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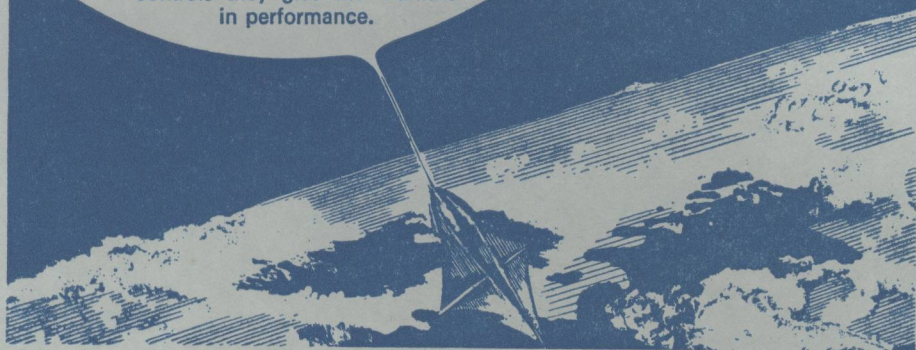
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# THE METEOROLOGICAL MAGAZINE

Vol. 98, No. 1169, December 1969

551-509-334:551-589.1

## AN ANALYSIS OF MONTHLY MEAN PRESSURE PATTERNS NEAR THE BRITISH ISLES, WITH POSSIBLE APPLICATIONS TO SEASONAL FORECASTING

By R. F. M. HAY

**Summary.** A catalogue has been made of monthly mean pressure patterns in the vicinity of the British Isles during each month of the period December 1873 to November 1963. Analysis of the results suggests that a well-known rule due to Baur, related to forecasting for late winter in Germany, can also be applied to central England; and a few other seasonal relationships likely to be useful for long-range forecasting have also been disclosed.

**Introduction.** Monthly pressure patterns near the British Isles have been used in long-range forecasting in a variety of ways besides being a valuable research tool. Recently a catalogue of these patterns has been compiled for each month in the period December 1873 to November 1963 and this catalogue now serves as a homogeneous classification for the period as a whole, and simplifies objective comparisons between particular months and seasons.

The method of classification adopted is broadly similar to the one used by Lamb<sup>1</sup> in the preparation of his catalogue of classified daily synoptic patterns for a similar period of years in the vicinity of the British Isles. A full description of the rules observed by the writer in preparing this catalogue of monthly pressure patterns is available, together with the complete catalogue, in the Meteorological Office, Bracknell.\*

The most useful data in this catalogue are the descriptions of the pressure patterns of each month in terms of their curvature and directions of airflow near the British Isles. Thus the patterns in two typical cases would be described as 'cyclonic westerly' (CW) and 'anticyclonic north-westerly' (ANW). Curvature is related to the three categories — cyclonic (C), straight flow (F) and anticyclonic (A), while direction is given referred to the eight main directions, i.e. N, NE, etc., or to 'no direction' (O).

\* After a little practice a nearly uniform classification of these monthly pressure patterns can be achieved by anyone with sufficient synoptic experience. This was shown by the results of an independent assessment by another scientist of a sample of 98 months selected at random from the whole period covered by the catalogue. Only 2 months were found when the classification he obtained was appreciably different from that given in the catalogue, and another 4 months when the independent description differed slightly from that in the catalogue.

**Analysis of the catalogue.** Only a preliminary analysis of the material has so far been attempted, and this paper presents the results of a study mainly devoted to the winter months.

TABLE I—FREQUENCIES\* OF DIRECTION OF MONTHLY MEAN FLOW NEAR THE BRITISH ISLES IN DECEMBER, JANUARY AND FEBRUARY, SUBDIVIDED ACCORDING TO TEMPERATURE QUINTILES

DECEMBER temperature (quintiles †)	SW	W	Direction of flow							No direction	Totals
			NW	N	NE	E	SE	S			
5	7	7	0	0	0	0	1	2	0		17
4	7	10	0	0	0	0	0	0	0		17
3	10	10	1	0	0	0	0	0	0		21
2	4	9	2	0	0	0	0	2	0		17
1	4	4	4	1	1	1	2	0	1		18
Totals	32	40	7	1	1	1	3	4	1		90
JANUARY temperature (quintiles †)											
5	7	11	0	0	0	0	0	0	0		18
4	9	7	0	0	0	0	0	1	0		17
3	9	7	1	0	0	0	0	1	0		18
2	9	6	0	0	0	0	0	3	0		18
1	3	3	2	2	0	3	5	1	0		19
Totals	37	34	3	2	0	3	5	6	0		90
FEBRUARY temperature (quintiles †)											
5	10	8	0	0	0	0	0	1	0		19
4	6	9	0	0	0	0	0	1	0		16
3	8	8	1	0	0	0	0	1	0		18
2	4	5	6	0	1	0	2	1	0		19
1	0	0	0	2	2	4	4	4	2		18
Totals	28	30	7	2	3	4	6	8	2		90
3-month totals	97	104	17	5	4	8	14	18	3		270

\* Each frequency includes cyclonic, straight-flow and anticyclonic patterns.

† Temperature quintiles related to the month of the same name during winters 1874-1963.

Frequency distributions of monthly pressure patterns by directions and according to quintiles of temperature in central England are given in Table I. (Quintile 1 (very cold) is sometimes denoted in this article by  $T_1$ , and notation such as  $T_{45}$  is used to denote a month with temperature in quintile 4 or 5, i.e. mild or very mild.) Table I shows the following interesting features :

- (i) 31 out of 34 mild Decembers ( $T_{45}$ ) occur with SW and W types of pattern.
- (ii) 7 Decembers (out of 90) showed NW types of pattern; 4 of these were  $T_1$  Decembers and 2 were  $T_2$  Decembers.
- (iii) NW types of pattern are rare in January.
- (iv) 33 out of 35 mild Februaries ( $T_{45}$ ) occur with SW and W patterns.
- (v) 6 out of 7 Februaries having a NW pattern were cold ( $T_2$ ).

**Analysis of winter monthly pressure patterns as a whole.** Tables II and III afford further insight into the characteristics of winters in the British Isles, and show up the high proportion of mild winter months ( $T_{45}$ ) which are associated with SW and W pressure patterns. Table III also shows that a high proportion of very cold and cold winters ( $T_{12}$ ) occur with cyclonic

TABLE II—FREQUENCIES OF DIRECTION OF MONTHLY MEAN FLOW NEAR THE BRITISH ISLES IN DECEMBER, JANUARY AND FEBRUARY, SUBDIVIDED ACCORDING TO CURVATURE OF PRESSURE PATTERNS

Type of curvature	Months	Direction of flow								No direction	Totals
		SW	W	NW	N	NE	E	SE	S		
Cyclonic (C)	December	18	20	4	1	1	0	1	2	1	48
	January	19	13	2	1	0	0	1	4	0	40
	February	12	14	2	0	1	0	1	5	1	36
	Winter months	49	47	8	2	2	0	3	11	2	124
		(40*)	(37)	(6)	(2)	(2)	(0)	(2)	(9)	(2)	(100)
Straight flow (F)	December	10	10	0	0	0	0	1	0	0	21
	January	7	9	0	1	0	2	1	2	0	22
	February	6	9	1	0	0	0	1	1	0	18
	Winter months	23	28	1	1	0	2	3	3	0	61
		(37)	(46)	(2)	(2)	(0)	(3)	(5)	(5)	(0)	(100)
Anticyclonic (A)	December	4	10	3	0	0	1	1	2	0	21
	January	11	12	1	0	0	1	3	0	0	28
	February	10	7	4	2	2	4	4	2	1	36
	Winter months	25	29	8	2	2	6	8	4	1	85
		(29)	(34)	(10)	(2)	(2)	(7)	(10)	(5)	(1)	(100)

\* Figures in brackets are percentage frequencies.

TABLE III—FREQUENCIES OF DIRECTION OF MONTHLY MEAN FLOW IN WINTER NEAR THE BRITISH ISLES, SUBDIVIDED ACCORDING TO OVERALL WINTER TEMPERATURE QUINTILES AND TO CURVATURE OF PRESSURE PATTERNS

Type of curvature	Quintiles	Direction of flow								No direction	Totals
		SW	W	NW	N	NE	E	SE	S		
All types	5	28	23	1	0	0	0	1	4	0	57*
	4	24	25	1	1	1	0	0	2	0	54
	3	24	19	5	0	0	1	3	4	1	57
	2	10	25	6	1	3	1	1	3	1	51
	1	11	12	4	3	0	6	9	5	1	51
	All	97	104	17	5	4	8	14	18	3	270
Cyclonic (C)	5	15	9	0	0	0	0	1	2	0	27
	4	12	11	0	0	0	0	0	2	0	25
	3	14	11	0	0	0	0	1	3	1	30
	2	4	12	5	0	2	0	0	1	1	25
	1	4	4	3	2	0	0	1	3	0	17
	All	49	47	8	2	2	0	3	11	2	124
Straight flow (F)	5	4	9	0	0	0	0	0	1	0	14
	4	7	7	0	0	0	0	0	0	0	14
	3	5	4	1	0	0	0	1	0	0	11
	2	5	4	0	1	0	0	1	1	0	12
	1	2	4	0	0	0	2	1	1	0	10
	All	23	28	1	1	0	2	3	3	0	61
Anticyclonic (A)	5	9	5	1	0	0	0	0	1	0	16
	4	5	7	1	1	1	0	0	0	0	15
	3	5	4	4	0	0	1	1	1	0	16
	2	1	9	1	0	1	1	0	1	0	14
	1	5	4	1	1	0	4	7	1	1	24
	All	25	29	8	2	2	6	8	4	1	85

\* The number of years included in each winter temperature quintile differs from the numbers of years included in the monthly temperature quintiles in Table I. The numbers for the winter quintiles are shown below :

Quintile :	$T_5$	$T_4$	$T_3$	$T_2$	$T_1$
No. of winters :	19	18	19	17	17

NW and anticyclonic W patterns. A rearrangement of this data in Table IV contrasts the distribution of cyclonic pattern directions during  $T_{12}$  winters with the distribution during the remaining winters ( $T_{345}$ ).

TABLE IV—FREQUENCY OF DIRECTION OF MONTHLY MEAN FLOW IN WINTER (CYCLONIC PATTERNS ONLY), SUBDIVIDED ACCORDING TO TWO GROUPS OF QUINTILES OF WINTER TEMPERATURE

Winter temperature (quintiles)	Direction of flow					Totals
	SW	W	NW	SE, S	N, NE, E, No direction	
$T_{12}$	8	16	8	5	5	42
$T_{345}$	41	31	0	9	1	82
All	49	47	8	14	6	124

A value of chi-square of 29.23 was found for this  $5 \times 2$  contingency table, which indicates that the difference between the distribution of monthly pressure pattern directions in  $T_{12}$  winters and in  $T_{345}$  winters is significant at better than the 0.1 per cent level. The largest contribution to the value of chi-square is made by winter months having cyclonic NW pressure patterns. Synoptic implications of this result have been discussed elsewhere.<sup>2</sup> Similar tables (not reproduced here) were derived to show distributions of cyclonic pattern directions for  $T_1$  contrasted with  $T_{2345}$  winters, also for  $T_2$  contrasted with  $T_{1345}$  winters, and these suggest that the association of cyclonic NW pressure patterns with  $T_2$  winters is stronger than it is with  $T_1$  winters.

**December pressure patterns and subsequent late winter temperatures (mean of January and February).** Table V yields results of some use for forecasting late winter temperatures (January and February together) in central England.

TABLE V—DISTRIBUTION OF TEMPERATURE IN JANUARY–FEBRUARY FOLLOWING VARIOUS DECEMBER PRESSURE PATTERNS

Curvature	December pressure pattern	Direction of flow	Number of cases in each temperature quintile (January and February)					Totals	Chi-square*
			$T_1$	$T_2$	$T_3$	$T_4$	$T_5$		
Straight flow	}	W	9	2	3	3	3	20	8.0
Anticyclonic									
Cyclonic,	}	W	14	4	6	8	8	40	7.0
Straight flow,									
Anticyclonic	}	SW	1	9	9	7	6	32	6.7
Cyclonic,									
Straight flow,	}	SW	0	4	6	4	4	18	5.3
Anticyclonic									
Cyclonic	}	All directions excluding SW and W	2	3	3	1	1	10	2.0
Cyclonic									

\* The value of chi-square for the 10 per cent significance level is 7.8.

It is evident that westerly patterns (straight flow and anticyclonic) in December are favourable for cold late winters, while south-westerly patterns are not. These results suggest that Baur's rule<sup>3</sup> relating the westerliness of the first half of December over Germany with late winter temperatures in that country, also applies broadly to central England. The last result in the table suggests that any December when the pressure pattern has been cyclonic (with the direction not SW or W) is seldom followed by a  $T_{45}$  winter, although this conclusion is based upon too few cases for it to be significant.

**Applications of monthly pressure patterns to forecasting winter temperatures (central England).** From the catalogue of monthly pressure patterns a table (not included here) was derived, giving frequencies of monthly pressure patterns in each month of the autumns which respectively preceded winters in central England in quintiles 1, 2, 3, 4 and 5. In order to simplify subsequent analysis the 27 individual monthly pressure patterns already described were grouped together. Descriptions of these groups (e.g. cyclonic blocked) were chosen to relate to large-scale synoptic patterns, while the pressure patterns included in each of the seven groups were intended to be representative of synoptic patterns typical of autumn (Table VI).

