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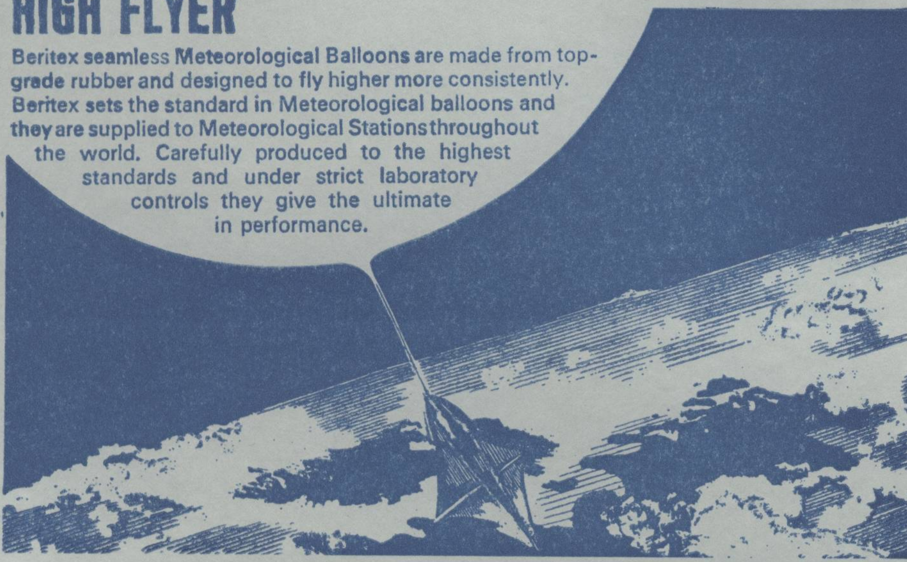

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SUNSHINE AND SOLAR RADIATION IN SINGAPORE

By CHIA LIN SIEN
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Since 1929 the Singapore Meteorological Service has maintained observations of the duration of bright sunshine using a Campbell-Stokes sunshine recorder. Observations were started on 1 January 1929 at Mount Faber. The meteorological station was shifted to the Kallang Aerodrome in June 1934. Observations were interrupted during the period January 1942 to April 1949 by the war in the Pacific. In August 1955 the station was shifted once more when the new Paya Lebar International Airport was opened. The British Meteorological Office also maintained Campbell-Stokes sunshine recorders at Seletar, starting in February 1957, and at Tengah, monthly totals for which are available for 1951 to January 1957. The locations of these stations are shown in Figure 1.

Solar radiation as measured by the Casella bimetallic actinograph has been recorded by the Singapore Meteorological Service since January 1961 at the Paya Lebar station. Also, Webb[1] carried out a two-year period of solar radiation observations using a Kipp solarimetric thermopile at the University of Singapore from April 1952 to March 1954.

This paper summarizes the available data of these two related climatic elements. The relationship between solar radiation and the duration of sunshine is also examined.

Sunshine

Total annual sunshine. Dale,[2] in his map of mean annual hours of sunshine for Malaya, shows the southern tip of Johore and the island of Singapore as areas receiving less than 2100 hours of sunshine per year. However, Table I shows that there are appreciable differences in the mean

TABLE I—MEAN ANNUAL SUNSHINE AMOUNTS FOR FIVE STATIONS IN SINGAPORE

Station	Co-ordinates	Height above MSL *feet*	Period of observations	Mean annual sunshine *hours*
Mount Faber	01°16′N, 103°49′E	296	Jan. 1929–May 1934	2183·6
Kallang	01°18′N, 103°53′E	7	Jan. 1934–Dec. 1941 and May 1949–July 1955	2077·8
Paya Lebar	01°21′N, 103°54′E	25	Sept. 1955–Mar. 1968	1977·1
			1958–1967	1994·8
Seletar	01°25′N, 103°52′E	29	Feb. 1957–Mar. 1968	1971·3
			1958–1967	1971·3
Tengah	01°23′N, 103°43′E	25	Jan. 1950–Mar. 1968	1849·2
			1958–1967	1863·5

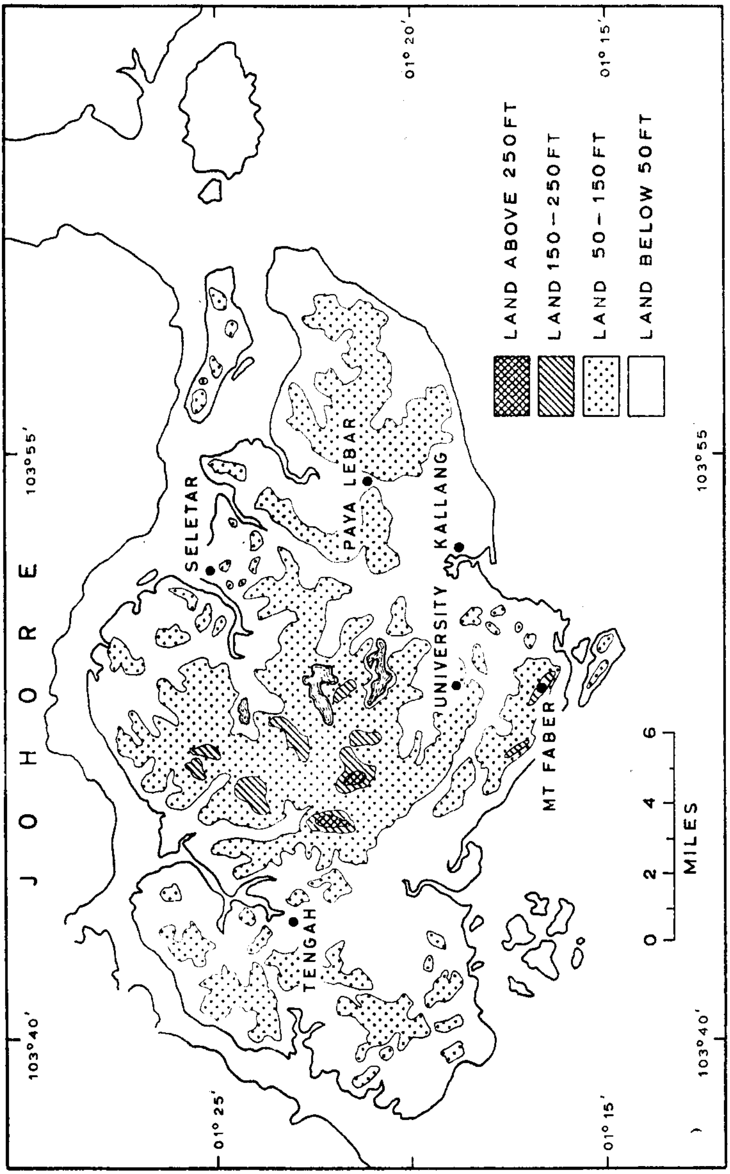

FIGURE 1—STATION LOCATION MAP, SINGAPORE

total sunshine per year received by the five stations in Singapore. Mount Faber and Kallang receive the most sunshine with 2183·6 and 2077·8 hours per year respectively. Paya Lebar and Seletar receive slightly less with 1977·1 and 1971·3 hours respectively. Tengah has the least, with only 1849·2 hours. The mean annual total sunshine hours appear therefore to decrease from the southern coast inland to the north-west of the island.

Figure 2 attempts to show the secular changes in the total annual sunshine amounts using all available data. There appear to be two sunshine peaks in 1930 and 1940 with lower amounts in between. The amounts of sunshine received prior to the war in the Pacific seem to be generally higher than in the post-war years. After the war, peaks are shown for the years 1951 and 1958. The period 1954–56 appears to be especially gloomy. The trend in the sunshine amounts received after 1958 is a downward one generally with very regular biennial fluctuations from 1960 until 1966. Note also that Seletar which received higher sunshine amounts between 1958 and 1960 than Paya Lebar has been receiving less than Paya Lebar since then. The generally less sunny conditions over Tengah are clearly shown in the diagram.

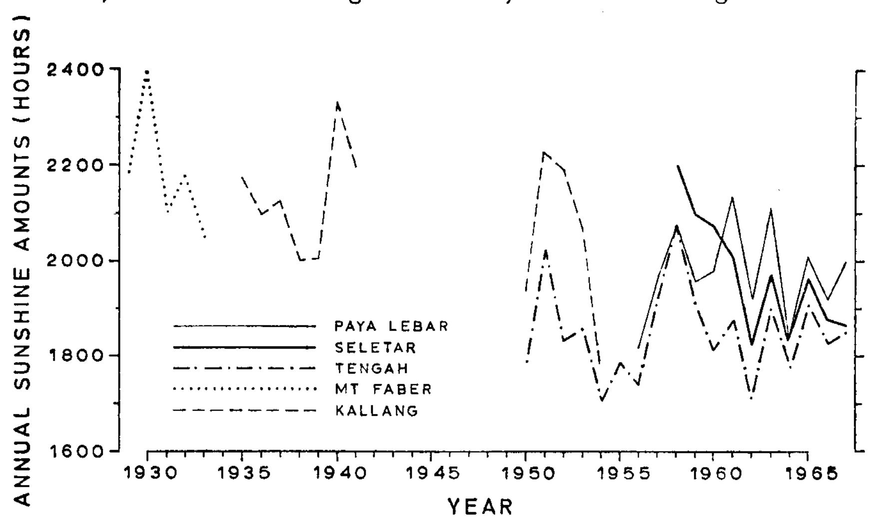

FIGURE 2—ANNUAL SUNSHINE AMOUNTS FOR FIVE STATIONS IN SINGAPORE

Seasonal variations. Variations of monthly average sunshine per day for the five stations are shown in Figure 3. The graphs for Paya Lebar, Seletar and Tengah have been drawn for the same period, 1958–67, to allow for direct comparisons. These three stations show very similar patterns of seasonal variations with two peaks in April/May and July and a low minimum in December. Generally, sunshine amounts are higher from February to September and lower for the rest of the year. The amounts of sunshine received at Tengah are consistently lower than those of Paya Lebar and Seletar throughout the year. Kallang exhibits generally higher amounts of sunshine received than Payar Lebar, Seletar and Tengah although the variations seasonally are similar. Mount Faber is anomalous in that there are three peaks of sunshine occurring in February, March and August, the August peak being the highest; sunshine during the rest of the year is much

