Met.O.826
METEOROLOGICAL OFFICE

the meteorological magazine

MARCH 1970 No 1172 Vol 99
Her Majesty's Stationery Office

METEOROLOGICAL OFFICE Met.O.826

THE METEOROLOGICAL MAGAZINE

Vol. 99, No. 1172, March 1970

551.501.4:551.521.11(414)

A METHOD OF ADJUSTING SUNSHINE AVERAGES AT AN OBSTRUCTED SITE TAKING INTO ACCOUNT OBSTRUCTIONS AND DIURNAL VARIATION OF SUNSHINE

By D. F. FURMAGE

Summary. A method is given of adjusting the sunshine averages at a station where there is some obstruction of sunshine by obstacles, in order to obtain an estimate of what the averages would be at an unobstructed site in the vicinity. The method takes into account the diurnal variation of sunshine as well as the percentage of the sun's path which is obstructed.

Introduction. A considerable number of stations record the duration of bright sunshine by using a Campbell-Stokes or Universal Recorder. Summaries of their records are published in the *Monthly Weather Report,** and averages have been published for stations with a sufficiently long record.[1,2] Maps have also been prepared from these averages.[3] Several of these published records are annotated 'S' for some months, especially the winter ones. This annotation means that at the site of the recorder the direct sunshine is obstructed by some object which obscures more than 5 per cent of the sun's path above 3° elevation during the month but the published figures are not corrected for obstruction. (It is accepted as a general working rule that the sun will not cause a burn on the card in the recorder until it has risen more than 3° above the horizon.)

Ideally, the sun recorder should be placed so that buildings, trees, etc., never obstruct the sun when it has an elevation of more than 3°. In some cases this can be done by careful siting; sometimes the best site is on the roof of a building, but the card in the recorder must be changed daily and this restricts the choice of site. Unobstructed sites may be available in the vicinity but it may not be possible to provide adequate protection for the instrument and a partially obstructed site may have to be accepted. If there are permanent obstructions, usually in the form of trees or neighbouring buildings, the average durations of bright sunshine obtained from the recorder are not truly representative of the sunshine régime at an unobstructed site in the area. The following paragraphs suggest a method of making estimates of the corrections to be applied to the durations recorded at an obstructed site to make them representative of an open site in the vicinity. The starting point is the 'obstruction diagram' which is prepared for each obstructed site.

* London, Meteorological Office. *Monthly Weather Report.*

This gives the azimuth and elevation of all obstructions above 3° elevation, as seen from the sun recorder, between north-east and north-west through south. From this diagram and a knowledge of the apparent path of the sun at various times of the year it is possible to calculate the percentage of the daily duration during which the sun's rays cannot reach the instrument because of an obstruction. These percentages are calculated for all obstructed sites, by months, and they form the basis of the 'S' annotations in publications. However, these percentages, obtained by considering local obstructions, cannot be used directly to correct the recorded durations. Obstructions are normally relatively low in the sky and, as can be seen from Figure 1, less sunshine occurs per hour, at the unobstructed site at Eskdalemuir for example, during the early and late hours than during the intermediate hours. This means that less sunshine is lost than the percentage loss by obstruction would suggest, and if the percentages were applied to the recorded durations to obtain an estimate of the unobstructed durations, the result would be a considerable overestimate.

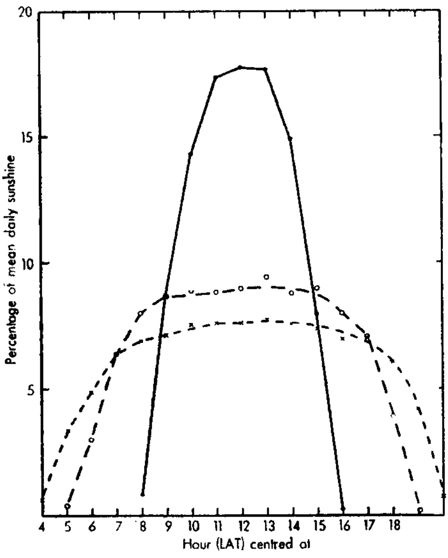

FIGURE 1—DIURNAL VARIATION OF SUNSHINE AT ESKDALEMUIR FOR THE PERIOD 1911–20

•———• January o—o—o April x– –x– –x June

The site at Eskdalemuir was unobstructed during the period 1911–20.

Method. To illustrate the method, the sun recorder site at Marchmont has been chosen (55°44′N 02°25′W, 498 feet above MSL). Marchmont, on the southern slopes of the Lammermuir Hills, has obstructions in every month of the year (see Col. 4 of Table I and Figure 2). The loss by obstruction at Marchmont, expressed as a percentage, is abnormally large, but until recently it was the only sun recorder in the lower Tweed valley and was presumably installed originally (1914) to fill a very large gap in the network. Until the end of 1966 it was used as a District Value Station in the *Monthly Weather Report* and the published monthly departures of sunshine duration from average probably had some real significance. However, the absolute values could not be regarded as representative of the open countryside around.

TABLE I—MARCHMONT SUNSHINE AVERAGES ADJUSTED FOR OBSTRUCTION AND DIURNAL VARIATION OF SUNSHINE AT ESKDALEMUIR

Month	Possible daily sunshine	Actual daily average	Actual monthly average	Loss by obstruction	Loss adjusted for diurnal variation	Adjusted average sunshine Daily	Adjusted average sunshine Monthly
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
		hours			*per cent*		*hours*
Jan.	6·7	1·42	44	21·9	15·5	1·68	52
Feb.	8·7	2·16	61	29·9	20·2	2·71	77
Mar.	10·9	3·13	97	17·2	7·8	3·39	105
Apr.	13·2	4·74	142	5·9	3·0	4·89	147
May	15·0	5·55	172	6·5	2·9	5·72	177
June	16·1	6·00	180	6·3	1·2	6·07	182
July	15·6	5·00	155	5·9	1·4	5·07	157
Aug.	14·0	4·58	142	6·2	1·5	4·65	144
Sept.	11·9	3·91	117	10·3	3·2	4·04	121
Oct.	9·5	2·46	76	27·1	17·3	2·97	92
Nov.	7·1	1·57	47	26·1	19·9	1·96	59
Dec.	5·7	1·16	36	27·2	21·7	1·48	46
Yearly average		3·48		13·1	7·2	3·72	
Yearly total			1269				1359

The obstructions, as can be seen from the diagram in Figure 2 are in almost every direction. Though the elevations of the obstructions vary, a study of the obstruction diagram suggests that the sunshine lost by obstruction during any month may be roughly divided equally between the morning and the evening when the sun is at a low angle.

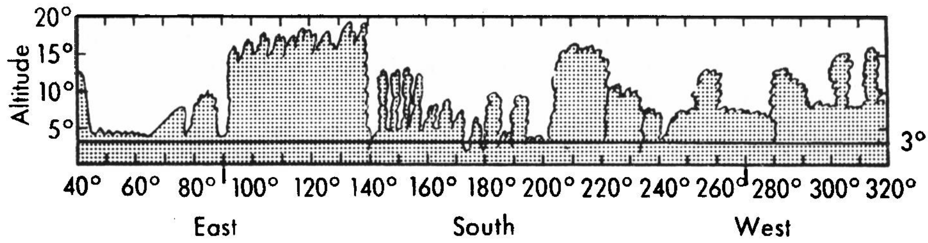

FIGURE 2—OBSTRUCTION DIAGRAM FOR MARCHMONT
Directions are true.

The first problem is to obtain a measure of the diurnal variation of sunshine in the area. Unfortunately very few stations with unobstructed sites measure hourly values of sunshine, and the nearest inland station to Marchmont for which hourly values of sunshine are available is Eskdalemuir (55°19′N 3°12′W, 794 feet above MSL). For some years the shelter belt of trees complicated the horizon of the sun recorder at Eskdalemuir, but there was no obstruction between the years 1911 and 1920 and it was considered that the data for these years would suffice to establish the general diurnal pattern. The mean hourly sunshine was expressed as a percentage of the mean daily sunshine and the values are given in Table II. The hours in the table are Local Apparent Time (LAT) and the percentage values refer to periods of 60 minutes centred at these hours. It might be thought that Eskdalemuir is rather remote fom Marchmont, but stations measuring hourly sunshine are so few that this is likely to be the situation in general and as is shown later the hourly percentage values are not too critical.

The procedure from this point is best illustrated by an example. From astronomical tables the mean daily number of hours of possible sunshine (sun

TABLE II—MEAN HOURLY SUNSHINE AT ESKDALEMUIR (1911–20) AS PERCENTAGE OF THE MEAN DAILY SUNSHINE

Month	Hour (LAT) centred at :																
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
									per cent								
Jan.					0·8	8·8	14·4	17·4	17·8	17·7	14·8	8·0	0·3				
Feb.				0·3	5·4	10·7	13·1	14·6	13·7	14·2	13·0	9·7	5·1	0·2			
Mar.			0·1	4·1	8·1	10·0	11·1	12·0	11·5	11·5	10·6	9·8	7·6	3·4	0·2		
Apr.		0·4	3·0	6·4	8·0	8·6	8·9	8·8	9·0	9·5	8·8	9·1	8·0	7·1	3·9	0·5	
May	0·3	2·2	4·8	6·0	7·0	8·2	8·2	8·5	8·3	8·0	7·6	7·5	7·2	6·7	6·1	3·2	0·2
June	0·6	3·4	4·9	6·3	6·9	7·2	7·6	7·6	7·6	7·8	7·6	7·4	7·0	7·1	6·1	4·2	0·7
July	0·2	2·5	4·9	6·2	6·4	7·2	7·6	7·8	8·0	8·0	8·4	8·6	8·0	6·9	5·7	3·2	0·4
Aug.		0·8	3·1	5·5	7·5	8·1	8·3	9·4	9·7	9·2	9·1	8·6	8·5	7·2	4·1	0·9	
Sept.			0·5	4·1	7·5	9·5	10·1	10·3	10·4	10·5	10·8	10·2	8·9	6·0	1·2		
Oct.				1·5	7·8	11·6	12·2	12·0	12·8	12·7	11·5	9·9	7·0	1·0			
Nov.					2·0	10·5	14·8	15·9	16·0	15·1	14·2	10·0	1·5				
Dec.					0·1	6·2	15·2	18·5	20·1	18·8	15·3	5·8					
Year	0·2	1·2	2·7	4·6	6·6	8·6	9·6	10·2	10·2	10·2	9·7	8·7	7·0	5·3	3·4	1·6	0·2

above 3°) can be calculated for given latitudes. Column 1 of Table I gives the possible sunshine (above 3°) for 55°N.

The mean daily number of hours of possible sunshine in April is 13·2 hours; of these, the period 0530 LAT to 1830 LAT accounts for 13 hours, the remaining 0·2 hours occurring in the two hours centred at 0500 LAT and 1900 LAT. From Column 4 of Table I the percentage loss by obstruction of possible sunshine at Marchmont in April is 5·9 per cent; the number of hours in which obstruction is effective is 5·9 per cent of 13·2 hours = 0·8 hours.

From Table II, if the diurnal variation of mean hourly sunshine at Marchmont is the same as that at Eskdalemuir, the hourly percentages of actual mean daily sunshine are :

Hour (LAT)	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19
Percentages	0·4	3·0	6·4	8·0	8·6	8·9	8·8	9·0	9·5	8·8	9·1	8·0	7·1	3·9	0·5

Therefore, if it is assumed that there is equal obstruction in morning and evening, the 0·2 hours possible in the hours centred at 0500 LAT and 1900 LAT correspond to $0{\cdot}4+0{\cdot}5=0{\cdot}9$ per cent of the mean daily sunshine and are assumed to be completely sunless. The 0·6 hours required to make up a total of 0·8 hours per day in which the obstruction is effective must come from the hours centred at 0600 and 1800 LAT. Assuming that in each of these periods centred at 0600 and 1800 LAT there is equal obstruction, then

$$0{\cdot}3 \times 3{\cdot}0 = 0{\cdot}9 \text{ per cent}$$

is the percentage loss in the hour centred at 0600 LAT and

$$0{\cdot}3 \times 3{\cdot}9 = 1{\cdot}17 \text{ per cent, or } 1{\cdot}2 \text{ per cent approximately,}$$

is the percentage loss in the hour centred at 1800 LAT.

Thus 0·2 hours correspond to 0·9 per cent loss

0·6 hours correspond to 2·1 (i.e. 0·9 + 1·2) per cent loss,

and therefore 0·8 hours correspond to 3·0 per cent loss.

The 5·9 per cent loss by obstruction is thus seen to correspond with a 3·0 per cent loss of actual sunshine.

