the thunderstorm threshold value of 94 suggested by Boyden for temperate latitudes which was surpassed at Gan on 97 per cent of occasions throughout the five-year period.

Pressure (mb)	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC.
100	2·76	3·17	3·08	2·66	3·25	3·15	3·39	3·32	3·54	2·89	3·12	3·06
150	2·46	2·95	2·36	2·32	2·46	2·10	1·98	2·30	2·68	2·24	2·17	2·49
200	2·08	2·27	1·79	2·08	1·83	1·98	1·50	1·63	1·87	1·71	1·64	1·98
250	1·70	1·84	1·59	1·91	1·58	1·68	1·41	1·48	1·54	1·50	1·42	1·68
300	1·57	1·52	1·34	1·50	1·45	1·52	1·32	1·27	1·26	1·33	1·26	1·46
400	1·42	1·28	1·32	1·08	1·07	1·24	1·28	1·58	1·16	1·09	1·01	1·08
500	1·08	1·05	1·23	0·88	0·97	1·20	1·16	1·09	0·99	0·89	0·97	1·03
600	1·04	1·05	1·15	0·98	1·05	1·18	1·11	1·00	1·08	0·99	0·92	1·11
700	1·03	1·11	1·02	1·00	1·06	1·12	1·07	1·24	0·85	1·01	0·90	1·03
800	0·98	1·09	0·95	0·86	1·06	1·09	0·95	0·94	0·96	0·89	1·01	0·99
850	0·78	1·05	0·88	0·82	0·89	0·98	0·83	0·85	0·80	0·74	0·85	0·83
900	0·66	0·83	0·79	0·80	0·81	0·84	0·74	0·69	0·69	0·71	0·72	0·77
Surface	1·13	1·33	1·33	1·54	1·37	1·09	1·28	1·57	1·24	1·33	1·29	1·36

FIGURE 3—STANDARD DEVIATIONS OF MONTHLY MEAN TEMPERATURES AT GAN IN DEGREES CELSIUS

The mean monthly values of Jefferson's index vary from 27·6 to 29·3 and are very close to the thunderstorm threshold value of 28 quoted by the author. However, this is not necessarily the appropriate value to use in the tropics.

The mean values of Rackliff's index, on the other hand, are always below the suggested thunderstorm threshold of 30.

The significant differences in the mean values of Jefferson's and Rackliff's indices may be explained by the additional moisture parameter included in Jefferson's index.

(iv) *Relation between stability and indices.* A comparison of mean monthly soundings for wet and dry days shows a consistent temperature difference. In each season, the mean sounding for wet days indicates an upper troposphere warmer than the dry days by about 1 degC on average (see Figure 4). This would be expected from the release of latent heat in deep convection. Below the 500-mb level the air on wet days is cooler and moister than on dry days. This is essentially the result found by Harris and Ho using Saigon data. Although it was not possible to separate diurnal temperature variations as done by Harris and Ho, a statistical analysis by Preedy[7] shows that the nocturnal bias of rainfall at Gan is slight. Calculations on data for a four-year period indicate that 54 per cent of the total rain at Gan falls by night.

Comparison of the instability indices points to a slight decrease in stability on wet days in the mean (see Table I). Values of Boyden's index for wet days in January, April and July show a slight increase over the mean values. Similarly the Rackliff and Jefferson mean indices on wet days suggest a less