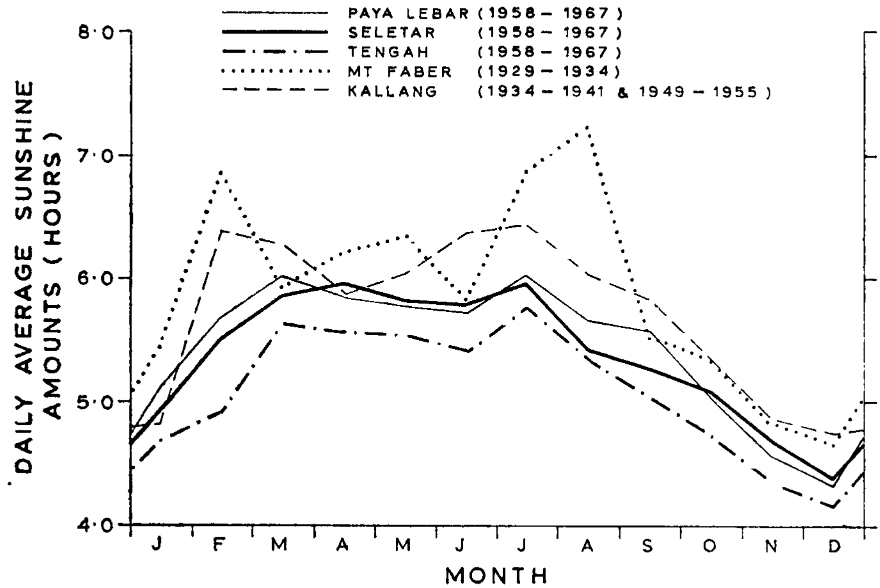

FIGURE 3—SEASONAL VARIATIONS OF SUNSHINE FOR FIVE STATIONS IN SINGAPORE

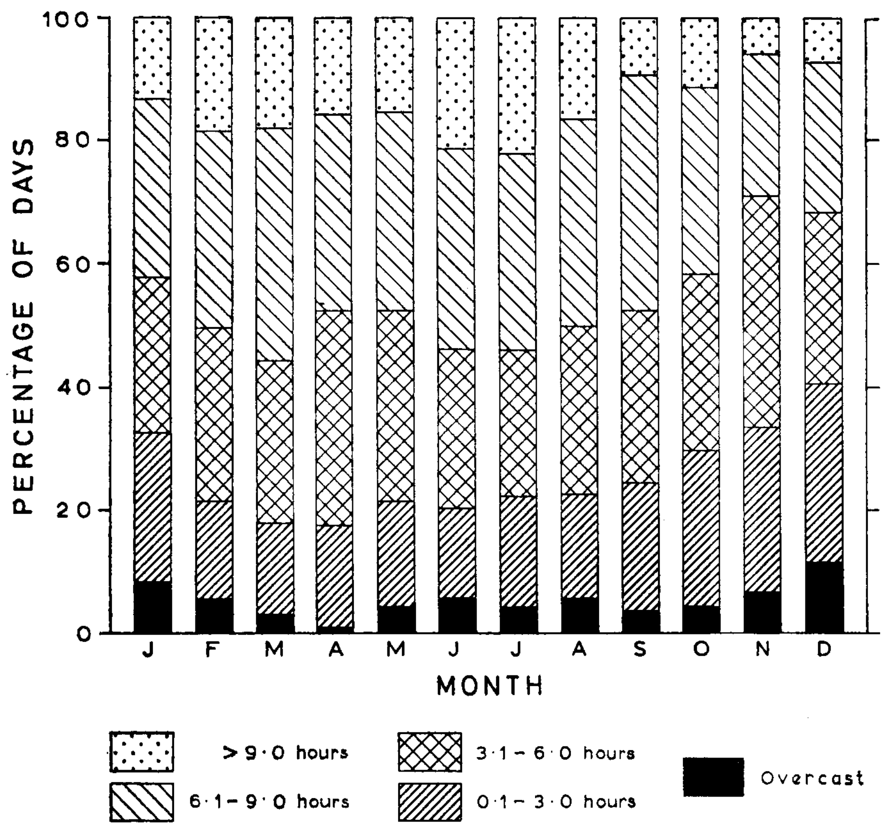

FIGURE 4—SEASONAL VARIATIONS OF THE PERCENTAGES OF DAYS WITH VARIOUS AMOUNTS OF SUNSHINE FOR PAYA LEBAR, 1956–67

the same as that of Kallang. It must be remembered that Kallang and Mount Faber cannot be compared with one another or with the other three stations directly owing to the difference in the period of observations.

Seasonal variations in the percentage of days with various amounts of sunshine are shown in Figure 4. June and July have relatively higher percentages of sunny days while the period September to December has smaller percentages of days with high sunshine hours. Overcast days without sunshine are most frequently experienced in December with January a close second, and their incidence decreases to a minimum in April. July and August have relatively larger percentages of days without sunshine. It is to be noted that February, June, July and August, which have high percentages of days with more than 9·0 hours of sunshine, also have significant percentages of overcast days.

Diurnal variation. Diagrams showing the diurnal variation of sunshine for all five stations have been constructed. However, only that for Paya Lebar is presented here (Figure 5) as most of the features showing differences among the five stations can be inferred from discussions in the previous sections. The seasonal variation of sunshine amounts for Paya Lebar is clearly

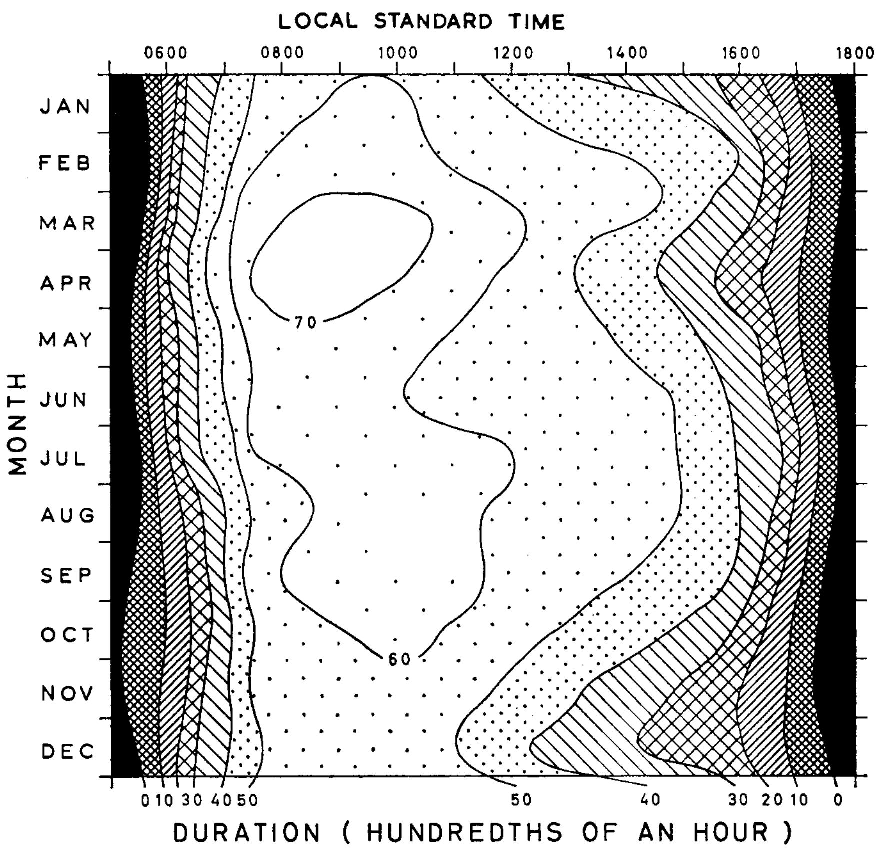

FIGURE 5—DIURNAL VARIATIONS OF SUNSHINE FOR PAYA LEBAR, 1958–67

seen from the diagram. The zero isopleth has been constructed from the times of sunrise and sunset. The rapid increase in amounts of sunshine from the time of sunrise to the period of maximum sunshine applies throughout the year. Thereafter average sunshine amounts decrease unevenly during the year.

Figure 6 shows the variation of the time of maximum duration of sunshine for the five stations in Singapore. In general, maximum sunshine is received between 0900 and 1000 local standard time. This variation may be compared to that of the University of Malaya, Kuala Lumpur (Chia[3]), where the time of maximum duration of sunshine occurs at least an hour later than in Singapore. Still further inland, Dale,[2] shows that the maximum duration of sunshine occurs around the noon period in Temerloh, Pahang, in the Malayan Peninsula. Examination of Figure 6 indicates that Kallang and Mount Faber, the two stations near the south coast, have a slightly different régime from the other more inland stations. The time of maximum duration of sunshine is later for these two stations from about April to June than for the other three stations. During the rest of the year, however, the times are much the same. Other peculiarities are that Seletar, in December and January, experiences maximum sunshine one to one-and-a-half hours later than the other stations. Tengah, on the other hand, experiences its time of maximum sunshine during July and August with about the same time lag relative to the other stations. Variations of this nature are related to the seasonal disposition of cloudiness over the island.

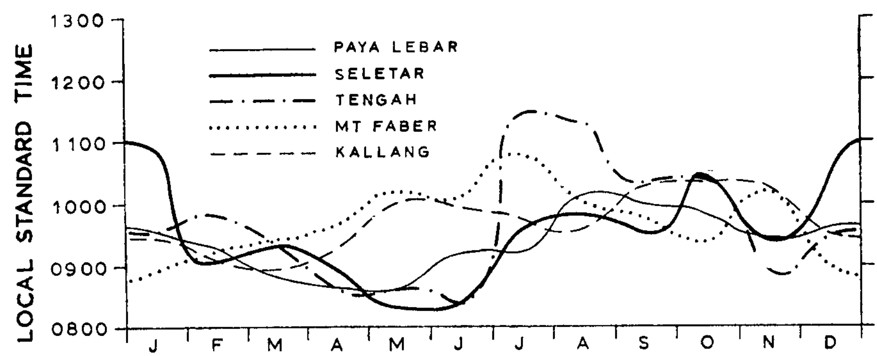

FIGURE 6—SEASONAL VARIATIONS OF THE TIME OF MAXIMUM SUNSHINE FOR FIVE STATIONS IN SINGAPORE

Solar radiation. Observations of total solar radiation incident on a horizontal surface as measured by the Casella bimetallic actinograph are available from January 1961. In 1965 a new actinograph was acquired and simultaneous measurements of incoming solar radiation revealed large discrepancies between the two sets of data. The first actinograph was sent to the manufacturer for recalibration and was subsequently reinstalled. The second actinograph has since been stored and taken out every six months for comparative readings. The procedure adopted by the Singapore Meteorological Service for correcting the records made prior to the purchase of the second actinograph is as follows. Records for days under clear-sky conditions for the first actinograph were selected from the period of comparative readings. The charts for the same days or one day on either side from the previous years were taken out. Envelopes were drawn on the charts to represent the traces for clear-sky conditions and the areas were planimetered. From the results a single factor for each year was chosen and applied to the daily readings.

The mean annual total incoming radiation at Paya Lebar is 147 750 cal/cm^2. The highest was in 1965 with 157 183 cal/cm^2 and the lowest in 1962 with 141 980 cal/cm^2 (see Table II). The values obtained by Webb[1] for the University of Singapore for the period June 1952 to March 1954, included in Table II, are generally much lower. The total for 1953, 112 474 cal/cm^2, is 24·5 per cent less than the mean annual total for Paya Lebar. However, values obtained by Tan Beng Cheok[4] also for the University of Singapore for the period March to August 1962 compare well with those of Paya Lebar. Both Webb and Tan used Kipp solarimeters for their observations although the latter had the advantage of using a more sensitive solarimeter as standard.

The seasonal variations of incoming solar radiation show a maximum in March and a secondary maximum in September, and a minimum in December and a secondary minimum in July. The seasonal pattern follows the changes in the solar radiation receipts over Singapore assuming a completely transparent atmosphere. The low amounts of solar radiation received in November and December are due to greater cloudiness during the period.

Diurnal variation of solar radiation receipts over Paya Lebar is shown in Table III. Solar radiation increases generally rapidly in the morning after sunrise under the clearer morning skies and declines more gradually during the afternoon. Maximum solar radiation receipts are experienced between 1100 and 1200 local standard time in most months except for May and July which show maximum receipts between 1200 and 1300. Thus maximum radiation occurs some two to three hours after the time of maximum duration of sunshine. This is to be expected as the intensity of solar radiation increases to a maximum at noon assuming complete transparency of the atmosphere. Thus, in spite of increasing cloudiness after about 1000 the actual intensity of solar radiation received continues to increase until the noon period.