In April the daily average recorded sunshine is 4·74 hours (from Table I). From the foregoing discussion it can be seen that this corresponds to only 97 per cent of the actual sunshine on average. Therefore the total sunshine for an unobstructed site at Marchmont is $(4{\cdot}74 \times 100)/97 = 4{\cdot}89$ hours. If the loss of actual sunshine is assumed to be 5·9 per cent, the total sunshine would be $(4{\cdot}74 \times 100)/94{\cdot}1$ hours, which is probably much too high.

The procedure was followed for each month of the year. The adjusted percentage losses of sunshine and the adjusted averages are given in Table I. If these adjusted percentages are used to correct the recorded durations at Marchmont for individual months before using the figures in preparing the monthly sunshine maps which are drawn as a routine for internal use in Meteorological Office, Edinburgh, some of the difficulties in drawing the maps disappear, especially in winter months when the loss by obstruction is large, and the Marchmont figures accord much better with neighbouring stations.

This affords some confirmation of the validity of the method, but as a further check Marchmont's actual and adjusted sunshine durations were compared with those recorded at Lauder over the period 1961 to 1966. The results are given in Table III. Lauder is an inland station fairly near Marchmont and with a similar situation (55°44′N 02°25′W, 550 feet above MSL). The site is unobstructed except in midsummer when a cottage cuts off a negligible amount of the evening sunshine. It will be seen from Table III that the adjusted Marchmont sunshine fits the pattern of Lauder's sunshine better than the recorded sunshine. Marchmont's actual sunshine in the least obstructed months is usually higher than that at Lauder, so it is to be expected that the adjusted annual total for Marchmont should be higher than that for Lauder.

TABLE III—COMPARISON OF THE ACTUAL AND ADJUSTED SUNSHINE AT MARCHMONT WITH THE SUNSHINE AT LAUDER, 1961–66

	MARCHMONT				LAUDER	
	Actual mean sunshine		Adjusted mean sunshine		Actual mean sunshine	
Month	Daily	Monthly	Daily	Monthly	Daily	Monthly
	hours		*hours*		*hours*	
Jan.	1·53	47·4	1·81	56·1	1·83	56·7
Feb.	1·89	53·2	2·37	66·7	2·37	66·7
Mar.	3·01	93·3	3·26	101·1	3·33	103·2
Apr.	4·33	129·9	4·46	133·8	4·37	131·1
May	5·95	184·4	6·13	190·0	5·93	183·8
June	5·58	167·4	5·65	169·5	5·15	154·5
July	4·77	147·9	4·84	150·0	4·81	149·1
Aug.	4·63	143·5	4·70	145·7	4·52	140·1
Sept.	3·73	111·9	3·85	115·5	3·80	114·0
Oct.	2·37	73·5	2·87	89·0	3·10	96·1
Nov.	1·73	51·9	2·16	64·8	2·30	69·0
Dec.	1·63	50·5	2·08	64·4	1·79	55·5
Yearly total		1254·8		1346·6		1319·4

At some stations obstruction may occur only in the morning or only in the evening. The method can easily be adapted to meet this case. For the case of Marchmont in April, if it is assumed that all the 5·9 per cent obstruction occurs in the evening only, the calculation would proceed as follows :

number of hours of possible sunshine lost = 0·8 hours
0·1 hours now correspond to 0·5 per cent,
0·7 hours now correspond to $0{\cdot}7 \times 3{\cdot}9 = 2{\cdot}73$ per cent,
i.e. 0·8 hours now correspond to 3·2 per cent,

and the adjusted daily average would then be 4·90 hours.

If there is an isolated obstruction in one direction only, the actual loss of sunshine has to be calculated in the same way using the obstruction diagram and the solar diagram giving the apparent path of the sun.

Pattern of diurnal variation of sunshine. Table IV gives the percentage hourly sunshine for Aberdeen, 1881–1910, when the only obstruction was a very thin flag pole. The table shows a marked similarity to Table II but the difference in the length of day makes a noticeable difference, especially in winter. Table V gives the adjusted actual monthly percentage losses based on obstruction losses of 5, 10, 15, 20, 25 and 30 per cent, when adjustment is

TABLE IV—MEAN HOURLY SUNSHINE AT ABERDEEN (1881–1910) AS PERCENTAGE OF THE MEAN DAILY SUNSHINE

Month	Hour (LAT) centred at :																
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
									per cent								
Jan.						3·8	14·1	19·9	20·5	19·9	16·0	5·8					
Feb.					2·3	9·7	13·6	15·2	15·2	14·8	14·0	10·9	4·3				
Mar.			0·3	3·0	8·0	10·2	11·6	11·8	11·6	11·0	10·7	9·6	8·0	3·9	0·3		
Apr.		0·4	3·0	6·0	7·7	8·7	9·1	9·3	9·5	9·5	9·1	8·9	8·1	6·7	3·4	0·6	
May	0·2	2·9	5·3	6·2	6·9	7·4	7·7	7·7	8·1	7·9	8·1	7·9	7·5	6·7	5·8	3·4	0·3
June	1·2	3·9	5·2	5·9	6·4	6·9	7·1	7·4	7·6	7·6	7·7	7·4	7·1	6·7	6·1	4·5	1·3
July	0·8	4·0	5·4	6·4	7·1	7·3	7·3	7·6	7·8	7·6	7·6	7·3	7·0	6·2	5·6	4·0	1·0
Aug.		1·3	4·6	6·3	7·8	8·2	8·6	8·8	9·1	9·1	8·8	8·2	7·6	6·1	4·2	1·3	
Sept.			0·9	5·0	8·2	9·7	10·5	10·2	10·5	10·5	10·0	9·5	8·5	5·7	0·8		
Oct.				0·7	5·3	10·9	13·0	13·0	13·3	13·3	12·6	10·6	6·3	1·0			
Nov.					0·6	6·3	14·9	16·5	18·3	18·8	16·0	8·0	0·6				
Dec.						0·9	12·7	21·8	23·7	22·7	15·5	2·7					
Year	0·3	1·6	3·0	4·3	6·2	8·1	9·8	10·3	10·8	10·6	10·0	8·4	6·5	4·9	3·3	1·6	0·3

TABLE V—ADJUSTED MONTHLY PERCENTAGE SUNSHINE LOSSES FOR SPECIFIED PERCENTAGE LOSSES BY OBSTRUCTION

(a) Using the mean hourly sunshine at Aberdeen (1881–1910) and the solar diagram for Aberdeen

Month	Loss by obstruction (per cent)*					
	5	10	15	20	25	30
			per cent			
Jan.	2	5	7	10	15	20
Feb.	2	4	6	9	13	17
Mar.	2	4	7	10	14	19
Apr.	2	4	6	10	14	18
May	2	4	7	11	15	20
June	1	3	7	11	15	19
July	2	5	8	11	16	20
Aug.	2	4	7	10	14	18
Sept.	1	3	6	10	13	17
Oct.	2	5	8	10	13	18
Nov.	3	6	8	12	14	18
Dec.	3	6	9	13	17	21

(b) Using the mean hourly sunshine at Eskdalemuir (1911–20) and the solar diagram for Eskdalemuir

Month	Loss by obstruction (per cent)*					
	5	10	15	20	25	30
			per cent			
Jan.	3	7	11	14	18	23
Feb.	3	6	8	11	16	20
Mar.	2	5	7	10	14	18
Apr.	2	5	7	11	16	21
May	2	4	7	11	15	19
June	1	3	6	9	14	18
July	1	3	6	9	13	17
Aug.	1	3	6	8	12	17
Sept.	1	3	6	9	13	18
Oct.	2	5	9	12	16	20
Nov.	4	8	12	15	19	23
Dec.	4	7	11	15	20	24

* Samples of percentage losses by obstruction such as might occur at neighbouring obstructed sites.

made for diurnal variation of sunshine by using the hourly percentage figures for Eskdalemuir and Aberdeen and by assuming that the obstructions are at a low angle and are equally divided between morning and evening. The adjusted values for Aberdeen are more uniform throughout the year than are those for Eskdalemuir and the Aberdeen values tend to be lower than the Eskdalemuir values in the winter half of the year. At certain seasons in Britain an inland station such as Eskdalemuir will normally have clearer mornings and evenings than will a coastal station, with more cloud developing during the middle of the day. Therefore there is a tendency for the adjusted percentage loss to approach the loss by obstruction more closely at an inland station than at a coastal station.

The number of stations measuring hourly sunshine in Scotland is unfortunately limited and most of them are coastal or semi-coastal. The actual percentage losses for various percentage losses by obstruction in March were calculated for Benbecula (1957–67), Kinloss (1954–67), Stornoway (1954–67), Tiree (1954–67), Renfrew+Abbotsinch (1936–56) and Turnhouse (1951–66). In the calculations allowance was made for the fact that, since 1921, hourly values are measured for the 60 minutes ending at the exact hour LAT. March was chosen to avoid the complication of varying day length as the duration of possible sunshine above 3° elevation is 10·8 hours at all these stations in March. The results are given in Table VI. Considering the first five stations, which are all coastal, there is a variation of approximately 1 per cent from the mean figures 2, 4, 8, 10, 16 and 18 per cent. Tiree has the highest mean March sunshine of 116 hours (3·75 hours per day). An error of 1 per cent in an adjustment at such a station would amount to about 0·04 hours per day, which is well within the error normally expected in daily sunshine records, or a little over one hour in the monthly total.

TABLE VI—ADJUSTED MONTHLY PERCENTAGE SUNSHINE LOSSES FOR SPECIFIED PERCENTAGE LOSSES BY OBSTRUCTION IN MARCH, FOR VARIOUS STATIONS

Station	Period	Loss by obstruction (per cent)*					
		5	10	15	20	25	30
		per cent					
Aberdeen	1881–1910	2	4	7	10	14	19
Benbecula	1957–67	2	4	9	11	17	19
Kinloss	1954–67	2	4	8	11	16	18
Stornoway	1954–67	1	3	7	10	14	17
Tiree	1954–67	1	4	8	10	16	17
Eskdalemuir	1911–20	2	5	7	10	14	18
Renfrew+ Abbotsinch	1936–56	1	3	6	9	12	16
Turnhouse	1951–66	1	3	6	8	11	15

* Samples of percentage losses by obstruction such as might occur at neighbouring obstructed sites.

The figures for Renfrew+Abbotsinch and Turnhouse suggest that in the more industrial areas the pattern resembles that of a coastal station rather than that of a rural inland station.

General comment. If sunshine duration figures are required for an open site and it is known that the site of the nearest or most appropriate sun recorder is subject to some reduction of sunshine by local obstructions, an attempt must be made on an *ad hoc* basis to adjust the record from the sun recorder. Within its limitations, it is considered that the method described above will provide a better estimate of the true values than either the unadjusted values from the recorder or the values obtained by applying a percentage correction based on the percentage lost by obstruction. If a diurnal variation pattern appropriate to the area is chosen, the estimates should be a close approximation to the true values within the range of obstruction elevations normally encountered in practice. When the obstruction is caused by a major natural feature, e.g. a range of mountains, the same method could be applied to calculate the sunshine at a hypothetical open site, but it would not normally be appropriate to do so since the natural feature is relevant to the climate of the area.

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551.508.71

A RECORDING RESISTANCE PSYCHROMETER

By H. E. PAINTER

Summary. A continuously recording aspirated psychrometer is described which uses resistance elements as sensors. It records dry-bulb and wet-bulb temperatures to an accuracy of ±0·2 degC.

History. During 1867 a photothermograph[1] was installed at Kew Observatory to record the dry-bulb and wet-bulb temperatures in a wooden louvered screen attached to the north wall of the Observatory. Until the end of 1968 a continuous record was obtained with this thermograph, and the dry-bulb and wet-bulb temperatures published for Kew over this period are the temperatures as recorded by this photothermograph. Two mercury-in-glass thermometers are used in the thermograph, one to measure the dry-bulb temperature and the other to measure the wet-bulb temperature. In each of the mercury columns of the thermometers is a small air bubble, and light from small lamps is projected, by means of a simple optical system, through the air bubbles and brought to a focus on to a sheet of photographic paper round a drum. The drum revolves around a vertical axis and is driven by clockwork; it makes one revolution in just over two days. A third light spot is also projected on to the photographic paper to produce a straight datum line when the chart is developed. The projection of the spots of light is so arranged that the resultant traces do not overlap. A shutter operated by the clock every two hours, intercepts the three light beams to give time marks on each trace. Each of the thermometers has a long stem bent twice at right angles to enable the bulb to be exposed outside the building in a screen whilst the vertical stem is inside the building within a light-tight room. Two large graduated thermometers having bulbs similar to those of the thermograph are mounted side by side and close to the thermograph bulbs. Control readings are taken six times daily from these thermometers for comparison with the corresponding thermograph readings. These control thermometers are periodically calibrated at the National Physical Laboratory.

