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TEMPERATURE COMPENSATION OF THE MOLL-GORCZYNSKI PYRANOMETER

By B. G. COLLINS* and E. W. WALTON*

Summary.—A simple thermistor and resistor network fitted inside the pyranometer is used to compensate for the variation of sensitivity with ambient temperature. A minimum of modification to the instrument is required and standard components, readily available, are used.

Introduction.—Global and sky radiation are frequently measured by Moll-Gorczynski pyranometers using Moll thermopiles as radiation detectors. Their sensitivity varies with ambient temperature, and the coefficient is −0·2 per cent/degC with reference to the sensitivity at 20°C.[1] Thus an ambient temperature range of 5–35°C involves errors of up to 3 per cent, and to obtain good quality records some form of correction is necessary.

Manual correction is tedious and an automatic method is desirable. According to Bener[2] the temperature coefficient is mainly due to the low thermal conductivity of the air under the glass hemispheres, and replacement of the air by hydrogen gives an eightfold increase in thermal conductivity. This practically eliminates the temperature coefficient, but the pyranometer sensitivity is reduced to about one third of normal. Furthermore, a continuous hydrogen feed is necessary, including gas cylinder and pressure reducing valve, and a simpler method is to be preferred.

The method described does not reduce the temperature coefficient, but rather compensates for it electrically. A simple circuit using a negative temperature coefficient resistor, or thermistor, in a voltage divider network is suitable and effective and involves but a small loss in voltage output.

A thermistor temperature compensation system has been developed for and is optionally available on the Eppley pyranometer which, however, has an entirely different design of thermopile.

Compensating circuit.—The pyranometer has a negative temperature coefficient, i.e. the e.m.f. generated by a given intensity of radiation falls with increasing temperature. Therefore the thermistor must be used as a series control of the current in the load circuit to provide compensation. Of the commonly available thermistors none has exactly the right resistance characteristics to compensate completely without a suitable fixed resistor in parallel. However, a Philips type B8 32001 A5OE thermistor (a disc $\frac{1}{4}$ in in

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diameter and $\frac{1}{8}$ in thick) shunted by 30–35 ohms with a load resistance of about 170 ohms provides good compensation over the temperature range required. The circuit is then as in Figure 1.

Then if E is the e.m.f. generated by the thermopile and the resistances are as indicated in the diagram, the output e.m.f. e is given by

$$e = \frac{E.R_L}{R_i + R_L + \dfrac{R_S R_T}{R_S + R_T}} .$$

Typical values for the various resistances are : $R_i = 10$ ohms, $R_L = 170$ ohms, $R_S = R_T = 30$ ohms, and these give $e = 0{\cdot}87E$, and as temperature ranges from 10 to 40°C, the total resistance as seen by the recording instrument is from 26 to 22 ohms approximately. In general the loss in output will be in the range 10–20 per cent.

Mechanical arrangement.—The Moll thermopile has a number of constantan/manganin strips acting as thermo-junctions. They are mounted on, but electrically insulated from, a copper base-plate by copper supports, the ends of which form the cold junctions. It is essential, in order to compensate accurately for temperature changes, that the thermistor should be in good thermal contact with the copper base-plate, and thus be maintained at cold-junction temperature. In the present design, the existing small threaded hole in the centre of the base-plate was carefully reworked with a 5 BA tap to carry a small brass housing for the thermistor. A brass washer served to improve the thermal contact between the thermistor housing and the base-plate (Figure 2). The thermistor itself was wrapped in two thicknesses of Mylar film (0·00025 in thick) to provide electrical insulation and was fixed firmly into the brass housing with strong terylene thread before screwing the whole into the copper base-plate.

The shunt and load resistors were wound from 40 s.w.g. minalpha wire onto a small ebonite bobbin which was fixed to the bottom of the pyranometer housing. The optimum values were calculated from the resistance curves supplied with the thermistors, by successive approximation, knowing the internal resistance and sensitivity of the pyranometer. Final trimming of the resistors was done after testing in a controlled temperature room.

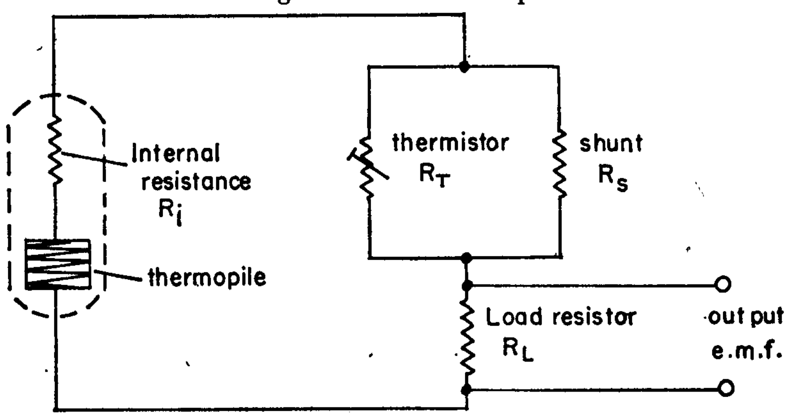

FIGURE 1—TEMPERATURE COMPENSATION CIRCUIT OF THE MOLL-GORCZYNSKI PYRANOMETER

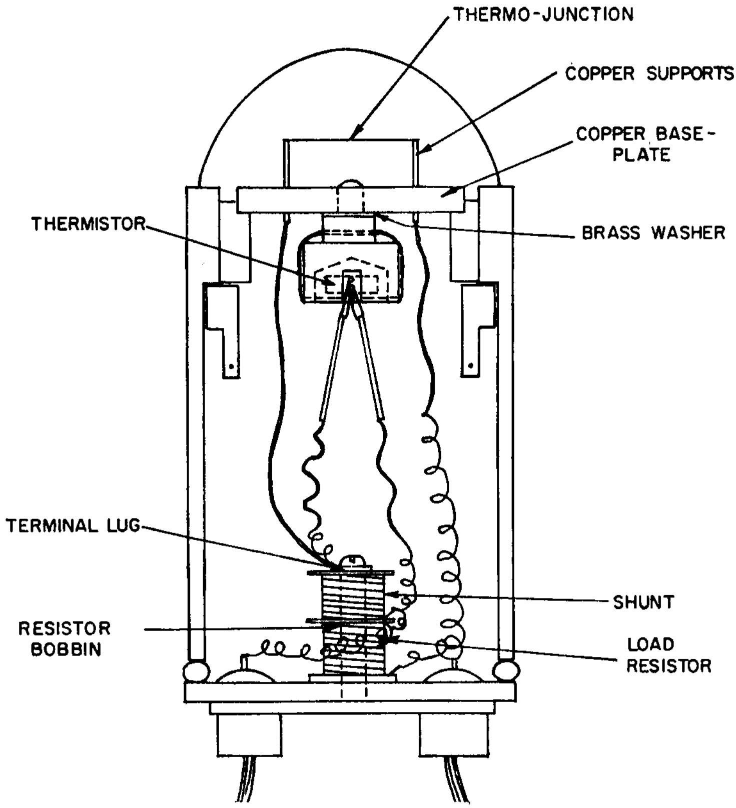

FIGURE 2—THERMISTOR AND RESISTOR MOUNTINGS ON THE MOLL-GORCZYNSKI PYRANOMETER

Testing.—Three pyranometers fitted with compensating circuits were exposed to a short-wave source of radiation in a controlled-temperature room. The source was a 250-volt 500-watt tungsten filament lamp underrun at 190 volts from a stabilized power supply, and it was assumed that, over the range of temperatures used (10–40°C), the output of the lamp was constant. The output of the pyranometers was measured at seven temperatures within this range. The difference between exposed and shaded readings (i.e. the light source occulted from the pyranometers) was taken, and expressed as a percentage deviation from the 20°C value. The results obtained from one pyranometer, after final trimming of the shunt and load resistors, are given in the table, together with the values without temperature compensation.

Temperature	Output			Percentage deviation from value at 20°C	Percentage deviation, uncompensated
	Exposed	Shaded	Difference		
°C		*millivolts*			
10	5·889	0·055	5·834	0·0	+2·6
15	5·888	0·060	5·828	−0·1	+1·5
20	5·893	0·058	5·835	0·0	0·0
25	5·896	0·068	5·828	−0·1	−0·4
30	5·918	0·069	5·849	+0·2	−1·3
35	5·906	0·075	5·831	−0·1	−1·9 (33°C)
40	5·915	0·060	5·855	+0·3	—

Thus in the range of day-time temperatures commonly encountered the errors in radiation measurement would be reduced to about one fifteenth of the original value.