Relation between solar radiation and duration of sunshine. The relationship between solar radiation and duration of bright sunshine at Paya Lebar was obtained using the formula :

$$Q/Q_A = a + bn/N$$

where Q and Q_A are the observed incoming solar radiation and the incoming solar radiation incident upon a horizontal surface, respectively, assuming a completely transparent atmosphere; n and N are the actual and maximum possible hours of sunshine, respectively; and a and b are constants. Daily values of Q_A were obtained by interpolation of the values given in the Smithsonian Meteorological Tables (List[5]) using 2·00 cal/cm^2 min as the solar constant.

TABLE II—INCOMING SOLAR RADIATION AT THE UNIVERSITY OF SINGAPORE* AND PAYA LEBAR†

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
						cal/cm²							
University of Singapore													
1952						340·0	245·2	280·3	384·2	397·8	303·4	341·2	—
1953	317·9	327·3	327·3	321·3	263·8	316·2	273·7	317·0	300·1	304·1	294·0	337·1	112 474
1954	310·1	389·3	367·7										—
1962			389	402	406	354	364	352					—
Paya Lebar													
1961	409·6	443·3	456·5	408·1	395·4	400·6	420·5	430·2	443·3	395·8	379·6	335·3	149 507
1962	319·9	448·2	388·5	408·1	419·0	374·8	378·7	367·2	416·1	409·1	379·5	365·3	141 980
1963	364·2	397·0	492·5	521·6	421·7	392·1	427·6	411·0	390·5	369·8	376·5	309·7	148 228
1964	427·7	382·2	436·8	397·7	400·0	407·8	341·6	462·7	381·4	379·6	379·2	311·1	143 609
1965	466·7	472·8	468·6	448·5	394·1	415·8	448·2	439·5	443·6	394·2	416·1	363·5	157 183
1966	396·4	475·7	436·6	435·0	413·4	420·2	405·0	396·6	446·2	407·5	351·7	336·0	149 447
1967	355·5	400·2	494·3	392·0	384·0	386·6	369·3	411·5	416·7	401·6	340·7	332·7	144 295
Mean	391·4	431·3	453·4	430·1	403·9	399·7	398·7	417·0	419·7	393·9	374·8	336·2	147 750

* Values for the University of Singapore taken from Webb[1] (1962 from Tan[5])

† Corrected values used for the period Jan. 1961 to Mar. 1965

1 cal/cm² = 4·19 × 10⁴ joules/m²

TABLE III—MEAN HOURLY VALUES OF INCOMING SOLAR RADIATION AT PAYA LEBAR, APRIL 1965 TO MARCH 1968

Month	06–07	07–08	08–09	09–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20
							Local time cal/cm²							
Jan.	2·4	14·6	29·3	41·6	50·3	55·3	50·8	47·2	37·8	29·1	17·8	6·7	0·2	0·0
Feb.	2·2	16·2	32·8	46·3	59·1	65·3	58·9	59·1	47·0	35·5	22·4	9·2	0·3	0·0
Mar.	3·3	18·8	35·6	48·5	58·5	61·8	59·4	57·0	45·5	33·7	20·6	7·5	0·3	0·1
Apr.	5·5	22·2	37·6	48·3	55·3	59·2	56·9	48·5	37·1	28·5	16·8	6·4	0·1	0·0
May	5·4	19·3	34·2	44·2	48·2	52·9	55·2	49·2	39·2	28·4	16·1	4·8	0·2	0·0
June	5·0	18·5	33·1	43·4	50·8	54·9	52·2	49·7	44·1	31·3	18·7	6·1	0·0	0·0
July	4·1	18·4	32·3	44·7	51·7	55·5	55·6	48·6	39·1	31·9	19·6	6·9	0·1	0·0
Aug.	3·8	17·4	31·3	42·9	52·7	56·5	56·2	49·7	43·8	34·2	20·2	11·1	2·3	0·0
Sept.	5·5	20·5	35·3	48·5	57·6	61·0	57·2	52·2	42·7	31·5	18·1	5·5	1·7	0·0
Oct.	7·2	22·8	35·6	47·6	57·3	58·6	52·1	44·9	33·8	24·6	13·0	3·4	0·1	0·0
Nov.	7·6	22·1	35·3	44·7	50·3	53·2	50·1	41·2	30·7	20·7	10·9	2·8	0·0	0·0
Dec.	4·1	15·3	28·2	39·6	47·3	49·4	45·3	39·0	33·0	24·0	13·7	4·0	0·1	0·0
Mean	4·7	18·8	33·4	45·0	53·3	54·8	54·2	48·9	39·5	29·5	17·3	6·2	0·5	0·0

1 cal/cm² = 4·19 × 10⁴ joules/m²

Table IV presents for each year from 1961–67 values of the constants *a* and *b* in the above formula using the method of least squares, and the values of $a + 0{\cdot}45b$. Corrected values for the period January 1961 to March 1965 were used when the older actinograph was in operation prior to the purchase of the second actinograph. Except for 1967, the value of $a + 0{\cdot}45b$ increases slightly. There is a similar increase in the values of *a* and $a + b$, though not as clearly seen. These imply that there is a small systematic error in the radiation measurements which the correction factor has failed to eliminate.

TABLE IV—VALUES OF COEFFICENTS *a* AND *b* AND $a + 0{\cdot}45b$ FOR VARIOUS PERIODS FOR PAYA LEBAR

Period	*a*	*b*	$a+0{\cdot}45b$	Remarks
1961	0·245	0·460	0·452	
1962	0·234	0·493	0·456	
1963	0·235	0·474	0·448	Corrected values
1964	0·245	0·494	0·467	
1965	0·266	0·485	0·484	
1965 (Apr.–Dec. only)	0·260	0·485	0·478	
1966	0·274	0·471	0·486	Uncorrected values
1967	0·238	0·467	0·459	
1961–64	0·240	0·478	0·455	Corrected values
1965–67	0·260	0·472	0·472	Uncorrected values

Monthly regression coefficients were obtained and the results are presented in Table V. Values of *a* vary from 0·231 in April to 0·284 in August, while values of *b* range from 0·411 in August to 0·506 in April. There is generally an inverse relationship between *a* and *b*. There does not appear to be any consistent trend in the values of either of the constants over the year.

TABLE V—MONTHLY VALUES OF COEFFICIENTS *a* AND *b* FOR PAYA LEBAR, 1961–67

Month	*a*	*b*	Month	*a*	*b*
Jan.	0·245	0·497	July	0·259	0·451
Feb.	0·266	0·473	Aug.	0·284	0·411
Mar.	0·280	0·440	Sept.	0·252	0·459
Apr.	0·231	0·506	Oct.	0·241	0·468
May	0·250	0·464	Nov.	0·256	0·437
June	0·259	0·456	Dec.	0·236	0·486

Values of coefficients of the regression formula of stations near the equator obtained by various workers are presented in Table VI. Values obtained here are close to those obtained by Tan[4] for the University of Singapore. However, Tan's coefficients were obtained from a period of five months' observations, although the correlation coefficient found was 0·91. The values for Kabete, Kenya and those of Trinidad are also similar except that the value of *b* for Kabete is much higher than that of Paya Lebar. The high value of *b* for Kabete may be expected as the station is some 6000 ft above MSL.

TABLE VI—VALUES OF COEFFICIENTS FOR STATIONS NEAR THE EQUATOR

Station	Latitude	*a*	*b*	Authority
University of Singapore	01°19′N	0·23	0·46	Tan[4]
Trinidad, West Indies	11°N	0·27	0·49	Smith[7]
Kabete, Kenya	01°16′S	0·26	0·57	Glover and McCulloch[8]
15 stations in Kenya, Tanzania and Uganda	5°N – 10°S	0·23	0·53	Woodhead[9]
Djakarta, Tjibodas and Bandung	6°11′S – 6°54′S	0·29	0·29	Black *et alii*[6]

Under cloudless conditions values of Q/Q_A should be higher, and this will result in a higher value for the slope of the regression line. The values obtained by Black, Bonython and Prescott[6] for the three stations Batavia (now Djakarta), Tjibodas and Bandung are anomalous in that the value of b is only 0·29. This is much lower than those for the other stations. This could only occur if there is a high percentage of days with thin high clouds which will still allow the sunshine recorder to burn a trace on the card although the amount of solar radiation at the surface is reduced. There is, however, no reason to believe that such a condition exists over Indonesia. The results must therefore be viewed with suspicion.

Conclusion. Variations of climatic elements with distance from the coast and over islands in the tropics have been noted elsewhere. In Singapore, variations in time and space of wind, cloudiness, temperature and sunshine are commonly observed. The paper illustrates the rapid transition of the amounts of sunshine and solar radiation with distance from the open sea surface.

Acknowledgements. The author wishes to express his thanks to the staff of the Singapore Meteorological Service for their willing assistance, to the British Meteorological Office for making available the necessary data, and to Mr K. Rajendram for his critical comments.

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SOME RELATIONSHIPS BETWEEN THE 100-MILLIBAR CHART AND SURFACE WEATHER

By N. E. DAVIS

Summary. Ridges at 100 mb are highly persistent and slow moving. Each ridge at 100 mb may be associated with a succession of surface highs, most of which are found on the eastern side of the 100-mb ridge.

The rainfall pattern at the surface is such that a deficiency of rain occurs under the eastern side of a 100-mb ridge and an excess of rain under the eastern side of a 100-mb trough.

As the 100-mb pattern is persistent and slow moving, it can on many occasions be forecast for a long time ahead and hence it is possible to make a general forecast of the precipitation distribution and of anticyclonic areas at the surface.

Introduction. In a previous paper[1] the author showed that north and north-west winds at 100 mb were associated with dry weather at London/

Heathrow Airport. An earlier paper[2] showed the possibility that stratospheric flow had some effect on the subsequent surface developments. Labitske[3] pointed out that sudden warmings in the stratosphere in winter were generally followed by a blocking in the troposphere. Boville,[4] Charney and Drazin,[5] Sun Chu Ching and others[6] have made mathematical calculations of the interactions between stratosphere and troposphere. The present paper attempts a statistical investigation of the relationship between the stratosphere and the surface, in particular the relationships between ridges at 100 mb and highs at the surface and between the ridge–trough pattern at 100 mb and rainfall.

In addition the persistence of ridges at 100 mb over the America-to-Europe area is examined and the speed of movement of such ridges compared with the speed of movement of surface features. Ridges at 100 mb are highly persistent. Their average life is some 14 days and their mean speed is only 4 knots from west to east. Surface highs move with a mean speed of about 15 knots and the mean west-to-east component of their motion is about 8 knots, i.e. about twice the speed of the ridge at 100 mb. Surface highs have a mean persistence of about four to five days, i.e. about one-third of the persistence of the upper ridge so that each ridge at 100 mb is associated with a succession of surface highs. The speed of the surface high is greatest in the upper south-westerlies on the western side of the 100-mb ridge and least within 10 degrees of longitude east of the axis of the upper ridge.

As the majority of surface highs are to be found on the eastern side of the 100-mb ridge, a further examination of the rainfall pattern in relation to the positions of the 100-mb ridges and troughs was made and this showed a highly significant connection.

These relationships would suggest that the 100-mb chart could be used as an aid in extended forecasting, and a possible line of attack is appended.

Speed of movement of ridges at 100 mb. The 100-mb charts for 0000 GMT for each day of the period January to December 1962 were examined for ridges between 50°N and 55°N and the longitude positions of the ridges at latitude 52°30′N were listed. All ridges between about 50°E and 130°W, i.e. over Europe, the Atlantic and North America, were included. There were normally two or three ridges in this half of the northern hemisphere.