Temperatures are measured from the photographic record with the aid of engraved glass scales appropriate to each recording thermometer. These scales are graduated so as to read temperatures vertically and time horizontally. The scales are set by the datum line on the thermograms, and after hourly readings have been obtained for the whole record comparisons are made with the readings from the control thermometers in the screen. The residual corrections so determined are applied to the tabulation. These corrections are necessary to take account of any expansion or contraction of the photographic paper.

This briefly describes the method employed for recording temperatures at Kew for the past century. The great disadvantage of the method is, of course, the poor and non-standard exposure of the thermometer bulbs. These are about 40 cm from an outside wall of a large building and about 3 m above a stone slab on the artificial mound on which the Observatory is built. The screen has only single louvers and there is no forced ventilation. The non-standard exposure of the north-wall screen has long been appreciated and comparisons have been made (by Whipple[2] for the years 1879–81, by Stagg[3] for 1923–26, by Drummond[4] for 1914–43 and by Chandler[5] for 1958–60) between temperatures from the north-wall screen and temperatures from other screens at Kew with better exposures; Craddock[6] has given a brief summary of such comparisons.

Requirements for a recording psychrometer. The replacement for the photothermograph was designed to satisfy the following requirements :

(i) The instrument should record the dry-bulb and wet-bulb temperatures of the air at the standard height of 1·25 m above a grass surface at an unobstructed site.

(ii) The thermometer bulbs should be aspirated.

(iii) The recording thermometers should be resistance elements recording on a self-balancing resistance bridge.

(iv) Reference mercury-in-glass thermometers should be used in conjunction with the resistance thermometers.

An unobstructed site at Kew was readily selected in the lawn area; underground cables from this site to the main Observatory building about 100 m away were used to connect the sensors to a self-balancing bridge recorder which measures the resistance of the temperature elements and plots the temperatures on a strip-chart.

There are two main reasons for associating mercury-in-glass thermometers with the resistance elements. Firstly, it was desired to use commercially available resistance elements and a commercially available recorder. The manufacturer's tolerance (that is, the allowable departure from the assumed resistance – temperature specification) for the resistance element is equivalent to a temperature difference of ± 0·6 degC. In addition, errors of up to 0·7 degC have been found in the scale of a recorder in use, and so it is possible at a particular point on the recorder that the true temperature of the element may differ from the indicated chart temperature by more than ± 1·0 degC. It is thus necessary to determine these differences and to supply corrections. The easiest way to do this is to have a reference thermometer in intimate thermal contact with the resistance element. Secondly, although these combined corrections (which will, of course, in general vary with the temperature) should remain constant with time, periodic readings of the mercury-in-glass thermometers enable any faults in the electrical system to be detected quickly.

Design of the thermometer bulb. To ensure that the resistance element and the reference mercury-in-glass thermometer are measuring the temperature of the same sample of air a special bulb has been designed and made at Kew in which the resistance element and the bulb of the reference mercury-in-glass thermometer are immersed one above the other in a mass of mercury contained in a stainless-steel tube closed at the lower end. By this means the two temperature sensors are in good thermal contact with each other and with the stainless steel, so that any temperature differences between the two thermometers must be very small and transient. The design of the complete bulb was influenced greatly by the need to make it suitable for use as a wet-bulb element in which it is important to ensure that the conduction of heat down the thermometer stem does not lead to unacceptable errors. To this end the open end of the steel bulb is screwed on to an extension tube, made of poorly conducting material. The stem of the reference thermometer is inserted into this tube which fits tightly enough to hold the reference thermometer bulb in the required position inside the steel bulb. The wet-bulb sleeving covers the whole of the steel bulb and a large part of the extension tube.

One of the bulbs of the psychrometer is shown in section in Figure 1. It is 12·7 cm long and 1·3 cm in diameter. The resistance element is made to British Standard Specification (B.S.S.) 2G148, with a nominal resistance of 130 ohms at 0°C and a change of approximately 0·5 ohms/degC. The leads of the resistance element are embedded in the walls of the extension tube so that this tube and the resistance element form a unit. The standard three-lead system[7] is used to connect the resistance element to the recorder, thus making the recording independent of the resistance of the connecting cable. Two leads are taken from the resistance element and enter the lower end of the extension tube. These two leads are embedded in small grooves in the tube and then emerge from the top. A third lead is also embedded in the tube and this lead is soldered to one of the resistance leads near the lower end of the tube to form the third compensating lead; this lead also emerges from the top of the extension tube. The resistance element and its leads are of course electrically isolated from the remainder of the bulb.

The mercury-in-glass reference thermometer is approximately 40 cm long with a maximum diameter of 6·5 mm, graduated from − 10°C to 40°C in steps of 0·1 degC. The bulb of the reference thermometer and about 9 cm of its stem are inserted within the combined stainless-steel bulb and its extension tube. In the assembly of the complete bulb a small quantity of mercury is put into the stainless-steel bulb which is then screwed on to its extension tube. Care has to be taken that the level of the mercury is not above the top of the stainless-steel tube after the reference thermometer has been fitted otherwise the conduction of heat down the stem of the wet-bulb thermometer may be significantly increased to cause an error in the wet-bulb temperature.

Assembly of the psychrometer. The assembly of the various components of the psychrometer is shown in Plate I. There is a closed box from the lower

To face page 70

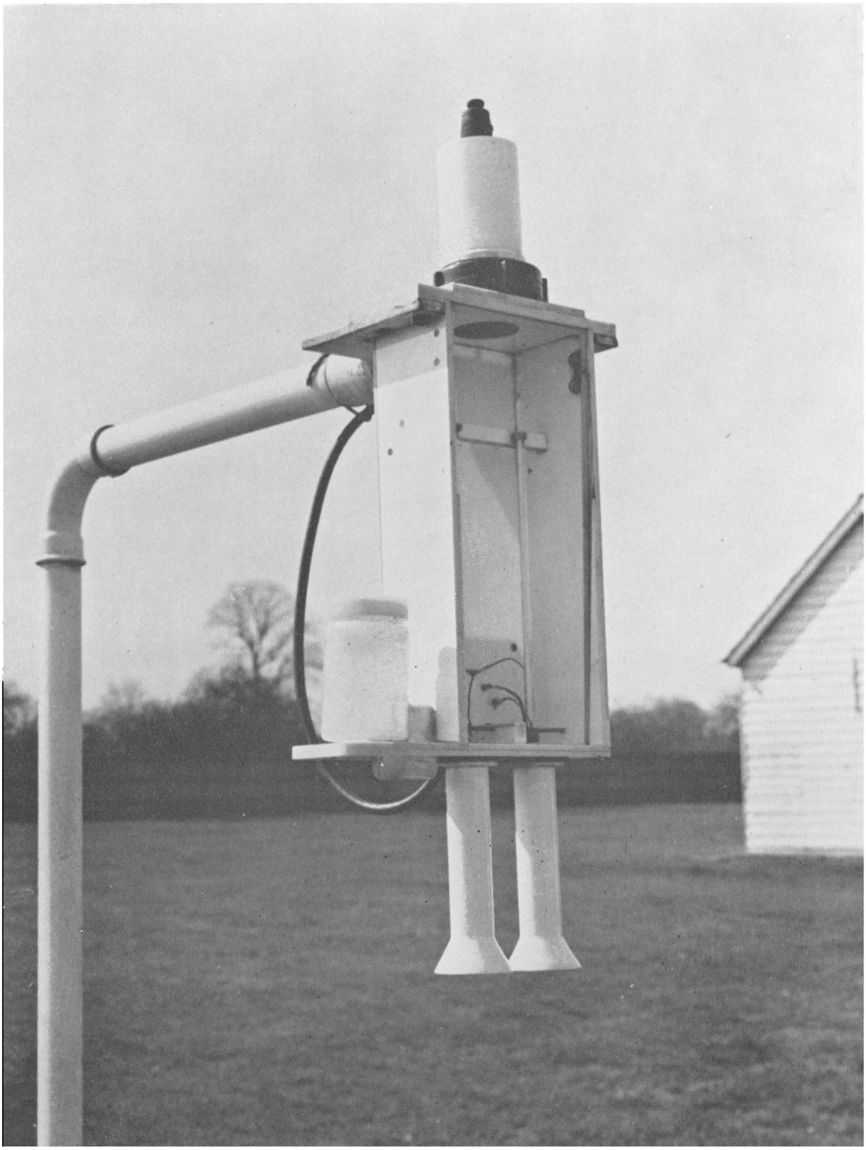

PLATE I—GENERAL VIEW OF THE RECORDING RESISTANCE PSYCHROMETER AT KEW OBSERVATORY

See page 70.

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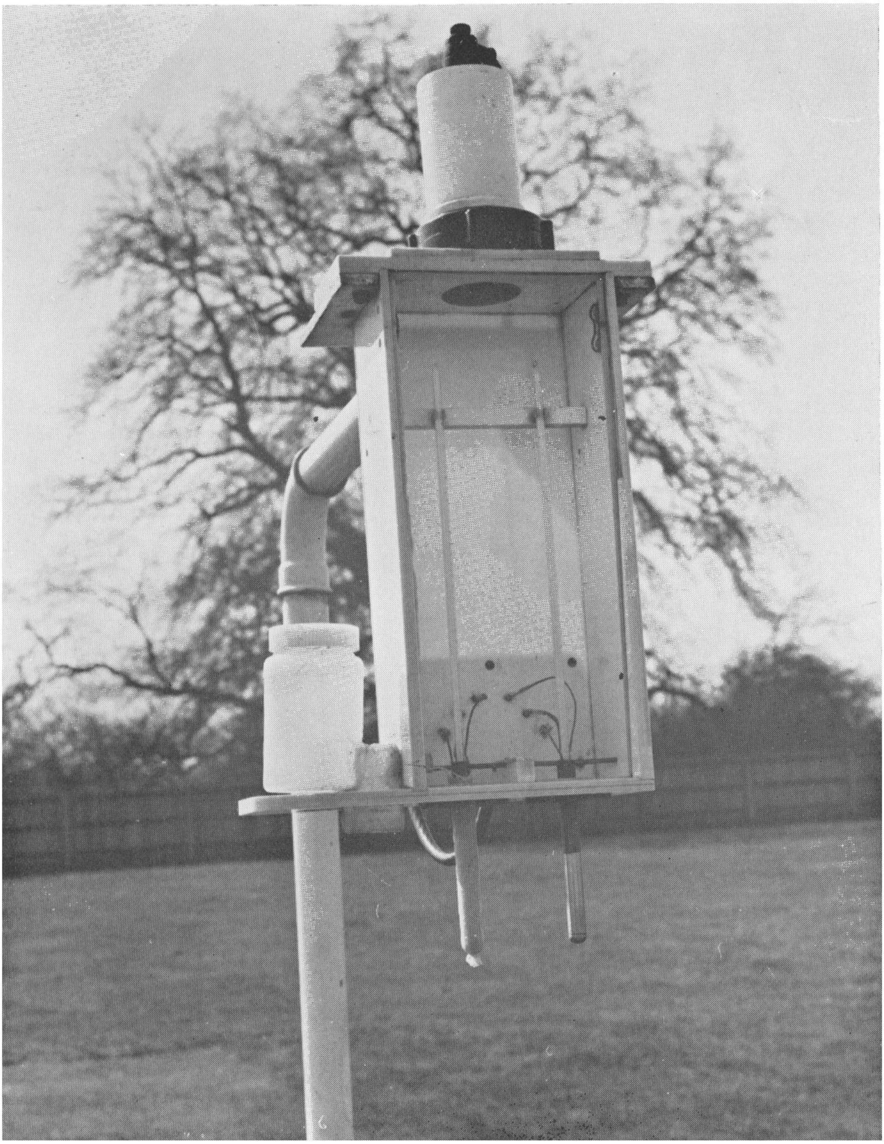

PLATE II—CLOSE-UP VIEW OF DRY-BULB AND WET-BULB THERMOMETERS WITH RADIATION SHIELDS REMOVED

See page 71.