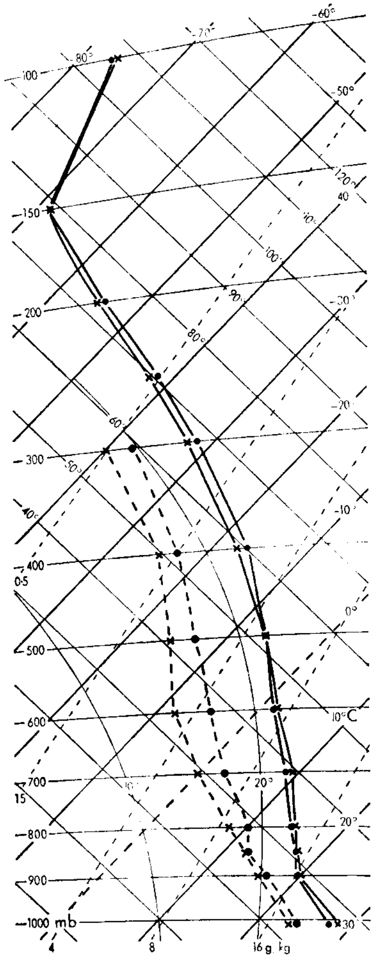


FIGURE 4—MEAN MONTHLY ASCENTS FOR WET AND DRY DAYS AT GAN (JULY 1960–64)

. ——— . Wet days dry-bulb temperature	x ——— x Dry days dry-bulb temperature
. – – – . Wet days dew-point temperature	x – – – x Dry days dew-point temperature

stable atmosphere on wet days than the mean. Although these variations from the mean are statistically significant, they are of no practical value (see Figure 5).

The moisture-deficit index clearly indicates a large increase in moisture content on wet days. This implies that the large variations in the Rackliff and Jefferson indices compared with Boyden's are mainly due to the inclusion of moisture parameters. Humidity is plainly the most sensitive element in differentiating between wet and dry days.

Mean thunder-day calculations were based on small samples because of the infrequent occurrence of thunder at Gan.[7] Nevertheless, the mean soundings for thunder days show a variation in stability which is similar to that for wet days. This is not surprising since most thunder days were also wet ones.