Table I gives the frequency of the distances moved by the ridges in 24 hours, expressed in terms of the number of degrees of longitude in latitude 52°30′N.

TABLE I—NUMBER OF RIDGES AT 100 mb IN VARIOUS RANGES OF 24-HOUR MOVEMENT IN LATITUDE 52°30′N IN 1962

	24-hour movement								
	Degrees westward			Stationary	Degrees eastward				
	>10°	6–10°	1–5°		1–5°	6–10°	11–15°	16–20°	>20°
No. of ridges	23	67	164	88	215	166	55	27	18
Percentage of total	3	8	20	11	26	20	7	3	2

The mean speed of the 823 ridges was 2·6 degrees of longitude from west to east in 24 hours which equals 4 kt (in latitudes 50°N–55°N). The mean speed irrespective of direction was about 6 degrees in 24 hours, 57 per cent moving 5 degrees or less in 24 hours (8 kt or less) and 85 per cent 10 degrees or less (16 kt or less).

Persistence of ridges at 100 mb. The charts were further examined and the number of days each ridge persisted was determined. Table II gives the number of ridges which persisted for certain specified numbers of days (grouped in 5-day classes).

TABLE II—NUMBER OF RIDGES AT 100 mb PERSISTING IN 1962 FOR VARIOUS PERIODS GROUPED IN 5-DAY CLASSES

Number of days	1–5	6–10	11–15	16–20	21–25	26–30	>30
Number of ridges	12	14	17	5	6	3	5
Percentage of total	19	23	27	8	10	5	8

The average number of days the 62 ridges persisted at 100 mb in 1962 was between 13 and 14, i.e. the total number of ridge days (823) divided by the number of ridges grouped as persisting (62).

The general history of a particular ridge is progression for a day or two after formation, then a longer period in which the ridge progresses slowly or remains oscillating slightly about a fixed longitude, followed by a final period of more rapid progression for a day or two as it collapses.

The large amount of westward motion (retrogression) — more than 30 per cent — in Table I, is due to ridges tending to oscillate about a fixed position rather than to some third of the ridges having a long period of retrogression whilst the other two-thirds move eastward. About 19 situations were noted in which retrogression continued for more than 48 hours. These examples involve about 80 of the 823 ridges in Table I (equivalent to a frequency of about 10 per cent of the total) and as there were 254 westward-moving ridges in Table I it can be deduced that only one-third of these retrogressed for more than 48 hours.

As the mean speed is 2·6 degrees of longitude to the east in 24 hours, ridges on the average will move some 35 to 40 degrees of longitude eastward in their life span of 14 days. Indeed, as a closer consideration of the percentage frequencies in Table I shows, for 12 per cent of the time the ridge moves east at a speed greater than 10 degrees of longitude per day (and this relatively fast speed occurs generally at the beginning and end of the life of a ridge), for 20 per cent of the time it moves east at 6 to 10 degrees per day, and for the remainder of the time the ridge is stationary or oscillating slightly at a relatively slow speed; so that on average a ridge will move east about 15 degrees on the first day, another 10 degrees in the next day and a half, remain more or less stationary for the next nine days and finally move away eastward with increasing speed in the final two and a half days.

In short, ridges at 100 mb are stationary or oscillating slightly for more than half their life.

Distribution of surface highs relative to 100-mb ridges and speed of movement of surface highs. Surface charts for the period January to December 1962 were examined and the positions of all surface highs between 50°E and 50°W and north of 40°N at 0000 GMT were determined and compared with the longitudinal position of the nearest ridge at 100 mb (in the same latitude as the surface high). In Figure 1, if H is the position of the surface high, AA′, BB′, CC′, etc. the contour lines at 100 mb, and EFG the axis of the ridge where E, F, and G are the most northerly points of the

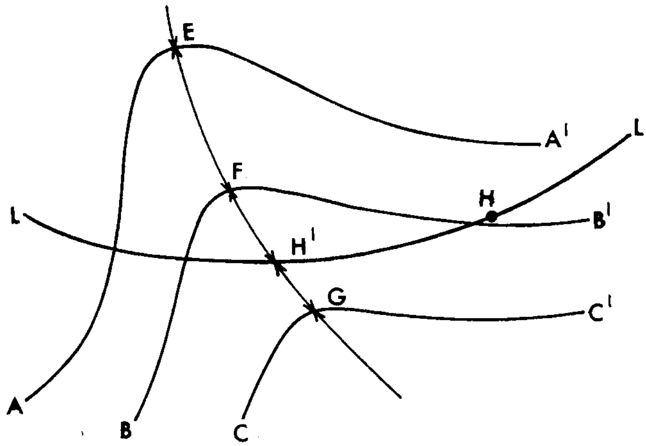

FIGURE 1—DISTANCE OF SURFACE HIGH (H) FROM RIDGE (EFG) AT 100 mb

contours AA′, BB′ and CC′, then the distance of the surface high from the axis of the 100-mb ridge is the longitudinal distance HH′ where H′ is the point where the latitude circle LL′ through H cuts EFG.

As this note is concerned with the moving highs of temperate latitudes (especially those between 50°N and 55°N), it was considered that the semi-permanent high of subtropical latitudes (the Azores–Bermuda high) should be excluded. Furthermore as there are only three upper air stations in the Atlantic south of 40°N (Bermuda, ocean weather station 'E' and Lajes in the Azores), it was frequently difficult to fix the position of the ridge at 100 mb south of 40°N. (Even so, the centre of the subtropical high was nearly always associated with winds from the north-west quarter at 100 mb.)

Only surface highs north of 40°N were therefore considered in compiling Tables III, IV and V.

Table III gives the number and percentage frequency of the surface highs at various longitudinal distances from the axis of the ridge at 100 mb (in the same latitude as the surface high).

TABLE III—FREQUENCY OF SURFACE HIGHS NORTH OF 40°N IN 1962 GROUPED ACCORDING TO DISTANCE FROM THE AXIS OF THE 100-mb RIDGE IN THE SAME LATITUDE

	Degrees west of 100-mb ridge		Coincident with axis	Degrees east of 100-mb ridge		
	> 10°	1–10°		1–10°	11–20°	> 20°
Number of surface highs	22	31	19	161	94	69
Percentage frequency	5	8	5	40	24	18

Table IV gives the frequency of the distance moved by the surface highs (in degrees of longitude) in 24 hours irrespective of amount of latitudinal change.

The mean speed of the 408 surface highs is 5·2 degrees of longitude from west to east in 24 hours which equals 8 kt in latitude 50°N–55°N.

TABLE IV—NUMBER OF SURFACE HIGHS NORTH OF 40°N IN VARIOUS RANGES OF 24-HOUR MOVEMENT IN 1962

	24-hour movement								
	Degrees westward			Stationary	Degrees eastward				
	>10°	6–10°	1–5°		1–5°	6–10°	11–15°	16–20°	>20°
Number of surface highs	9	18	54	20	111	90	62	29	15
Percentage frequency	2	4	14	5	27	22	15	7	4

Persistence of surface highs. Table V gives the number of surface highs which persisted north of 40°N for a certain specified number of days (grouped in 5-day classes).

TABLE V—NUMBER OF SURFACE HIGHS NORTH OF 40°N PERSISTING IN 1962 FOR VARIOUS PERIODS GROUPED IN 5-DAY CLASSES

Number of days	1–5	6–10	>10
Number of surface highs	84	19	9
Percentage frequency	75	17	8

The average number of days surface highs persisted in 1962 was about four.

In compiling Tables III, IV and V only surface highs north of 40°N were considered. These tables are to be taken as applying to moving highs of temperate latitudes and not to the semi-permanent subtropical high. This is especially so in the case of Table V.

Deductions from tables.

(i) From Table II, the 100-mb ridge is highly persistent, 58 per cent lasting more than 10 days. From Table I, it is often slow moving, 57 per cent being stationary or moving 5 degrees or less in 24 hours.

(ii) From Table III, the association between the 100-mb circulation and the surface features is such that surface highs are more frequently found under the eastern side of the 100-mb ridge and seldom under the western side. The normal wavelength at 100 mb is between 70 and 180 degrees (with two to five ridges and troughs round the northern hemisphere) so that a quarter wavelength is normally between 17½ and 45 degrees. Table III shows that 64 per cent of surface highs are found under the eastern side of the 100-mb ridge and within 20 degrees of the axis of the ridge. Hence the majority of surface highs are found under the eastern (forward) side of the ridge at 100 mb.

(iii) Tables I and II are not strictly comparable with Tables IV and V as the 100-mb ridges were examined over the section 130°W to 50°E, whilst the surface highs were examined over the section 50°W to 50°E, but the mean speed of ridges over the sector 50°W to 50°E was only slightly higher than the mean speed over the whole sector 130°W to 50°E (2·9 degrees instead of 2·6 degrees in 24 hours). Hence the relative persistence and speed of surface highs and 100–mb ridges indicate that each ridge at 100 mb may be associated with several successive surface highs. Surface highs appear to form from the intensification of surface ridges under the south-westerly flow to the west of the 100-mb ridge, then move rapidly to a position just east of the 100-mb ridge axis, become slow moving and finally are absorbed by the next surface high or move away south-east with increasing speed.

Relationship between rainfall and 100-mb features. As it had already been shown by the author that north to north-west winds at 100 mb are associated with dry weather at London/Heathrow Airport and Table III shows that anticyclones are associated with the eastern (forward) side of 100-mb ridges where winds would be north-west, a more detailed examination of the relationship between rainfall and the 100-mb features was undertaken.

The position of the trough and ridge nearest to Heathrow (51° 29′N 00° 27′W) at 0000 GMT was noted and every day was classified as FT, RR, FR or RT according to Figure 2.

Suppose T_1T_1', R_1R_1', and T_2T_2' are the axes of a trough–ridge–trough system at 100 mb, cutting the latitude circle (LL′) of Heathrow at A, C and E respectively. Further, let B be the mid-point of AC and D the mid-point of CE. Then a day was classified FT (forward, i.e. east, of trough) if W (the position of Heathrow) was between A and B. A day was classified RR (rear, i.e. west, of ridge) if W was between B and C. Similarly a day was classified FR (forward, i.e. east, of ridge) if W was between C and D and it was classified RT (rear, i.e. west, of trough) if W was between D and E.

The rainfall was that measured at Heathrow between 0600 GMT on the day in question and 0600 GMT on the following day. If no rainfall or a trace was recorded the day was classified as *O*; if the rainfall was 0·1 to 0·9 mm the day was classified as *r* and if 1·0 mm or more it was classified as *R*.