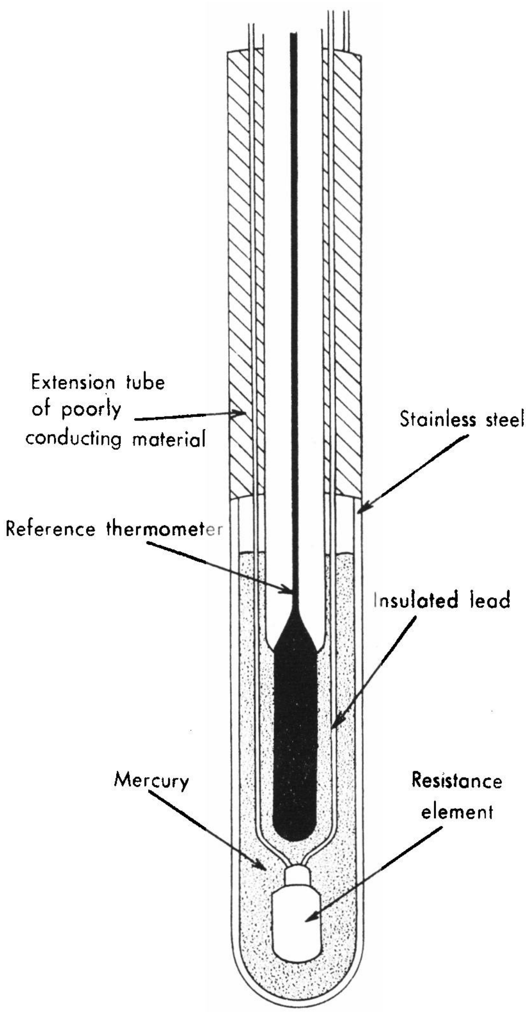

FIGURE 1—SCHEMATIC SECTION OF THERMOMETER BULB

end of which the two thermometer bulbs of the psychrometer project. Connected to the top of the box is a ventilation fan to provide the aspiration. The box is made of white opal material throughout except for the front panel which is clear so that the reference thermometers can be read. Access to the inside can readily be gained by sliding the front panel upwards.

Surrounding the thermometer bulbs are double-walled copper radiation shields through which air is drawn past the bulbs by the ventilation fan. The shields can be unscrewed from the base of the box. (See Plate II.) The lower end of each outer shield is flared outward in order to prevent the entry of rain with the aspirated air. The outside surface of the outer shields together with the inside surface of the flares are painted with white enamel; all the other surfaces of these double-walled shields are painted black. The position of each bulb relative to its radiation shield is of some importance since it is necessary to minimize the amount of reflected radiation from the ground that can directly reach the base of the bulb. The base of each radiation shield is 7·5 cm lower than the base of the associated bulb and experiments showed that at this distance the increase in the temperature of the bulb on a bright sunny day, due to reflected radiation from the ground, was less than 0·1 degC. Further tests showed that differences in the temperature reading due to variations in the long-wave radiation from the ground were undetectable.

To one side of the box is a platform on which stands the container for the distilled water. This container consists of two polyethylene bottles welded together so that water can flow freely from one to the other through a small connecting aperture; the larger bottle acts as a reservoir to maintain a constant water-level in the smaller one which is near the base of the large one. An outlet tube from the lower bottle extends to near the top of the bulb of the wet-bulb thermometer. This arrangement has the advantage that it is possible to fill the reservoir while it is still in position by temporarily inserting a small bung in the outlet tube and removing the screwed cap of the reservoir. The cap is fitted with a gasket so that when it is screwed to the reservoir a perfect air seal is obtained and hence atmospheric pressure acts to prevent an excessive flow of water to the smaller bottle. The covering for the wet bulb is a woven cotton sleeve cut to an appropriate length so that the bulb is covered to within 2 cm of its top. Threaded through the woven sleeve are three cotton strands which pass into the constant-level water container. It has been found that variations in the weave of the sleeving require changes in the number of strands threaded through it in order to maintain an adequate water supply to the wet-bulb. The best results are obtained with a sleeve with a tight weave. Plate II gives a close-up view of the psychrometer with the radiation shields removed from the bulbs. The wet-bulb sleeve and the distilled-water container can be seen.

The box containing the thermometers is mounted on a tubular iron stand, in the shape of an inverted L, so that the reference thermometers can be viewed from the north. This stand is painted white. The bases of the radiation shields are 1·25 m above a grass surface on an unobstructed site. The leads from the resistance elements are connected through the back panel of the box on to a cable which runs through the iron stand and then underground to the recorder in the main Observatory building. A second cable goes to the motor (30 volts a.c.) of the ventilation fan.

Care is needed regarding the general electrical insulation because an error of 0·1 degC will be introduced if a resistance of 350 000 ohms is placed across the resistance element. Such a resistance could easily be produced by water across any pair of uninsulated leads of the resistance element.

Characteristics of the psychrometer. Tests on the variations of wet-bulb depression with changes of voltages applied to the motor of the ventilation fan and hence changes of aspiration, showed that at 10-degC depression there was no change in the depression when the voltage was increased beyond 28 volts. The air speeds over the bulbs were determined by the hot-bulb method.[7] With 30 volts a.c. applied to the motor of the ventilation fan, the air speed past the thermometer bulbs was 13 m/s. The lag coefficients at this speed were 130 and 85 seconds respectively for the dry bulb and the wet bulb.

The aspiration at 1·25 m does not draw air from an appreciably lower level; smoke tests have shown that 6 cm is the greatest depth below the radiation shields from which air is drawn.

It was also shown that the temperatures obtained by the aspirated psychrometer were representative of temperatures at 1·25 m by comparing its temperature with those of a similar psychrometer placed horizontally with its air intake facing north at a height of 1.25 m; no detectable difference could be found between the minimum or other simultaneous temperatures measured by the two aspirated psychrometers.

The recorder. The resistances of the resistance elements are measured and recorded on a standard commercial multi-channel self-balancing resistance bridge which prints a reading from each channel every two minutes on a chart calibrated in temperature. The range of the chart is −30°C to +50°C and the speed used is one inch an hour. Time marks are made every hour by an auxiliary pen on the side of the chart which is controlled by a master clock in the Observatory. Three channels are used for recording, one each for dry-bulb and wet-bulb temperatures and a third channel to register the reading from a fixed reference resistor, corresponding to 30°C, of high stability with respect to both time and temperature. The trace from this reference resistor registers changes of expansion in the paper chart since the chart is positively located at the −30°C reading and is free to expand or contract at the +50°C reading. From the reading produced by the fixed resistor a proportional correction is found for any position on the chart.

To obtain temperatures from the recorder chart to an accuracy of 0·1 degC it is necessary to have a detailed calibration of the recorder obtained by applying resistances corresponding to temperatures at degree intervals. Such calibrations made on two recorders have shown that, after making the reading at 30°C coincident with the chart for that temperature, corrections of up to 0·7 degC were needed to the scale of the recorder chart at other points. These corrections moreover were very variable over the scale and in a 5-degC interval their value could change by 0·5 degC. Either by selecting recorders or by changing slide-wires it is possible to minimize the absolute values of the correction and also the rate of change of correction with temperature, but it is still necessary to know in detail the calibration of the recorder. With careful measurements a single determination of a correction at a particular point of the recorder scale can be made with a standard deviation of 0·05 degC.

Temperature control readings. In addition to corrections to the recorder there are also small corrections necessary because there are manufacturing tolerances on the thermometer resistance elements. To obtain the overall correction arising from both of these sources simultaneous readings are taken from the reference mercury-in-glass thermometers and the recorder. It has been found desirable to make consecutive readings (usually six) at two-minute intervals and from these the mean difference between the reference thermometer and the chart reading is evaluated. One person with a stopwatch can do this by first reading the reference thermometers at two-minute intervals and then returning to the recorder to obtain the corresponding chart readings. The reference thermometers are read to 0·02 degC and the recorder to 0·1 degC. The corrections thus obtained have to be combined with any chart corrections as shown by the record of the fixed resistor.

In a set of observations obtained in the manner just described an individual observation very rarely differs by more than ±0·2 degC from the mean value of the set of six observations. The overall correction to a chart reading can be as much as ±1·0 degC depending upon the resistance element in use. These corrections, of course, apply only for the particular time and temperature at which they are taken. With sufficient observations over an adequate temperature range, mean correction curves are obtained for the recordings of the dry bulb and wet bulb. These correction curves are similar in shape to (but with a constant displacement from) the correction curve obtained for the recorder by applying known resistances. Generally the overall chart correction is evaluated once a day by the method described above of taking the mean of six consecutive readings on the chart and simultaneous readings of the mercury-in-glass reference thermometer, so that any systematic difference from the correction curves can readily be discovered.

Over a period of several months the random error of the daily corrections from the mean correction curve was found to be approximately ±0·2 degC. On 70 per cent of occasions however, the random error was within 0·1 degC. The random error is caused by the instability of the various components and by random errors in the eye readings of the thermometers and the chart.

The specification (B.S.S.) of the resistance elements requires that when they are cooled from 0°C to −80°C for 15 minutes and then restored to 0°C they shall return to their initial resistance to within the equivalent of 0·13 degC. Under the much less severe conditions in which the elements are used in the present psychrometer the stability is probably within ±0·05 degC.

The accuracy of the reference mercury-in-glass thermometer is given on the NPL certificate as ±0·05 degC, and there will be a small random error in the eye reading.

The random error contributed by the recorder amounts to about ±0·1 degC and this is the major portion of the total.

Discussion. The resistance psychrometer has a greatly improved exposure compared with the photothermograph, and its record is immediately available instead of there being a delay of up to two days before a photographic chart is developed. The limitation of the resistance psychrometer lies in the accuracy and stability of the electronic recorder, and for the accurate recording of temperatures there is still the need to have reference mercury-in-glass thermometers, particularly as any slight adjustment to the electronic recorder may alter the corrections to the chart readings. The design of the complete bulb containing the resistance element and the bulb of the reference thermometer ensures that both types of thermometer are at the same temperature. The simplicity and durability of the recorder of the photothermograph is striking in comparison with the complexity of the electronic recorder and its requirement for regular calibration and servicing. At Kew a simple pendulum clock has driven the drum of the photothermograph for over a hundred years; it is too much to hope that a modern recorder will run continuously without replacement for a quarter of that time.

This resistance psychrometer in its present form was brought into use at Kew on 1 June 1966, and from 1 January 1969[8] it replaced the north-wall screen photothermograph as the official instrument at Kew for measuring dry-bulb and wet-bulb temperatures. The photothermograph will, however, continue to record for some further time to ensure that an adequate overlap of the two instruments is obtained so that the effect of the changes in instrument, site and exposure can be fully evaluated. To this end, hourly readings of dry-bulb, wet-bulb and the daily maximum and minimum temperatures from both instruments are measured and sent monthly to the Climatological Services Branch of the Meteorological Office for analysis.

The routine measurement of air temperatures for meteorological purposes with a continuously recording aspirated resistance psychrometer is an important change and a significant development from the long established method of temperature measurements in a naturally ventilated screen. This new psychrometer meets the general requirements specified by the World Meteorological Organization.[9] Similar recording resistance psychrometers were installed at Eskdalemuir and Lerwick Observatories in the early part of 1967 and after an overlap period with the screen temperatures it is intended that the new psychrometer will also become the standard instrument for measuring and recording temperatures at these places.

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TEMPERATURES IN HIGH SUMMER, AND HONEY PRODUCTION

By G. W. HURST

Summary. Honey production in Great Britain from 1929 to 1968 is considered in relation to summer temperatures, and close agreement is shown between good annual honey yields and high frequencies of days with temperatures above 20°C or 25°C in July (especially) and August. It is also shown that warm or hot days were more frequent in the two decades 1921–40 than since, or in many years before, and that the same has been true of warm spells at Kew. Brief comparison is made between early records of honey yields at Street, Somerset, and meteorological records for Bath. Finally, high correlation is shown between early stratospheric warming and high honey yields.

Introduction. In previous papers,[1,2] average monthly temperatures in spring and, more especially, in summer were considered in relation to honey production from 1928 onwards, and a strong relationship was established between average temperatures in the months of July and August and honey yields in the same year; naturally, high temperatures and good yields went together. Examination of climatic records indicated that the years 1931–50 represented 20 years with unusually high summer temperatures.

A disadvantage of this analysis is that the particularly warm days when the bee activity may be great are not taken into account; occasionally a month can enjoy above-average temperatures in rather dull weather with few really warm or hot days.

Another approach to the problem was therefore made by considering the number of days in particular months in the period 1928–69 when the maximum temperature exceeded levels of 20°C, 25°C and 30°C for a number of scattered localities in Great Britain and Northern Ireland. As before, the honey data for 1928–68 were those provided for Great Britain by courtesy of the Bee Farmers Association.* For many purposes it has been convenient to consider good and bad honey years. Good years were taken as those with a national average yield of over 62 lb of honey per hive, and bad years with less than 18 lb per hive; the actual years are listed in Table I. It was found in practice that the frequency of summer days with temperatures above 30°C was so low as to be uninformative; interesting results have emerged however from consideration of temperatures above 20°C and above 25°C.