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FURTHER CRITERIA CONCERNING FINE SPELLS IN SOUTH-EAST ENGLAND DURING THE PERIOD MAY TO OCTOBER

By R. A. S. RATCLIFFE and P. COLLISON

Summary.—As a supplement to the criteria recently developed for forecasting fine spells in south-east England, new rules associated with the position of a closed-contour high on the 500 mb chart are presented. The rules are developed from data in the 10 years 1957–66 and tested on independent data for the 4 years 1953–56 inclusive.

Introduction.—Fairly satisfactory criteria for forecasting fine spells in south-east England, based on flow patterns at 500 mb, were developed recently (Ratcliffe[1]). When an attempt was made to derive similar rules for south-west Scotland it was found necessary to divide the data into two distinct classes, one rather similar to the criteria developed for south-east England but the other dependent on the position of closed-contour highs on the 500 mb surface (Ratcliffe[2]). A logical further step was thus to return to the case of south-east England to try to uncover rules, based on the position of closed-contour upper highs, which would be relevant to that area. This paper shows the results of such an investigation.

In order to maintain consistency with the previous work, fine spells were defined as 6 consecutive 12-hour periods in each of which both Kew and London (Heathrow) Airport were dry or had no more than a trace of rain.

Data used.—All the 500 mb charts published in the *Daily Aerological Record* for 0000 GMT in the 10-year period 1957–66 inclusive (May to October only) were scrutinized with a view to discovering any relationship which might exist between the position of closed-contour 500 mb highs and the occurrence of fine spells in south-east England.

The 12-hour rainfall periods corresponded with those reported in the *Daily Weather Report*, i.e. 0900–2100 GMT and 2100–0900 GMT.

Forecasting criteria.—The results of the investigation suggested the following fine-spell forecasting criteria :

(i) A closed-contour high on the 500 mb surface of 570 decametres (18,800 ft) or higher must be in the area 50°N to 60°N, 20°W to 10°E.

(ii) There should not be a 500 mb trough or vortex near the British Isles from 20°W to 5°E including Biscay and France (see comments on criterion (ii)).

(iii) If the 500 mb wind at Shanwell, Long Kesh or Valentia is between south and west it must not exceed 45 kt at any of these 3 stations.

If these three provisos are satisfied a fine spell has either begun, or is expected to begin within 24 hours.

Typical 500 mb charts illustrating these criteria are shown at Figures 1–3 and Table I gives a summary of the results obtained.

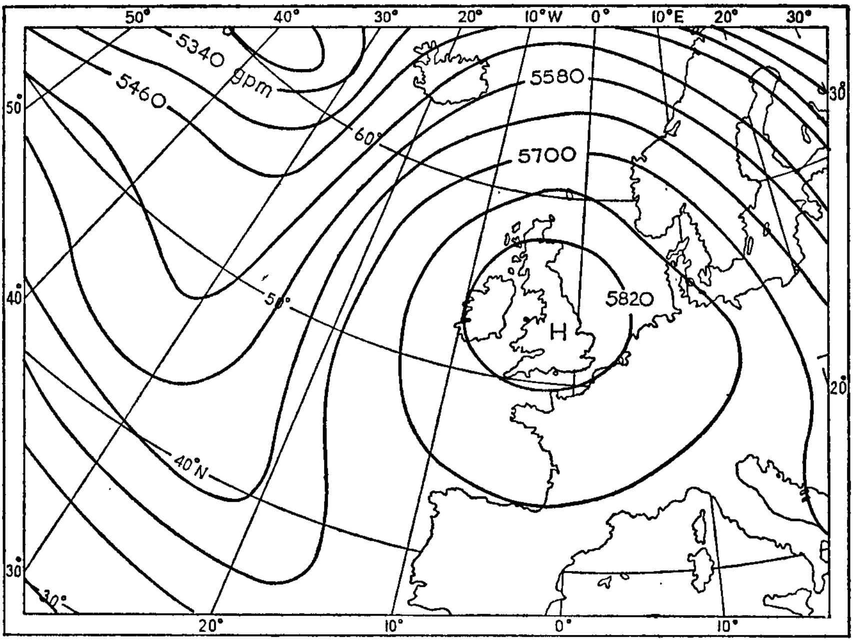

FIGURE 1—500 MB CONTOUR CHART FOR 0000 GMT ON 21 OCTOBER 1962 ASSOCIATED WITH A FINE SPELL

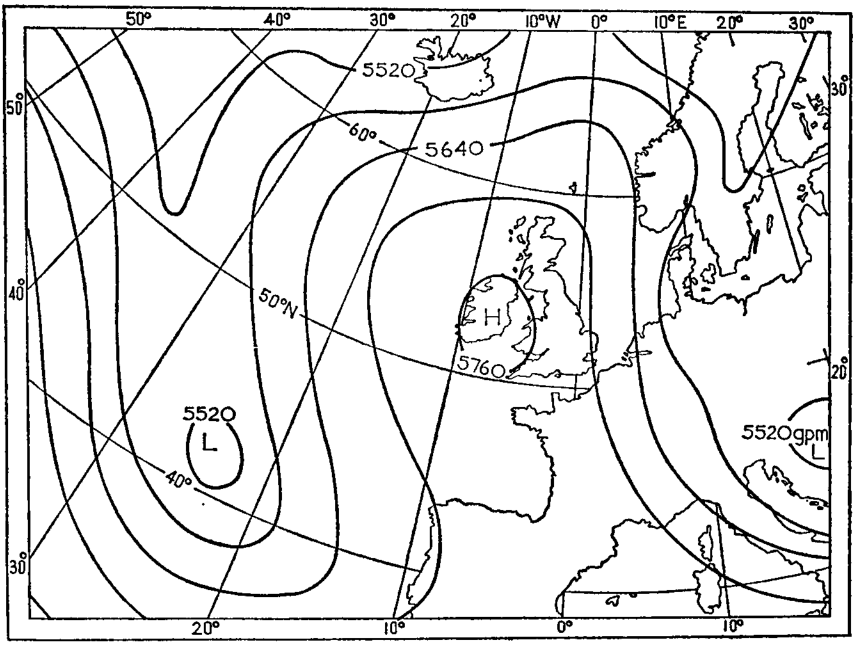

FIGURE 2—500 MB CONTOUR CHART FOR 0000 GMT ON 29 MAY 1966 ASSOCIATED WITH A FINE SPELL

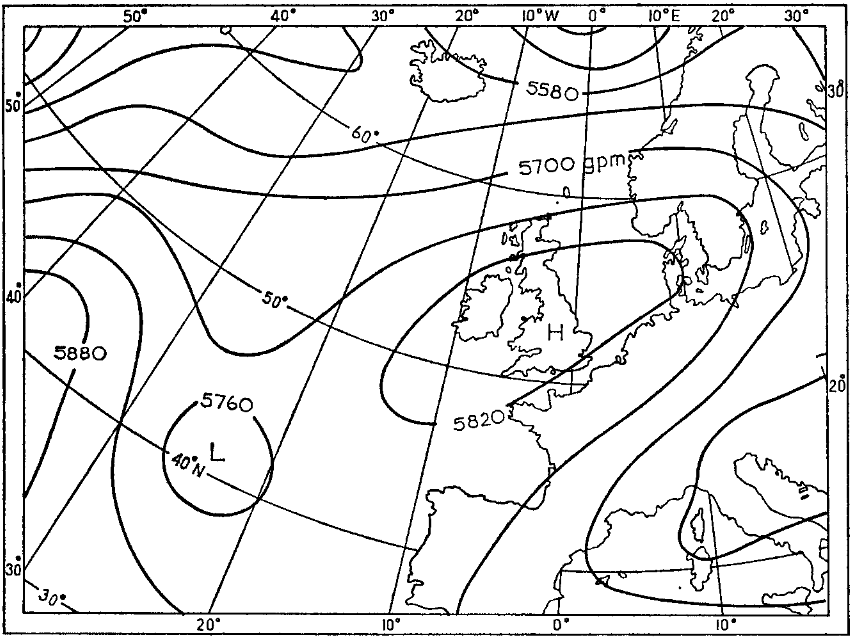

FIGURE 3—500 MB CONTOUR CHART FOR 0000 GMT ON 8 JUNE 1962 ASSOCIATED WITH A FINE SPELL

TABLE I—NUMBER OF FINE SPELLS IN SOUTH-EAST ENGLAND FROM MAY TO OCTOBER 1957–66 AND THE NUMBER FORECAST BY THE CRITERIA

	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	All years
Number of fine spells	11	10	12	10	13	13	14	14	11	15	123
Number forecast by the criteria	3	4	7	3	2	5	5	3	3	3	38

It has already been pointed out[2] that fine spells in south-west Scotland were much more commonly associated with 500 mb highs in the vicinity of the British Isles than were those in south-east England, therefore it is not surprising that the new rules should only forecast about 30 per cent of all fine spells occurring in south-east England.