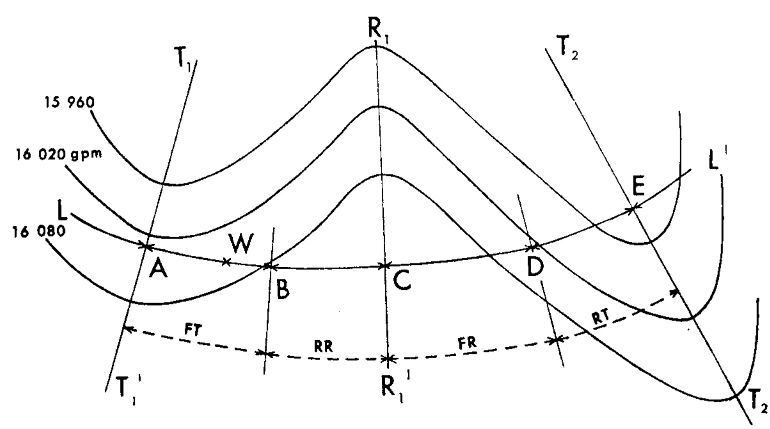

FIGURE 2—100-mb TROUGH–RIDGE–TROUGH SYSTEM AND DEFINITION OF FT, RR, FR AND RT

Tables VI, VII and VIII give the 3 × 4 contingency tables relating rainfall to 100-mb trough–ridge pattern. Table VI gives the actual values *(A)* for the year 1962. Table VII gives the expected values *(E)* with the given total number of days, FT, RR, FR and RT and the given total number of days of *O*, *r* and *R* on the basis that there was no correlation between the precipitation and the 100-mb pattern, i.e. on the basis that the 206 days with rainfall O were distributed between the classifications FT, RR, FR, RT in the proportions 69:55:122:119, which were the frequencies of occurrence of FR, etc. in 1962.

Table VIII gives the actual minus expected values $A - E$.

TABLE VI—FREQUENCY TABLE OF DAYS OF FT, RR, FR AND RT WITH DAYS OF O, r AND R (ACTUAL VALUES IN 1962)

Rainfall amount	Circulation type FT	RR	FR	RT	Total
O	24	29	85	68	206
r	14	6	23	21	64
R	31	20	14	30	95
Total	69	55	122	119	365

TABLE VII—CONTINGENCY TABLE SHOWING EXPECTED VALUES, E, DERIVED FROM THE TOTALS IN TABLE VI

Rainfall amount	Circulation type FT	RR	FR	RT	Total
O	38·94	31·04	68·86	67·16	206
r	12·10	9·64	21·39	20·87	64
R	17·96	14·32	31·75	30·97	95
Total	69	55	122	119	365

TABLE VIII—CONTINGENCY TABLE SHOWING ACTUAL VALUES, A, MINUS EXPECTED VALUES, E

Rainfall amount	Circulation type FT	RR	FR	RT
O	−14·94	−2·04	+16·14	+0·84
r	+1·90	−3·64	+1.61	+0·13
R	+13·04	+5·68	−17·75	−0·97

The value of $\chi^2 = \Sigma(A-E)^2/E$ is 33·12 which with 6 degrees of freedom is very highly significant (the 0·1 per cent level is 22·46). There is thus a very distinct relationship between precipitation and trough–ridge pattern at 100 mb. Table VIII shows this is mainly due to the fact that there is an excess of occasions of moderate to heavy rain associated with the forward trough position and a deficiency of occasions of no rain, and the reverse in the case of the forward ridge position.

Table IX gives the total of the 24-hour rainfall amounts at Heathrow for the year 1962 for each type of trough–ridge position preceding the 24-hour period in the manner described.

TABLE IX—RAINFALL TOTALS AT HEATHROW OVER THE 24-HOUR PERIOD FOLLOWING VARIOUS 100-mb CIRCULATION TYPES IN 1962 COMPARED WITH FREQUENCY OF TYPES

	Circulation type FT	RR	FR	RT	Year	
Rainfall (mm)	238·4	106·1	47·2	135·0	516·7	(86% of long-term average)
Percentage of 1962 rainfall	45	20	9	26		
Frequency of type (days)	69	55	122	119	365	
Percentage of year	19	15	33	33		
Mean fall per day (mm)	3·46	1·93	0·39	1·13	1·44	

Table IX shows that FT occurs for only 19 per cent of the year but accounts for 45 per cent of the total rainfall, while FR occurs for 33 per cent of the year but accounts for only 9 per cent of the total rainfall. Also the mean fall per day in 1962 to the east of a 100-mb trough was nearly nine times the mean fall to the east of a 100-mb ridge.

As Heathrow is in one of the drier parts of the U.K. an examination was made of the rainfall data for Eskdalemuir (55° 19′N 03° 12′W, elevation 749 ft) where the mean annual rainfall is 1581 mm, two and a half times that at Heathrow. A similar classification was adopted and the value of χ^2 was 27·92 (very highly significant — the 0·1 per cent level is 22·46 as before). The largest contribution to this value comes from a deficiency of occasions of no rain in FT conditions and an excess of occasions of no rain in FR conditions.

Rainfall, at least over the U.K., is highly correlated with the position of the troughs and ridges at 100 mb. Dry days are a feature of the weather under the forward (eastern) side of a ridge at 100 mb whilst wet weather is generally under the forward (eastern) side of a trough at 100 mb.

Use in extended forecasting. As ridges at 100 mb are very persistent and slow moving, it is frequently possible to forecast their position for a long time ahead. If the U.K. lies under the forward side (FR) (see Figure 2) of the upper ridge, the weather will generally be anticyclonic with below normal precipitation; but if the U.K. lies under the forward side (FT) of the upper trough, weather will generally be wet and unsettled. In winter, anticyclonic weather generally implies below normal temperatures, and unsettled weather implies above normal temperatures. In summer, the opposite occurs; anticyclonic weather implies above normal temperatures and unsettled weather below normal temperatures. As long as the position of the troughs and ridges at 100 mb can be forecast with any confidence so can a general statement be made about the expected surface weather.

The pattern at 100 mb can be used as a guide and aid in constructing extended prebaratics. If there is no ridge at 100 mb over the forecast area and no ridge is expected to move in, any surface highs which would appear to be moving into the forecast area are likely to weaken and collapse. On the other hand, if there is a stationary ridge at 100 mb over the forecast area, a surface anticyclone would be expected to persist on the forward side of such a ridge or a second anticyclone would be expected to develop and move north-east to a position on the forward side of the 100-mb ridge absorbing the previous high.

Examples of 100-mb charts and corresponding surface charts. Figures 3–7 show the 100-mb contour charts for 0000 GMT for 27 and 28 February 1961 and 1, 2 and 5 March 1961.

Figure 3 shows a ridge at 100 mb developing east of Newfoundland. It would be expected to move east fairly quickly at first as it intensified (following the normal development) and then to become slow moving (or to oscillate). Figures 4 and 5 show its steady motion across the Atlantic. As it intensifies over the U.K. it flattens and destroys the previous ridge that has been lying across western Europe. Figure 6 shows the ridge slowing up as it crosses the U.K. and Figure 7 shows the position three days later on 5 March with the ridge oscillating over the U.K.