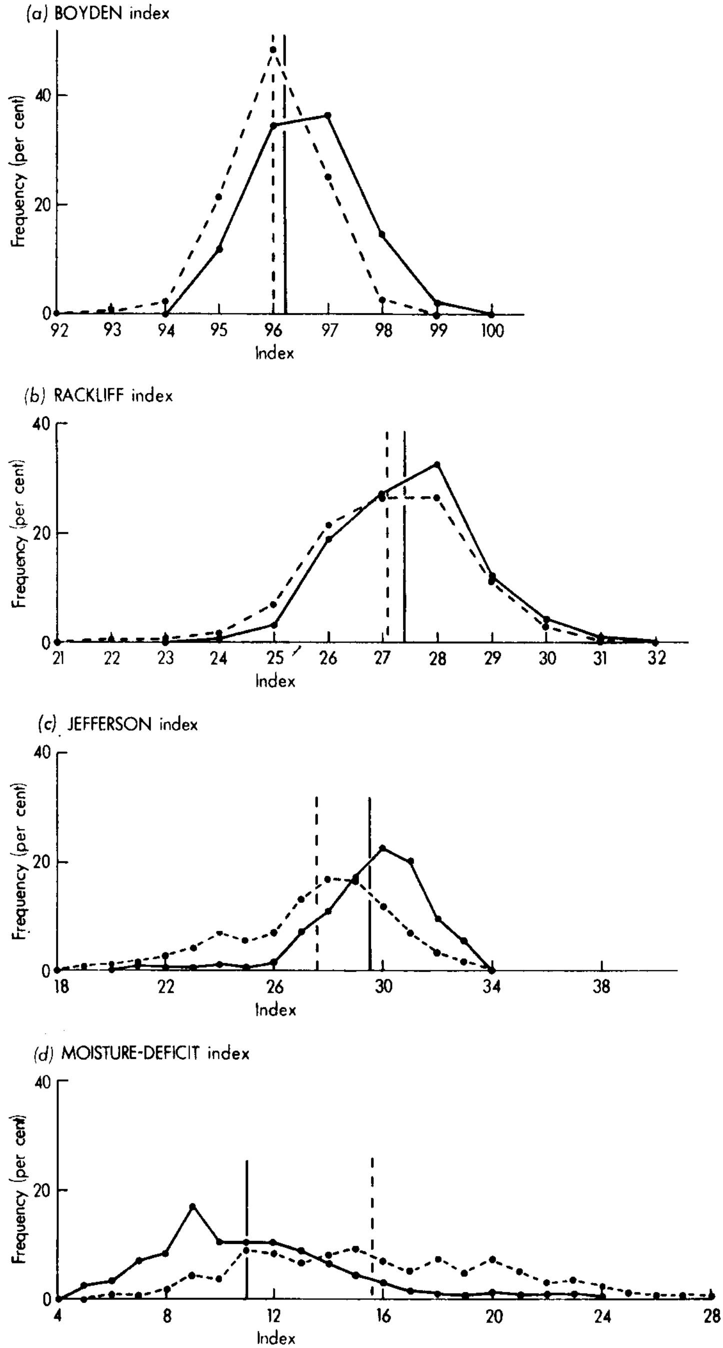


FIGURE 5—FREQUENCY OF INDEX VALUES ON WET AND DRY DAYS AT GAN (JANUARY, APRIL, JULY AND OCTOBER)

——— Wet days – – – Dry days

Mean of distribution shown by vertical line.

TABLE I—INSTABILITY INDICES AT GAN

	January	April	July	October
BOYDEN (94)				
Mean monthly	96·0	96·3	96·1	96·1
Mean wet days	96·1	96·4	96·3	96·1
Mean dry days	95·9	96·2	96·0	96·1
Mean thunder days	96·5	96·0	96·1	95·8
Mean non-thunder days	95·9	96·3	96·1	96·1
RACKLIFF (30)				
Mean monthly	27·1	27·5	27·5	27·0
Mean wet days	27·4	27·6	27·7	27·2
Mean dry days	26·9	27·3	27·4	26·7
Mean thunder days	28·5	28·4	28·3	28·0
Mean non-thunder days	27·0	27·4	27·4	26·9
JEFFERSON (28)				
Mean monthly	28·2	29·3	27·6	28·4
Mean wet days	29·4	30·2	29·2	29·2
Mean dry days	27·6	28·5	27·0	27·3
Mean thunder days	30·1	31·0	30·1	30·6
Mean non-thunder days	28·1	29·2	27·5	28·3
MOISTURE-DEFICIT				
Mean monthly	13·7	13·3	15·7	12·2
Mean wet days	11·1	11·1	12·0	10·5
Mean dry days	15·0	15·2	17·0	14·4
Mean thunder days	11·9	10·2	12·0	8·5
Mean non-thunder days	13·8	13·5	15·8	12·3

Numbers in brackets after index names indicate thunderstorm threshold values for temperate latitudes.

The Rackliff and Jefferson indices on thunder days suggest a decrease in stability over wet days. The wet-day and thunder-day means of Jefferson's index were about the threshold value of 28. On the other hand, the means of Rackliff's index were below threshold.

(v) *Day-to-day variations.* The next step was to investigate the variations of the indices on a day-to-day basis. An attempt was made to use the moisture-deficit index as an indicator for rainfall in the 24 hours following the sounding. By selecting a suitable critical value, a forecast of rain or no-rain was made according to whether the moisture-deficit index was below or above this value. This is basically a persistence method using humidity content as parameter. The results on average over the five-year period were no better than those obtained for a forecast by persistence of type (that is, predicting a rain day to follow a rain day and a dry day to follow a dry one).

The frequency distributions (see Figure 5) show that none of the indices are capable of satisfactorily discriminating between a wet and a dry day.

(vi) *Comparison with other tropical stations.* The data from several tropical upper air stations for January, April, July and October were analysed to provide a comparison with the Gan results. Five-year means were calculated for Aden and Nairobi. Seychelles data were available for a period of 16 months and Christmas Island data for three years.

At Aden (12° 50′N, 45° 02′E), seasonal variations in temperature in the lower troposphere were much greater than at Gan (see Figure 6). This result would be expected from continental influences.

At Nairobi (01° 18′S, 36° 45′E), the seasonal variations were larger than those at Gan and were confined to a shallow surface layer.

Throughout the troposphere, data for Seychelles (04° 37′S, 55° 27′E) exhibited a slightly larger seasonal variation than did data for Gan, but the variation did not exceed 3 degC below the 150-mb level.