Table II gives a more detailed comparison between the results obtained using the method presently described and results obtained using the method depending on the 500 mb flow pattern in the Atlantic.[1] It will be appreciated that in a fine spell lasting, say, 8 days, one method may forecast the spell on the 1st day while the criteria for the second method may not be satisfied until say, the 3rd day. Therefore it is possible to state which method, on any one occasion, could have been used to forecast the fine spell earlier than the other.

Table II indicates that the new criteria, though useful, do not add a great deal to the original Atlantic flow-pattern method. Only about one fine spell per year on average is forecast independently by the new method.

Comments on the criteria.—Criterion (i). It was found necessary to restrict the 500 mb high centres to north of 50°N. It is believed that one cannot regard the British Isles as being in a blocking situation if the upper

TABLE II—NUMBER OF FINE SPELLS IN SOUTH-EAST ENGLAND MAY TO OCTOBER AND THE NUMBER FORECAST BY TWO METHODS

	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	All years
Number of spells forecast earlier by new rules	1	1	3	1	0	2	1	0	1	2	12
Number of spells forecast earlier by old rules	6	3	4	3	7	6	6	6	5	5	51
Number of spells forecast by both rules simultaneously	1	1	2	1	1	0	0	2	1	1	10
Total number forecast (both methods)	8	5	9	5	8	8	7	8	7	8	73
Total number of fine spells occurring	11	10	12	10	13	13	14	14	11	15	123

high is further south than this. Certainly a rule allowing upper highs as far south as 48°N would have resulted in more failures than that described here.

Criterion (ii) (*a*). The requirement of no 500 mb trough or vortex near the British Isles from 20°W to 5°E is a fairly obvious restriction since any upper trough crossing the British Isles is likely to give some rain in the south-east of England. It is found, however, that troughs embedded in a general north or north-east flow over the southern North Sea and France are not important and can usually be ignored : Figure 4 shows such a pattern associated with a fine spell. These troughs over France become important only when they link

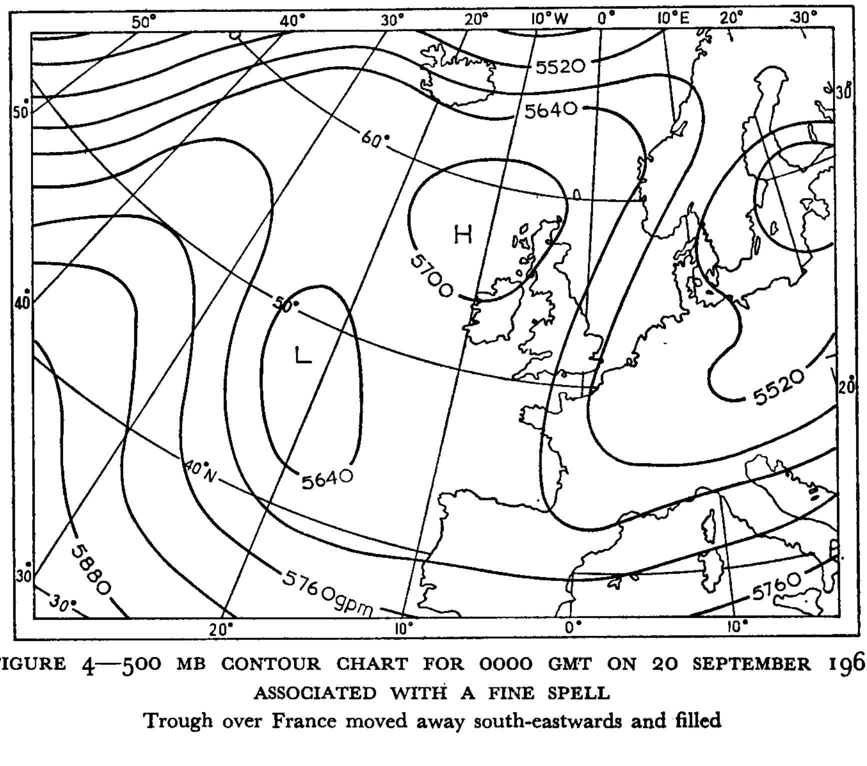

FIGURE 4—500 MB CONTOUR CHART FOR 0000 GMT ON 20 SEPTEMBER 1962 ASSOCIATED WITH A FINE SPELL

Trough over France moved away south-eastwards and filled up with a trough in the Atlantic extending south-eastwards towards the Bay of Biscay. Figure 5 is a good example of such a pattern *not* associated with a fine spell. This pattern usually leads to rain in south-east England within 3 days. The boundary of the area from which troughs should be excluded may be taken as a line joining the north-west corner of Spain to 50°N 20°W. Biscay troughs are particularly liable to bring rain if there is a strong westerly 500 mb flow further west to the rear of the trough as shown in Figure 6.

Criterion (ii) (*b*). The presence of a strong westerly or north-westerly flow behind an upper trough is in any case always a danger signal ; one or two cases of failure of the new rules were associated with such patterns when the trough was near or west of 20°W. One of these failures is illustrated in Figure 7.

Criterion (iii). The restriction about strong south to west winds at Valentia, Long Kesh or Shanwell is found to be a useful indicator that the closed-contour high is rather too far to the east for its influence to be dominant over south-east England for the following 3 days (see Figure 8).

Additional tests of the criteria.—It has been shown in Table I that the criteria can be used to forecast about 30 per cent of all fine spells in south-east England. It is also necessary to show that the criteria do not occur on many occasions when a fine spell does not follow. All cases when the criteria were satisfied in the years 1957–66 inclusive were therefore examined and tested to see whether or not they were associated with fine spells. Results are shown in Table III.

The number of failures is considerably lower than for the original rules based on the Atlantic flow pattern and most failures involve small amounts of rain on one day only (usually the third). Only two cases, 15 October 1957 and 25 September 1962, were total failures.