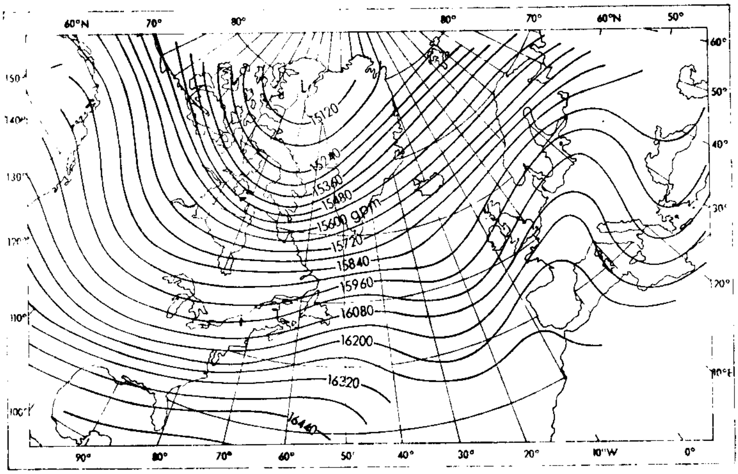

FIGURE 3—100-mb CONTOUR CHART, 0000 GMT, 27 FEBRUARY 1961

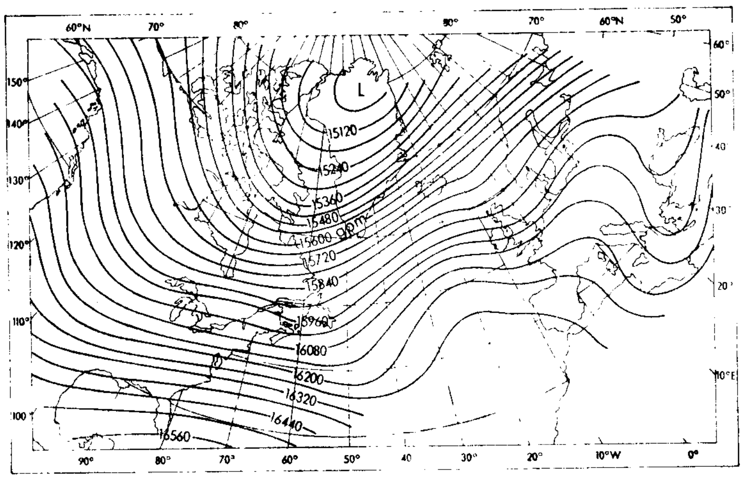

FIGURE 4—100-mb CONTOUR CHART, 0000 GMT, 28 FEBRUARY 1961

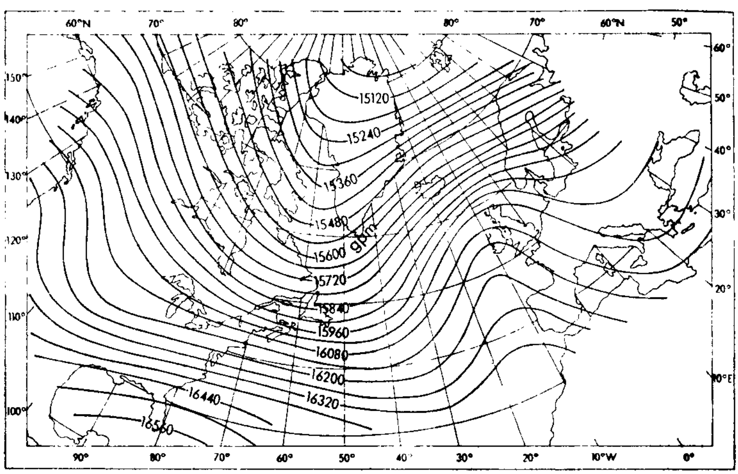

FIGURE 5—100-mb CONTOUR CHART, 0000 GMT, 1 MARCH 1961

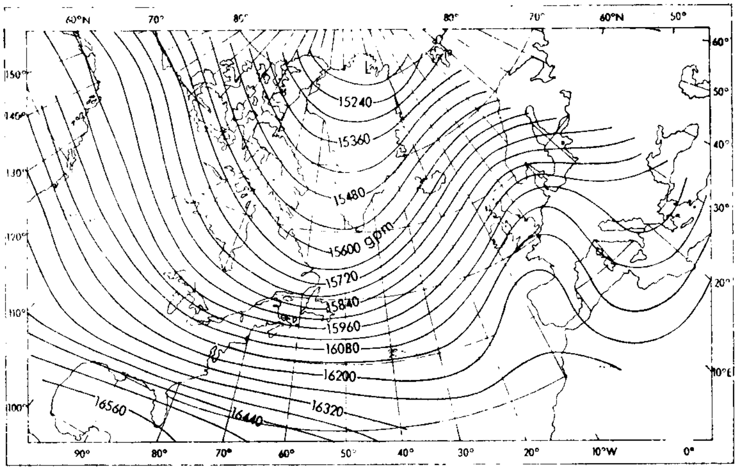

FIGURE 6—100-mb CONTOUR CHART, 0000 GMT, 2 MARCH 1961

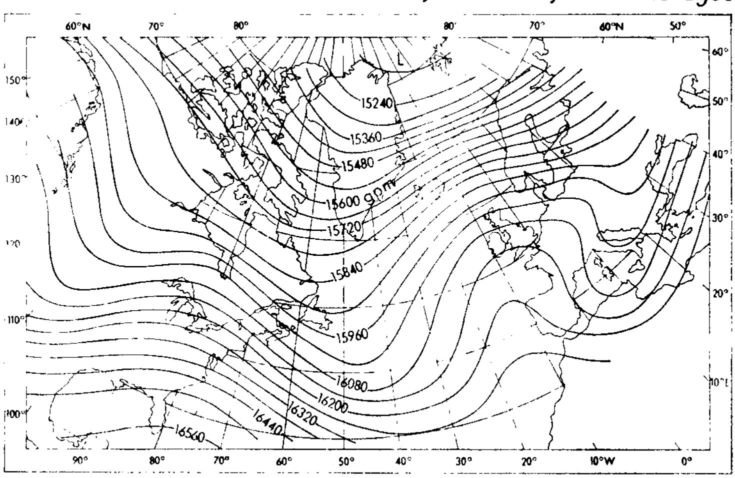

FIGURE 7—100-mb CONTOUR CHART, 0000 GMT, 5 MARCH 1961

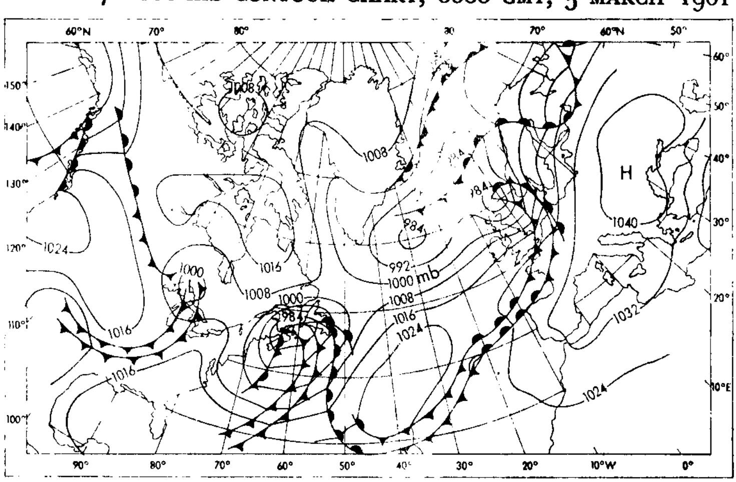

FIGURE 8—SURFACE CHART, 0000 GMT, 27 FEBRUARY 1961

Figure 8 shows the surface chart for 0000 GMT on 27 February 1961. Comparing this with Figure 3, the three major surface highs, viz. those north of the Black Sea, in mid-Atlantic and over the Pacific coast of the U.S.A., are centred just forward of a ridge at 100 mb. A fourth high over the north Hudson Bay region is centred a long way from any ridge. It disappears in 24 hours.

The anticyclone north of the Black Sea has been drifting southwards and intensifying slightly (central surface pressure rising from 1044 to 1047 mb over the previous 30 hours).

Figures 9 and 10 show the surface charts for 0000 GMT on 28 February and 1 March 1961. As the upper ridge which was over western Europe on the 27th is destroyed by the upper ridge advancing into the U.K., so the associated surface anticyclone collapses with the surface pressure north of the Black

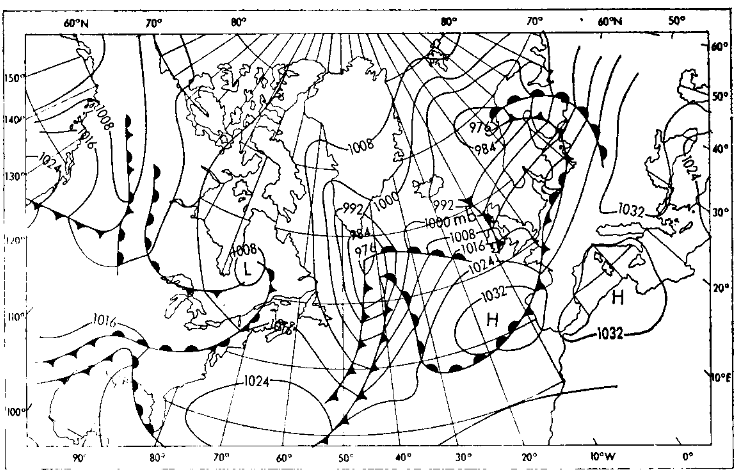

FIGURE 9—SURFACE CHART, 0000 GMT, 28 FEBRUARY 1961

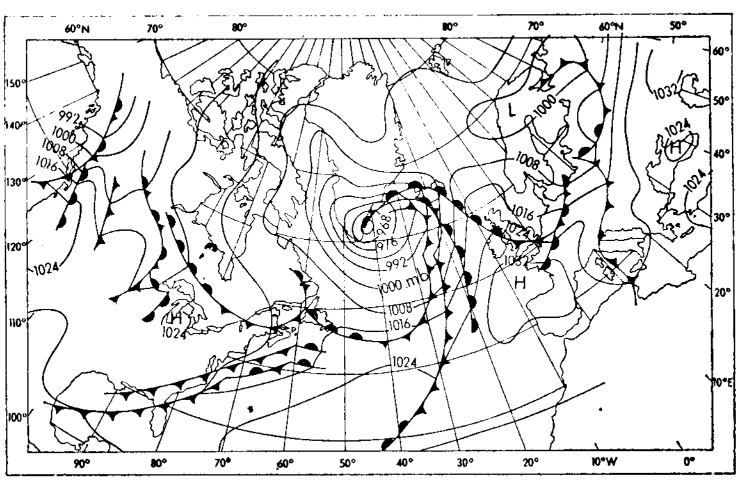

FIGURE 10—SURFACE CHART, 0000 GMT, 1 MARCH 1961

Sea falling by more than 20 mb. Furthermore, as the upper ridge advances into the U.K., the surface high in mid-Atlantic accompanies it into the Bay of Biscay and a large rise of surface pressure takes place over the U.K. amounting to more than 30 mb at 60°N 0°.

Figure 11 shows the surface chart for 0000 GMT on 2 March 1961 with the surface anticyclone slowing down over northern France. Figure 12 shows the surface chart for 0000 GMT on 5 March with a stationary high over western Europe (forward of the upper ridge over the U.K.). A long dry spell commenced on 2 March with no measurable rain at Heathrow until the 18th.

On the continent, precipitation mostly occurred ahead of the 100-mb trough which advanced from a position about 20°W on 27 February across the U.K. on the 28th and joined with the trough from the Black Sea to Cyrenaica to produce a slow-moving trough over the central Mediterranean on 2 March.

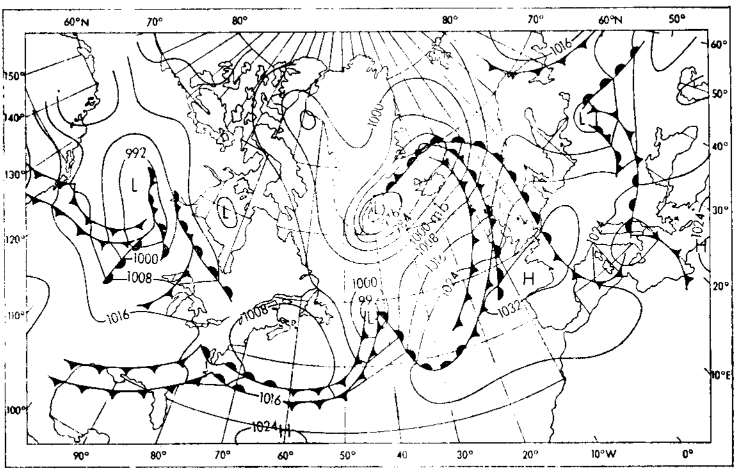

FIGURE 11—SURFACE CHART, 0000 GMT, 2 MARCH 1961

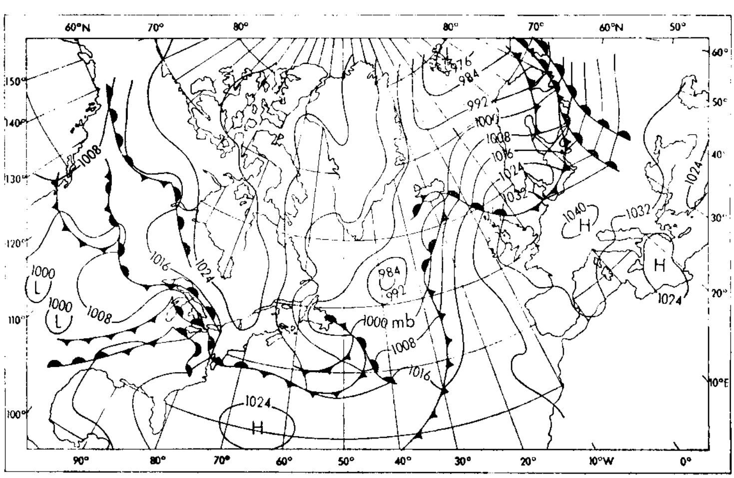

FIGURE 12—SURFACE CHART, 0000 GMT, 5 MARCH 1961

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MINIMUM ROAD TEMPERATURES

By G. E. PARREY

Summary. Over a period in 1967–68 readings were taken at Watnall of a minimum thermometer whose bulb was in contact with a concrete road surface. Air minimum temperatures were also read and the individual differences between air minimum and road minimum were plotted against the date over a seven-month winter period. A smoothed curve drawn through the individual differences showed a remarkable similarity to the curve giving the number of hours each day between sunset and sunrise i.e. the differences depended largely on the length of time available for outgoing radiation. An appropriate regression equation was constructed so that forecasts of air minimum could be used as a basis for forecasting road minimum.

Attempts to correlate road minima with other variables gave no useful results but a brief account is given of the trials.

Introduction. In an attempt to produce an aid for the forecasting of minimum road temperatures and hence the likelihood or otherwise of ice formation on road surfaces, an experiment was begun at Watnall in February 1967, whereby readings were taken of a grass-minimum thermometer which had been exposed overnight on a concrete road surface. The area of road selected for the experiment had to be free of both pedestrian and vehicular traffic and the best site that could be found was approximately 80 yards from the standard thermometer screen. The road itself and the surrounding land was horizontal and almost flat. The nearest obstruction was a small petrol installation about 5 feet high and 12 feet away from the thermometer site. The thermometer was placed horizontally with the bulb in contact with the road, a piece of wire about five inches long being looped round the end opposite the bulb to prevent the instrument from rolling.

The readings cover the periods February to the end of April 1967 and October 1967 to mid-May 1968. There was a break of about 10 days at the end of October 1967 due to the breakage of the thermometer.

Results. Attempts were made to find a correlation between the minimum road temperatures and various other variables, including the grass-minimum temperature, the mean cloud amount and geostrophic wind overnight as well as the general weather conditions. A comparison was made with the one-foot earth temperatures recorded daily at Nottingham Castle, five miles from Watnall.