Data for Christmas Island (01° 59′N, 157° 29′W) showed remarkably small variations of temperature throughout the seasons. It is apparent that the stations nearest to the equator experience the smallest seasonal variations in temperature.

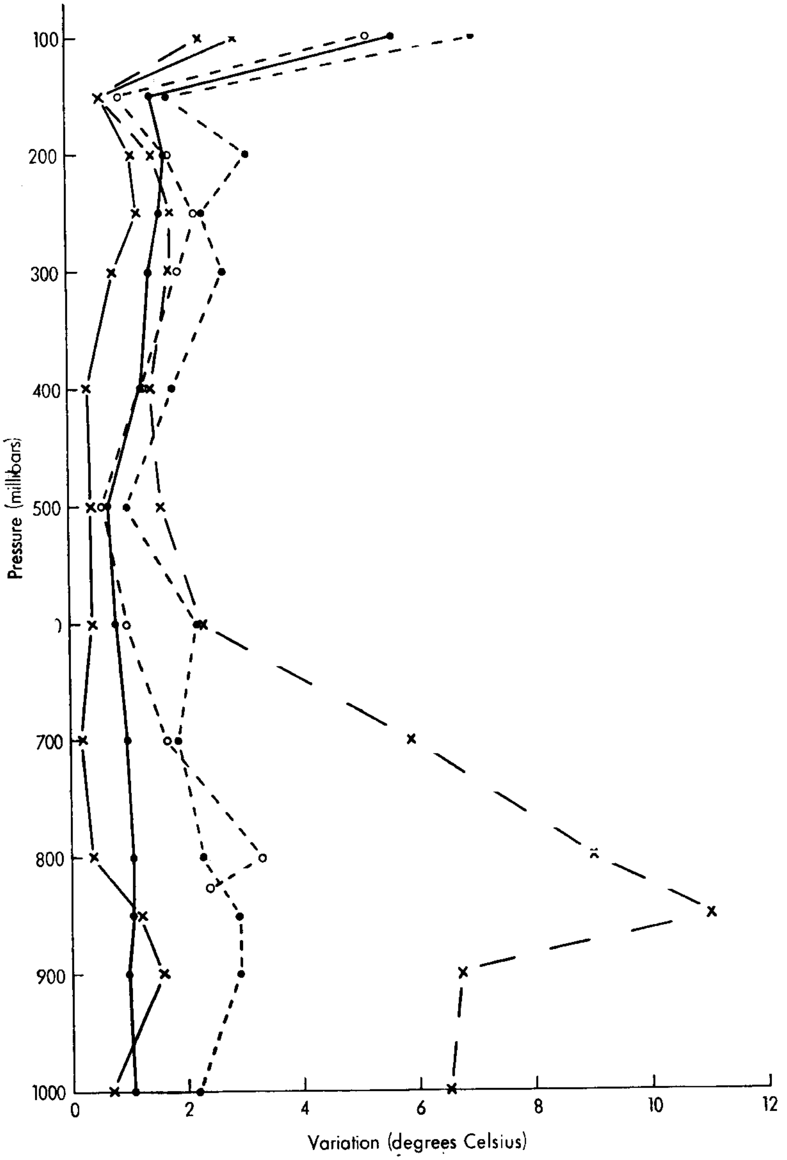


FIGURE 6—RANGE OF MEAN SEASONAL TEMPERATURE

x — — —· x Aden x ——— x Christmas Island · - - - · Seychelles
· ——— · Gan o - - - o Nairobi

Indices for wet and dry days at Seychelles and Christmas Island behaved in a similar manner to those at Gan, with a small variation in Boyden's index and rather larger variations in the Jefferson, Rackliff and moisture-deficit indices. The mean soundings were also similar, with cooling in the lower troposphere and warming in the upper troposphere on wet days.

Discussion. The results confirm that temperature variations in the tropics are small, particularly in oceanic environments near to the equator. Mean ascents show that the atmosphere is conditionally unstable in the lower troposphere on both wet and dry days, and support the hypothesis that increases or decreases in convective activity are synoptically controlled.