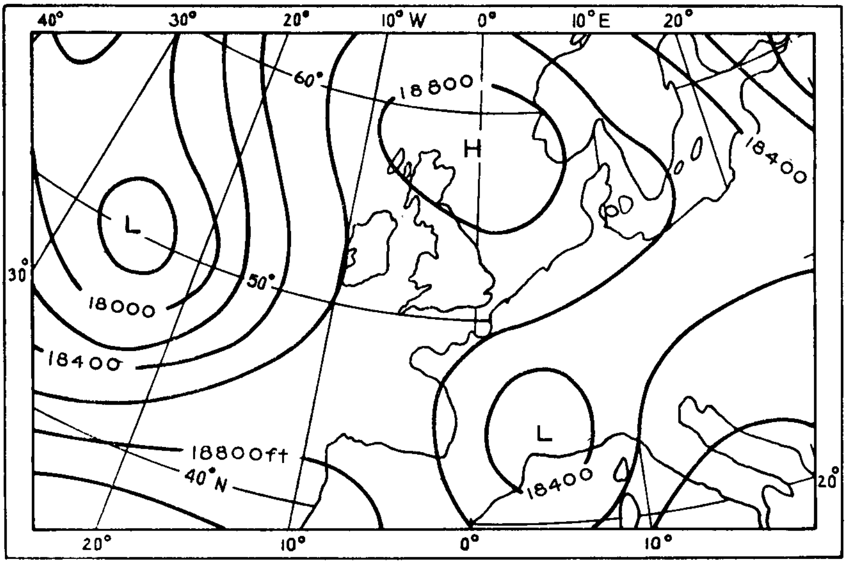

FIGURE 5—500 MB CONTOUR CHART FOR 0000 GMT ON 4 JUNE 1954 NOT ASSOCIATED WITH A FINE SPELL

Trough over the Atlantic joined up with one over France across the Bay of Biscay

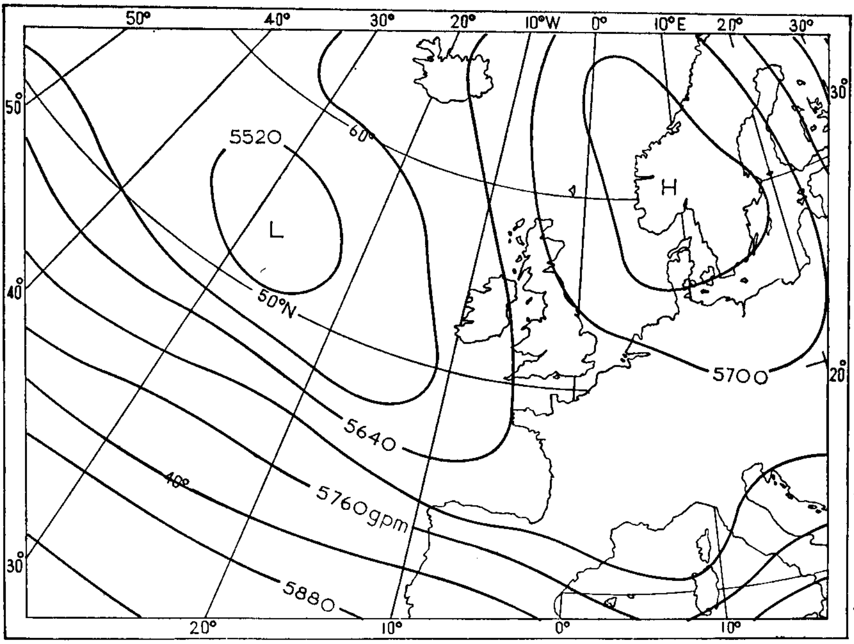

FIGURE 6—500 MB CONTOUR CHART FOR 0000 GMT ON 28 AUGUST 1966 NOT ASSOCIATED WITH A FINE SPELL

Trough over the Bay of Biscay moved north-eastwards and intensified

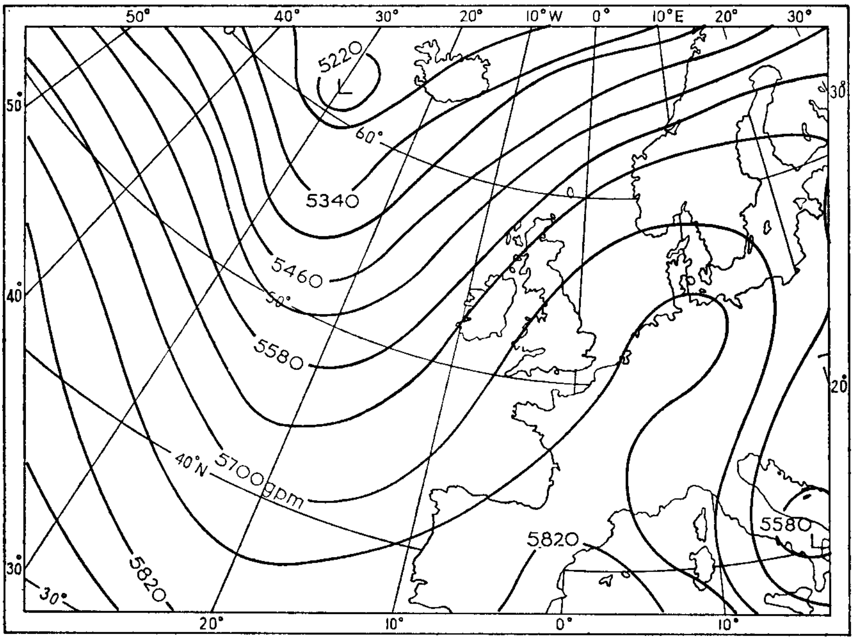

FIGURE 7—500 MB CONTOUR CHART FOR 0000 GMT ON 25 SEPTEMBER 1962 NOT ASSOCIATED WITH A FINE SPELL

Strong north-westerly winds behind the trough moved it fairly quickly and developed it

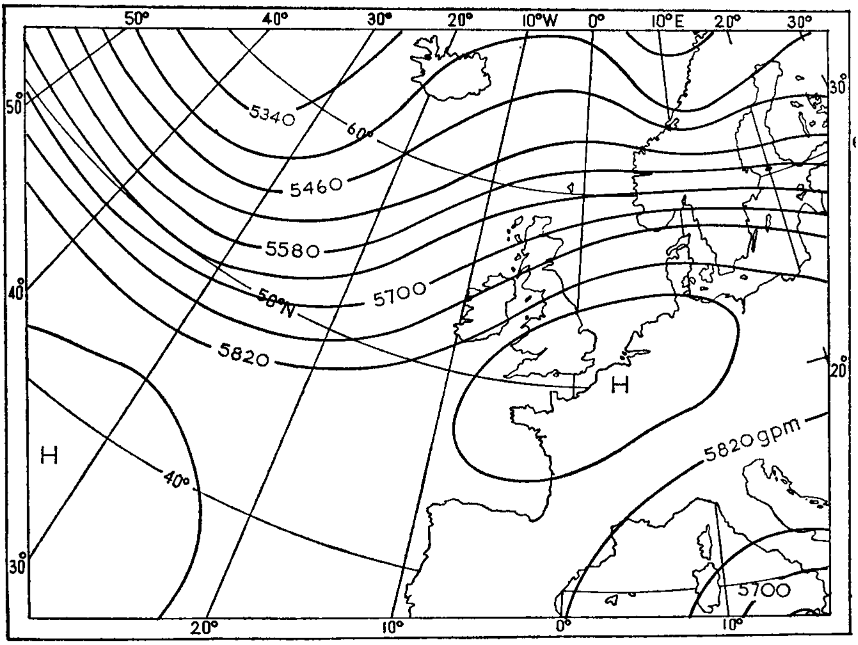

FIGURE 8—500 MB CONTOUR CHART FOR 0000 GMT ON 22 SEPTEMBER 1965 NOT ASSOCIATED WITH A FINE SPELL

Strong winds over Scotland and Ireland exceeded 60 kt at Shanwell, Long Kesh and Valentia

TABLE III—ANALYSIS OF FORECASTS OF FINE SPELLS 1957–66

Year	Number of days on which criteria were satisfied with success*	Number of days on which criteria were satisfied with failure	Comments on failures
1957	4	3	2 June — Followed by 2½ dry days.
			27 Sept. — Marginal case, failed on 3rd day
			15 Oct. — Very small 500 mb high
1958	12	2	17 Sept. — Westerly jet in Atlantic in low latitudes — failed on 3rd day
			28 Oct. — Small amount of rain (0·1 mm) at one station on 29 and 30 Oct.
1959	33	0	
1960	7	1	4 June — Failed on 3rd day. Trough at 20°W
1961	3	1	15 Oct. — Failed on 3rd day. Trough at 20°W with strong north-westerly behind it.
1962	26	1	25 Sept. — Trough at 20°W with strong north-westerly behind it
1963	8	2	20 and 21 Sept. — Slight drizzle on 21 and 23 Sept.
1964	8	0	
1965	11	2	12 and 13 Oct. — Rain on 14 Oct.
1966	16	0	
Totals	128	12	

* Criteria were applied to the 0000 GMT chart for all days and were deemed to be successful if followed by 3 dry days starting at 0900 GMT.

As a further check the criteria were tested on completely independent data for the period 1953–56 inclusive with the results shown in Tables IV and V.

TABLE IV—RESULTS OF USING THE CRITERIA OVER TEST PERIOD 1953–56

	1953	1954	1955	1956	All years
Number of fine spells: observed	10	11	14	11	46
forecast	3	2	6	3	14

TABLE V—ANALYSIS OF FORECASTS OF FINE SPELLS IN TEST PERIOD 1953–56

Year	Number of days on which criteria are satisfied with success*	with failure	Comments on failures
1953	15	2	5 July — Trough west of Scotland 20 Oct. — Followed by 2 dry days
1954	2	3	11 and 12 May — Doubtful cases, suspected strong southerly winds at Valentia but no winds reported 19 May — Failed on 3rd day
1955	15	0	
1956	5	1	14 Oct. — Followed by 2½ dry days
Totals	37	6	

* Criteria were applied to the 0000 GMT chart (0300 GMT before 1 April 1957) for all days and were deemed to be successful if followed by 3 dry days starting at 0900 GMT.

Conclusions.—It is shown that about 30 per cent of the fine spells which occur in south-east England can be forecast by considering the position of any closed-contour 500 mb high and the flow pattern around any such high.