TABLE I—COMPARISON OF FREQUENCIES OF TEMPERATURES ABOVE 20°C AND ABOVE 25°C AT KEW IN YEARS OF HIGH AND OF LOW HONEY YIELDS IN THE PERIOD 1928–68

Year	Honey yield per hive *lb*	Days with temp. above 20°C July	Days with temp. above 20°C Aug.	Days with temp. above 25°C July	Days with temp. above 25°C Aug.
(a) Years of high honey yield (over 62 lb per hive)					
1928	90	24	15	9	1
34	65	30	20	14	1
35	75	27	24	10	9
40	80	11	22	1	3
47	95	21	29	9	14
49	70	27	27	13	7
55	75	25	23	10	8
59	65	25	26	11	9
Average	76·9	23·7	23·3	9·6	6·5
(b) Years of low honey yield (less than 18 lb per hive)					
1930	15	14	15	1	5
36	10	10	19	0	5
48	15	11	9	5	1
53	15	9	22	0	3
54	10	7	7	0	0
58	10	18	12	2	1
63	16	14	9	4	0
65	10	10	18	0	0
Average	12·6	11·6	13·9	1·5	1·9

Frequency of temperatures above 20°C and above 25°C. The pattern of monthly relationships between honey yield and days with temperatures above 20°C and 25°C did not differ greatly amongst the six or seven stations considered in the U.K., and the results for Kew in the south-east and Cockle Park in the north-east of England are shown in Figure 1. The difference

* Sugar for Commercial Bee-keepers. An unpublished report issued by the Bee Farmers Association; sight of this report may be obtained by reference to the Secretary, Mr H. C. Hilder, Brunswick House, Church Laneham, near Retford, Notts.

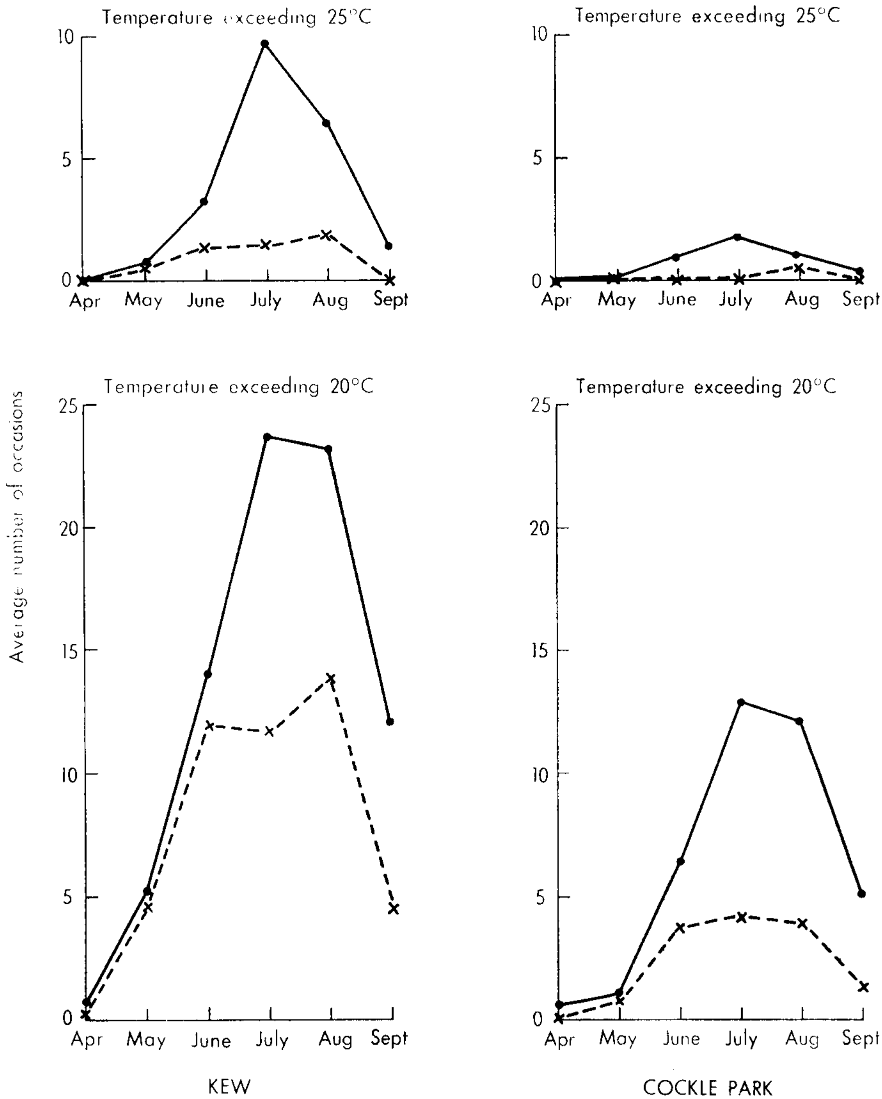

FIGURE 1—FREQUENCY OF DAYS IN GOOD AND BAD HONEY YEARS WITH TEMPERATURES EXCEEDING SPECIFIED LEVELS AT KEW AND COCKLE PARK

•———• Years of well-above average honey yield
x – – x Years of well-below average honey yield
(Years of well-above and well-below average are listed in Table I.)

between average totals of days with temperatures above 20°C in good and bad honey years at Kew is very slight in April and May, is noticeable in June, and is very considerable in July (especially), August and to a lesser extent September. When the 25°C level is considered the differences between good and bad years becomes greater, especially in July. The graphs for Cockle Park are very similar in character but totals of warm days are, of course, much lower. Interestingly, there seems no suggestion that later months (August or possibly September) may be more relevant to nectar collection in the north than in the south. Clearly, in both areas July and August appear to be the key months, and the actual figures for good and bad honey years for Kew are given in Table I.

Apart from 1940 (a good year for honey, with very warm sunny weather in June), no year with a high honey yield had less than 21 days in July when the temperature exceeded 20°C and no year with a low yield had more than 18 such days; and there were never less than 9 days in July with maximum temperature above 25°C in good yield years, or more than 5 days in bad years. August figures are similar in general character but differences between good and bad honey years are not as clear cut.

A further point of interest is that there were eight Julys in which the temperature exceeded 25°C on 10 days or more. These included five of the good honey years (see Table I); the other three Julys were in 1929 (40 lb), 1933 (60 lb) and 1941 (40 lb), in none of which years was the total yield less than the 41-year average of 39·4 lb; the average for these eight years was 61 lb. Similarly, of the eight Julys when temperatures never reached 25°C, four are included in the bad honey years; the other four years were 1931 (25 lb), 1942 (40 lb), 1960 (21 lb) and 1962 (18 lb); the average for these eight years was 19 lb.

Temperatures at Kew above 20°C and above 25°C since 1914. In an endeavour to make a comparison of temperatures over a longer period, similar data for temperatures at Kew above 20°C and 25°C were examined for the period 1914–69; this information is given in Table II.

TABLE II—AVERAGE ANNUAL NUMBER OF WARM AND HOT DAYS IN JULY AND AUGUST AT KEW FROM 1914 TO 1969

Period	JULY Average number of days above 20°C	above 25°C	AUGUST Average number of days above 20°C	above 25°C
1914–20	14·7	1·9	17·3	3·3
21–30	19·6	6·7	14·8	2·0
31–40	18·4	4·7	20·7	5·7
41–50	20·9	6·5	16·3	3·9
51–60	16·6	4·7	14·2	2·3
61–69	18·0	3·6	15·1	1·9
Average	18·0	4·7	16·4	3·2

It is obvious in this table that over the two months together the 1930s and 1940s were much more fortunate with warm, and especially hot, days than any other period — in each decade, for example, there is an average of over 10 days in July and August together with temperatures over 25°C.

Warm spells at Kew from 1881. Records have been maintained for Kew of warm spells — periods with day maximum temperatures of 75°F (23·9°C) or more on five consecutive days, but a period in which the maximum temperature only reaches the range 70–74°F (21·1–23·9°C) on one of the days is still deemed to qualify (Brazell[3]). The data are summarized in Table III in decades; included in these figures are any warm spells in the year from as early as May to as late as September. The table also shows the average number and duration of spells in good and bad years for honey yield (as given in Table 1).

PLATE III—LIGHTNING FLASH *Photograph by R. Addie*

The photograph was taken at about 1900 GMT on 14 November 1969 at Bemerton Heath, Salisbury, with the camera looking south-east. The camera, with shutter open, was hand held against a window for about 45 seconds until the flash was observed. Only one flash was visible to the naked eye. The blob on the extreme right was caused by refraction through a raindrop on the window.

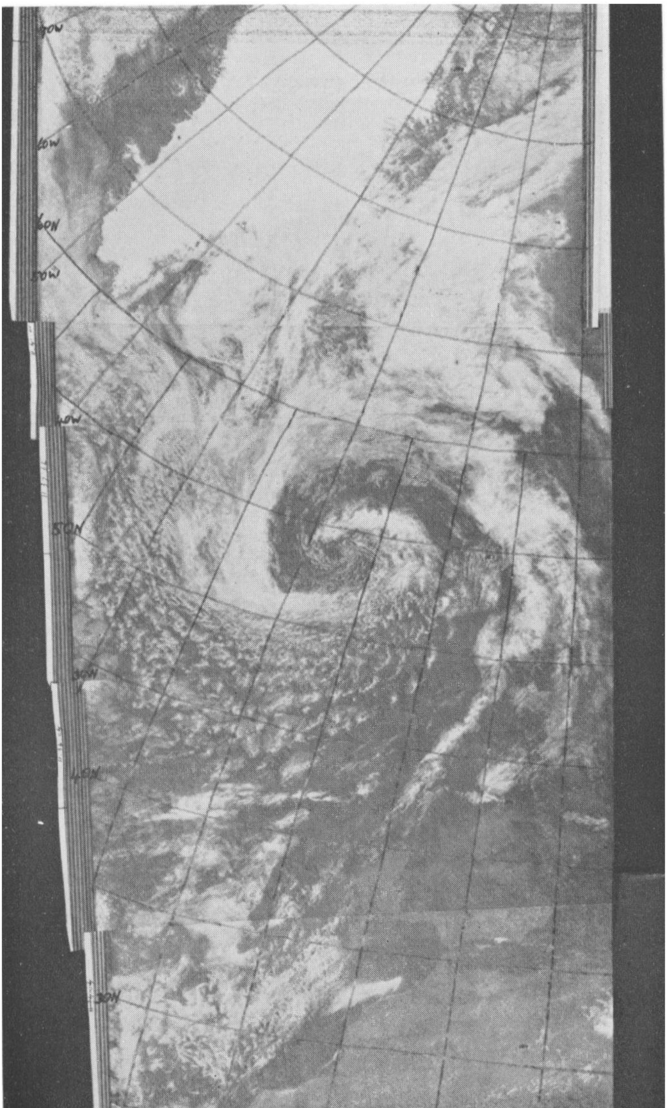

PLATE IV—COMPOSITE CLOUD PHOTOGRAPH FROM NIMBUS SATELLITE, 1134–1144 GMT ON 4 AUGUST 1969

TABLE III—NUMBER OF WARM SPELLS AND TOTAL NUMBER OF DAYS IN WARM-SPELL WEATHER AT KEW DURING THE PERIOD 1881–1969, WITH SIMILAR FIGURES FOR GOOD AND BAD HONEY YEARS IN 1928–68

Decade	Average annual number of spells	Average annual number of days involved
1881–90	1·4	8·5
91–1900	1·9	13·9
1901–10	1·7	11·4
11–20	1·5	12·1
21–30	1·4	14·0
31–40	2·3	15·4
41–50	2·1	15·0
51–60	2·0	11·7
(61–69	1·2	7·7)
Honey yields, 1928–68		
Good years	4·1	31·6
Bad years	1·4	9·1

The average number of warm spells per year was higher in the 1930s and 1940s than at any other time, and so too were the number of days involved.

Honey records at Street compared with meteorological data at Bath. So far, only national honey figures have been compared with records from a small, but it is hoped fairly representative, number of stations. A more exact comparison can be made for a particular locality near Street, Somerset, at which yield figures were carefully maintained from 1918 to 1936, because meteorological data exist for a climatological station at Bath, reasonably nearby. A comparison is made in Table IV between the best five and the worst five honey years at Street and the frequency at Bath of days with temperatures above 20°C and 25°C in June, July and August. It will be noticed that the yields given in this table, for an individual very efficient apiary, are considerably higher than the national averages given in the introduction and used in Table I.