It soon became apparent that the one relationship which was both significant and useful as a forecasting tool was the relationship between the date and the difference: minimum screen (or 'air') temperature minus minimum road temperature, $(M_A - M_R)$. Figure 1 shows the values $M_A - M_R$ plotted against the date for the seven-month winter period October 1967 to

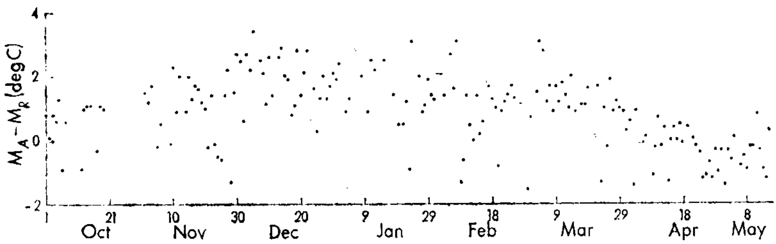

FIGURE 1—DIFFERENCE BETWEEN AIR TEMPERATURE, M_A, AND ROAD TEMPERATURE, M_R, AT WATNALL, OCTOBER 1967–MAY 1968

April 1968. To assist in drawing a smooth curve through these points, 31-day running means were calculated and plotted in Figure 2. Root-mean-square deviations of the individual daily values from the smoothed curve were calculated for each of the 10-day periods 1–10 October, 11–20 October and so on (see Table I).

TABLE I—ROOT-MEAN-SQUARE DEVIATIONS* FOR 10-DAY PERIODS 1 OCTOBER 1967–28 APRIL 1968

	October			1967 November			December	
1–10,	11–20,	21–30,	31–9,	10–19,	20–29,	30–9,	10–19,	20–29,
0·7	0·7	—	1·0	0·6	1·4	1·0	0·8	0·7 degC
	January			1968 February			March	
30–8,	9–18,	19–28,	29–7,	8–17,	18–27,	28–8,	9–18,	19–28,
0·9	1·0	1·2	0·9	1·3	0·7	1·4	0·7	1·0 degC
				April				
			29–7,	8–17,	18–28			
			0·7	0·7	0·6 degC			

* Evaluated from the smoothed curve of Figure 2.

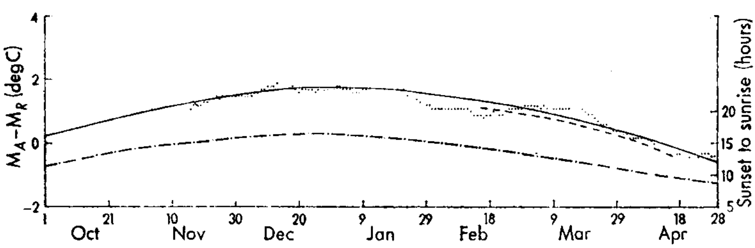

FIGURE 2—GRAPHS OF *(a)* DIFFERENCE BETWEEN AIR TEMPERATURE, M_A, AND ROAD TEMPERATURE, M_R, (31-DAY RUNNING MEANS) AND *(b)* NUMBER OF HOURS FROM SUNSET TO SUNRISE

(a) $M_A - M_R$: Plotted points are 31-day running means, Oct. 1967–April 1968
Smoothed curve for Oct. 1967–April 1968 ————
Smoothed curve for Feb. 1967–April 1967 – – – – –
(b) Number of hours from sunset to sunrise —·—·—

Although the individual differences $M_A - M_R$ for the period February to April 1967 are not shown, an additional smoothed curve, obtained by taking 31-day running means, is drawn for this period in Figure 2 and is seen to be in close aggreement with the curve for the following year. Also drawn in Figure 2 is a curve showing the number of hours, each day, between sunset and sunrise. The similarity between the two curves is remarkable.

It is interesting to note that the results obtained at Watnall are somewhat similar to those obtained in 1925 by N. K. Johnson and E. L. Davies.[1] Only monthly means are given in their paper for a plot of tarmac 15 cm deep and 1 m square, with an ordinary minimum thermometer set 1 cm below the surface. The values are given in Table II (converted to degrees Celsius for comparison) :

TABLE II—A COMPARISON OF MEAN TEMPERATURES IN AIR (SCREEN) AND IN TARMAC, FROM READINGS MADE IN 1925[1]

Month	Mean air minimum temperature	Mean tarmac minimum temperature	Difference
		degrees Celsius	
October	6·0	6·5	−0·5
November	1·2	0·0	1·2
December	—	—	—
January	1·7	1·3	0·4
February	0·8	0·3	0·5
March	−0·2	−0·2	0·0
April	1·7	2·3	−0·6

As previously mentioned, attempts to correlate the minimum road temperatures with other variables proved abortive but a brief account of these trials will be given.

Values of $M_R - M_G$ (where M_G is grass-minimum temperature) were plotted against the date. There appeared to be some relationship between the temperature difference and the date, or length of night, but in the opposite sense to that shown by $M_A - M_R$. However, the dispersion about the mean was too great for the relationship to have practical value.

It may be objected that the deviations of the individual values of $M_A - M_R$ from the mean curve are too great for practical value. Some of the occasions when departures (both positive and negative) from the curve were great were therefore examined in more detail to see if any consistent reason for the departure could be found.

TABLE III—A SELECTION OF OCCASIONS WHEN DEPARTURES FROM THE MEAN CURVE OF $M_A - M_R$ WERE LARGE

Date	Departure from curve	Mean cloud amount	Overnight weather	Mean geostrophic wind
$M_A - M_R >$ curve	*degC*	*oktas*		*knots*
13 November 1967	2·0	7	drizzle	22
5 December 1967	1·8	5	drizzle	37
14 January 1968	1·7	8	rain and drizzle	31
16 January 1968	1·7	7	rain	31
$M_A - M_R <$ curve				
15 April 1967	1·3	obscured	fog	15
6 October 1967	1·3	8	rain	25
21 November 1967	1·5	8	drizzle	8
23 November 1967	1·5	8	drizzle	9
24 November 1967	1·9	8	drizzle	6
25 November 1967	2·0	8	rain	8

On most of the occasions in Table III there were seven or eight oktas of cloud accompanied by precipitiation. There was also a predominance of strong winds when the difference $M_A - M_R$ was greater than would have been expected from the smoothed curve, but it has already been noted that there is little correlation between $M_A - M_R$ and wind speed. It was therefore decided to examine all occasions when there was (i) complete cloud cover throughout the night with some precipitation and (ii) complete cloud cover and no precipitation. Both exercises proved inconclusive because there were many occasions when one or other of the above conditions was satisfied and yet $M_A - M_R$ fell close to the curve.

To establish whether or not there is a relationship between the minimum road temperature and the one-foot earth temperature, the daily differences $M_A - M_R$ recorded at Watnall were compared with the daily differences between the air minimum and the one-foot earth temperatures recorded at Nottingham Castle over the same period. The correlation coefficient was 0·08. The daily values of one-foot earth temperature at Nottingham Castle were compared with the Watnall $M_A - M_R$ values and the correlation coefficient was found to be 0·28.

Results show that the minimum road temperature is influenced by both cloud amount and wind speed — as indeed is the minimum air temperature. The correlation coefficient between $M_A - M_R$ and mean cloud amount was 0·09. The correlation with wind speed was not calculated but a comparison of the appropriate plotted values indicated no significant relationship.

It was thought that perhaps the day temperatures (at screen level) over, say, the previous two days might have some bearing on the night-time depression of the road temperature below air temperature. The correlation coefficient in this case, however, was only −0·38.

The predominant fact remains that, for a given road, the depression of the road temperature at night below the air temperature at four feet depends largely on the length of time available for outgoing radiation; the correlation coefficient for the 300 pairs of observations was 0·59. In the Watnall experiment, negative values were obtained especially when the time between sunset and sunrise fell below about 10 hours. The relationship between $M_A - M_R$ in degrees Celsius and the time between sunset and sunrise in hours (t) is given by the regression equation :

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

This indicates that negative values of $M_A - M_R$ are to be expected when the time between sunset and sunrise falls below about 10 hours, although the scatter of the individual points about the curve is such that some of the daily values are negative at almost any time of the year.

Discussion. The night minimum temperature of a given road surface will depend upon (i) the amount of outgoing radiation, which in turn depends on the temperature of the ground surface and the length of night, (ii) the back radiation, which depends upon the water vapour content of the air, the cloud amount and thickness, (iii) any evaporation or condensation at the road surface and (iv) conduction to, or from, lower layers of the ground. Geiger[2] shows that there are further contributions due to conduction and convection from the overlying air. Knighting[3] and Lake[4] both suggest that the latter contributions can be important under certain conditions. Most successful methods of forecasting the minimum air temperature take some account, in an empirical way, of factors (ii) and (iii). By taking the date, and hence the length of night, into consideration allowance is made for (i) and to some extent (iv).

One would also expect the minimum temperatures of the roads in a particular locality. to vary with the type of material used in their construction, their colour and thickness and with the local topography.

The multiplicity of variables involved, and the difficulty in estimating them, make the direct mathematical approach to forecasting the road minimum temperatures almost insuperable. It is for this reason that the Watnall findings seem to offer a more practical, indirect approach. The air minimum temperature, given a good estimate of overnight cloud amount and geostrophic wind speed, can usually be satisfactorily forecast using one of several published methods. A single value may then be subtracted from, or added to, the forecast M_A to give a reasonable estimate of M_R according to the length of night.

One and a half winter seasons is of course too short a time in which to expect conclusive results from an experiment of this kind, but in view of the urgency and importance of the problem, this note is presented rather as an interim report than as a final solution. Readings from the original site at Watnall are continuing and it will be particularly interesting to compare these with the 'concrete minimum temperatures' which were introduced officially on 1 December 1968 using a standardized concrete slab in the screen enclosure.

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551·509·314:551·509·323

FORECASTING NIGHT MINIMUM AIR TEMPERATURE BY A REGRESSION EQUATION

By J. GORDON, J. D. PERRY and S. E. VIRGO, O.B.E.

Summary. A regression equation for forecasting night minimum air temperatures at Mildenhall was derived from data for 1967 and tested by using data for 1966 and 1968. The root-mean-square errors obtained were similar to those obtained by using McKenzie's tables or by using methods based on the cooling curves of Saunders. In practice there is little to choose between the results obtained by any of the methods based on carefully constructed tables, cooling curves or regression equations.

Craddock and Pritchard[1] developed a regression equation as a means of forecasting night minimum screen temperatures in eastern England. Based on observations from 16 stations it is appropriate to a general area rather than to a particular place. It was therefore decided to derive a regression equation for one particular place, Mildenhall, and to compare the results of forecasting night minimum air temperatures by this method with those obtained by McKenzie's method[2] based on a table also worked out specifically for Mildenhall.[3]

To accord as nearly as possible with the way in which Craddock and Prichard selected their cases it was decided that the criteria should be that the change in dew-point should be 2 degC or less at Mildenhall, that no noticeable front should have passed during the period and that nights when fog formed should be excluded. Like Craddock and Prichard the present authors chose to relate the forcast minimum temperature with the 1200 GMT temperature (T_{12}) and dew-point (D_{12}).

Two regression equations were worked out using data for 1967, one based on 50 observations and the other based on a further 46 observations, making 96 in all. There was very little difference in the root-mean-square error. There was however a difference of about 0·4 in the numerical constant as measured in degrees Celsius. This gives some indication of the number of observations needed to construct a regression equation applicable to a single station.

Craddock and Pritchard used a single regression equation for the whole year but Tinney and Menmuir,[4] in an investigation of the Saunders method of forecasting night minimum temperatures [5,6] at several stations, including Mildenhall, divided the year into two seasons: summer from April to September and winter from October to March. Two regression equations were therefore constructed, one for each season, and the forecast minima compared with those from a single equation for the whole year. Extreme values of T_{12} and D_{12} were inserted in the three equations and, as the value of T_{min} obtained from a seasonal equation did not differ by more than 0·7 degC from T_{min} obtained from the equation for the year as a whole, it was decided that a single equation would suffice.