If a closed-contour 500 mb high is within the area 50–60°N, 20°W–10°E, a fine spell can be forecast with a chance of success approaching 90 per cent provided that certain flow-pattern restrictions are considered. In particular a 500 mb trough or vortex must not occur near the British Isles between 20°W and 5°E or extend south-eastwards from the Atlantic into the Bay of Biscay.

The new rule overlaps with that described in an earlier paper but nevertheless a net gain of about 10 per cent in the total number of spells forecast is obtained.

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2. RATCLIFFE, R. A. S.; Criteria concerning fine spells in south-west Scotland during the period May to October. *Met. Mag., London*, **95**, 1966, p. 98.

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WIND RECORDS AND THEIR APPLICATION TO STRUCTURAL DESIGN

By H. C. SHELLARD, B.Sc.

Summary.—The nature of the continuous wind records that are maintained in the United Kingdom and the distribution of the stations providing such records for the Meteorological Office are described. The method of routine analysis of the records is indicated. For structural design purposes only the strongest winds are relevant and the statistical method used to analyse the annual extremes in order to obtain estimates of the probable maximum speeds likely to be exceeded only once in 50 or 100 years is outlined. Other important aspects affecting the choice of design speed for a structure are the variation of speed with height above the ground, the relationship between maximum speed and averaging time and the effects of ground roughness and topography. Current practices for dealing with these are described, indicating their background and what is being done to overcome certain limitations.

This paper is one of several which were included in the proceedings of the 'Symposium on natural draught cooling towers—Ferrybridge and after' which will be published by the Institute of Civil Engineers at the end of this year.

Measurement of wind in Britain.—Although a considerable number of meteorological stations of various types make routine observations of the wind speed and direction at fixed times every day, most of our detailed knowledge of wind is based on the continuous records provided by anemographs. An early form of recording instrument was the cup anemograph of Robinson and Beckley which recorded the direction and the run of the wind in miles and was in routine use at a few stations from 1868 onwards. Following the Tay Bridge disaster in 1879, however, special attention was directed to the measurement of gusts, and the Robinson and Beckley instrument which gave only the mean wind speed was superseded by the pressure-tube anemograph devised by W. H. Dines. The pressure-tube anemograph gives continuous records consisting of a connected series of nearly vertical lines the tops of which indicate the gusts and the bottoms the lulls caused by the turbulent eddies always present in the natural wind. The speed shown by the trace at any moment is the mean value over a period of about three seconds, though it depends to some extent on the diameter and length of the pressure and suction pipes connecting the head to the recorder and for this reason the ½-in diameter pipes of the early instruments were later replaced by 1-in pipes. A full account of the instrument has been given by E. Gold[1] who included illustrations of records showing special characteristics. Details are also given in the 'Handbook of Meteorological Instruments'.[2] The pressure-tube anemograph became the recognized standard and revolutionized the measurement of wind. It was introduced near the end of the 19th century and the numbers in operation in the United Kingdom increased steadily to 10 in 1910, 14 in 1920, 30 in 1930, 43 in 1940, 50 in 1950 and 56 in 1955. In that year the Meteorological Office electrical cup anemograph (Hartley[3]) was first introduced and in the last decade this instrument has gradually been replacing the pressure-tube type. Its chief advantages are its use of a strip chart lasting about a month in place of the separate daily charts of the pressure-tube instrument, the fact that the recorder can be installed at a considerable distance (up to a mile or so) from the head and its relative ease of maintenance.

The time-scale of the chart of the pressure-tube anemograph is 15 mm to the hour and that of the electrical anemograph, 1 in to the hour. There is no reason to believe that the change has affected the homogeneity of our wind records, field and wind tunnel tests having indicated that mean and maximum values are in good agreement and that response times are about the same.

Distribution and exposure of anemographs.—There are at present about 105 anemographs in the United Kingdom providing records for the Meteorological Office. Of these only 30 are now pressure-tube instruments the remainder being electrical cup anemographs. Their distribution is shown in Figure 1 and it probably represents the closest network of continuous and reliable wind records to be found in any part of the world. The map also shows the positions of stations now closed which have provided at least 10 years of anemograph records. In Table I the stations are listed giving position, heights of cups (or vane) and type of instrument concerned (D for pressure-tube and E for electrical cup anemograph). Heights given are : above mean sea level, above ground and 'effective'. The effective height is an estimate of the height over open level ground in the vicinity of the anemograph at which the mean wind speeds would be the same as those actually recorded.

When siting an anemograph, the meteorologist aims at getting a record that fairly represents the general airstream at a standard height of 10 m

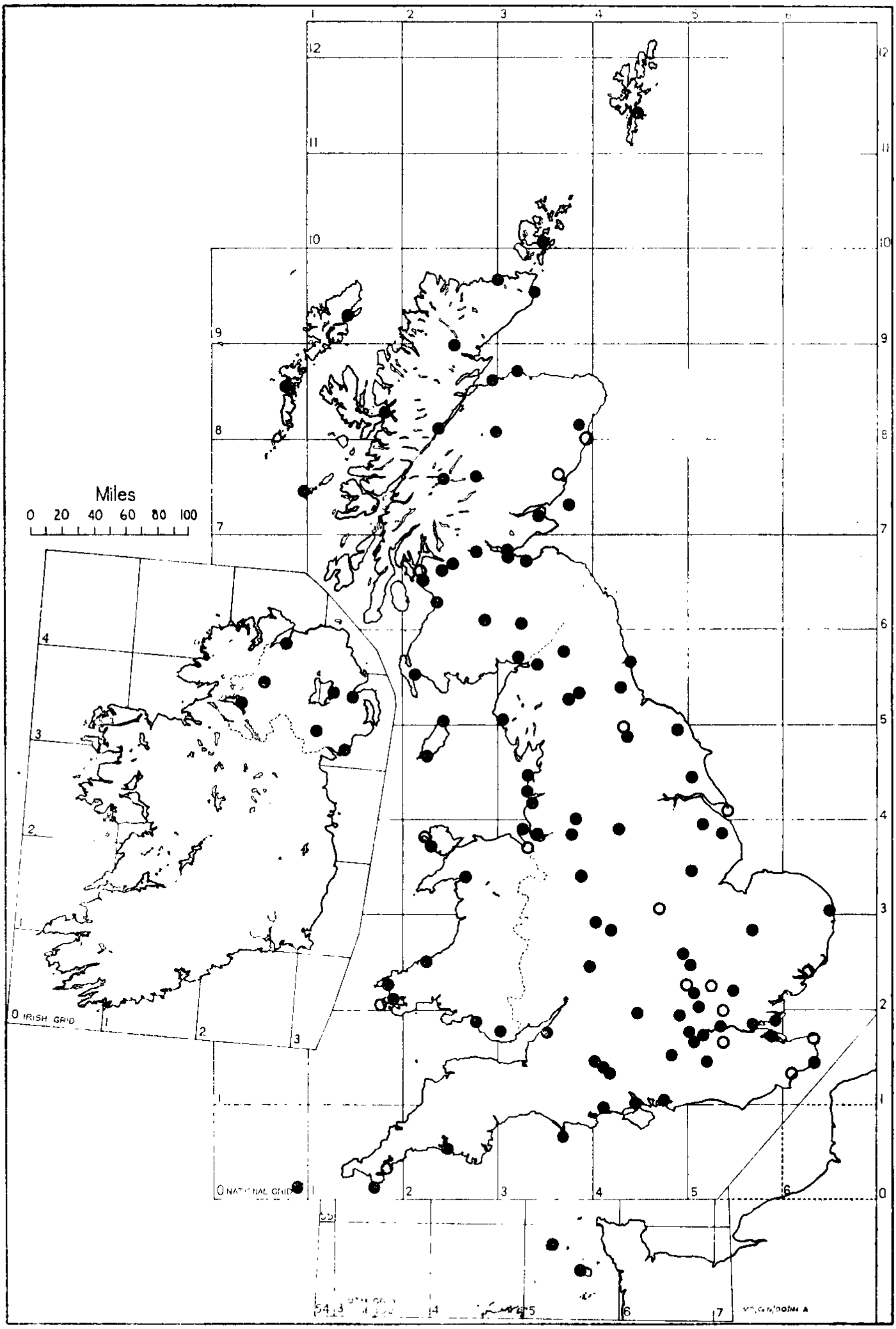

FIGURE I—DISTRIBUTION OF ANEMOGRAPHS PROVIDING WIND RECORDS FOR THE METEOROLOGICAL OFFICE

● Current stations
○ Closed stations for which records exist for at least 10 years

(33 ft) over open level ground in the district. It is rarely possible to achieve this fully. Ideally the instrument should be at the standard height of 33ft on a mast or lattice tower with no obstacles such as trees or buildings within a 200 to 300 yards radius. Failing this it may be necessary to raise the anemograph head to a greater height in order to clear the immediate effects (wake) of local obstructions and in such cases the effective height may exceed 33 ft. In very built-up areas it will usually be necessary to place the instrument at least 33 ft above the general level of the buildings.