TABLE IV—COMPARISON OF FREQUENCIES OF TEMPERATURES ABOVE 20°C AND ABOVE 25°C AT BATH IN YEARS OF HIGH AND OF LOW HONEY YIELDS AT STREET IN THE PERIOD 1918–36

Year	Honey yield per hive *lb*	Days with temp. above 20°C			Days with temp. above 25°C		
		June	July	Aug.	June	July	Aug.
(a) Years of high honey yield							
1919	167	15	15	24	1	0	8
21	170	20	30	16	5	16	2
25	148	21	20	15	5	8	2
33	189	16	24	25	5	9	8
34	163	16	31	18	5	14	1
Average	167·4	17·6	24·0	19·6	4·2	9·4	4·2
(b) Years of low honey yield							
1920	62	9	2	7	0	0	0
24	59	8	12	4	0	2	0
30	63	19	12	10	2	0	5
31	52	11	8	7	0	0	0
36	49	13	7	20	3	0	2
Average	57·0	12·0	8·2	9·6	1·0	0·4	1·4
(c) All 19 years							
Average	105·5	11·9	16·6	15·4	1·9	4·8	2·5

It is clear from this table that there is a very strong link between warm/hot days in July and honey yield; the comparison between 9·4 and 0·4 is very striking. The only year which really does not agree closely with the premise that hot Julys are associated with high honey yield is 1919, when August was quite hot, and so was May and to a lesser extent June.

The lack of sensitivity of June as an indicator is suggested by the closeness between the average number of occasions with temperatures above 20°C in June in all years (11·9) and in the bad honey years (12·0). Another interesting feature in this table is the difference between the average number of warm/hot days in July and in August in years with high honey yields, although the average number of days with temperatures above 20°C for all 19 years *(c)* is not very different between the 2 months.

Honey yields and final stratospheric warming. Mr N. E. Davis has given a correlation between high honey yield and his optimum summer weather index,[4] and has also noticed a close relationship between honey yield and the date of final stratospheric warming. The onset of the warming over the British Isles is often sudden and well marked and can usually be categorized as either early or late (Ebdon[5]); but occasionally the onset is less clear cut and then categorization is more difficult. There is also a well-marked relationship between the date of warming and the July temperatures.

Figure 2 shows the relationship between early and late warming, honey yields and the number of days in July with temperature above 20°C. The agreement is not quite as perfect as the figures suggest because 1960, 1963 and 1967 were by no means clear-cut examples of years with early or late warming. However, the agreement between early warming and high honey yields and the number of warm/hot Julys appears striking.

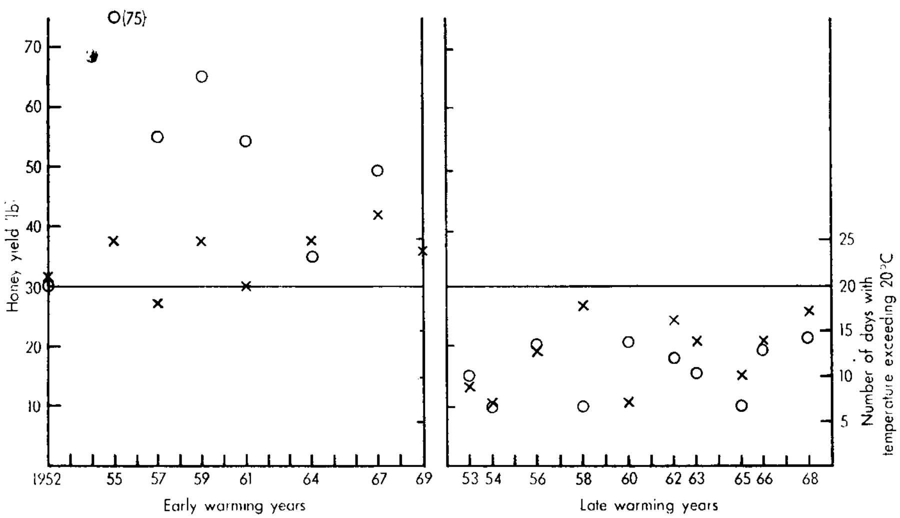

FIGURE 2—HONEY YIELDS FOR GREAT BRITAIN AND JULY TEMPERATURES AT KEW EXCEEDING 20°C RELATED TO EARLY AND LATE STRATOSPHERIC WARMING

o Honey yield x Temperature exceeding 20°C

The future. One cannot do a great deal more about casting into the future than review the past and attempt to draw cautious conclusions. In Hurst,[2] summer average temperatures from 1841 to 1968 were reviewed, and it might be of interest briefly to summarize these data (brought up to date) (Table V).

TABLE V—FREQUENCY DISTRIBUTIONS OF SUMMER TEMPERATURES OVER THREE PERIODS BETWEEN 1841 AND 1969

Period	Summer temperature	Number of occasions in period	Proportion in 10 years
1841–1930	W/VW	10	1·1
1931–50	W/VW	5	2·5
1951–69	W/VW	2	1·1
1841–1930	C/VC	50	5·5
1931–50	C/VC	4	2·0
1951–69	C/VC	8	4·2

VW Very warm } departure from average ≥2·0 degF; VC Very cold
W Warm } departure from average of 1·0–1·9 degF; C Cold

Out of interest, spring figures are very similar, and details will be found in the same paper. The reason why the number of C/VC years is so much higher than W/VW is of course that the standard period for calculation of the average temperatures is 1931–60, a warm period as we have seen.

Lamb[6] gives a very interesting diagram, partly reproduced as Figure 3, which shows patterns of mean temperature in high summer (July and August) for nearly 300 years as decade averages, based on Manley's data,[7] with a curve showing the 100-year average running means back to the year 1500.

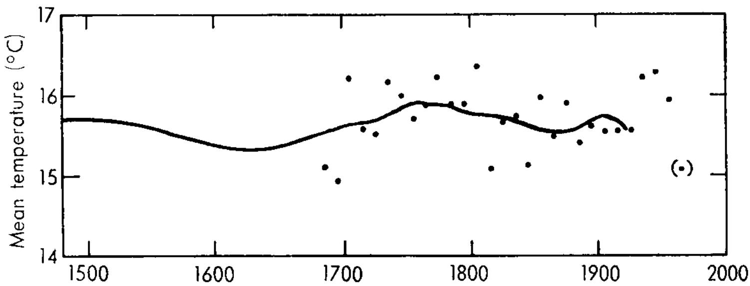

FIGURE 3—MEAN AIR TEMPERATURE IN CENTRAL ENGLAND IN HIGH SUMMER DURING THE PERIOD 1680–1965 (AFTER MANLEY[7]) WITH 100-YEAR RUNNING MEANS BACK TO 1500

• Mean temperature as decade average

Obviously the earlier records must be somewhat less reliable than the more recent, but even with this reservation, it is difficult not to recognize that the 1930s and 40s were amongst the warmest three or four decades during the period, and at no time were there two other consecutive decades with temperatures as much above average. The tentative figures for the 1960s show the decade to be one of the coolest on record. It is impossible to extrapolate with real confidence from this type of information, but one can certainly say there are no obvious grounds for optimism that summer temperatures will be high in the next decade or two.

Conclusions.

(i) A strong relationship has been shown between years with a warm or hot high summer (especially July) and years with high honey yields.

(ii) Records of temperature deviation from average show that the 1930s and 1940s are two of the warmest decades for summer temperatures over the last 300 years. Several different forms of analysis for more detailed meteorological data from 1841 onwards agree with this conclusion.

(iii) A relationship exists between the date of onset of stratospheric warming and honey yield and July temperatures in the following summer.

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551.509.311:551.515.8

AN UNEXPECTED DETERIORATION IN WEATHER CONDITIONS IN A NORTH-WESTERLY AIRSTREAM AT BRUGGEN, NORTH-WEST GERMANY, ON 28 JUNE 1966

By D. W. SUTTON

Introduction. In a forecast of weather conditions for the area around Bruggen, issued at 0700 GMT on 28 June 1966, the day was expected to be partly cloudy to cloudy with occasional showers but with a belt of rain and low stratus, associated with an occlusion, affecting Bruggen during the evening. In fact a marked deterioration set in soon after 0900 GMT and conditions remained worse than expected almost throughout the day. (Place names are shown on Figure 5*(b)*.)

The synoptic situation. At 00 GMT a depression of 989 mb was centred over Denmark with an associated cold front from the centre to Cologne to Orléans moving quickly east. A strong west-north-westerly gradient (40–50 kt) soon became established over north-west Germany extending back across the North Sea to Scotland. During the day the depression moved slowly east-south-east and the gradient over north-west Germany and the North Sea slowly veered, because there were more rapid pressure rises over Scotland and the northern North Sea than over Germany (see Figures 1*(a)* and *(b)*). The back-bent occlusion from the depression centre to north-east Scotland at 00 GMT was dropped from the 06 GMT and later charts, as the thickness analyses gave no evidence of an occlusion extending as far back across the North Sea as this. In fact a thermal trough extended down the North Sea at 00 GMT and had penetrated well into north-west Germany by 12 GMT (axis Rotterdam to Essen to Berlin). However, there was evidence of a fairly well-marked trough over the North Sea at 00 GMT, up to the 300-mb level, although this had become relatively shallow by 12 GMT.

Basis for forecast weather conditions. The whole forecast hinged on the presence of the back-bent occlusion from the depression centre to north-east Scotland and most of the evidence available did in fact point to the presence of this occlusion. It seemed a good way of explaining the rain which

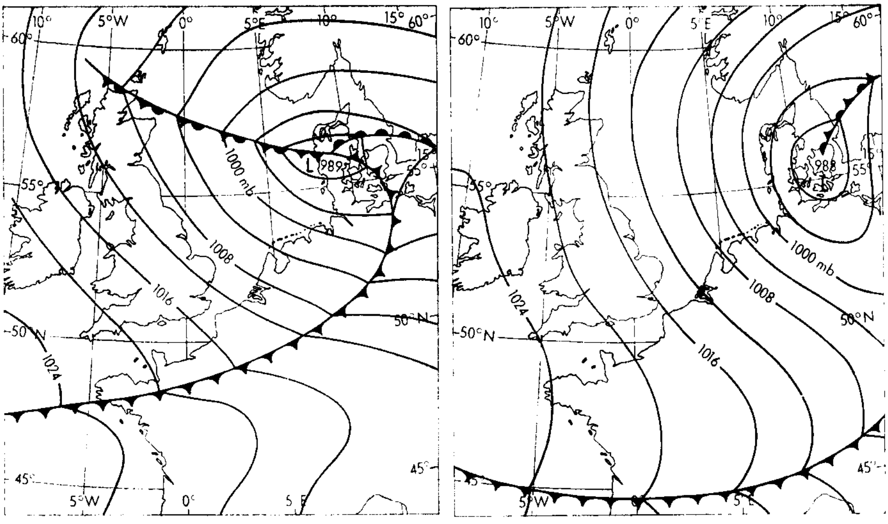


FIGURE 1—SURFACE SYNOPTIC SITUATION, 28 JUNE 1966

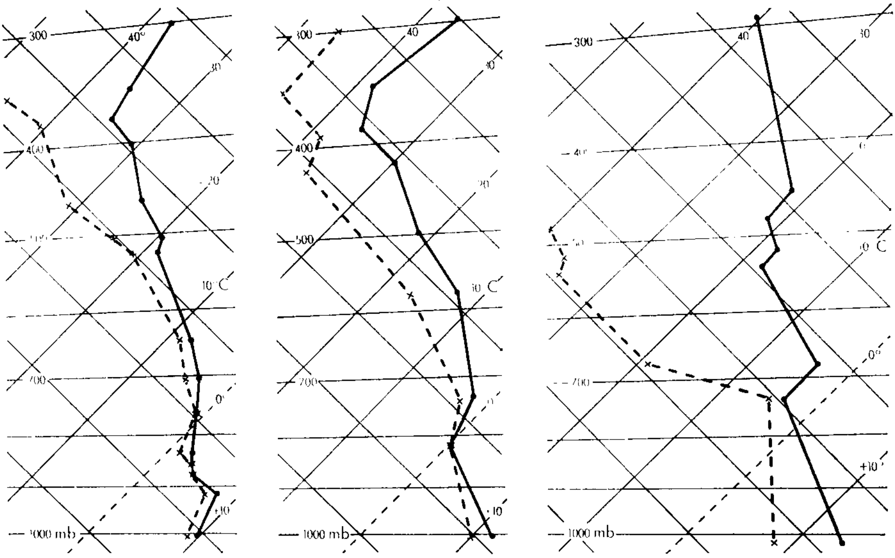
was occurring over east Scotland at 00 GMT and 03 GMT and the Shanwell ascent was quite moist compared with those further south, although no warmer. There was also some historical evidence for the occlusion; the Bracknell analyses of the previous day, and for that matter at 00 GMT as well, had all shown an occlusion extending back from the main depression centre.

Once committed to the presence of the occlusion the rest of the forecast followed quite logically, the upwind ascents at De Bilt, Emden, Uccle, Hemsby, and Aughton were all unstable but reasonably dry, and neither general rain nor any appreciable wind veer could be expected until the passage of the occlusion during the evening.