Instability and moisture-deficit indices are unsuitable as tools for forecasting rainfall in the tropics, although there are significant differences between the mean index values for wet and for dry days. However, the predominant element giving rise to these differences is the moisture content, and variations in stability are small. Warming in the upper troposphere on wet days is accompanied by slight cooling in the lower layers.

There is evidence to suggest that the tropical atmosphere exhibits greater instability in association with thunderstorm activity than is present in non-thundery wet situations, but the differences are so marginal as to be of no value in forecasting.

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NOTES AND NEWS

Retirement of Mr S. E. Virgo, O.B.E.

Mr Sidney Eustace Virgo joined the Meteorological Office at the start of the Second World War as a Forecaster II early in 1940. During the next three years he served at Bicester, HQ No. 15 Group Royal Air Force (Liverpool), Swinderby and Gloucester, finally settling for a spell at Prestwick.

In 1943 Mr Virgo was commissioned Flight Lieutenant in the Meteorological Branch of the RAFVR and after a time in Dorval near Montreal he returned again to Prestwick.

Following his promotion to Squadron Leader he served in Trinidad for nearly three years from 1945 to 1948. In 1948 he was posted, as a Principal Scientific Officer, to London Airport on the senior forecasters' roster and then in 1949 became Senior Meteorological Officer at HQ No. 18 Group, Pitreavie, where he stayed for three years. Following a further three years as Senior Meteorological Officer, Prestwick, he became Chief Meteorological Officer 2nd Tactical Air Force, Germany, until September 1958 when he returned to become Chief Meteorological Officer HQ Bomber Command. In this post he was promoted to Senior Principal Scientific Officer in June 1960 and remained as Chief Meteorological Officer Bomber Command RAF, later Strike Command, until he retired from his senior grade in May 1969. In 1968 he was appointed an Officer of the Order of the British Empire in the New Year Honours List.

During more than 10 years at High Wycombe Sidney Virgo impressed his personality throughout his wide field of subsidiary stations and staff. Very well liked by all, he showed his qualities of leadership in the very considerable amount of investigational work carried out and published by the staff at his stations.

A regular contributor to technical journals over the years, his subjects ranged from föhn winds in Switzerland, weather at Piarco, Trinidad, and instability over Scotland to much work on the forecasting of night minimum temperatures.

After retirement from his senior post, Mr Virgo accepted a disestablished post as Senior Scientific Officer at the Meteorological Office Training School, and finally left the Office on 31 August 1970.

Without doubt a 'character' who will be missed from our ranks; we wish him and Mrs Virgo many years of happy retirement.

V.R.C.

REVIEWS

Clouds and weather, by R. K. Pilsbury. 215×205 mm, pp. 90, *illus.*, B. T. Batsford Ltd, 4 Fitzhardinge Street, London W1, 1969. Price: 25*s*.

The author is known to most meteorologists for the cloud photographs which have appeared above his name in a variety of meteorological texts and journals. This book is in large measure a vehicle for the publication of a selection of 107 of his photographs; they are in black and white and are reproduced, each with its explanatory note, two to a page.

These photographs comprise the latter two-thirds of the book and they are preceded by a general account, in six short chapters, of cloud nomenclature and methods of cloud formation. The treatment is aimed at the level of the layman, follows fairly conventional lines and is generally sound. The author's wording is not, however, always as unambiguous as would be wished and there must be reservations about the helpfulness or accuracy of a few of the statements which he makes: as, for example, 'the forming of steam' (from a boiling kettle) 'is similar to the forming of cloud and fog'; or, in illustration of condensation by mixing of two air masses of different temperature, as occurring 'when warmer, moist air drifts in from the sea and is cooled by contact with the cold ground and with the cooler air over the land'. Again, though the appropriate choice of units in a text of this kind presents particular difficulties, the author is surely unduly indiscriminate in the way in which he uses °F at some times and °C at others (for lapse rates as well as for surface conditions).