When the regression equation for the year as a whole was finally worked out, it was found that there was no significant difference between the coefficients of T_{12} and D_{12}. In the equation the same coefficient could therefore be assigned to T_{12} and D_{12}; this was very convenient as it enabled the equation to be presented to forecasters by means of a simple table. The equation for Mildenhall is

$$T_{min}=0{\cdot}395\ (T_{12}+D_{12}) - 1{\cdot}334$$

Temperatures are in degrees Celsius. The correlation between T_{min} and ($T_{12}+D_{12}$) was 0·87 and the root-mean-square error was 2·34 degC.

Craddock and Pritchard worked out a correction table to allow for variations in mean gradient wind speed and cloud amount during the night. Although this was based on observations at 15 other stations besides Mildenhall the corrections are generally so small that the table has been accepted as applicable to Mildenhall alone without calculating afresh.

The working papers from a previous investigation,[3] including forecasts of cloud amount and wind speed, were available, so that the equation could be tested on a whole year's data from 13 January 1966 to 12 January 1967.

The following were the root-mean-square errors :

McKenzie	2·09 degC
Regression equation	2·20 degC

A subsequent test on current data for the period 16 January 1968 to 15 January 9969 gave the following root-mean-square errors :

McKenzie	2·14 degC
Regression equation	2·30 degC

Although the difference between the results by McKenzie's method and by regression equation is statistically significant at the 5 per cent level, there is little to choose between them in practice as no forecaster is interested in differences of less than 0·2 degC. Moreover the regression equation was based on 96 cases but the McKenzie table was based on 704 cases; it is therefore possible that the difference may be in some measure a reflection of the quantity of data used in obtaining the table and the equation respectively.

Gordon and Virgo[3] found a root-mean-square error of 2·16 degC for Mildenhall for the first period (13 January 1966 to 12 January 1967) by the method of Saunders. It is therefore fair to conclude that there is very little to choose between the results obtained by any of these three methods in practice, provided that sufficient trouble is taken to establish a reliable basis (in the form of a table, a regression equation or a set of cooling curves) for whichever method the forecaster intends to use.

Acknowledgement. The authors thank the forecasters at Mildenhall for carrying out the test.

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HONOURS

The following awards were announced in the Queen's Birthday Honours List 1969:

I.S.O.

Mr. J. K. Bannon, Assistant Director (Public Services) Meteorological Office.

B.E.M.

Mr W. T. Newman, the officer in charge of the HMSO unit at Bracknell.

NOTES AND NEWS

551.5:92

Retirement of Commander C. E. N. Frankcom, O.B.E.

Commander Frankcom retired from his post as Marine Superintendent of the Meteorological Office on 27 June 1969. He was appointed to this post in January 1939. During the past three decades, therefore, his career has spanned some of the most momentous years in meteorology and he has been closely associated with all major developments concerned with maritime meteorology, including the organization of observations by the voluntary observing fleet and by ocean weather ships.

Commander Frankcom was born in Wiltshire in 1903 and at the age of 15 he joined H.M.S. *Conway* for training and subsequently served an apprenticeship with the Royal Mail Lines Ltd. He obtained his Second Mate's certificate in 1924 and became an Extra Master six years later. In 1933 he transferred to the Bristol City Line and in a short while was appointed Master of the *New York City* which operated on the North Atlantic trade. From the early days of his career Commander Frankcom has also served in the Royal Naval Reserve and has gained much experience in submarines.

In 1935 Commander Frankcom was appointed a Nautical Surveyor and Examiner in the Board of Trade and held this post until January 1939 when he joined the Meteorological Office as Marine Superintendent and Editor of the *Marine Observer*. An important undertaking during his early years in the Office was the preparation of climatic atlases of the oceans, using the data assembled from ships' logs since the early 19th century. This work was interrupted, however, in November 1940 when Commander Frankcom went on active service with the Royal Navy and was appointed Commodore of coastal convoys. For these duties he was made an Officer of the Most Excellent Order of the British Empire. From 1943 onwards he was engaged in combined operations in the Mediterranean and at the end of the Second World War he left the Royal Navy and resumed his post as Marine Superintendent in the Meteorological Office.

At the end of the war there were two major tasks in marine meteorology — the reorganization of the voluntary observing fleet and the establishment of the North Atlantic Ocean Station System. Commander Frankcom played a leading part in all this work and from 1946 until 1956 he was President of the World Meteorological Organization (WMO) Commission for Maritime Meteorology. From 1954 until his retirement he was Chairman of the Advisory Committee of European Operating States on North Atlantic Ocean Stations. Commander Frankcom has also represented the World Meteorological Organization at many meetings of other international organizations including the Inter-Governmental Maritime Consultative Organization and the International Load Line Convention.

Commander Frankcom is a member of the Honourable Company of Master Mariners, a Fellow of the Institute of Navigation and a Member of the Challenger Society and of the Society of Underwater Technology. He has written numerous articles concerning ocean networks, ocean currents, meteorological problems of ships' cargoes, and the weather routeing of ships.

In meteorology, national or international, we have come to regard Eddie Frankcom as an immense figure. Well known in many international organizations besides WMO, he has earned respect and admiration for his enthusiasm, his spirit of co-operation, and his ability to appreciate what was required for maritime meteorology and to organize its fulfilment. In a lifetime of unending activity in his profession, he nevertheless found time to join in a host of social and cultural pursuits which are so important in the corporate life of large organizations. In sport, amateur dramatics, and in many other ways Eddie Frankcom has given much by his leadership, his enthusiasm and his sense of fun. In 1968 he was awarded the Sutton Rose Bowl as the one who had done most for the social and sporting life of the Meteorological Office. He has had a splendid career and both meteorology and meteorologists owe much to him. His impact remains and will be lasting.

We all wish Eddie and his wife a long and happy retirement.

P.J.M.

REVIEWS

The weather business, by Bruce W. Atkinson. 140 mm×215 mm, pp. 192, *illus.*, Aldus Books Ltd, 17 Conway Street, London, W.1., 1968. Price: 16*s*.

This book is a very comprehensive review of the weather business. The first chapter deals with the effect of weather on the human body and on agriculture, transport and industry. The second chapter deals with routine observations and then discusses three types of non-routine observations: those designed for the United States National Severe Storms Project, aircraft reports and cloud photogrammetry. The third and fourth chapters deal in detail with analysis of surface and upper air charts and short-range forecasting by the human forecaster; they also deal with numerical prediction and long-range forecasting. The fifth chapter reviews the possibilities of modifying the weather and climate, and the last looks to the future under the title 'Prospect'.

The author has obviously read widely and is well informed about recent developments. He has organized his facts and presentation well, and the book is well produced in clear type and lavishly illustrated with coloured diagrams and photographs. These are right up to date; they include photographs of an automatic chart plotter, a zebra chart drawn by computer and pictures from weather satellites. The diagram of the vertical cross-section through a warm and a cold front on page 64 therefore comes as a shock. The cloud sequence ahead of a typical warm front is well known, starting with cirrus and ending with a bank of nimbostratus of considerable vertical extent; but the cloud in the diagram bears no relation to this sequence. Furthermore, it is questionable whether the zone of transition from moist to dry air above the cold frontal zone is a vertical column as shown in the diagram. The warm front in the diagram seems to be derived from a model of cyclonic development in a continuous baroclinic fluid. This is a research tool which, it is hoped, may lead to a clearer understanding of the dynamical meteorology of a cyclone, but something has yet to be done to the model to make it yield the cloud formation which actually occurs. This is not made clear in the book. Moreover, on the middle of the three figures higher up on the same page there is an inexplicable kink in one of the isobars.

Although the reviewer enjoyed reading the book, it is difficult to envisage the reader for whom it is intended. There is too much detail about station plotting models, tephigrams, hodographs and the like to interest the general reader. Moreover, on page 86 the reader is suddenly confronted with wet-bulb potential temperature without explanation and on page 122 he meets 'the partly filtered nongeostrophic model'. Even with the explanation which follows the general reader might find this somewhat abstruse. If, however, the book is intended as background reading for practising meteorologists, details of codes and plotting models and elementary analysis are superfluous as they will have learnt about these elsewhere. Perhaps (as the author is a lecturer in geography at Queen Mary College, London University) it is intended for students of geography.

Although the book is from an English publisher, it has a mid-Atlantic flavour: 'center' and 'sulfate' appear in the text. The author also gives the concentration of silver iodide particles under certain circumstances in cloud-seeding experiments as $10^{12.7}$ per gram — an unusual index ! 5×10^{12} would be easier to understand.

S. E. VIRGO

Climate and weather, by Hermann Flohn. 190 mm × 130 mm, pp. 253, *illus.*, World University Library, Weidenfeld and Nicolson, 5 Winsley Street, London, W.1, 1969. Price: 30*s*. (paperback, 18*s*.)

This is the English translation by B. V. de G. Walden of Professor Flohn's recently published book in the World University Library series. Professor Flohn is of course well known for his fine work in climatology and synoptic meteorology, particularly with reference to low latitudes. The book is intended primarily as an introduction to the subject for university students and the general reader.

As suggested by the title, the book covers a very wide range of topics, including radiation, cloud physics, atmospheric circulation, climatic variation and weather modification. Despite the nearly complete absence of mathematics the general treatment is essentially rigorous. The scientific basis of all aspects of climate and weather is emphasized and the discussion throughout is liberally supported with appropriate climatological statistics and numerical estimates of physical quantities. This thorough approach is evident right from the start in the first chapter on 'Radiation and the heat budget'. Here is a wealth of information on the physical processes in the atmosphere arising from the emission of solar radiation. This long first chapter certainly gets down to the basic physics and contains a very useful summary for most meteorologists, but it may be rather heavy going in places for the general reader for whom the work is mainly intended; however, he would be well advised to persevere because the chapters which follow tend to become more readable and, at least to the reviewer, more interesting.

Synoptic meteorology and forecasting are presented as problems in mathematical physics which depend for their practical solution primarily on modern technology and on a much improved observational network, but Professor Flohn wisely leaves in a caveat on our present lack of knowledge of the limits of predictability.

The very informative chapter on 'Climate and climatic zones' should present no difficulty to the general reader. Here in particular the reviewer gained the impression that most of the places so aptly and refreshingly referred to for illustrative purposes were indeed personally known to Professor Flohn.

The chapter on 'Climatic variations' makes adequate reference to the work of three British meteorologists, C. E. P. Brooks, G. Manley and H. H. Lamb. The ground covered is fairly well-worn, but the chapter should make interesting reading to the non-specialist, covering as it does such topics as temperature and rainfall variations from instrumental records, the observations of the retreat and advance of glaciers, the possible effects on radiation and circulation of dust thrown into the atmosphere by volcanic eruptions, the dating of tree rings and fossilized pollen by radio-carbon techniques. The final chapter on 'Weather and climate modification' naturally follows. The themes are mainly the activity in cloud seeding in the past 20 years, the modifications in microclimates, for example, by planting trees and hedges and possible influences on the macroclimate by various means, for example, by reducing the albedo of snow and ice in May, but clearly the ultimate effects of man's intervention, especially on the scale of the macroclimate, are far from certain.

This book is undoubtedly very good value for money. It should prove helpful to the professional meteorologist as well as to the general reader for whom the book is primarily intended.

R. A. MURRAY

CORRECTION

Meteorological Magazine, July 1969, p. 215. In the caption to Figure 18, for 'Summer' read 'High summer' (July–August).

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CONTENTS

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