The actual weather conditions at Bruggen and over north-west Germany. By 03 GMT the cold front had cleared north-west Germany and the weather was mainly dry with variable stratocumulus and cumulus south of 53°N, but with outbreaks of rain and patchy low stratus over the extreme north of Holland and north-west coasts of Germany. However, by 07 GMT outbreaks of rain were showing up along the whole of the Dutch coast and by 10 GMT periods of rain or drizzle were affecting the whole of Holland and all German stations north of 50·5°N.

The rain reached Bruggen at about 0830 GMT and rain or drizzle was almost continuous during the morning becoming intermittent during the afternoon and evening. Stratus, 6/8–8/8, soon formed in the precipitation with base in the range 600 to 1000 feet (confirmed by aircraft reports) during the morning, lifting slightly during the afternoon with the lower cloud becoming more broken and cumuliform. Visibility was reduced to the 1·0 to 3 n.miles range during the morning but improved to 5 to 10 n.miles during the afternoon.

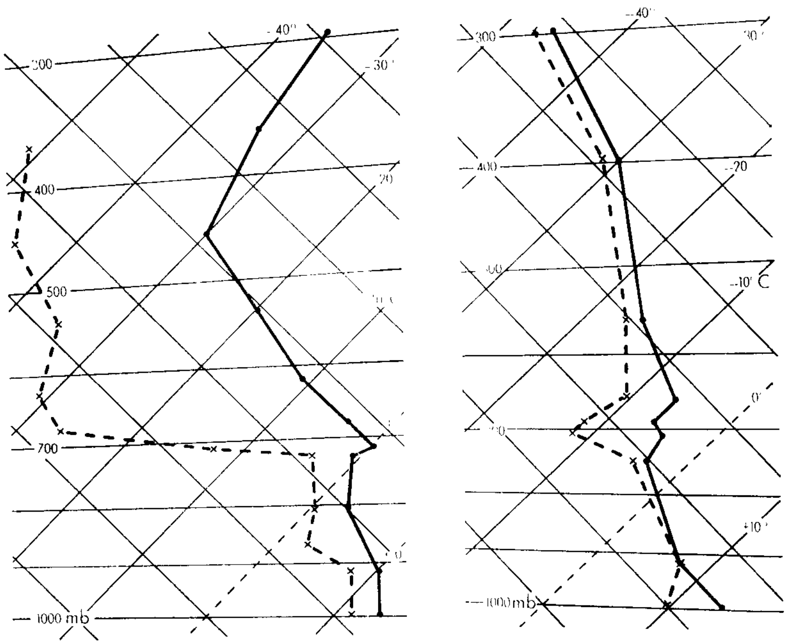
The 12 GMT Essen ascent gives a good representation of the cloud conditions at Bruggen during the late morning period; a change occurred to the 12 GMT De Bilt ascent during the afternoon. The 12 GMT Uccle ascent, just outside the main rain area, seems a good example of the type of air mass originally forecast for the Bruggen area. (See Figure 2.)



(a) Essen *(b)* De Bilt *(c)* Uccle

FIGURE 2—ASCENTS FOR 12 GMT, 28 JUNE 1966

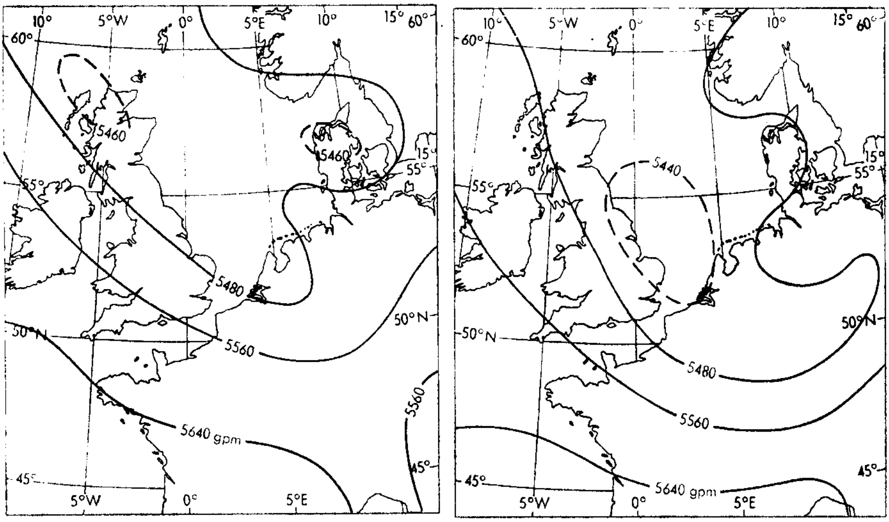
Probable reasons for the deterioration. A study of the 00 GMT and 12 GMT upper air ascents for De Bilt, Essen and Hemsby tends to rule out the possibility of the precipitation being frontal in nature, all the ascents being



(a) 00 GMT *(b)* 12 GMT

FIGURE 3—ASCENTS FOR EMDEN, 28 JUNE 1966

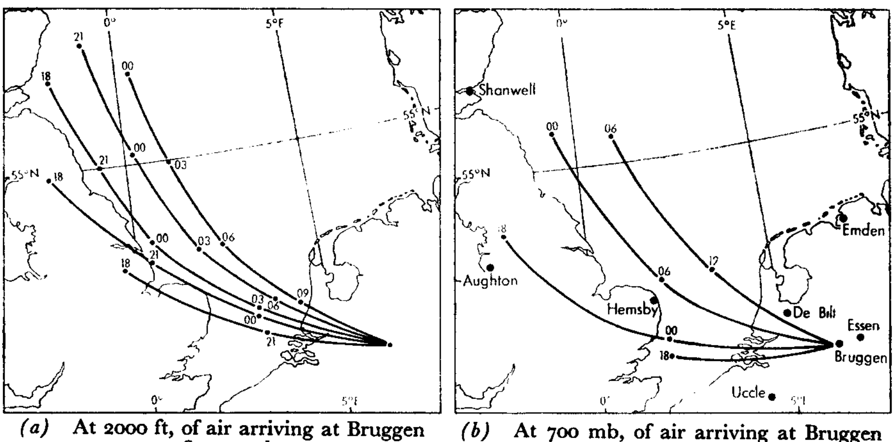
slightly cooler at 12 GMT than at 00 GMT, although all show considerable moistening in the lower layers (up to 600 mb). The Emden ascents (Figures 3*(a)* and *(b)*) however, also show considerable moistening of the upper layers (600 mb to 300 mb) between 00 GMT and 12 GMT, and also some warming at these levels. This can probably best be explained by drawing a short, slow-moving, back-bent occlusion from the depression centre westwards, there being evidence on the Offenbach thickness analysis for 00 GMT (Figure 4*(a)*) of a short tongue of slightly warmer air extending back from the depression centre along the 55°N line of latitude (just north of Emden) moving to near or just south of Emden by 12 GMT (Figure 4*(b)*). The initial



(a) 00 GMT *(b)* 12 GMT

FIGURE 4—OFFENBACH 500–1000-mb THICKNESS ANALYSES, 28 JUNE 1966

dryness of the post-frontal ascents at 00 GMT was probably due to the air having a comparatively short sea track from Britain (see Figures 5*(a)* and



(a) At 2000 ft, of air arriving at Bruggen at 00, 03, 06, 09 and 12 GMT on 28th

(b) At 700 mb, of air arriving at Bruggen at 00, 06, 12 and 18 GMT on 28th

FIGURE 5—TRAJECTORIES BACKWARDS FROM BRUGGEN ON 28 JUNE 1966

(b)), another possibility being the presence of a zone of drier air immediately behind the cold front. However, there seems little doubt that the moistening of the lower layers was due to the veering gradient producing a long sea track. Figures 5*(a)* and *(b)* seem to confirm this, both the 2000-ft and 700-mb trajectories showing a marked change from short to long sea track between 00 GMT and 12 GMT. The trajectories also show why the precipitation extended only as far south as 50·5°N, at least during the morning.

The fairly well-marked trough previously mentioned over the North Sea at 00 GMT, probably goes some way towards explaining why the air over the North Sea was so moist to such a high level, and although the trough had become quite shallow by 12 GMT, the subsequent 12 GMT ascents and also the 00 GMT Shanwell ascent seem to confirm that there was in fact quite a large area of moist air over the North Sea at 00 GMT, somewhat unstable to sea temperatures.

It is thought that the strength of the gradient was at least partly responsible for the persistence of the rain and low cloud, the temperature inland remaining around 12 to 13°C all day, a degree or so below the coastal temperatures. With a less-strong gradient or less-persistent precipitation it is thought that insolation would have been sufficient to at least have raised the temperature a few degrees and the cloud base to cumulus levels.

Discussion. It is probably true to say that more forecasting errors are made in the Bruggen area with the surface gradient in the north-west quadrant than in any other. These errors are mainly due to some unexpected (i.e. unobserved) phenomena being advected from the North Sea, or insufficient weight being given to local upslope effects. This situation provides a good example of the former. The bulk of the evidence pointed to a partly cloudy to cloudy day with occasional showers, although in retrospect there was probably enough evidence to strike a note of caution in the forecast, e.g. the comparatively large pressure rises over Scotland, showing up as early as 21 GMT on 27 June, implying a slow veer in gradient and lengthening sea track of the air reaching Bruggen.

To sum up, it is thought that all that can be done in these circumstances is to keep a close watch on the Dutch coastal observations and take the appropriate amendment action when it becomes obvious that the original forecast will be wrong. Of course a weather ship in the North Sea would often make the situation easier to handle.

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REPORT ON A SEMINAR ON WEATHER SATELLITE CLOUD PHOTOGRAPHS, HIGH WYCOMBE, OCTOBER 1969

By N. HOLDSWORTH

On 2 October 1969 a seminar on weather satellite cloud photographs was held by the U.S. Air Force at High Wycombe, Bucks. The major part of this was concerned with analysis techniques and the relation between cloud photographs and the synoptic chart. The more noteworthy items have been reproduced in diagram form to accompany this note.

Figure 1 shows the relationship between *(a)* active and *(b)* inactive surface

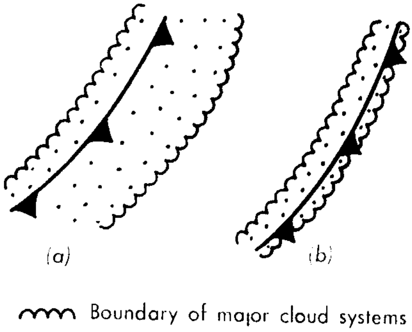

FIGURE 1—SURFACE COLD FRONT RELATED TO COLD-FRONT CLOUD BAND
(a) Active front *(b)* Inactive front

cold fronts and the associated cloud band. This is a generalization of course and not every front will conform, but in most cases the relationship will hold.

Figure 2 shows vorticity in the cold air behind a cold front. A vorticity centre of this kind can induce a wave on the cold front when it is located within about 400 miles of the front. The surface isobars may not reveal the presence of this feature but it is usually well marked on the cloud photograph.

With a mature depression the vortex centre will eventually become divorced from the warm air. Cold air moving round the vortex will be comparatively free from cloud in many cases and will show as a wedge of clear air, the so called 'dry slot', wrapped around the centre. Further deepening of the depression is unlikely after the dry slot has moved to the top side of the vortex as shown in Figure 3.