The main value of this book lies, in fact, in the plates, which have been well chosen to illustrate the genera, species and varieties of the international cloud classification. Their reproduction is good and the author gives a careful explanation of the particular classification which he allots. It does seem a pity, however, that he did not take the opportunity to add the place and date and a brief reference to the prevailing synoptic situation in each case, and thereby inject additional life and meaning to the clouds.

D. H. McINTOSH

Hydrological forecasting. WMO Technical Note No. 92 (Proceedings of the WMO/Unesco Symposium on Hydrological Forecasting, Australia 1967). 270 mm × 210 mm, pp. xvi+325, *illus.*, Geneva, WMO, 1969 (supplier HMSO, London). Price: £6.

The World Meterorological Organization has included in its admirable series of *Technical Notes*, the Proceedings of the WMO/Unesco Symposium on Hydrological Forecasting which was held in Surfers' Paradise, Queensland, Australia, in 1967. In his comprehensive keynote address, Max A. Kohler gave the principal theme of the Symposium as the 'forecasting, especially for shorter time-intervals, of rainfall floods'. He outlined the problem areas of data acquisition and transmission, and pointed to the rapid developments in forecasting procedures using atmospheric and catchment models. In the future, reliable quantitative precipitation forecasts would constitute the data input to improve catchment models with, as a consequence, much more accurate river-flow forecasts.

The Proceedings contain 30 papers grouped into six parts. Part 1 contains three general review papers, Part 2 four papers on the forecasting of precipitation, Part 3 three papers on data acquisition and instrumentation, Part 4 ten papers on forecasting techniques, Part 5 four papers on operational aspects of forecasting and Part 6 six papers presented by title only at the Symposium.

The subject matter of hydrological forecasting may be considered under three headings: the forecasting of precipitation from the atmosphere, the forecasting of high discharges and flood peaks along a river course, and the interaction between the atmospheric and land phases of the hydrological cycle. The review papers by Popov and Philip cover the last two topics in masterly fashion but it is unfortunate that the paper from Smagorinsky is merely a one-page summary of a previous paper in the *Monthly Weather Review* and does little justice to the too expansive title: 'The hydrological cycle — its physical basis and its predictability'.

In Part 2 some readers might again be disappointed by another one-page presentation of results by Smagorinsky from the American nine-level hemispheric model. 'Researches in India on objective precipitation assessment' and two valuable contributions by Hill on the hydrologically important cyclonic disturbances in the upper troposphere over Australia and New Zealand are welcome contributions.