TABLE I—LIST OF ANEMOGRAPH STATIONS PROVIDING RECORDS TO THE METEOROLOGICAL OFFICE DURING 1967, GIVING POSITION, TYPE AND HEIGHTS

Station	Latitude	Longitude	Type*	Height of cups/vane above MSL	Height of cups/vane above ground *feet*	Effective height
Lerwick	60° 08′ N	01° 11′ W	E	304	33	33
Kirkwall	58° 58′ N	02° 54′ W	E	134	50	33
Dounreay	58° 35′ N	03° 45′ W	E	110	39	30
Wick	58° 27′ N	03° 05′ W	E	147	33	33
Shin	57° 57′ N	04° 25′ W	E	78	33	33
Stornoway	58° 12′ N	06° 22′ W	D	120	40	36
Duirinish	57° 19′ N	05° 41′ W	E	125	65	55
Benbecula	57° 28′ N	07° 22′ W	E	52	33	33
Cairngorm	57° 08′ N	03° 39′ W	E	3525	31	31
Fort Augustus	57° 08′ N	04° 43′ W	E	189	53	53
Kinloss	57° 39′ N	03° 34′ W	E	57	41	41
Lossiemouth	57° 43′ N	03° 20′ W	D	101	80	60
Dyce	57° 12′ N	02° 12′ W	E	234	30	30
Bell Rock	56° 26′ N	02° 24′ W	D	128	131	124
Rannoch	56° 41′ N	04° 35′ W	E	1006	56	57
Tummel Bridge	56° 42′ N	04° 01′ W	E	528	53	53
Leuchars	56° 23′ N	02° 52′ W	E	78	40	40
Forth Road Bridge	56° 00′ N	03° 23′ W	E	237	—	237
Turnhouse	55° 57′ N	03° 21′ W	E	137	40	33
Edinburgh, Blackford Hill	55° 55′ N	03° 11′ W	E	496	50	34
Tiree	56° 30′ N	06° 53′ W	D	89	60	47
Cumbernauld	55° 58′ N	03° 58′ W	E	543	33	33
Paisley	55° 51′ N	04° 26′ W	D	188	81	31
Abbotsinch	55° 52′ N	04° 26′ W	E	52	33	33
Lowther Hill	55° 23′ N	03° 45′ W	E	2415	43	33
Hunterston	55° 43′ N	04° 52′ W	E	41	30	30
Prestwick	55° 30′ N	04° 35′ W	E	68	33	33
Chapel Cross	55° 01′ N	03° 13′ W	E	310	50	50
Eskdalemuir	55° 19′ N	03° 12′ W	D	825	50	35
West Freugh	54° 51′ N	04° 57′ W	E	81	33	33
Ronaldsway	54° 05′ N	04° 38′ W	E	82	33	33
Point of Ayre	54° 25′ N	04° 22′ W	E	64	33	33
Durham	54° 46′ N	01° 35′ W	D	389	53	33
South Shields	55° 00′ N	01° 26′ W	D	73	57	44
Leeming	54° 18′ N	01° 32′ W	E	138	33	33
Silpho Moor	54° 20′ N	00° 31′ W	D	680	50	30
Leconfield	53° 53′ N	00° 26′ W	E	58	33	33
Binbrook	53° 26′ N	00° 12′ W	E	386	33	33
Cranwell	53° 02′ N	00° 30′ W	E	288	47	47
Manby	53° 21′ N	00° 05′ E	E	85	33	33
Gorleston	52° 35′ N	01° 43′ E	E	54	43	43
Mildenhall	52° 22′ N	00° 28′ E	D	98	83	60
Bedford	*52° 13′ N*	*00° 29′ W*	E	*322*	*42*	*30*
Cardington	52° 07′ N	00° 25′ W	E	226	133	133
Garston	51° 42′ N	00° 23′ W	E	307	50	33
Rothamsted	51° 48′ N	00° 21′ W	D	461	41	33
Stansted	51° 53′ N	00° 13′ E	E	351	31	31
Coryton	51° 30′ N	00° 31′ E	D	66	57	48
Shoeburyness	51° 32′ N	00° 49′ E	E	118	106	91
Sheffield	53° 23′ N	01° 29′ W	D	533	83	35
Edgbaston	52° 28′ N	01° 56′ W	D	643	118	73
Elmdon	52° 27′ N	01° 45′ W	E	343	31	31
Amersham	51° 22′ N	01° 09′ W	E	500	50	50
Keele	53° 00′ N	02° 16′ W	D	706	50	33
Pershore	52° 08′ N	02° 02′ W	E	154	33	33
Avonmouth	51° 30′ N	02° 43′ W	D	92	61	33
London Weather Centre	51° 31′ N	00° 07′ W	E	306	229	125
Heathrow	51° 29′ N	00° 27′ W	E	115	33	33
Hampton	51° 25′ N	00° 22′ W	D	139	101	100
Kew	51° 28′ N	00° 19′ W	D	92	75	50
Gatwick	51° 09′ N	00° 11′ W	E	232	38	33
Isle of Grain	51° 27′ N	00° 43′ E	D	48	40	33
Dover	51° 07′ N	01° 19′ E	D	68	38	62
Thorney Island	50° 49′ N	00° 56′ W	E	51	33	33
Abingdon	51° 41′ N	01° 19′ W	E	295	40	40

TABLE I — *contd*

Station	Latitude	Longitude	Type*	Height of cups/vane above MSL	above ground	Effective height
					feet	
Hurn	50° 47′ N	01° 50′ W	E	86	53	46
Calshot	50° 49′ N	01° 18′ W	E	50	41	33
South Farnborough	51° 17′ N	00° 45′ W	E	318	69	35
Larkhill	51° 12′ N	01° 48′ W	E	491	51	36
Boscombe Down	51° 10′ N	01° 45′ W	E	425	53	53
Porton	51° 07′ N	01° 42′ W	E	394	33	33
Sellafield	54° 25′ N	03° 30′ W	E	83	39	35
Carlisle	54° 56′ N	02° 57′ W	E	137	42	30
Spadeadam	55° 02′ N	02° 38′ W	D	959	51	50
Great Dun Fell	54° 41′ N	02° 27′ W	E	2813	33	33
Moor House	54° 41′ N	02° 23′ W	D	1960	50	45
Squires Gate	53° 46′ N	03° 20′ W	E	88	55	35
Southport	53° 40′ N	02° 58′ W	D	63	45	36
Fleetwood	53° 56′ N	03° 01′ W	D	112	50	31
Speke	53° 21′ N	02° 53′ W	E	109	41	33
Manchester Weather Centre ..	53° 29′ N	02° 15′ W	E	268	147	55
Bidston	53° 24′ N	03° 04′ W	D	262	64	39
Ringway	53° 21′ N	02° 16′ W	E	261	33	33
Valley	53° 15′ N	04° 32′ W	E	86	53	40
Trawsfynydd	52° 47′ N	04° 03′ W	E	638	33	33
Aberporth	52° 08′ N	04° 34′ W	E	442	41	37
Milford Haven	51° 42′ N	05° 03′ W	E	155	33	33
Brawdy	51° 53′ N	05° 09′ W	D	432	68	45
Port Talbot	51° 34′ N	03° 45′ W	D	91	40	35
Rhoose	51° 24′ N	03° 21′ W	E	237	37	32
Portland Bill	50° 32′ N	02° 27′ W	E	190	155	155
Mount Batten	50° 21′ N	04° 07′ W	E	209	42	42
Scilly	49° 56′ N	06° 18′ W	D	230	65	57
Lizard	49° 57′ N	05° 12′ W	D	315	75	60
Ballykelly	55° 04′ N	07° 01′ W	D	56	50	35
Aldergrove	54° 39′ N	06° 13′ W	E	263	33	33
Belfast Harbour	54° 38′ N	05° 53′ W	E	68	59	59
Kilkeel	54° 03′ N	05° 59′ W	E	115	60	45
Glenanne	54° 15′ N	06° 30′ W	E	471	33	33
Carrigans	54° 40′ N	07° 19′ W	E	424	33	33
Castle Archdale Forest	54° 28′ N	07° 42′ W	E	263	43	43
Guernsey Airport	49° 26′ N	02° 36′ W	E	363	36	33
Jersey Airport	49° 12′ N	02° 11′ W	E	359	86	50

* D=Pressure-tube anemograph, E=electrical cup anemograph.