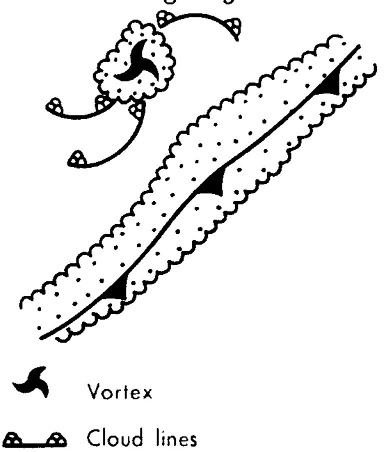

FIGURE 2—VORTICITY CENTRE IN THE COLD AIR WITHIN ABOUT 400 MILES OF THE COLD FRONT MAY INDUCE A FRONTAL WAVE

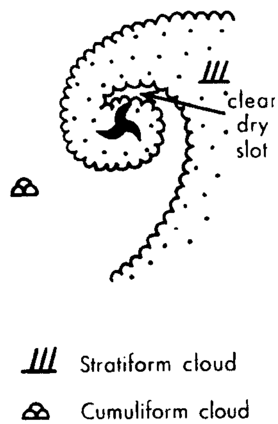

FIGURE 3—FURTHER DEEPENING OF THE VORTEX IS UNLIKELY WHEN THE 'DRY SLOT' OF COLD AIR HAS CIRCULATED TO THE TOP SIDE OF THE VORTEX

The location of the 500-mb trough in relation to cloud features is illustrated in Figures 4 and 5. The comma-shaped cloud shown in Figure 4 is the familiar pattern of cloud associated with positive vorticity advection (pva max). It

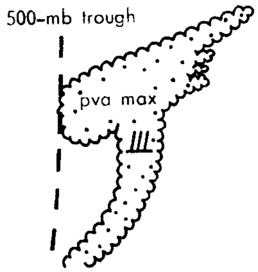

FIGURE 4—500-mb TROUGH LOCATION ASSOCIATED WITH A pva MAXIMUM
pva = positive vorticity advection

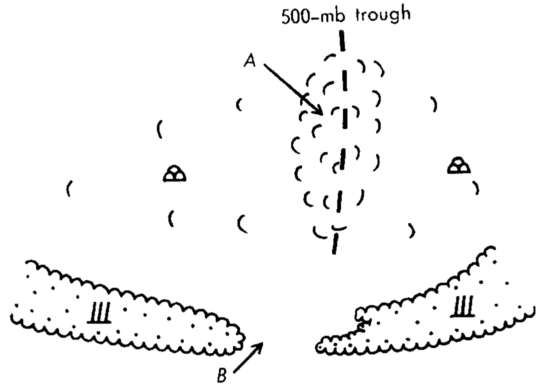

FIGURE 5—500-mb TROUGH MARKED BY ENHANCED CUMULUS DEVELOPMENT, *A*, AND WEAKENED FRONTAL CLOUD, *B*

signifies the intensification of cyclonic motion. The 500-mb trough line can be related to the rear edge of the main cloud mass. Figure 5 shows the 500-mb trough as a zone of increased cumuliform cloud. The frontal link to the south shows a break in frontal cloud on and behind the trough line.

Cirrus clouds associated with high-level troughs and ridges form in extensive bands between the trough and a line just ahead of the preceding ridge — see Figure 6. Cirrus will sometimes spread downwind ahead of the ridge but generally cloud in this area is weak.

In the case of the polar-front jet stream the cirrus cloud is a warm air feature. The strongest winds coincide with the cloud edge as shown in Figure 7. Lateral banding appearing in the jet cirrus is indicative of turbulence in the area.

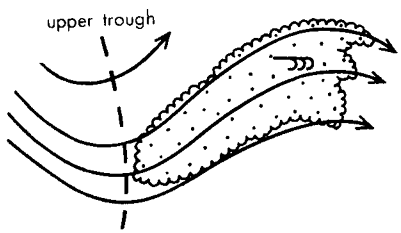

FIGURE 6—LOCATION OF CIRRUS CLOUD ASSOCIATED WITH UPPER RIDGES AND TROUGHS

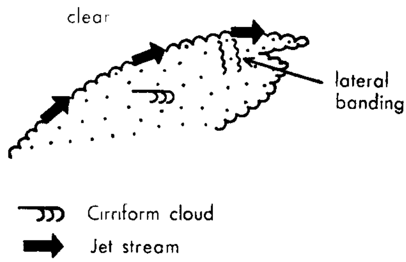

FIGURE 7—LATERAL BANDING IN JET-STREAM CIRRUS SUGGESTS TURBULENCE

Surface ridges can be identified in polar air as cloud type discontinuities, (Figure 8). Southerly flow tends to be stratiform and northerly flow cumuliform. However, these features are often obscured by higher cloud.

The subtropical surface ridge line is more easily seen and Figures 9, 10 and 11 show some methods of location. Cloud type identification is shown in Figure 9 with stratocumulus type cloud to the north of the ridge line and

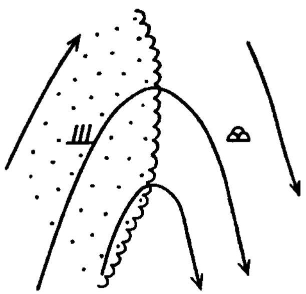

FIGURE 8—SURFACE RIDGE LOCATION IN POLAR AIR BY REFERENCE TO CLOUD TYPE

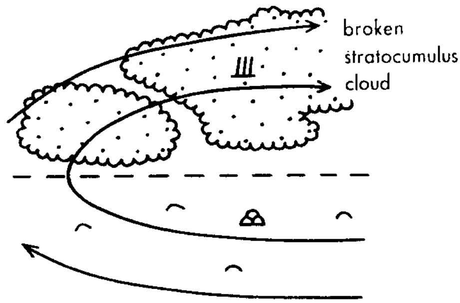

FIGURE 9—SURFACE RIDGE LOCATION IN SUBTROPICAL AIR BY REFERENCE TO CLOUD TYPE

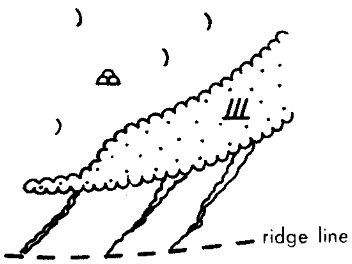

FIGURE 10—SUBTROPICAL SURFACE RIDGE LINE INDICATED BY THE TERMINATION OF CLOUD FINGERS FROM A COLD FRONT

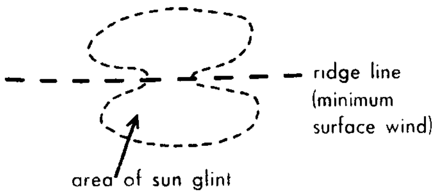

FIGURE 11—SUN GLINT INDICATING THE SUBTROPICAL RIDGE LINE. MINIMUM SUN GLINT AREA CAN BE EQUATED WITH LOW SURFACE WIND SPEEDS

cumulus cloud to the south. A front to the north of the ridge, Figure 10, will sometimes show narrow lines of cloud (cloud fingers) extending towards the high pressure centre and these often terminate on the ridge line. A third method using sun glint can sometimes be employed. The image of the sun reflected by the sea surface is small and intense when the sea is smooth. As the surface becomes rougher the image becomes larger and more diffuse. Figure 11 shows how the diminished area of sun glint can be related to the minimum surface wind associated with the ridge line. This method can only be employed satisfactorily in lower latitudes, i.e. south of the polar front.

A new term 'occluded frontogenesis' was used during the seminar. This is intended to indicate the development of a pseudo-occlusion or trough line connecting a secondary depression or wave to the primary and having the characteristics of an occlusion without having undergone the preliminary occluding process, Figure 12. This term is in common use amongst American meteorologists but as yet has not earned official status.

The climatological aspect of satellite cloud photography was also introduced. In the U.S.A., computers are used to process and store cloud data. This information is then reprinted in various ways to facilitate climatological study. For example, charts of mean cloudiness are produced covering periods of from 5 to 90 days. These charts can be compiled into a time-lapse film and

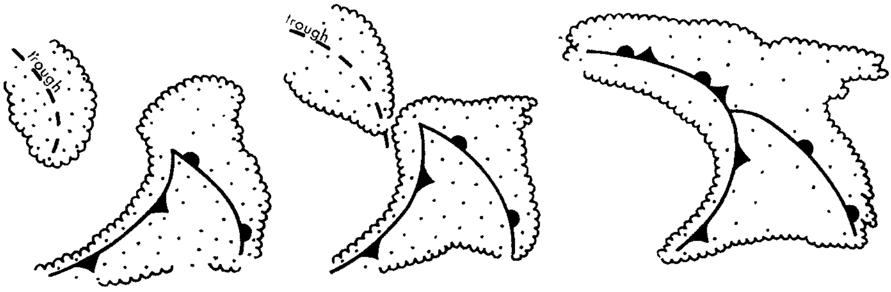

FIGURE 12—THREE STAGES IN THE PROCESS OF OCCLUDED FRONTOGENESIS

when shown in this way illustrate the seasonal fluctuations of semi-permanent synoptic features such as the intertropical convergence zone and the subtropical anticyclones.

Time-lapse film sequences from the stationary satellite ATS I over the Pacific are also prepared. The original photographs are taken every 30 minutes, and even a one-day sequence can be very revealing. It is now current practice in the U.S.A. to prepare such films on a daily basis to assist operational weather forecasting.

Infra-red photographs available from the NIMBUS III satellite provide useful information on the position and intensity of the major cloud systems during the night-time period. The direct read-out facility used by the British Meteorological Office is received in seven shades from black to white representing temperatures from 185 degrees Kelvin to 330 degrees Kelvin (− 88°C to + 57°C). The main cloud features can be seen on these photographs but small differences of temperature are not apparent. Future developments are expected to include improved direct read-out infra-red data and further work in the field of carbon-dioxide radiation measurements.

The following is a selection of useful references :

POTHECARY, I. J. W. and RATCLIFFE, R. A. S.; Satellite pictures of an old occluded depression and their usefulness in analysis and forecasting. *Met. Mag., London*, **95**, 1966, pp. 332–338.
POTHECARY, I. J. W. and JAMES, D. G.; Some aspects of satellite meteorology. *Met. Mag., London*, **94**, 1965, pp. 193–202.
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CORMIER, R. V. and DOWNEN, D. W.; A digest of the interpretation of meteorological satellite data. *Navy Weather Research Facility Tech. Paper* No. 8–68, Norfolk, Virginia, 1968.

REVIEW

A 700 mb atlas for the northern hemisphere, by E. W. Wahl and J. F. Lahey. 280 mm × 220 mm, pp. 147, *illus.*, University of Wisconsin Press, c/o American Universities Publishers Group, 27–29 Whitfield St, London, W.1. Price: 47*s*.

This is a very nicely produced atlas showing the 5-day mean 700-mb height field over the northern hemisphere for each pentad of the year together with similar charts of standard deviation and of height change from one pentad to the next. It follows a similar atlas of 5-day mean sea-level pressure charts for the northern hemisphere which was published by the University of Wisconsin Press in 1958.

The maps were produced from 15 years of daily data (1951–65) for each of 469 grid points covering the northern hemisphere. Each grid point therefore on the pentad maps was the average of 75 values (except for the pentad containing 29 February which had more). Although daily charts for 00 and 12 GMT were available these mean charts were produced using only the 12 GMT data. The intension here was to avoid diurnal effects and at the same time to use the greatest amount of data.

These charts will form a valuable addition to the armoury of the synoptic climatologist; they are useful in drawing attention to major pentad-to-pentad changes and may lead to better understanding of the hemispherical nature of some of the well-marked singularities.

Although the quality of the reproduction is very good, one would like to have seen, at least faintly, the major latitude and longitude lines on the maps. It is also rather surprising that units throughout are in feet despite the almost universal use of decametres for this type of work since the late 1950s.

One looks forward to the promised production of similar charts for other levels, indeed it is surprising that 500 mb was not the first level to be considered but this was probably because the 700-mb data were more readily available. Altogether this is a very useful atlas and the first of its kind I have seen.

R. A. S. RATCLIFFE

NOTES AND NEWS

International co-operation in weather investigations in November 1969

During the month of November 1969, meteorologists all over the world, with the aid of mariners, pilots and volunteer weather observers from many walks of life, assembled a collection of data about the state of the atmosphere which will be the most extensive yet compiled.

This was done in support of the basic data set project arranged by the Joint Organizing Committee for the Global Atmospheric Research Programme (GARP). GARP is a joint international venture of the World Meteorological Organization and the International Council of Scientific Unions, aimed at the investigation of scientific problems which stand in the way of a fuller understanding of the atmosphere's structure and behaviour. The basic data set project is designed to provide fundamental information for the planning of the global GARP experiment, to take place in the middle seventies.

In addition to the substantial extra contribution by all meteorological services of the world, active support to the project was given by the International Air Transport Association, the International Federation of Airline Pilots' Association and the International Civil Aviation Organization. Thanks to these agencies, pilots of scheduled airlines observed and reported weather conditions on the world air routes. Arrangements were also made for pilots of non-scheduled flights and government aircraft to participate.

Aims of the project are to gather from every possible source information additional to that provided on a routine basis by the international weather observation network of reporting stations, by satellites, by aircraft, by ships at sea, etc.; these data, some of which will arrive by mail, will then be checked, assembled and analysed at three centres, Washington (U.S.A.) for the northern hemisphere, San José (Costa Rica) for the tropical belt, and Melbourne (Australia) for the southern hemisphere.

The data collected during this period will then be available for workers conducting research, mainly with computers, into the behaviour of the atmosphere.

A repetition of this project is planned for June 1970.

OBITUARY

It is with regret that we have to record the death of Mr M. J. Oliver (Scientific Assistant) on 13 November 1969.

THE METEOROLOGICAL MAGAZINE

VOL. 99 NO. 1172 MARCH 1970

CONTENTS

NOTICES

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

and published by

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