TABLE VI—GROUPING OF PRESSURE PATTERNS

Group	Description of group of pressure patterns	Pressure patterns included in group
1	Cyclonic blocked	CO, CNE, CE, CSE
2	Anticyclonic blocked	AO, ANE, AE, ASE, FNE, FE, FSE
3	Cyclonic progressive	CSW, CW, CNW
4	Mixed progressive	FSW, FW, FO (col)
5	Anticyclonic progressive	AW
6	Northerly meridional	CN, FNW, FN, ANW, AN
7	Southerly meridional	ASW, CS, FS, AS

A comparison made between the expected and actual frequencies of these seven groups of synoptic patterns in autumn months in a contingency table related to subsequent winter temperatures in central England proved of little value for the forecasting of extreme winters ( $T_1$  and  $T_8$ ). Next the case of winters following autumns when the grouped pressure pattern was cyclonic progressive and/or mixed progressive (groups 3 and/or 4) in all three months was considered. The 24 autumns when these conditions were satisfied were followed by 3, 10, 6, 3 and 2 winters in the quintiles 1 to 5 respectively. For this distribution the value of chi-square is 8.9, which is significant at just below 5 per cent. In this instance a forecast of a winter in  $T_{123}$  would have been correct in 19 cases out of 24, (79 per cent).

The contingency table (not included here) showing associations between monthly pressure patterns in autumn months and subsequent winter temperature quintiles was next used to derive frequencies of cyclonic, straight-flow and anticyclonic patterns in September and October in the same year. In this instance no account was taken of the directions of the patterns. The results, statistically significant in the majority of cases, are shown in Table VII.

TABLE VII—DISTRIBUTION OF WINTER TEMPERATURES FOLLOWING VARIOUS  
PRESSURE PATTERNS IN EARLY AUTUMN

Case	Curvature patterns in :		Winter temperatures (quintiles)					Totals	Chi-square	Significance level <i>per cent</i>	
	Sept.	Oct.	1	2	3	4	5				
1	C	C	}	4	14	9	3	7	37	10.9	4
	F	C									
	C	F									
2	C	C	}	4	11	6	3	2	26	9.8	5
	F	C									
	C	C									
3	F	C		4	6	2	0	0	12	11.3	4
4	A	A	}	5	0	3	7	6	21	7.3	11
	F	A									
	A	F									

Cases 1, 2 and 3 in Table VII are useful for the forecasting of cold winters ( $T_3$ ), while case 4 has some potential value for forecasting mild winters ( $T_{45}$ ).

### Broad-scale considerations.

(i) *For forecasting winter temperatures.* Table VIII shows the relative frequencies of 'progressive' ( $P$ ) and 'blocked' ( $B$ ) months in autumns before winters in the various temperature quintiles. Progressive months have been defined as all months with patterns of groups 3, 4 and 5, and blocked months as all those with patterns of groups 1, 2, 6 and 7 as defined in Table VI.

TABLE VIII—RATIO ( $P/B$ ) OF FREQUENCIES OF PROGRESSIVE ( $P$ ) AND BLOCKED ( $B$ ) MONTHS IN AUTUMNS PRECEDING WINTERS IN SPECIFIED TEMPERATURE

Winter temperature quintile	Autumn	Ratio of progressive/blocked months*					
		Sept.	Oct.	Nov.	{ Sept. Oct.	{ Oct. Nov.	{ Sept. Nov.
5	1.5	2.8	1.1	1.1†	1.9	1.1†	1.9
4	2.0	0.8†	2.0	<b>8.0</b>	1.3†	3.5	2.0
3	2.4	3.7	2.2	1.7	2.8	1.9	2.5
2	<b>4.7</b>	<b>4.7</b>	<b>7.5</b>	<b>3.3</b>	<b>5.8</b>	<b>4.7</b>	<b>3.9</b>
1	1.4†	1.8	0.9†	1.8	1.3	1.3	1.8†
All winters	2.1	2.2	1.8	2.2	2.0	2.0	2.2

\* Progressive months are groups 3, 4 and 5 of Table VI.

Blocked months are groups 1, 2, 6 and 7 of Table VI.

† Minimum ratios in each month or season. Maxima are shown in bold figures.

This table shows that autumns before  $T_2$  winters have a much larger ratio ( $P/B$ ) of progressive to blocked months than autumns before any other type of winter. It is noteworthy also that both autumn and October pressure patterns show little difference in their  $P/B$  ratios between very mild ( $T_5$ ) and very cold ( $T_1$ ) winters. A possible explanation for these small  $P/B$  ratios, found in autumn before both  $T_5$  and  $T_1$  winters, may be that many of these winters also have small  $P/B$  ratios; that is they are rather blocked. Some support for this view can be found in Table III which shows that monthly mean pressure patterns with a south-westerly direction occur more frequently during  $T_5$  winters than during winters of any other type; while patterns with a south-easterly direction occur more frequently during  $T_1$  winters than during any other types of winter. However, a full explanation must await further research.

The high value of  $P/B$  (8.0) found in November before  $T_4$  winters (Table VIII) is worth attention for its possible forecasting value, although the small value found for  $P/B$  before  $T_5$  winters (1.1) suggests that the former value may arise from a statistical accident.

The results considered in this paper suggest that attempts to forecast cold winters ( $T_2$ ) in central England are more likely to be successful than any such attempts for winters in other quintiles, and that further progress is required to find differences in autumn circulation which will distinguish successfully between subsequent very mild and very cold winters.

(ii) *For forecasting spring and autumn temperatures.* Two more associations have so far been found (*a*) between winter and the following spring, and (*b*) between summer and the following autumn, which may be useful in forecasting. Results are shown in Tables IX and X.



TABLE IX—DISTRIBUTION OF SPRING TEMPERATURES FOLLOWING SPECIFIED OCCURRENCES IN WINTER MONTHS

	Spring temperatures (quintiles)					Totals	Chi-square	Significance level
	1	2	3	4	5			
Winter months of mixed progressive* pattern	8	9	6	19	9	51	10.2	Better than 5 per cent
Winters with 1, 2 or 3 months of mixed progressive pattern	7	9	4	16	8	44	8.5	8 per cent

\* Group 4 of Table VI.

TABLE X—DISTRIBUTION OF AUTUMN TEMPERATURES FOLLOWING SPECIFIED OCCURRENCES IN SUMMER

	Autumn temperatures (quintiles)					Totals	Chi-square	Significance level
	1	2	3	4	5			
Summer months of blocked or meridional pattern*	13	13	4	5	5	40	10.5	Better than 5 per cent
Summers with 1, 2 or 3 months of blocked or meridional pattern*	10	10	4	5	5	34	5.1	Not significant
Summers with 1, 2 or 3 months of meridional pattern excluding 1-month occurrences in July	10	9	2	4	4	29	8.4	Approximately 8 per cent

\* Groups 1, 2, 6 and 7 of Table VI.

It is concluded that winters with months showing mixed progressive pressure patterns are significantly associated with mild springs ( $T_4$ ) to follow.

It is concluded that summers with blocked and meridional pressure patterns (notably in June and August) are significantly associated with cold and very cold autumns ( $T_{12}$ ) to follow.

### Conclusions.

- (i) Cold and very cold winters ( $T_{12}$ ) are associated with monthly pressure patterns in which cyclonic NW patterns predominate.
- (ii) In December westerly patterns (straight and anticyclonic isobars) show some association with cold late winters. South-westerly patterns do not seem to be associated with very cold late winters. This result is broadly in line with the rule due to Baur which applies for a similar period over Germany.
- (iii) For autumns when pressure patterns were cyclonic progressive and/or mixed progressive (groups 3 and 4 as defined in Table VI), the 24 winters following had 3, 10, 6, 3 and 2 winters in the quintiles 1-5 respectively.
- (iv) The frequency of progressive months (groups 3, 4 and 5) in autumn shows a gradual increase through colder winters (i.e.  $T_6$  to  $T_2$ ), accompanied in the same circumstances by a large decrease in the frequency of blocked months (groups 1, 2, 6 and 7). October figures agree well with autumn figures while November shows marked disagreement. The relative frequencies of these pressure groups in autumn months before cold winters are markedly different from

those before very cold winters; the autumn values for very cold winters in fact revert to values which are nearly identical with those found before very mild winters.

- (v) Winters with months showing mixed progressive pressure patterns are associated with a mild spring ( $T_4$ ).
- (vi) Summers with months showing blocked and meridional pressure patterns are associated with cold and very cold autumns ( $T_{12}$ ).

**Acknowledgement.** Acknowledgement is due to Mr R. Blair for assistance with processing the data.

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551-577-37:551-589.1

## THE RECORD-BREAKING RAINFALL IN SOUTH-WEST ENGLAND ON 28-29 JULY 1969

By G. C. BRIDGE

The dry and mainly sunny conditions enjoyed by the south-west during July were brought to an abrupt end on the 28th of the month when rain began early in the morning, turning moderate around midday and heavy during the afternoon, thereafter generally persisting at this intensity through the evening and night until around 0300 GMT and finally ceasing at approximately 0800 GMT on the morning of the 29th. The unusual persistence of this intense rainfall led to widespread dislocation of traffic in many parts of Cornwall and Devon, because many roads suddenly acquired a treacherous surface. Roads were obstructed by localized flooding, or by mud, rubble and trees from rapidly swollen streams and rivers. If it had not been for the very dry state of the ground prior to the rain (soil moisture deficits of about 75-100 mm were common), widespread flooding would undoubtedly have occurred, which in conjunction with the relatively high tides at the time would have led to much more drastic consequences.

**Synoptic situation.** The synoptic situation may be seen by reference to Figures 1 and 2. A fairly shallow wave depression with central pressure of approximately 1014 mb had travelled across the Atlantic from west to east close to the 45°N parallel, and had then deepened appreciably to 1006 mb as it turned more east-north-east over the Western Approaches. The depression continued on this track travelling along the English Channel, with the warm front making only slow progress over southern England, but with the cold front accelerating eastwards over France. It would appear that the warm front may well have crossed north-westwards over much of the region during the evening to return eastwards as a pseudo-cold front early in the morning.

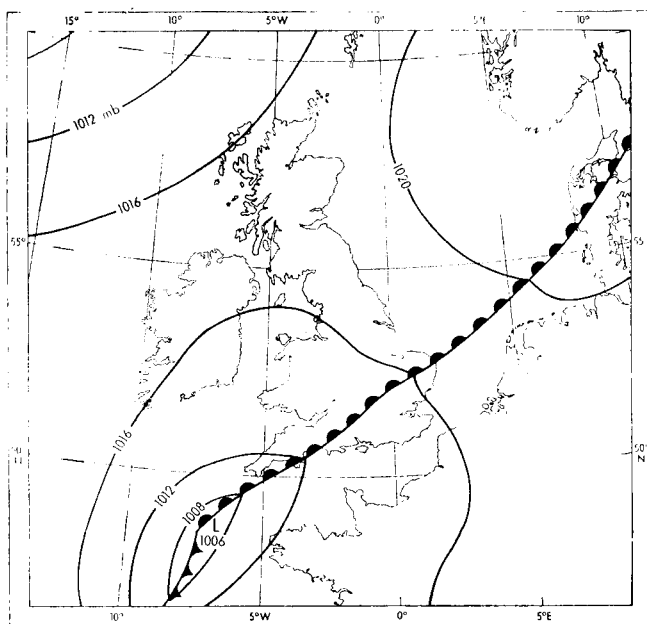


FIGURE 1—SYNOPTIC SITUATION AT 12 GMT, 28 JULY 1969

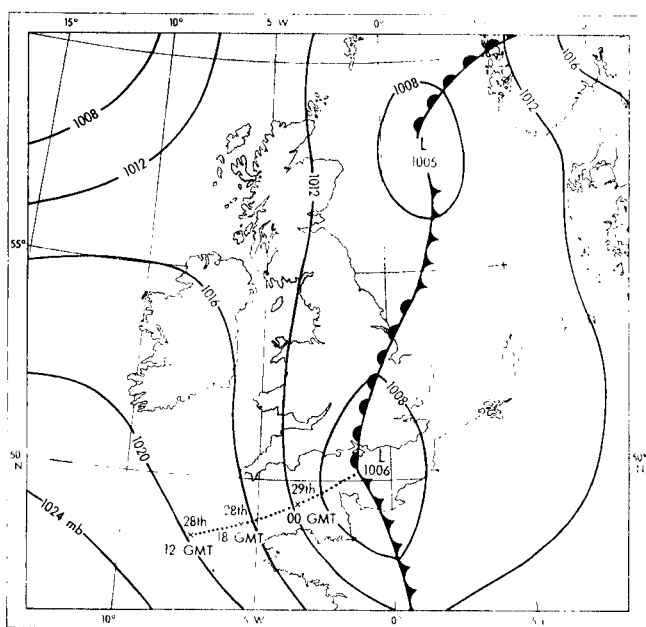


FIGURE 2—SYNOPTIC SITUATION AT 06 GMT, 29 JULY 1969, ALSO SHOWING TRACK OF DEPRESSION DURING PRECEDING 18 HOURS

Inspection of the 1000-500-mb thickness and 500-mb contour chart for 00 GMT, 29 July 1969, as shown in Figure 3, revealed quite marked troughing in the flow aloft associated with the depression. The upper south-south-west winds ahead of the centre maintained the flow of warm moist air which was becoming increasingly unstable as shown by the presence of thunderstorms over France. Continued advection of colder air from the west led to a packing of the thickness lines, or in other words an increased thermal contrast across the front, so enhancing and maintaining its activity. This would give one possible explanation for the persistence and the intensity of the rainfall.