It will be seen from Table I that a large majority of our anemographs have effective heights of between 30 and 40 ft, less than one in five having an effective height greater than 50 ft. The highest values occur where the instrument has had to be put on top of a structure such as a lighthouse, for obvious reasons. It is usually only in built-up areas that the effective height is markedly different from the actual height above the ground.

Routine tabulation and publication of summaries.—The 100 or so anemograph stations produce between them some 15 miles of chart per anum and these must all be measured and the results tabulated to form the basis of summaries of various kinds necessary for studies of our wind climate and for general use. The standard procedure in use for many years is to tabulate on a monthly basis on two special forms. On the first form are entered the mean speeds and mean directions over each complete hour. On the second form each day's records are separately analysed giving a frequency distribution of the hourly mean speeds, details of the highest speeds (hourly mean and maximum gust) of the day, the numbers of hours with gust speeds above certain values and notes on any special features. At the bottom of the form are entered the totals and extremes for the month which are published each month in Table II of the *Monthly Weather Report*[4] for most of the stations from which records are received. On the back of the form is an analysis of the hourly speeds and directions for the month. These form the basis of climatological wind summaries for periods of 10 years or more which are prepared from time to time and which can be represented as wind roses. The Annual Summary of the *Monthly Weather Report*[4] includes a tabular summary for each station for the year as a whole and also includes three special wind tables. The first of these gives the numbers of hours with gusts exceeding 33 and 47 kt in each month at each station, the second lists all occasions during the year when the hourly mean speed was 41 kt or more at each station, with details of the associated maximum gusts, and the third gives the dates on which gusts of 48 kt or more occurred at each station.

In addition to these routine monthly and annual summaries longer-period summaries are prepared from time to time and may be obtained on request. Collections of such summaries are published occasionally but the last such publication is unfortunately out of print. However, a completely new publication 'Tables of surface wind speed and direction over the United Kingdom' has recently been prepared and is expected to be published in 1968.

Analysis of extreme wind speeds.—For design purposes the engineer is concerned with the probable maximum speed likely to affect a structure during its lifetime. The highest speed actually recorded during a relatively short period of years at the nearest meteorological station may not be a very good guide. It may also be mentioned here that the maximum speed in a gust of about 3 seconds duration is usually between 50 and 100 per cent greater than the maximum hourly mean speed and, since a small light-weight structure may be fully enveloped by and fully responsive to a gust of 3 seconds duration while for a large building of heavy construction a mean speed sustained over a longer period would be more appropriate, the nature of the structure as well as its intended lifetime is an important consideration. Its height is also important because the natural wind normally increases in speed with increasing height. In a gale the mean speed at a height of about 350 ft over open country (and at only about 170 ft over a built-up area) may be some 50 per cent greater than the mean speed at the standard height of 33 ft. Although gust speeds increase considerably less rapidly with height than this, the effect is still important.

It has been shown by Van der Hoven[5] that there is a gap in the energy spectrum of wind speed centred at a frequency of about one cycle per hour and Davenport[6,7] has used this result, together with the results of a number of spectral analyses of strong wind records, to suggest that the most suitable averaging period for determining basic wind speeds for structural design should be somewhere between five minutes and an hour. On the other hand Newberry[8] has made measurements of the wind pressures on actual buildings in London which suggest that maximum speeds over periods of only a few seconds may be relevant to the wind loading of quite large buildings. It seems doubly fortunate therefore that the Meteorological Office has for so many years tabulated its wind records in terms of maximum speeds averaged over an hour and also of the maximum gust speeds measured by instruments capable of fully recording a gust of three seconds or longer duration.

The Meteorological Office records have been analysed by the writer[9,10,11] using the statistical theory of extreme values, following the method of Gumbel[12] as briefly described below. It has been found that the data are well fitted by the Gumbel type distribution. The great advantage of this type of analysis is that all the recorded extreme values are used and that the best available estimate is obtained of the speed which is likely to be exceeded on the average only once in any specified number of years, called the return period.

For a particular record of length n years the n annual extremes of speed v (which may be either highest hourly mean or highest gust speeds) are arranged in order of size from the smallest to the largest. The probability p that the mth value is not exceeded is then taken to be $m/(n+1)$ giving a value of p for each annual extreme. Thus if $n=19$ the probability of the tenth (middle) observation not being exceeded in any year is clearly $10/(19+1)=\frac{1}{2}$; that of the lowest only 1/20 ; and that of the highest 19/20. It is then assumed that the extremes fit a Type 1 statistical distribution, i.e. that

$$p_v = \exp(-e^{-y})$$

where $y=a(v-u)$, a being the scale factor measuring the scatter of the data, u being the mode of the data, and p_v the probability that the maximum speed in any one year does not exceed v. This assumption is generally a valid one for extreme wind speeds and is easily verified by checking that the data closely fit a straight line when plotted on special graph paper on which one axis is v and the other is $y=-\log_e(-\log_e p_v)$. Having established the straight line that best fits the data the speed corresponding to any desired probability can be obtained ; thus if p_v is 0·98 and 0·99 the corresponding speeds will be those which on average are likely to be exceeded only once in 50 and once in 100 years respectively.

A computer programme has been written which allows all the necessary calculations to be carried out rapidly. The station details and their annual extremes, punched on paper tape, are fed into the machine with the programme and the print-out gives for each station and set of extremes the equation of the best fitting straight line and also the values of v corresponding to return periods of 5, 10, 20, 50, 100 and 200 years. If the effective heights of the stations are included the output speeds can be reduced to the standard height of 33 ft using appropriate formulae for variation of mean speed and gust speed with height.

At stations with records shorter than 10 years this procedure is in general not applicable but if such a station is not too distant from a long-period station it has been found that the probable maximum speeds for the latter can be adjusted to provide good estimates for the former simply by multiplying them by the ratio of the sums of their annual extremes, corrected to 33 ft, during the common period of record.

The results of analysing extreme wind speeds in this way, both for maximum hourly means and for maximum gusts, have been presented elsewhere[13] for 100 stations. The computer programme can of course be re-run each year after adding an additional year's values and results for periods up to 1966 are available in the Meteorological Office. But the effect of adding data for an additional year or two is usually quite small.

Variations of speed with height.—It has been noted that the wind speed usually increases with increasing height. At a level somewhere between 1000 and 2000 ft the actual speed approaches the theoretical speed consistent with the pressure gradient being given approximately by the pressure gradient divided by $2\rho\omega\sin\varphi$ where ρ is air density, ω is the angular velocity of the earth's rotation and φ is the latitude. It is from this upper-level wind, through turbulence, that the surface wind is produced. The amount of turbulence in the lower layers depends on ground roughness and on the temperature distribution in the vertical. Thus in general any law expressing wind speed as a function of height will only apply strictly to one particular place and to one temperature lapse rate. However, in strong winds, which are all that need be considered for wind loading problems the temperature lapse rate will be adiabatic, or neutral, because of the thorough mixing in the lower layers. Most investigations have found that in neutral conditions the variation of speed with height (h) can most simply be expressed by the formula $v=kh^{\alpha}$ where k is a constant and α depends on the roughness of the terrain.

Over open country with only isolated trees and low hedges α has a value between about 0·15 and 0·17 for wind speeds averaged over periods between 5 and 60 minutes. Over very smooth surfaces such as marshland and flat coasts, surface winds are stronger and values of α smaller, between about 0·11 and 0·13. Over well-wooded farmland and suburban areas values are probably around 0·20 while over cities they may exceed 0·25 although few reliable measurements are available. Some workers have suggested values of 0·4 or more but in general their results are open to criticism because the low-level wind speeds were probably unduly affected by nearby obstructions of comparable height to that at which the observations were made, or because measurements for the different heights were not made at the same place.

Examination of any anemograph record shows that the wind is continually varying with gusts and lulls succeeding one another with intervals of the order of seconds. In gales the gusts can be considered to result from the descent of bodies of faster-moving air from a higher level and it is not therefore surprising that the variation of gust speed with height is less than that of speeds averaged over a longer period. Experimental measurements over open country[14] have established that the variation may be expressed by a formula similar to that for mean speeds but with a value of α which is approximately halved but no reliable information appears to be available for conditions over a built-up area.