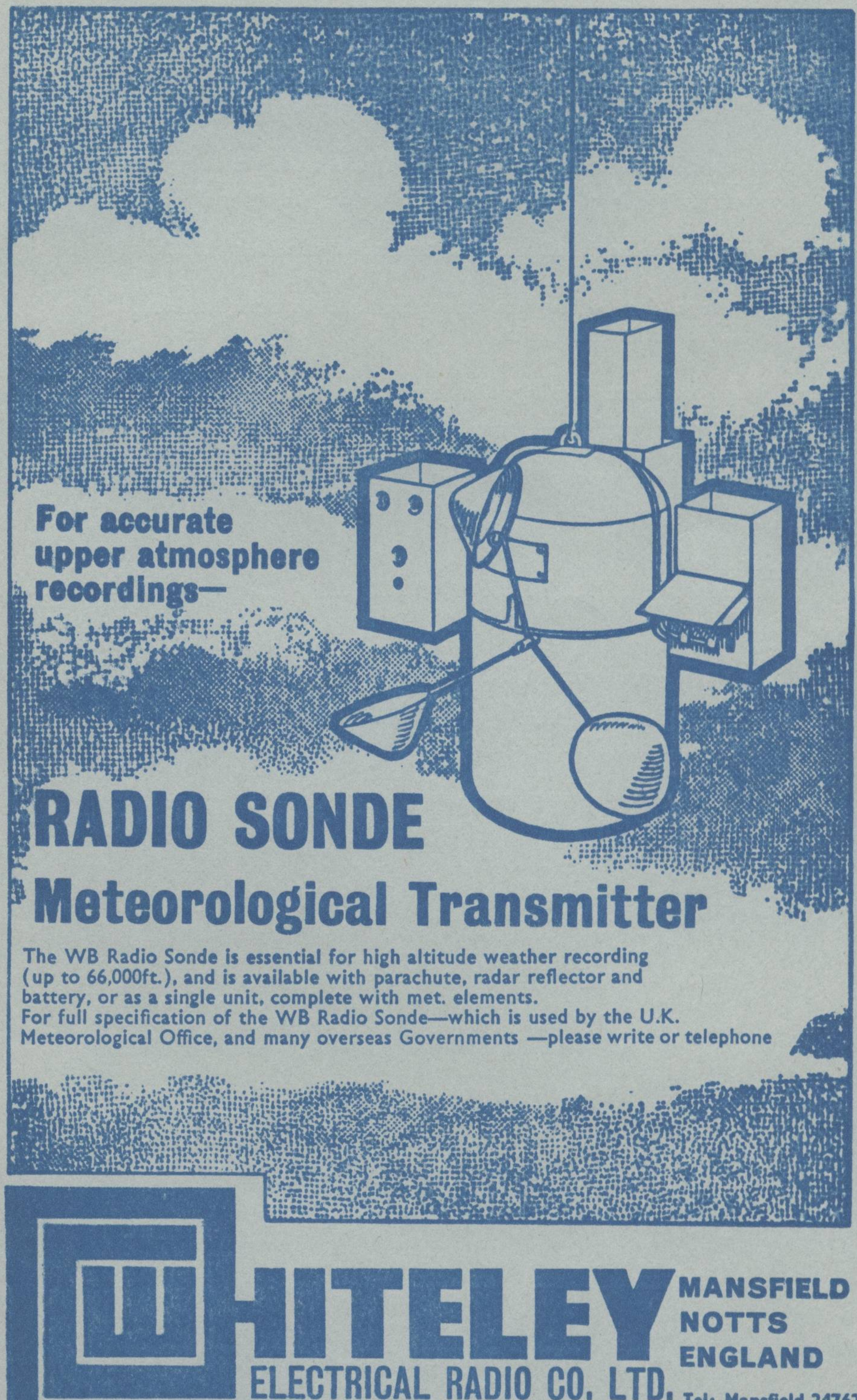
In data acquisition, the future value of observations from satellites is outlined by Rainbird, while Alexander develops mathematical models for the areal rainfall from significant storms.

The largest section, entitled 'Forecasting techniques', is mainly concerned with surface hydrology. In a very good paper on the 'Application of conceptual catchment models to river forecasting', Nordenson describes a selection of conceptual models developed in the United States and highlights the problems of adapting general-purpose models to forecasting where updating of input data and changing catchment conditions is necessary as flood discharges develop. A fuller explanation of the Stanford Watershed Model IV is reported by Crawford who stresses both the difficulties encountered with timing and volume errors in simulating the flood hydrograph and also the particular dangers of errors in the input data from mistaken observations. A paper by Nash and Sutcliffe (J. V.), misleadingly entitled 'Flood-wave formation', reviews the methodology and philosophy of catchment modelling and describes research in progress at the Institute of Hydrology. Further examples of work on models are given by Denisov, Bell, Gartsman and Lylo, and Burakov. There are also descriptions of the forecasting methods used in Korea, Venezuela (the Orinoco River) and on the Latrobe River of South Victoria.

On the operational aspects of forecasting, there are two general papers covering applications of discharge and water-level forecasts and the organization of flood warnings. The functioning of two major control schemes in Australia (Lake Burley Griffin in Canberra and the multi-purpose Somerset Dam in the Brisbane River catchment) conclude the presented papers.

In this rapidly developing subject, the delay in this publication is to be regretted. Many additional floods since 1967 have added to experience. Nevertheless, several of the contributions to the Symposium still merit detailed study and it is to be hoped that future international conferences on this subject will attract more than one paper from the United Kingdom.

E. M. SHAW and T. O'DONNELL



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