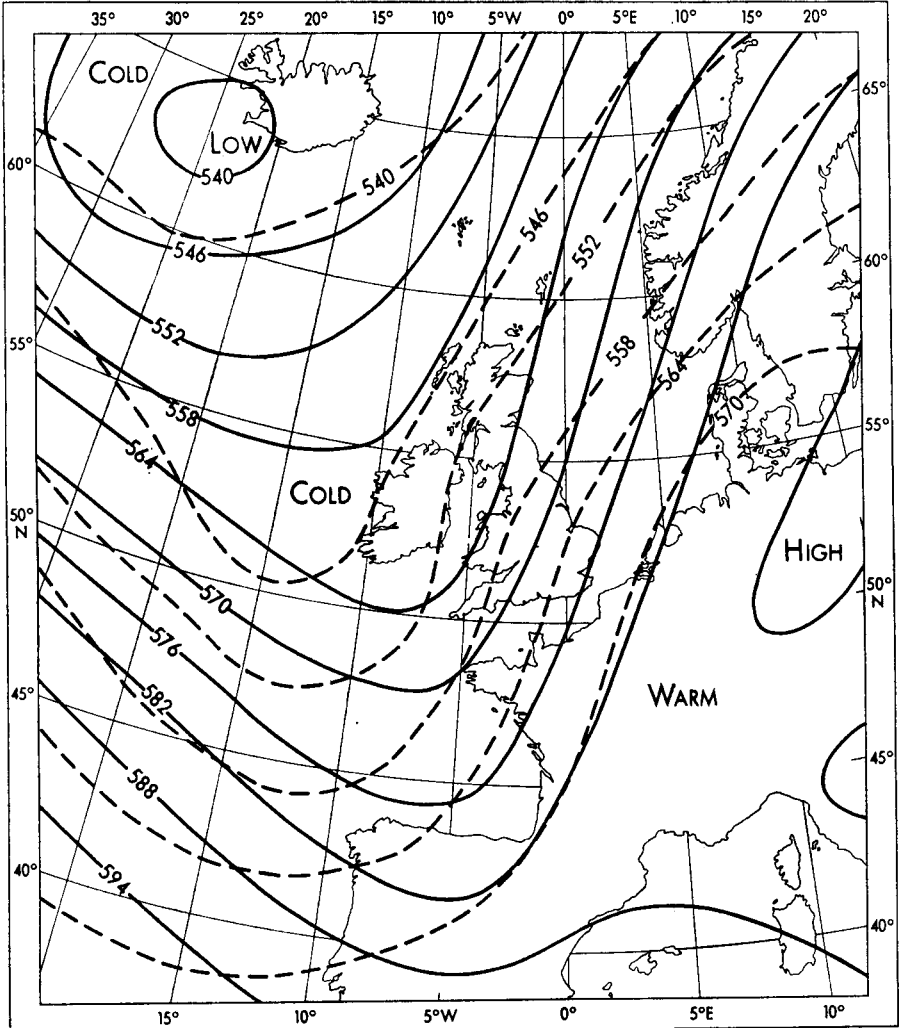


FIGURE 3—ISOPLETHS OF THE 1000-500-mb THICKNESS AND THE 500-mb

CONTOURS AT 00 GMT, 29 JULY 1969

----- 1000-500-mb thickness      \_\_\_\_\_ 500-mb contours  
Thicknesses and contours are expressed in geopotential decametres.

Benwell<sup>1</sup> has written of the possibility of using the jet stream at 500 mb as a predictor of heavy rain. On the occasion now under discussion the speeds

of the jet at 500 mb and 300 mb were marginally of sufficient strength to satisfy his suggested criteria. At 12 GMT, 28 July the direction of the jet was  $220^\circ$ , the most southerly direction of Benwell's criteria, but by 00 GMT, 29 July the jet had backed to  $200^\circ$ .

The pattern of the flow at 500 mb and 300 mb was not dissimilar to that during the period of heavy rain<sup>2</sup> which affected an area from east Devon to the Wash, on 10–11 July 1968.

In the early hours the frontal cloud became more unstable, which in conjunction with probable orographic uplift development, led to the formation of scattered thunderstorms over and to the south of Dartmoor.

**Rainfall and distribution.** The 24-hour rainfall at Mount Batten, Plymouth, totalled 113.2 mm and broke all previous records. Out of a series of observations extending over nearly 50 years at the station, the previous highest daily fall was 77 mm, which occurred on 15 August 1952 at the time of the Lynmouth flood disaster. The July monthly total was 132.7 mm, compared with the 35-year mean monthly rainfall of 65.5 mm taken over the period 1916–50.

Rainfall records were also broken at the Exeter Airport, Chivenor and St Mawgan Meteorological Office stations, together with those for several of the climatological stations in the area.

The persistent intensity of the rainfall may be seen from the autographic record for Mount Batten, as shown in Figure 4. The highest rainfall rate registered during the late evening was 29.3 mm in 80 minutes, which can be classified as a noteworthy fall. However, under Bilham's 'Classification of heavy falls of rain in short periods', published in *British Rainfall* 1935, the fall of 113.2 mm over a period of about 18 hours can be classed as a 'remarkable' fall. Inspection of the open-scale autographic record revealed a further short-term high fall rate of 2 mm in 2 minutes, which occurred just before midnight. Higher rainfall rates than these have been recorded at the station in the past but the persistence on this occasion was most unusual.

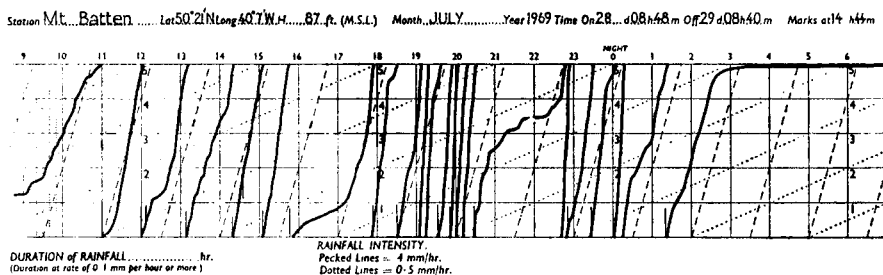


FIGURE 4—DIAGRAMMATIC REPRESENTATION OF RAINFALL RECORD FOR MOUNT BATTEN METEOROLOGICAL OFFICE, 28–29 JULY 1969

This order of fall may well have been fairly general over much of Devon at different times of the night since the Meteorological Office at Exeter Airport recorded a maximum fall rate of 29.7 mm in the hour between 0200 and 0300 GMT.

The rainfall distribution pattern for the south-west may be seen in Figure 5. Isohyets were compiled using data from the meteorological and climatological stations in the area, together with data acquired from the Cornwall, Devon and Somerset River Authorities. These data were collected immediately after the event and do not necessarily include all which may be available; consequently a more detailed examination of the data could give rise to some changes in the isohyets. However, further data obtained from the Devon River Authority since this occasion revealed a much more comprehensive network of gauges and hence isohyets are constructed on the basis of fuller information over Devon than elsewhere. A representative list of gauges may be found in Table I, with their corresponding numbered locations shown in Figure 6 but readings from all gauges were used in constructing the isohyets. The wealth of data for Devon was such that gauges listed are those which represent a fairly even coverage over the area, together with those showing extreme values.

TABLE I—RAINFALL FOR 24 HOURS ENDING 0900 GMT 29 JULY 1969 RECORDED BY VARIOUS RAIN-GAUGES IN THE SOUTH-WEST OF ENGLAND

Location number*	Location	Rainfall mm	Location number	Location	Rainfall mm
1	Penzance	88.1	33	Kings Nympton	100.4
2	St Ives	83.8	34	Brayford	82.4
3	Culdrose	86.4	35	Cheldon Barton	103.9
4	Gwennap	101.8	36	Hillerton	113.0
5	St Mawgan	71.1	37	Avonwick	111.6
6	Constantine Bay	67.8	38	Blackpits Gate	115.1
7	St Austell	93.7	39	Winstitchen	85.9
8	Bugle	74.9	40	Yellam	108.4
9	Delabole	88.9	41	Dartington Hall	105.7
10	Camelford	95.3	42	Porlock	94.5
11	Bude	72.9	43	Newhouse Park	110.0
12	St Cleer	100.3	44	Stoodleigh	106.6
13	Liskeard	99.1	45	Torquay	80.4
14	Hartland Point	58.9	46	Leigh Farm	98.3
15	Bastreet	114.3	47	Tiverton	101.8
16	Launceston	113.3	48	Withycombe	123.2
17	Milton Damerel	95.8	49	Exeter Airport	101.6
18	Virginstow	138.4	50	Clyst St Lawrence	105.9
19	Ellbridge	145.0	51	West Quantoxhead	97.8
20	Eastcott	98.9	52	Crowcombe	106.9
21	Tavistock	125.7	53	Hemyock	113.5
22	Plymouth Hoe	120.1	54	Wellington	106.7
23	Chivenor	70.6	55	Taunton	99.3
24	Mount Batten	113.2	56	Coran	101.6
25	Bury	106.6	57	Yarcombe	100.3
26	Southcott	142.7	58	Wembdon	105.4
27	Barnstaple	58.4	59	Bridgwater	94.0
28	North Hessary Tor	144.4	60	Chard	88.1
29	Princetown Prison	129.5	61	Morecombelake	45.0
30	Okehampton	113.3	62	Priddy	95.8
31	Burrator	114.8	63	Yeovilton	62.7
32	Post Bridge	113.3	64	Salcombe	72.4

\* See Figure 6 for position of location numbers.

The most noticeable feature of the chart is the large area of Devon and east Cornwall with a fall of 100 mm or more, and a peak fall of over 140 mm to the west and south-west of Dartmoor. It is of interest to include at this point the fall of 168.8 mm recorded near Fernworthy Reservoir, on Dartmoor. This gauge however is an interrogable tilting-bucket type and the doubtful accuracy of its recorded rainfall is such that it has not been included in the preparation of the distribution diagram. The BBC transmitting station on North Hessary Tor collected 144.4 mm, whilst Princetown Prison recorded



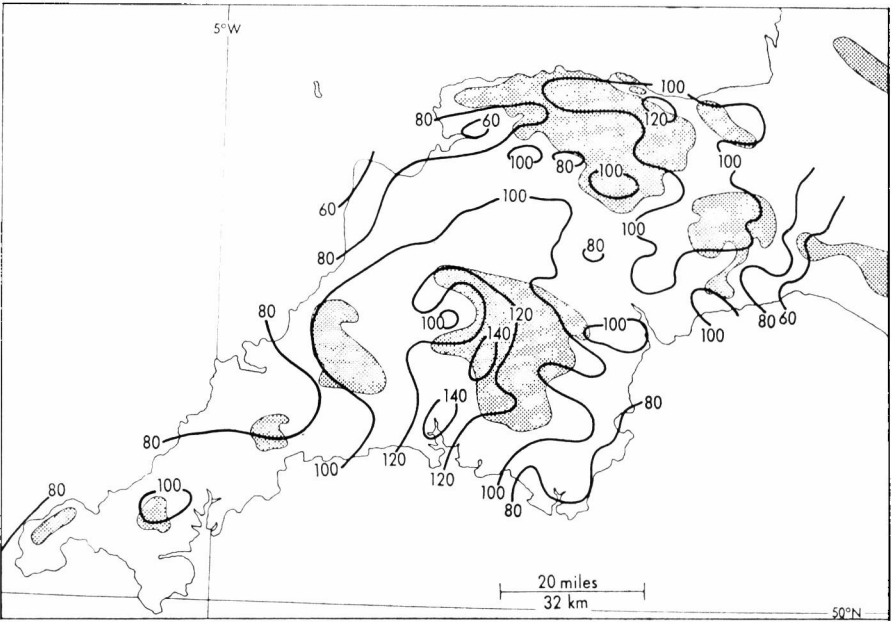


FIGURE 5—RAINFALL FOR THE 24 HOURS ENDING 0900 GMT, 29 JULY 1969  
Isohyets are in millimetres. Ground above 800 feet is shaded.

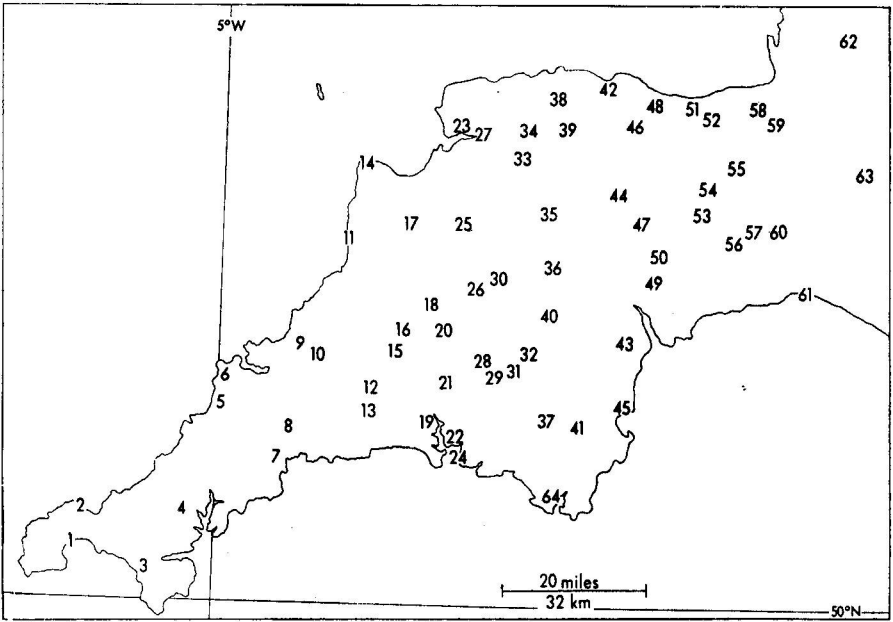


FIGURE 6—DISTRIBUTION OF RAIN-GAUGES LISTED IN TABLE I

129.5 mm on this occasion. Out of nearly 40 years of rainfall observations from the Prison, this value has been exceeded only twice in the past with falls of 136.9 mm in November 1931 and 173.5 mm in November 1946. It is conceivable, however, that this latter fall may well have been equalled or even exceeded on the occasion now under discussion, over a locality on the Moor with maximum exposure.

It is surprising to find the absence of any marked peaks over Exmoor or the high ground on the Devon-Somerset border, but this may well be attributed to the sheltering effect of Dartmoor during the southerly low-level flow prior to the passage of the frontal belt to the east.

In passing, however, it is of interest to recall that between 200 and 250 mm of rain<sup>3</sup> probably fell in 24 hours over parts of Exmoor at the time of the Lynmouth flood disaster in August 1952, but this was localized, and rainfall over the remainder of the region was substantially less than on the occasion here described.

**Acknowledgements.** The author is indebted to the Cornwall, Devon and Somerset River Authorities for making relevant rainfall records available.

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### THE SHELTON REGULATOR CLOCK AT EDINBURGH METEOROLOGICAL OFFICE

By W. K. YOUNG

**Summary.** The probable history of a regulator clock, made in 1756 by John Shelton, is put on record, including its adventures during the last 213 years, its association with the first voyage of Cook around the world, the Mason-Dixon Line, Ben Nevis Observatory, and the first voyage to Botany Bay.

**Introduction.** Any attempt to write the history of a scientific instrument, over a hundred years old, is bound to be dogged by conflicting information or the complete lack of it. However, an effort has been made to compile the adventures of one clock which has been in existence for over 200 years.

This article is based on the facts published in scientific journals during the life of the clock. Three excellent articles by Lt Cdr H. D. Howse (listed on p. 373) which are published in *Antiquarian Horology*, contain most of the references for those who wish to delve further into the individual events.

**John Shelton.** In the eighteenth century, when the modern scientific enlightenment of man commenced, Britain fared well in her share of inventors, explorers and scientists. Some of the greatest names of that period are still spoken of with reverence today.

Sadly, one man who deserves recognition for his craftsmanship is known only to the few interested bodies. Even in his own time he suffered hardships

he had not deserved. This man was John Shelton. Born in 1702 in Clerkenwell, London, he had become apprentice to a clockmaker by the age of 10. Eight years later he became a member of the Clockmakers' Company. While in his forties he worked for George Graham, the inventor of the dead-beat escapement and the mercury pendulum. These years were to bring him to the fore-front as a clockmaker of great repute. So highly thought of was he, that James Short, of the Royal Society, recommended his work to the crown of Russia in 1767.

By 1745 Shelton had his own shop in Shoe Lane, London. An early example of his work, showing little of the design of his later, and more famous, clocks is now kept by the Herschel family. In 1749 while still working for Graham, he made a clock for the Royal Observatory at Greenwich, in Graham's name, and this clock appears to have been used as the basic design on which his later work was modelled.

Alas, his eyesight eventually failed and in 1777 a letter was written on his behalf asking the Royal Society to assist him, as he was destitute. He faded into obscurity leaving only his clocks to sustain his memory.

**Description of the Shelton regulator clock at the Meteorological Office, Palmerston Place, Edinburgh.** The clock in this story is 5 ft 3 in tall and 1 ft 4 in wide at its widest point. The case is made from mahogany and parts of the back are strengthened by a second layer of the same wood. The movement is made of brass and steel and is almost completely in its original form. The face is 12 in square and has separate dials for minutes and seconds. The hours are seen through a small aperture in the central zone of the face. It is extremely accurate and is temperature compensated to perform equally well in all climates. There is one point of design that is unique when compared with the other Shelton regulators. The point of suspension of the pendulum has always been on the case although on other Shelton clocks the suspension was on the movement at first, being altered at some later date. It was assembled in 1756, and John Shelton signed and dated it, a thing he did not do on later clocks. (See Plates I and V.)

**History of the clock.** Several clocks were purchased from John Shelton for the eighteenth century Transits of Venus. It seems almost certain that five Shelton regulators which survive today are the 'Transit' clocks which were bought by the Royal Society and the Board of Longitude. The account which follows gives the most probable history of the Edinburgh clock. There is some difficulty in identifying which of the five clocks was used in various experiments before 1841, though the Edinburgh clock was used, for example, in the Foster experiments of 1828 to 1831, described later in the text. The Rev. Nevil Maskelyne took a Shelton clock, probably the Edinburgh clock, to St Helena to assist in the measurement of the transit of Venus across the sun in June 1761. On this same expedition it was taken to the Cape of Good Hope to make a comparison of gravitational attraction measured at Greenwich, St Helena and the Cape. In 1762 it was returned to London, where it was checked before being sent to Barbados to test the accuracy of the first really usable marine chronometer, 'Harrison's No. 4'. On arrival in Barbados the clock was used as a standard for one year to check the running of 'Harrison's No. 4', which had been entered in a competition, worth £20 000, for the first simple and reliable method of measuring longitude to within half a degree.

In 1765 the same clock probably went on a voyage to America and had its first accident. The ship ran aground on the coast of Pennsylvania. The spring suspension point was broken, and was repaired by Charles Mason and Jeremiah Dixon. The clock was then used to 'measure' the latitude of the boundary between Maryland and Pennsylvania — the 'Mason-Dixon Line'. This having been done, the clock was sent back to London.

After further checks and overhaul the clock was given to Lieutenant James Cook for use in measuring another transit of Venus, due in June 1769. Cook sailed to Tahiti via Cape Horn and after his observations returned to England by way of New Zealand, Australia, Java and the Cape of Good Hope, thus completing one circumnavigation of the earth. It is thought that the next experiment in which the clock was involved was in 1774. The Rev. Nevil Maskelyne, having used the same clock previously, used it in his investigation of the mass of Schiehallion, a mountain in Perthshire. The clock then had a rest and little is known of its whereabouts.

In January of 1787 a large fleet sailed to Botany Bay, in Australia. A Shelton regulator was taken and this was fitted up at Sydney Bay. The clocks used on the second and third voyages of Cook were fitted to tripods, but the clock used in Sydney was mounted on a post in the manner used by Mason and Dixon in 1766. It seems likely therefore, that the clock used was the same clock and could be the Edinburgh clock, this not having been adapted for use with the tripod. The clock returned to England in 1792. The clock was next stored and probably remained in St Katharine's Street, London, until 1820. Confusion as to which clocks were used in the experiments during the period 1820-28 arises from the fact that there were many Sheltons in existence and available. An attempt was made to list the instruments of the Royal Society in 1827, which did a little to alleviate the disorder. However, it is certain that the clock being described in this article did sail, in February 1828, to the South Atlantic. There Captain Foster made many gravity measurements and there, also, the clock had its second accident. A storm blew up while it was on Deception Island and the observatory tent was moved. The clock continued to function but, at times, stopped for several seconds. A clockmaker's mark shows that it was repaired at the Cape of Good Hope in July 1829. The experiment was then continued, but after the sudden and accidental death of Captain Foster the clock was returned to London in April 1831.

Again confusion arises as to which clocks were where in the ensuing years. In 1841, a clock was made available as a standard timepiece for Kew Observatory. It was later called 'K.O.' by the Kew Committee; this was also scratched on the clock, thus identifying it for the future. The clock in Edinburgh bears this mark.

The clock now in Edinburgh was loaned to Airy in 1854 for pendulum experiments to be carried out at Harton Colliery, near South Shields. The case of the clock bears marks which show how it was adapted by Airy to suit his experiments. It is interesting to note that Airy believed the clock was previously used by him at Dolcoath Mine, Cornwall, in 1826. This is not necessarily true but, if so, then his attempt to repeat the Dolcoath experiment in 1828 was done with another Shelton of similar design. On return to Kew the clock joined three others which were kept there in between experiments.

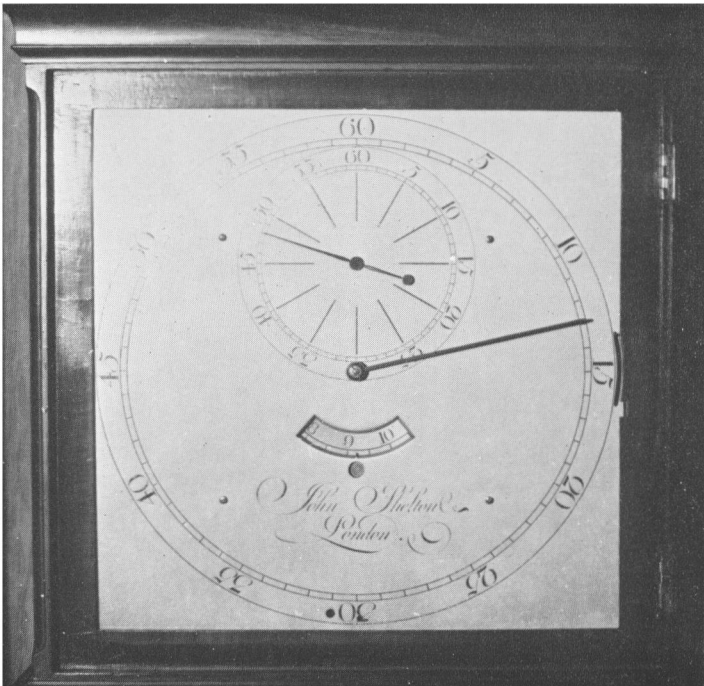
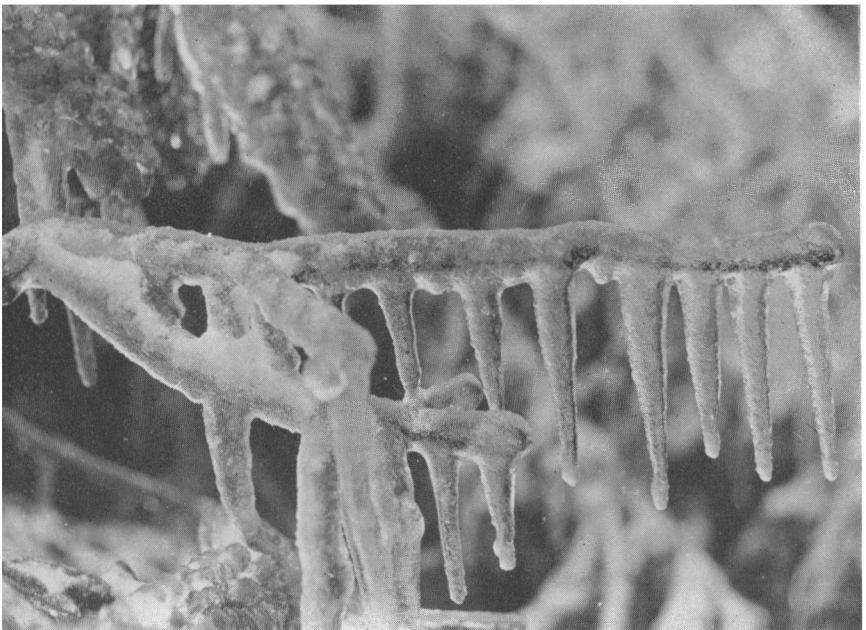
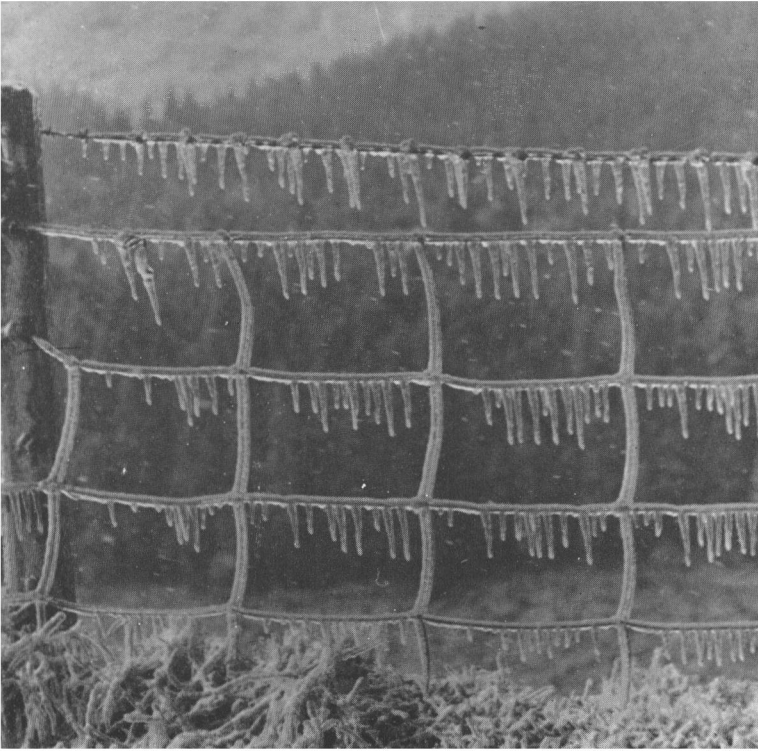


PLATE I—THE REGULATOR CLOCK MADE BY JOHN SHELTON IN 1756



*Photographs by John Dudley-Davies*

PLATE II—RAIN ICE IN THE LLANIDLOES AREA, CHRISTMAS EVE 1968





*Photograph by John Dudley-Davies*

PLATE III—RAIN ICE IN THE LLANIDLOES AREA, CHRISTMAS EVE 1968  
The accumulation of ice caused damage to young spruce and larch trees.



*Photograph by N. Elkins*

PLATE IV—SNOW ROLLERS AT KIRKWALL  
See p. 387

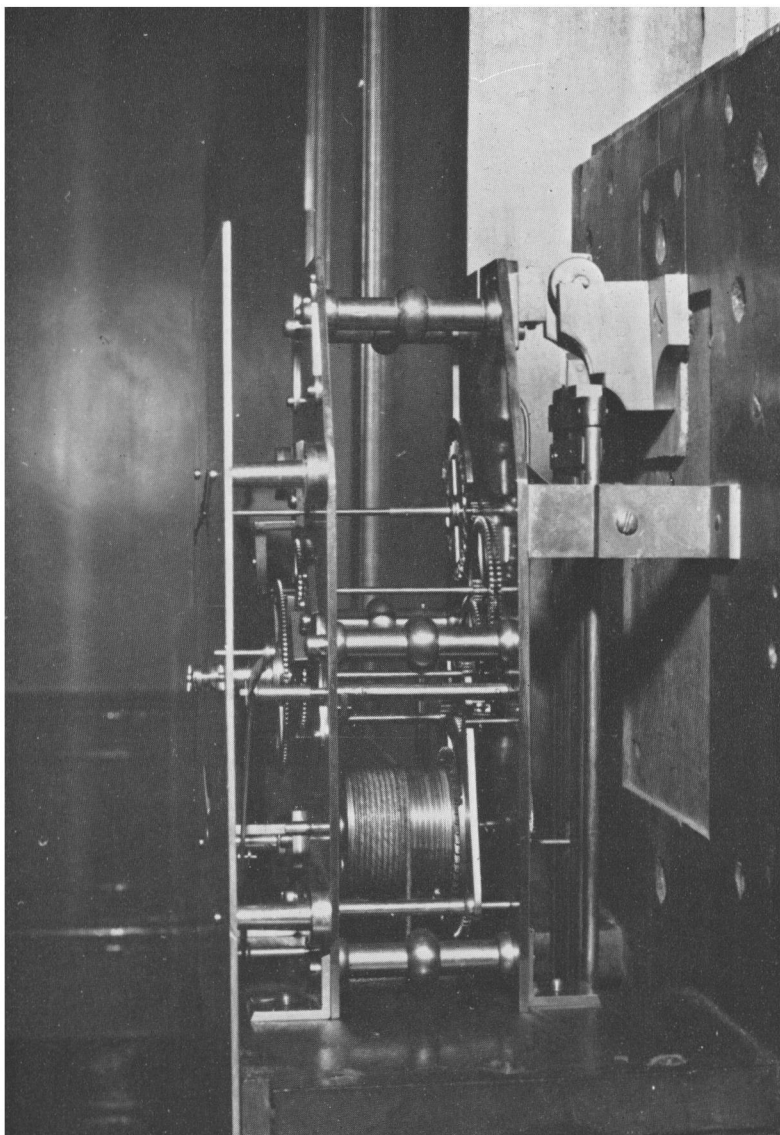


PLATE V—THE MECHANISM OF THE REGULATOR CLOCK MADE BY JOHN SHELTON  
IN 1756

Note that the pendulum is suspended from the back of the case.

'K.O.' was transferred to the Scottish Meteorological Society in 1888 and fitted in the new Ben Nevis Observatory as the standard mean-time clock. In 1904, owing to lack of funds, Ben Nevis Observatory was closed and 'K.O.' was sent back to Kew for repairs and cleaning.

Eskdalemuir Magnetic Observatory was opened in 1908 and the clock was modified so that it supplied pulses for the recording instruments. It remained there until 1960 when it was superseded by modern electronic devices and transferred to Edinburgh.

The Meteorological Office in Palmerston Place, Edinburgh, now has custody of this famous clock along with many of the instruments of the Ben Nevis Observatory. It stands against the south wall of the library and is firmly screwed to the wall to prevent vibrations in the floor from affecting its performance.

The many 'scars' of its adventures can be seen around the case and movement. These are, in themselves, proof of its adventures, since they can be related to the descriptions, diagrams and incidents recorded in the chronicles of the great men who used it.

There is no doubt that this clock has done well in the 213 years of its life and has been a perfect example of the great skill of the unfortunate John Shelton.

**Acknowledgements.** I am indebted to Lt Cdr H. D. Howse, M.B.E., D.S.C., R.N., of the National Maritime Museum, and the Superintendent of the Meteorological Office, Edinburgh, for their help and encouragement. To the many other people who have aided my researches in the last 2 years I also extend my thanks, especially the patient members of the library staff of the Royal Society of Edinburgh, and the staff of the Royal Scottish Museum.

#### **Further reading.**

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## **A METHOD OF DERIVING REPRESENTATIVE TEMPERATURE PROFILES, INCLUDING THE TROPOPAUSE, FROM THE THREE-LEVEL FORECAST MODEL**

By W. R. BRADY

**Summary.** An objective method is described for estimating heights and temperatures at various pressure surfaces and at the tropopause, if the heights of the standard surfaces 1000, 500, 200 and 100 mb are known or forecast. The stratosphere is first assumed isothermal and in a normal situation the significant tropopause temperature is taken to be equal to the mean temperature of the 200-100-mb layer. Special estimates are made when preliminary tests show that the tropopause is low. A temperature at 500 mb is chosen according to certain assumptions and a mean tropospheric lapse rate is then used to obtain the height of the significant tropopause temperature. Special methods are described for obtaining temperature at 200 mb. To obtain heights and temperatures at other pressure levels, layer thicknesses

can be added to or subtracted from the nearest pressure level whose height is known, working upwards within the troposphere and downwards within the stratosphere to avoid using the layer containing the significant tropopause. The thickness of this layer can be found as a remainder when the other layers have been calculated, and then a revised tropopause temperature can be obtained. A series of computing models known as tropopause models have been developed to control the computations.

A test made on actual data over the northern hemisphere for each of the 12 months showed results which compared well with actual values and which gave more detail than could be obtained by regression methods. Some possible advantages and applications are discussed.

**Introduction.** Predictions of contour heights at 1000, 500 and 200 mb are obtained by means of the 2-layer baroclinic forecasting model but the heights at the remaining standard levels and all the temperature fields from 850 to 100 mb were, until recently, obtained by a simple 3-level regression technique. This technique is based on the application of seasonally dependent coefficients to *D*-values (departures from the International Civil Aviation Organization (ICAO) standard atmosphere heights and temperatures) for 1000, 500 and 200 mb.

Woodroffe<sup>1</sup> showed that 4-level regression using 100-mb data would give significantly better results, particularly at 300 mb, and with the introduction of a 100-mb barotropic forecast in June 1968, 4-level regressions were introduced for the standard levels above 400 mb. All the equations now used have variable coefficients according to the season and certain coefficients are functions of the 1000–500-mb thickness. These changes have reduced the large errors, especially those in 200-mb temperatures, which occurred with the 3-level regressions but considerable smoothing of spatial gradients is inevitable with any form of regression. Another disadvantage is the arbitrary date which must be applied for the change of seasonal coefficients for use over all parts of the forecast area, irrespective of latitude or the synoptic situation.

The objectives of this paper are firstly, to describe a method for deriving the vertical temperature profile, including the tropopause discontinuity, over the whole forecast area at any time of the year, from the four forecast heights of the pressure surfaces at 1000, 500, 200 and 100 mb, and secondly, to show that by applying the technique to actual data and so eliminating forecast errors the results achieved by this method give improved representation of temperature gradients both vertically and horizontally, and that temperature profiles so derived will be hydrostatically consistent with the heights at each standard level.

**Calculation of the significant tropopause height.** The four heights of the pressure surfaces at 1000, 500, 200 and 100 mb and the interconnecting thicknesses cannot possibly specify the detailed structure which is observed on some profiles since the thicknesses are for very deep layers and, used in an unrelated fashion, will give no more than a reasonable estimate of the temperature near the middle of each layer. Marked discontinuities of lapse rate can and do occur within the troposphere at surface and subsidence inversions and in frontal zones, but these rarely match the importance of the discontinuity at the tropopause, where the lapse change is not only very marked but also maintained through deep layers of the atmosphere. It is necessary therefore first to determine the tropopause height before any calculations of the remaining heights and the full temperature profile between

standard levels are possible but, because of the limited amount of information available, a single discontinuity (from now on referred to as the significant tropopause height or  $H_i$ ) must be assumed.

Before the procedure for calculating  $H_i$  is discussed in detail it will simplify the problem if all the facts available from the basic data are determined first. From the four heights of the pressure surfaces at 1000, 500, 200 and 100 mb the three thicknesses 1000–500 mb, 500–200 mb and 200–100 mb may readily be obtained and from these the mean temperatures of the three layers 1000–500 mb, 500–200 mb and 200–100 mb are found by using the thickness equation,

$$z = \frac{RT_m}{g} \log_e \frac{P_o}{P}, \quad \dots (1)$$

in the form

$$T_m = \frac{z}{\frac{R}{g} \log_e \frac{P_o}{P}}, \quad \dots (2)$$

where  $P_o$  = pressure at the lower level,  
 $P$  = pressure at the upper level,  
 $R$  = specific gas constant,  
 $g$  = acceleration due to gravity,  
 $z$  = thickness of the layer  $P_o$  to  $P$ , and  
 $T_m$  = mean temperature of the layer  $P_o$  to  $P$ .

It will be convenient to refer to these mean temperatures as  $T_{m(10-5)}$ ,  $T_{m(5-2)}$  and  $T_{m(2-1)}$  respectively. The difference between  $T_{m(10-5)}$  and  $T_{m(5-2)}$  is important as it will give an indication of the mean tropospheric lapse rate between the mid points of the 1000–500-mb and 500–200-mb layers provided that both layers are predominantly tropospheric. This mean tropospheric lapse rate  $\Gamma$ , may be expressed in degrees Kelvin per metre by the formula :

$$\frac{T_{m(10-5)} - T_{m(5-2)}}{\left[ \frac{R}{g} \log_e \frac{690}{320} \right] [T_{m(10-5)} + T_{m(5-2)}] / 2}, \quad \dots (3)$$

where 690 mb and 320 mb are taken to be the points of intersection of the saturated adiabatics, corresponding to the layer thicknesses, with the mean isothermal temperatures of the layers 1000–500 mb and 500–200 mb respectively, and the expression  $[T_{m(10-5)} + T_{m(5-2)}] / 2$  is the mean temperature of the layer from 690 mb to 320 mb.

With no information above the 100-mb surface available, an initial assumption is made that the lower stratosphere is isothermal and that its temperature is approximately equal to  $T_{m(2-1)}$ . At a later stage of the computations however, it will be shown how this assumption is modified when the final 200-mb temperature is derived.

A starting height and temperature is now required for the  $H_i$  calculation. Nothing is known about the temperature at the 1000-mb and 200-mb levels and it seems that the 500-mb level may be the best reference level since a very good estimate of the temperature can be made.

Consider the deep layers 1000–500 mb and 500–200 mb in Figure 1. CX and WQ are the isothermals and DY and ZP are the equivalent saturated adiabatics corresponding to the respective thicknesses. KL represents the mean tropospheric lapse rate between 690 and 320 mb. The temperatures at Y and Z at 500 mb are determined by the saturated adiabatics DY and ZP and will be referred to as  $T_Y$  and  $T_Z$  respectively. It follows that if ZP and WQ are taken to be the extreme possible values of the *actual* mean lapse rate within the layer 500–200 mb and similarly, if DY and CX represent the extreme values of the *actual* mean lapse rate within the layer 1000–500 mb,

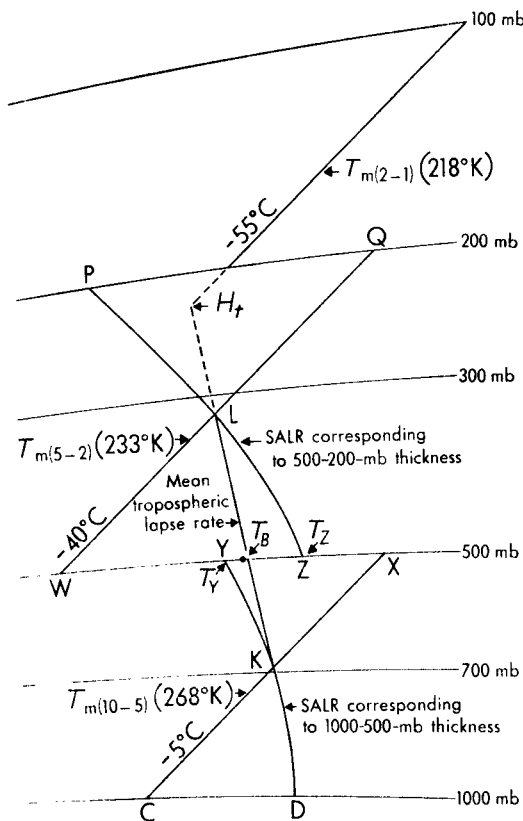


FIGURE 1—SIMPLIFIED TEPHIGRAM SHOWING THE INITIAL COMPUTATIONS WHICH MAY BE MADE FROM THE HEIGHTS OF THE PRESSURE SURFACES AT 1000, 500, 200 AND 100 mb

then the 500-mb temperature should be between the values of Y and Z. It has been found that the actual 500-mb temperature is approximately equal to the mean of W, Y, Z and X and this value should lie very close to the point of intersection of KL with the 500-mb level. This value of the 500-mb temperature will henceforth be referred to as the *B-value* ( $T_B$ ) and will be used extensively in all the computations where the layers 500–200 mb and 1000–500 mb are predominantly tropospheric. The  $H_t$  calculation is now straightforward and proceeds as follows :



$$H_t = \frac{T_B - T_{m(3-1)}}{\Gamma_t} + H_{500} \quad \dots (4)$$

When the stratosphere exists down to or below the 300-mb level,  $\Gamma_t$  and hence the  $B$ -value of the 500-mb temperature will be unrealistic and so it is necessary to detect such a situation before the calculations already described are allowed to proceed.

In Figure 2 the effect of a lower tropopause on the relative differences between the mean temperatures of the three layers 1000–500 mb, 500–200 mb and 200–100 mb and also the values of  $W$ ,  $Y$ ,  $X$ ,  $Z$  and  $T_B$  at the 500-mb level can be seen. An example of an actual profile is shown as a dashed line in Figure 2 and, to simplify comparison with Figure 1, the 500–200-mb thickness is the same in each case and therefore gives the same mean temperature,  $T_{m(5-2)} = -40^\circ\text{C}$  ( $233^\circ\text{K}$ ). It will be seen from a study of Figure 2 that the real mean tropospheric lapse rate shown by the actual profile is greater than  $KL$  and in fact lies between  $KL$  and  $KY$  where  $KY$  is the saturated adiabatic lapse rate (SALR) corresponding to the 1000–500-mb thickness. The actual 500-mb temperature  $T_{500}$  is lower than the  $B$ -value

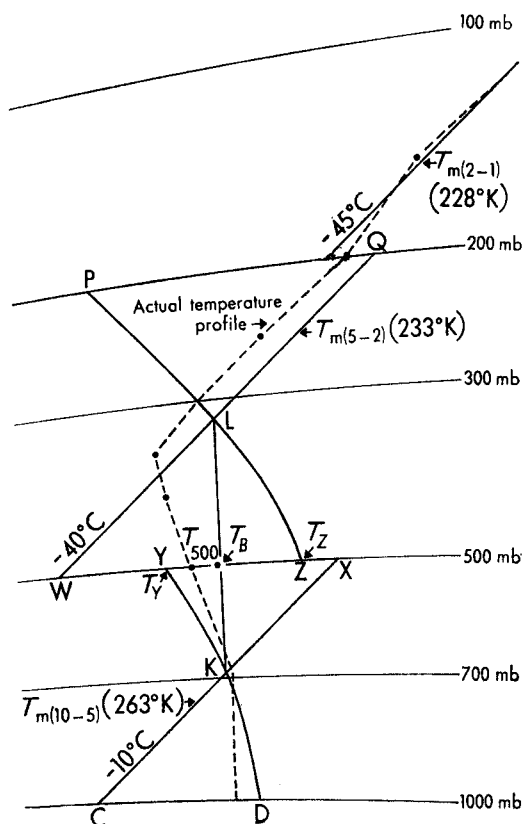


FIGURE 2—AN EXAMPLE OF AN ACTUAL TEMPERATURE PROFILE WITH A TROPOPAUSE BELOW 300 mb SHOWING THE RELATIONSHIP BETWEEN THE  $B$ -VALUE ( $T_B$ ) AND THE ACTUAL 500-mb TEMPERATURE ( $T_{500}$ )

and lies between the values of  $T_B$  and  $T_Y$ . With very low tropopause situations, the value of  $T_Y$  will be found to approach the temperature at W, i.e.  $T_{m(5-2)}$  for two reasons. Firstly, the 1000–500-mb thickness with cold air masses is relatively low (i.e. the mean temperature  $T_{m(10-5)}$  will be low) and therefore the upper part of the saturated adiabatic corresponding to the 1000–500-mb thickness will be steeper as the SALR approaches the dry adiabatic lapse rate (DALR) at lower temperatures and secondly, since the stratosphere extends well down into the 500–200-mb layer, the value of  $T_{m(5-2)}$  will not decrease by anything like the same amount. In fact in Figures 1 and 2 the values of  $T_{m(5-2)}$  are the same, i.e. W has a similar value but Y is  $6\frac{1}{2}$  degC lower in Figure 2. Finally, with low tropopause situations, the difference between  $T_{m(5-2)}$  and  $T_{m(2-1)}$  is normally small and as the stratosphere extends further into the 500–200-mb layer the values of  $T_{m(5-2)}$  and  $T_{m(2-1)}$  will more nearly approach one another. These facts may be used to make tests on the basic data to determine the type of low tropopause, and the following modifications to equation (4) for obtaining  $H_i$  are made at this stage. Firstly, the  $B$ -value of  $T_{500}$  is revised to  $T'_{500}$  by giving an increased weighting to the  $T_Y$  value so the the resulting 500-mb temperature to be used in the  $H_i$  calculation is actually lower than the  $B$ -value and secondly,  $\Gamma_i$  is modified by determining the lapse rate from K to the revised  $T_{500}$  value and extrapolating upwards to an isothermal value equivalent to a mean value of  $T_{m(5-2)}$  and  $T_{m(2-1)}$ .

The equation for calculating  $H_i$  would now become :

$$H_i = \frac{T'_{500} - \frac{T_{m(5-2)} + T_{m(2-1)}}{2}}{((T_{m(10-5)} + 1) - T'_{500}) / (H_{500} - H_{700})} + H_{500}, \quad \dots (5)$$

where  $T'_{500}$  is in degrees absolute and the value of  $H_{700}$  is precalculated as follows :

$$H_{700} = H_{500} - \left[ \left( \frac{R}{g} \log_e \frac{700}{500} \right) \left( \frac{T'_{500} + (T_{m(10-5)} + 1)}{2} \right) \right]. \quad \dots (6)$$

The expression in square brackets in equation (6) is the thickness of the 700–500-mb layer using the mean temperature obtained by taking the mean of the two temperatures at 500 and 700 mb. Initially the 700-mb temperature is assumed to be equal to the value of  $T_{m(10-5)}$  but with the addition of 1 degC to compensate for the fact that the point K is not exactly coincident with the 700-mb level.

**The tropopause models.** Having achieved the prime object of allocating a height to the significant tropopause discontinuity between the 500-mb and 100-mb levels and also having obtained a starting temperature at 500 mb, the next aim is to break down the deep 500–200-mb layer by calculating the 300-mb height. To do this, the thickness of either the 500–300-mb or the 300–200-mb layer is required and clearly the position of the tropopause is very important. If  $H_i$  is well above the 300-mb level a good approximation to the actual 300-mb temperature is obtained by extrapolation of KL in Figure 1 from 320 mb to 300 mb. The 300-mb height can then be calculated by :

$$H_{300} = H_{500} + \left( \frac{RT_m}{g} \log_e \frac{500}{300} \right), \quad \dots (7)$$

where  $T_m = \frac{1}{2}(T_{500} + T_{300})$ . Conversely, if  $H_t$  is calculated to be well below the 300-mb level, then the equation required for obtaining the 300-mb height will be :

$$H_{300} = H_{200} - \left( \frac{RT_m}{g} \log_e \frac{300}{200} \right), \quad \dots (8)$$

where  $T_m = \frac{1}{2} \left( T_{300} + \frac{T_{m(2-1)} + T_{m(5-2)}}{2} \right)$ .

If the computed value of  $H_t$  falls close to the 300-mb level then both equations (7) and (8) must be solved and the mean of the two results taken. It should be pointed out, however, that although the 300-mb level is close to the middle of the deep layer 500–200 mb of which the total thickness is known, the actual value of  $T_{300}$  will vary with the change of  $H_t$  within the 500–200-mb layer. This variation was found to be surprisingly small and in over 5000 examples tested more than 90 per cent fell within the range of  $T_{m(5-2)}$  and  $T_{m(5-2)} - 6$ .

The value  $(T_{m(2-1)} + T_{m(5-2)})/2$  used as a starting temperature at the 200-mb level in equation (8) was found to be accurate enough to obtain a good 300-mb height with the low tropopause types.

It is now possible to use equation (2) to calculate the mean temperatures of the 500–300-mb and 300–200-mb layers and, after making adjustments for height difference, to assign these values to the 400-mb and 250-mb temperatures provided that the tropopause does not intervene.

A series of temperature profiles, each one showing greater detail than its predecessor, are then generated by repeated application of equations (1) and (2) in such a way as to preserve hydrostatic consistency between the four given heights and the derived heights and temperatures. Layer thicknesses are added to or subtracted from the nearest pressure level whose height is given, or just calculated, to produce the heights for the missing standard levels. The calculations are made working upwards within the troposphere and downwards within the stratosphere, to avoid using the layer containing the significant tropopause height. The detailed application of the technique therefore varies with the tropopause height and a series of computing models, known as tropopause models, have been developed to control the computations depending on the value assigned to the significant tropopause height.

**The 200-mb temperature.** The expression  $(T_{m(2-1)} + T_{m(5-2)})/2$  used as the preliminary starting temperature at 200 mb in equation (8), although accurate enough to obtain good results for the 300-mb height with low tropopause situations, cannot be accepted as the final 200-mb temperature. This temperature is the most difficult value of all to deduce from the limited basic data available and the problem is made more complex by the fact that the average tropopause lies close to this level and that the 100-mb height is obtained by an independent barotropic forecast. The initial assumption that the lower stratosphere is isothermal would mean that the 200-mb temperature would equal the value  $T_{m(2-1)}$  in all cases where the significant tropopause height was calculated to be below the level of the 200-mb surface. Such an assumption would clearly lead to gross errors in the 200-mb temperature in an unacceptably large number of cases. However, if the original

assumption that the whole 200–100-mb layer is isothermal is restricted to the 150–100-mb layer, then a preliminary 150-mb height may be obtained by the equation :

$$H_{150} = H_{100} - \left[ \left( \frac{R}{g} \log_e \frac{150}{100} \right) (T_{m(2.1)}) \right], \quad \dots (9)$$

where the expression in square brackets is the thickness of the 150–100-mb layer.

At this stage of the computations there are several possible 200-mb temperature values which must be considered. They are :

- (a) The  $T_{m(2.1)}$  value.
- (b) The temperature at the 200-mb level derived by using the lapse rate from  $T_{250}$  at  $H_{250}$  to  $T_{150}$  at  $H_{150}$  provided that  $H_t$  does not lie between the 250-mb and 150-mb levels.
- (c) The temperature at the 200-mb level derived by extrapolation of the lapse rate from  $T_{300}$  at  $H_{300}$  to  $T_{250}$  at  $H_{250}$  provided that  $H_t$  does not lie between the 300-mb and 200-mb levels.
- (d) The temperature at the 200-mb level derived by using the lapse rate from :
  - (i) the temperature  $T_t$  at the significant tropopause height to  $T_{150}$  at  $H_{150}$  when  $H_t$  is below the 200-mb level, or
  - (ii)  $T_t$  to  $T_{250}$  at  $H_{250}$  when  $H_t$  is above the 200-mb level.

These values may be calculated by means of the following equations :

$$a = T_{m(2.1)}, \quad \dots (10)$$

$$b = T_{250} - \left[ \frac{(H_{200} - H_{250})(T_{250} - T_{150})}{(H_{150} - H_{250})} \right], \quad \dots (11)$$

$$c = T_{250} - \left[ \frac{(H_{200} - H_{250})(T_{300} - T_{250})}{(H_{250} - H_{300})} \right], \quad \dots (12)$$

$$d(i) = T_t - \left[ \frac{(H_{200} - H_t)(T_t - T_{150})}{(H_{150} - H_t)} \right], \quad \dots (13)$$

where  $T_t$  is precalculated as follows :

$$T_t = T_{250} - \left[ \frac{(H_t - H_{250})(T_{300} - T_{250})}{(H_{250} - H_{300})} \right], \quad \dots (14)$$

$$d(ii) = T_{250} - \left[ \frac{(H_{200} - H_{250})(T_{250} - T_t)}{(H_t - H_{250})} \right], \quad \dots (15)$$

where  $T_t = T_{m(2.1)}$ .

The actual value used in the final computations within each tropopause model will, of course, depend on the significant tropopause height calculation, but it has been found necessary to use combinations of these values in models where  $H_t$  lies between the 150-mb and 250-mb levels.

**The tropopause temperature.** As stated earlier, the calculations within each tropopause model are designed to operate upwards through the tropo-

sphere and downwards through the stratosphere in order to avoid the layer between two standard levels containing the tropopause itself. It follows therefore that the thickness of this layer becomes available after all the other work has been completed. Equation (2) is now used again to find the mean temperature of this layer in which the tropopause lies and the tropopause temperature may now be fitted to the profile such that the temperature assigned to  $H_t$  is as consistent as possible with the thickness of the layer.

If the mean temperature of the layer containing the tropopause is represented by  $x^\circ$  and  $P_t$  is the significant tropopause pressure converted from  $H_t$ , then the tropopause temperature may be calculated by the equations :

$$T_t = x - \frac{(\frac{1}{2}(P_o + P) - P_t)(x - T_1)}{\frac{1}{2}(P_o - P)}, \quad \dots (16)$$

when  $P_t \leq \frac{1}{2}(P_o + P)$ , or

$$T_t = x + \frac{(P_t - \frac{1}{2}(P_o + P))(T_2 - x)}{\frac{1}{2}(P_o - P)}, \quad \dots (17)$$

when  $P_t > \frac{1}{2}(P_o + P)$ ; temperatures  $T_1$  and  $T_2$  refer to the upper and lower pressure levels  $P$  and  $P_o$  of the layer.

The alternative would be to compute the lapse rates immediately above and below the layer and by extending them to  $H_t$  to obtain the tropopause temperature by taking a mean of the two results. The objection to this is that it would take no account of the thickness of the layer containing the tropopause and might lead to some inconsistencies in the final profile.

**Results.** This type of repetitive calculation is ideally suited to the electronic computer and so an ALGOL programme was written and developed to perform the required computations on actual data so that results could be compared with actual values. The data used for this work were the 00 GMT upper air observations received at the Central Forecasting Office (CFO) for the 15th of each month from January 1968 to December 1968 except that data for January 1968 were replaced by those for January 1967 for technical reasons. All observations which passed a simple quality control were used and the total number of ascents exceeded 4500 taken from all parts of the northern hemisphere.

The four heights of the surfaces at 1000, 500, 200 and 100 mb were extracted from each observation in turn and the computations made to deduce the heights at the remaining standard levels and the full temperature profile. The results obtained were then compared with the actual values at each level and a statistical summary of the errors for both height and temperature was made. The results are reproduced in Table I.

It should be remembered that the technique described in this paper deliberately sets out to achieve detail, where detail exists, and so attempts to avoid the 'middle-course' approach typical of many forms of regression. In some situations however, the tropopause modelling technique will give incorrect results which are reflected in the overall statistics in Table I. For example, when a double-tropopause situation exists in the actual temperature profile, then the significant tropopause must be a compromise and will result

TABLE I—STATISTICAL SUMMARY OF HEIGHT AND TEMPERATURE ERRORS OBTAINED BY APPLYING THE TROPOPAUSE MODELLING TECHNIQUE TO ACTUAL DATA USING THE HEIGHTS AT 1000 mb, 500 mb, 200 mb AND 100 mb

		No. of obs.	(a) Mean height errors and standard deviations					(b) Mean temperature errors and standard deviations									
			Standard levels (mb)					Standard levels (mb)									
			850	700	400	300	250	150	850	700	500	400	300	200	150	100	
			geopotential metres					degrees Celsius									
1967 January	350	Mean	+7	0	-1	0	-2	+1	+0.1	-0.9	+0.1	0	0	-0.3	-0.1	-0.2	
		$\sigma$	18	17	16	24	17	13	2.7	1.7	2.3	2.2	1.6	2.6	1.2	2.5	
1968 February	368	Mean	+9	+3	-3	-3	-6	-5	+0.5	-0.9	-0.2	-0.4	0	-0.6	-0.3	+0.9	
		$\sigma$	16	17	13	22	16	14	2.8	1.6	2.0	1.9	1.6	2.5	1.1	2.4	
March	365	Mean	+4	0	-2	-3	-5	-4	+0.6	-0.6	+0.2	-0.4	+0.1	-0.6	-0.3	+0.6	
		$\sigma$	16	18	15	25	19	15	2.7	1.8	2.3	2.2	1.6	3.2	1.1	2.3	
April	396	Mean	-2	-6	0	-1	-4	0	0	-0.2	+0.6	-0.3	-0.1	+0.1	-0.1	-0.4	
		$\sigma$	13	13	11	18	14	12	2.3	1.5	1.7	1.7	1.4	2.3	1.1	2.1	
May	402	Mean	+1	-5	-1	0	-3	+2	+0.1	-0.5	+0.5	-0.2	+0.1	+0.1	+0.1	-0.9	
		$\sigma$	14	15	13	22	17	14	2.2	1.4	1.9	1.9	1.6	2.8	1.2	2.5	
June	379	Mean	-1	-5	-4	-3	-5	+1	+0.4	-0.2	+0.2	-0.6	+0.4	-0.3	+0.3	-0.9	
		$\sigma$	12	12	11	19	16	16	2.0	1.4	1.6	1.6	1.4	2.8	1.2	2.8	
July	404	Mean	-2	-5	-5	-5	-6	-2	+0.6	-0.2	+0.1	-0.7	+0.4	-0.8	+0.4	-0.5	
		$\sigma$	12	12	12	22	17	14	2.0	1.4	1.6	1.8	1.5	2.8	1.3	2.8	
August	388	Mean	-1	-4	-5	-5	-6	-3	+0.7	-0.3	+0.1	-0.8	+0.3	-0.5	+0.2	-0.7	
		$\sigma$	11	12	11	19	17	14	2.2	1.4	1.7	1.5	1.4	2.9	1.2	2.6	
September	370	Mean	-1	-4	-3	-2	-5	-1	+0.9	-0.1	+0.2	-0.4	+0.3	-0.6	+0.2	-0.7	
		$\sigma$	11	12	11	19	16	16	2.1	1.3	1.5	1.6	1.4	3.0	1.1	2.6	
October	411	Mean	-1	-6	-2	0	-1	-2	+0.3	-0.3	+0.6	-0.3	+0.2	-0.9	+0.3	-0.6	
		$\sigma$	12	13	11	20	15	14	2.0	1.3	1.8	1.6	1.3	2.6	1.3	2.5	
November	376	Mean	+7	+1	-4	-5	-4	0	+0.7	-0.9	0	-0.6	+0.2	-0.3	0	-0.2	
		$\sigma$	14	15	14	24	19	14	2.5	1.5	2.1	1.9	1.2	2.4	1.1	2.4	
December	386	Mean	+11	+6	-4	-3	-5	0	+1.0	-1.1	-0.3	-0.4	-0.1	0	-0.2	+0.2	
		$\sigma$	16	17	14	24	16	14	2.6	1.7	2.1	2.0	1.6	2.5	1.2	2.7	
Overall results	4595	Mean	+3	-2	-3	-3	-4	-1	+0.5	-0.5	+0.2	-0.4	+0.1	-0.4	0	-0.3	
		$\sigma$	14	14	13	21	17	14	2.3	1.5	1.9	1.8	1.5	2.7	1.2	2.5	

$\sigma$  = Standard deviation.

$\sigma$  = Standard deviation.



in errors of both height and temperature in the layers near the tropopause, but experience has shown that the results achieved by 4-level regression techniques show similar errors in these situations.

It may be argued that since the results shown in Table I are based on actual data then, if the tropopause modelling technique is used on forecast heights, any forecast errors should be combined with these results. This is of course correct but it should be borne in mind that no allowance has been made in the statistics shown in Table I for either random or standard radiosonde errors in the data used and that all the included observations from all parts of the northern hemisphere were therefore accepted as perfect.

The reader may be interested to see the charts reproduced in Figures 3, 4 and 5. Figure 3 shows the 24-hour forecast of 500-mb temperature for 00 GMT on 11 December 1968 produced by the tropopause modelling technique, and Figure 4 is the chart produced by regression methods using the same forecast data. Figure 5 is the actual 500-mb temperature pattern

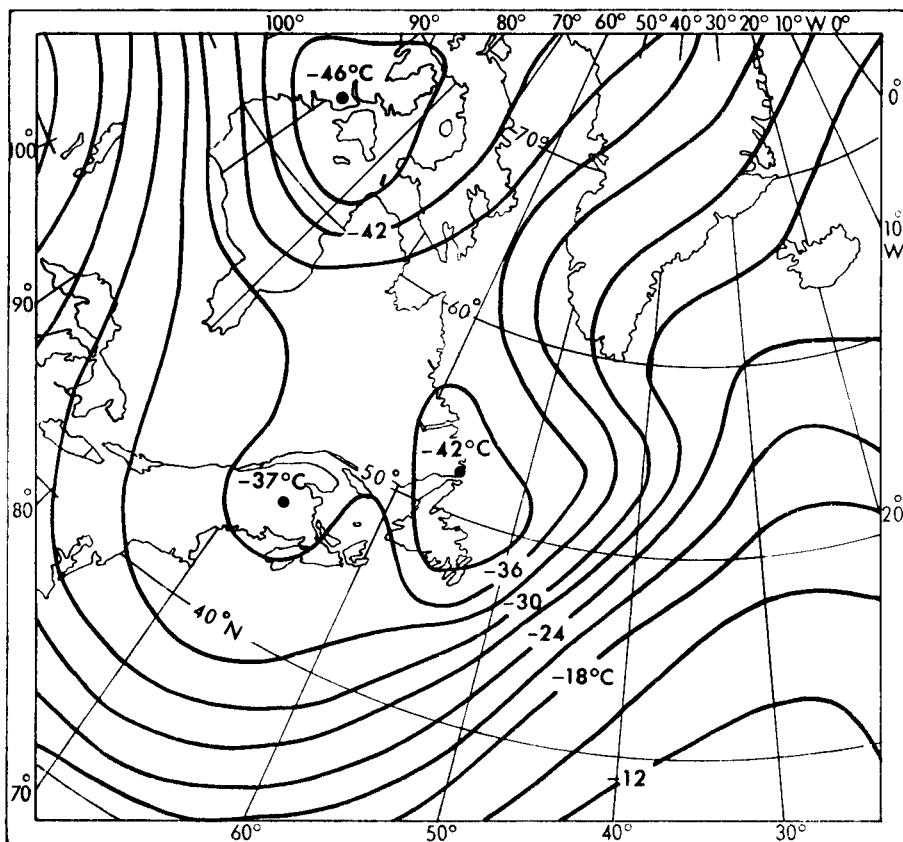


FIGURE 3—24-HOUR FORECAST OF 500-mb TEMPERATURE FOR 00 GMT, 11 DECEMBER 1968, DERIVED BY THE TROPOPAUSE MODELLING TECHNIQUE USING THE FOUR FORECAST HEIGHTS OF THE SURFACES AT 1000, 500, 200 AND 100 mb  
Isopleths are at intervals of 3 degC.

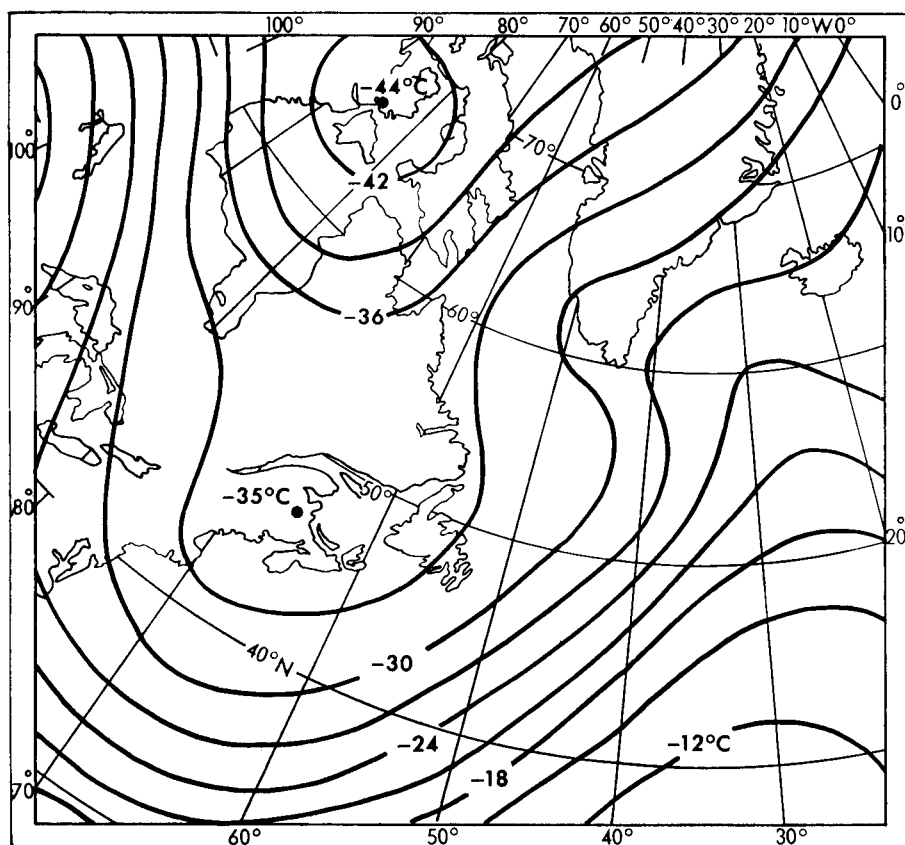


FIGURE 4—24-HOUR FORECAST OF 500-mb TEMPERATURE FOR 00 GMT, 11 DECEMBER 1968, CALCULATED BY REGRESSION EQUATIONS USING THE SAME FORECAST HEIGHTS AS THOSE USED IN FIGURE 3

at the time of verification drawn in CFO. This is a good example of the detail which can be extracted from the four forecast heights by using this method and it is interesting to notice the way in which the detail is lost in Figure 4 particularly over the north-west Atlantic.

**Discussion.** The tropopause modelling technique offers an alternative to regression methods for obtaining heights and temperature profiles not provided by the main forecast model. On the information at present available it has many advantages and applications and some of the more important ones may be briefly summarized as follows :

- (i) It will function without the necessity of using variable seasonal coefficients and is virtually independent of latitude.
- (ii) The computational procedures within the models work on forecast data, limited though these may be, without any reference to the ICAO Standard Atmosphere and therefore *D*-values are unnecessary.
- (iii) The method uses the basic material provided by the main forecast programme to calculate the significant tropopause height and

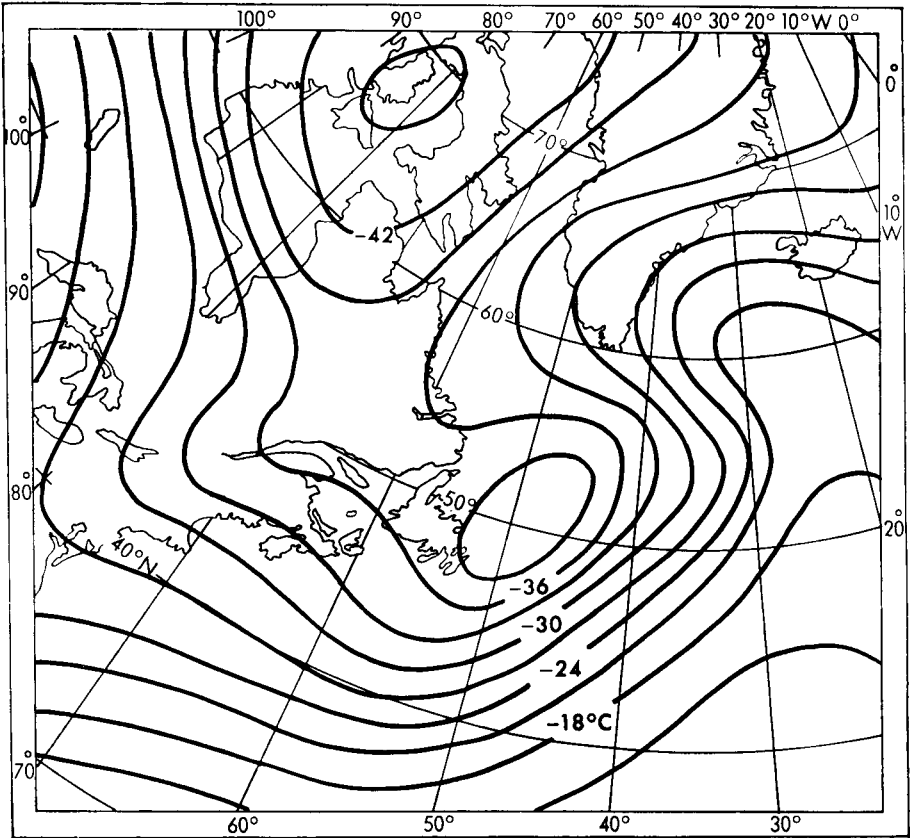


FIGURE 5—THE ACTUAL 500-mb TEMPERATURE CHART FOR 00 GMT, 11 DECEMBER 1968, DRAWN FROM THE CENTRAL FORECASTING OFFICE CHART

temperature as well as the heights and temperatures of the remaining standard levels. Forecast tephigrams could therefore be extracted for any grid point in the forecast area.

- (iv) Because the technique is based on the thickness equation, hydrostatic consistency between levels is assured, and the introduction of a significant tropopause discontinuity increases the prospect of identifying and maintaining more precise vertical and horizontal wind shears.
- (v) Charts of the significant tropopause height and the freezing-level height could be added to the operational output.
- (vi) By assuming  $H_i$  to be approximately the height of the maximum wind, it should be possible to use the temperature profiles and vertical wind shears above and below the level of  $H_i$  to produce a maximum wind chart. This possibility is being investigated.
- (vii) The technique described in this paper, although intended for use with the forecast heights at 1000, 500, 200 and 100 mb provided by the main forecast model, could be applied equally well to the analysis programmes. Contour charts derived in this way would obviate the necessity for a multi-level computed analysis which would

take up considerably more computer time with no assurance of better results over the sparse data areas such as the North Atlantic.

There are, of course, some disadvantages also and they may be briefly summarized as follows :

- (i) By definition the significant tropopause height implies a single major discontinuity. Should there be in fact two such discontinuities, then a compromise result will be obtained but, at least, the results under these circumstances will be very little different from those produced by regression.
- (ii) Since the method is aimed at an improved representation of spatial gradients of both height and temperature it must therefore increase the chance of generating larger errors at a point in space when the forecast heights from the basic forecasting model are seriously in error.

**Acknowledgements.** The author wishes to thank Mr R. Dixon and Mr E. A. Spackman for their advice and help with ALGOL programming. Acknowledgement is also made to Mrs M. Odell and Mrs M. Holmes of Met. O. 2b for the considerable amount of work involved in translating the ALGOL programme for use with the COMET operational programmes.

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### LETTER TO THE EDITOR

551.577.61:551.578.72(761/769)

#### Storm damage in Texas

Having just returned from one of my quick dashes across to the west coast, I write to tell you of an unusual weather experience while it is fresh in my mind.

On Tuesday, June 17, we drove into Amarillo, Texas Panhandle, at about 9.30 p.m. (fortunately picking the north side) under a wild sky — having completed 800 miles that day. We freshened up, had a drink and were in the local restaurant by 9.50 p.m. At 9.59 it started to rain very heavily for about 15 minutes and we fortunately were on the fringe of a storm. Returning to our motel, we found all the television programmes were cut so that the local station with some five outside reporters could give a blow-by-blow report of the damage which occurred in the south-west area (where we had been an hour before the storm broke).

The centre of the storm which hit the town apparently was about 1 mile in diameter and moving south-east. The hail was reported by eye-witnesses on the television as being the size of baseballs and in 10 minutes built up to 10 inches deep on the ground. Over 50 per cent of shop windows in the area and practically all house windows were broken, roofs were caved in and owners tied their cars to trees to prevent them being washed away by the flash floods which quickly followed (the temperature before the storm was 92°F). It was estimated in the town, by comparison with a less severe storm in 1963, that the damage caused in 10 minutes was \$5 000 000.

Even the following morning, the normal dry washes which, as you know, run across the open country, were quite full of water.

Amazing. Any aircraft in this, even on the ground, would, I am sure, be a little bent.

R. J. FENNER

(Representative in the U.S.A. of the Air  
Registration Board)

## NOTES AND NEWS

551.578.466:77

### Snow rollers at Kirkwall, Orkney

At 1500 GMT on 13 February 1969, large cylinders of snow were noticed lying on a snowbed some 50 yards from the Meteorological Office at Kirkwall Airport, Orkney (see Plate IV). The snowbed was on a shallow slope facing north where the snow had drifted, and was about 18 cm deep. Most of this was old snow but over this was about 1 to 2 cm of fresh snow. The cylinders, 3 large ones and numerous tiny ones, had formed and rolled uphill downwind. Their tracks were visible and measured about 10 metres in length. The largest cylinder was 35 cm long and 31 cm in diameter. The ends were hollowed out and the movement and growth could be seen from the shape of the track. It was deduced that they had formed during a squall at about 1435 GMT when the wind increased from 360°/12 kt to 360°/28 kt in a few seconds, as they had not been noticed prior to this. While measuring the cylinders it was noticed that small balls of dislodged snow were rolling uphill in the same manner. Although the sudden increase of wind was assumed to be the cause, the possibility that they had been caused by the slipstream of a light aircraft at about the same time could not be ruled out. The weather conditions during the period are given below :

Time GMT	Wind degrees/kt	Weather	Dry-bulb temperature degrees C	Relative humidity per cent
1250	300/12	snow shower	+0.8	80
1305	310/14	moderate snow shower		
1320	330/12	moderate snow shower		
1350	270/07	moderate snow shower	-0.3	96
1418	350/12	snow grains	+0.4	
1435	360/28	squall		
1450	340/31 gusting to 43	snow shower	+0.5	93

W. Kuhn<sup>1</sup> records a similar phenomenon and states that in Switzerland snow rollers are said to be exceptional. A. N. Tucker<sup>2</sup> records their formation at Kinloss, Morayshire.

N. ELKINS and D. LINKLATER

## REFERENCES

1. KUHN, W.; Snow cylinders at Geltwil, Switzerland. *Met. Mag., London*, 97, 1968, p. 350.
2. TUCKER, A. N.; Snow rollers at Kinloss airfield, 2 April 1968. *Met. Mag., London*, 97, 1968, p. 192.

### REVIEW

*Catalog of meteorological instruments in the Museum of History and Technology*, By W. E. Knowles Middleton. 285 mm × 215 mm, pp. v + 128, illus., Smithsonian Institution Press, Washington, D.C., 1969. Price: \$3.25.

This catalogue is much more than a listing and description of items in the Smithsonian collection. It contains a brief history of meteorological instruments illustrated by photographs of examples in that collection. As the author points out, museums acquire scientific instruments largely by chance and to some extent the resulting collections are unbalanced. Further, many instruments when received are not in a fit state for exhibition, as, more often than not, they require expert restoration. This is particularly so with certain types of meteorological equipment which, throughout their working lives, have been exposed to the weather. The Smithsonian collection is no exception to this general experience. Examples of thermometers, barometers and barographs are numerous whereas anemometers and wind vanes are held in relatively small numbers.

Following an introduction, the catalogue is divided into 10 chapters, each dealing with a particular instrument or group of instruments. With the author's remarks in mind, it is no surprise to find that Chapter 2 — barometers and barographs — extends to some 25 pages whereas Chapter 9 — upper air instruments, not telemetering — extends to 5 pages.

The book can be read as a story and, despite a degree of imbalance, is a valuable introduction to the history of meteorological instruments. The pictures and the general presentation are pleasing. The author must be congratulated for producing a catalogue in this form.

N. E. RIDER

### OFFICIAL PUBLICATION

The following publication has recently been issued :

*Observer's handbook, Third Edition.*

This new edition of the *Observer's handbook* incorporates many changes in observational procedures accepted within the past few years within the World Meteorological Organization including new definitions of clouds and 'meteors' and new instructions and nomograms for the determination of visibility at night. Many plates and diagrams are new, including a completely new set of cloud photographs.

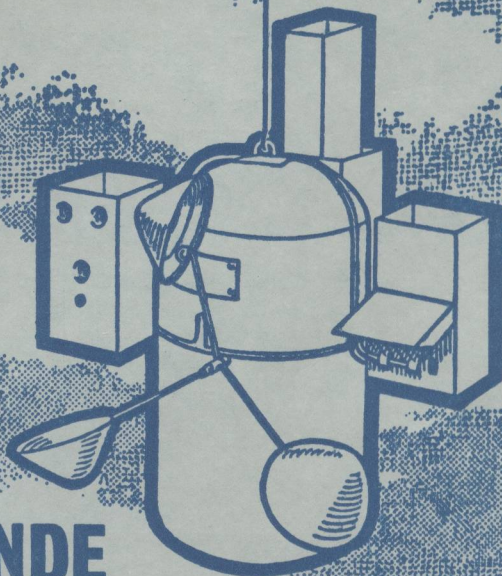
This book will help both the amateur and professional meteorologist to make good observations of the weather. Details of international coding procedures which are subject to revision from time to time have been omitted but the sources of these procedures are indicated where necessary. Fairly detailed instructions, however, are given for recording observations at climatological stations and health resort stations. Metric units have been used wherever practicable and new tables are consequently included.

### CORRECTION

*Meteorological Magazine*, May 1969, p. 142, Table I, Type 6, row of figures should read : 77 1·7    33 1·5    39 1·3



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## NOTICES

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

and published by

HER MAJESTY'S STATIONERY OFFICE

3s. 6d. [17½p] monthly

Annual subscription £2 7s. [£2.35] including postage