Maximum speed and averaging period.—Whereas anemograph records in this country are regularly tabulated in terms of hourly mean speeds and maximum gust speeds which are averages over three seconds or so, it frequently happens that estimates of maximum speeds averaged over some other period are required. In particular the current British Standard Code of Practice on Loading specifies a mean over one minute. Thus an important factor in estimating design wind speeds is the relationship between maximum speed and averaging time. Durst[15] has published figures for averaging times from half a second to one hour, based largely on an analysis of open-scale wind records from Cardington. More recently Deacon[16] has published a note on the relationship for averaging times from 2 to 60 seconds, based on data from Sale, Victoria and there is good agreement between the two sets of results. Both apply to open treeless country, although Deacon included some estimates of the changes that might be introduced over rougher terrain, based on the ratios of maximum gust to hourly mean speed published by the author.[9] Estimates for urban and city exposures have also been made by the author[11] and more recently[13] he has given a set of estimates for ratios of maximum gust to hourly mean speed ranging from 1·4, representing very smooth terrain, in steps of 0·1 up to 2·1, representing a city centre. But the only actual measurements over a city that are of sufficiently open time-scale to test these estimates are probably those currently being made in London on and near the Post Office Tower (height, 620 ft) as part of a project in which the Meteorological Office is collaborating with the Building Research Station. Measurements are being made at three levels in strong winds using a very open time-scale and when these are completed and analysed this aspect of the subject should be put on a firmer basis.

Topographical effects.—So far discussion has been confined to more or less level ground and to relatively low altitudes. Winds can be very materially affected by topography however, and its effects must be considered when estimating probable maximum speeds at sites on hills, in steep-sided valleys or in the vicinity of ranges of hills. Although the majority of anemographs are on open sites in relatively flat country there are now a number on the tops of hills and in other situations where the wind is affected by the topography and our knowledge of these effects is now such that appropriate advice can generally be given. If a structure is an important one, however, it will probably be necessary to make special measurements at the site and/or to arrange for wind-tunnel tests using models.

Conclusions.—Engineers in this country are fortunate in having an extensive network of wind recording stations probably unequalled anywhere else. Suitably analysed these records provide a sound basis for estimating probable maximum speeds for most sites where structures are likely to be erected. There are limitations in our knowledge regarding the variation of speed with height and the averaging time relationship over cities but action has been taken to overcome these deficiencies.

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NIGHT-TIME TEMPERATURES IN RELATION TO LEICESTER'S URBAN FORM

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Introduction.—In June 1961 the author presented evidence of thermally induced, near-surface winds across the boundary of a heat-island above Leicester.[1] Since then, substantial improvements have been made to the equipment used to measure temperature and humidity during car traverses along city streets[2] but before August 1966 the instruments were used mainly in London. The results suggested that local urban form was dominant over large-scale considerations in determining the urban temperature anomaly, more especially on calm, clear nights. In particular, the height and continuity of the buildings close to the line of traverse and the particular geometry of the spaces between them appeared to be more important than the overall size of the city, although the latter is clearly of some relevance because it influences the character of airflow in the boundary layer[3] (p. 68).

To test these early ideas, work is currently in progress to derive statistical relationships between the local intensity of the heat-island and the immediate urban structure, but as part of this same broad theme, temperature (and humidity) traverses were made during August and September 1966 in Leicester and a number of the surrounding settlements. This article presents some of the evidence for air temperature patterns related to the urban form of Leicester.

Equipment.—Basically, the instrumentation consists of a Land Rover ahead of which, at four feet above the ground, are shielded electrical resistance thermometer elements connected to a recording a.c. bridge instrument (strip-chart recorder) inside the vehicle. The sensitivity of the platinum elements is well adjusted to the scale of the investigation, being neither so sensitive as to register extraneous short-period fluctuations, such as those from engine exhausts, nor so slack as to smooth out significant local differences such as those between areas of different housing densities and between these and pockets of open land. The lag of the resistance elements is 1·6 s for a 50 per cent reaction to temperature change and 4·7 s for a 90 per cent reaction ; the latter being equal to half the time interval between successive readings on the recorder. One element registers air temperature, the other two form a hygrometer and differences in their resistances are converted by the recorder into readings of relative humidity. Temperature and humidity are alternately plotted on the recorder chart, each every 9·2 s which, at a vehicle speed of 20 miles/h gives readings of both temperature and humidity every 90 yd. To prevent engine-heated air entering the element shield while the vehicle is stationary, at traffic lights for instance, the bonnet of the Land Rover is covered with a thick pad of glass fibre and a small, switch-operated 12-volt fan blows air over the elements from behind. As an added precaution, a switch-operated pen gives a trace on the chart which is used to indicate halts. A second switch-operated trace is used to give chart positions to the closely-spaced locating points along the traverses (numbered from 1 to 42 in Figure 1), thus overcoming the problem of temporary halts.

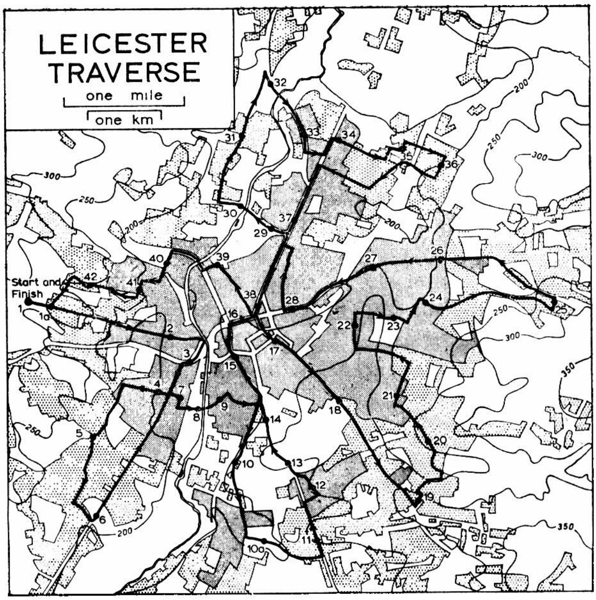

FIGURE 1—MAP SHOWING THE ROUTE OF THE LEICESTER TRAVERSES
Bold line denotes the route used.
At numbered positions on the traverse, locating marks are made on the recorder chart.
Contours are drawn at 50-ft intervals. For explanation of shading see page 246.

Description of traverses.—Using this equipment, traverses, mainly during the night, were made along a 30-mile, closed, star-shaped route in Leicester (Figure 1). At the census in 1961, Leicester had a population of almost 270,000 and covered about 27 square miles ; Greater London, at this time, had a population of almost 8¼ millions and covered nearly 750 square miles. The traverse route was chosen to sample all the major urban districts of the city and provide sufficient crossings and repeated measurements to calculate regional temperature (and humidity) variations during the period of traverse, totalling about 1½ hours. Using pairs of readings at each reference point (shown on Figure 1), the 600 or so observations taken during each of the traverses were standardized to the time of completion. They were then plotted along the line of traverse and used to construct an isoline map. The temperature maps which follow use broken lines where there is some uncertainty in the precise location of the isotherms.

Relief is of small overall consequence in a study of night-time temperatures in Leicester ; eastern, south-eastern and western outer suburbs being at the most 125 ft higher than those parts of the city built in the bottom of the Soar valley (Figure 1). Very locally, however, relief factors are responsible for cold air drainage and attention will be drawn to this in the following discussion of temperatures in Leicester on three nights in August 1966.

Discussion of temperature maps.—In each of the three temperature maps (Figures 2, 3 and 4), and also in Figure 1, the built-up area is divided, rather subjectively, into areas of different building densities. One, generally found in more central areas, is composed of mainly late eighteenth, nineteenth and early twentieth century buildings, both domestic and industrial, with few open spaces (dark shading on maps). Here, building densities are high and roads narrow. The other, typical of the outer suburbs, is a mainly post-1918 development of much lower building density and with numerous parks, allotments, gardens and other open spaces (lighter shading on maps).

19 August 1966.—During the day of 19 August 1966 the weather in central and southern England was bright and sunny, the synoptic situation being dominated by a slack pressure distribution over Great Britain between a weak anticyclone west of Scotland and a shallow depression over eastern Europe. A cold front moving slowly south across northern England reversed before dawn on the 20th but had no effect upon the weather in the English Midlands or south-east England. Temperatures around Leicester had risen to 25°C (77°F) during the afternoon of the 19th and subsequently fell during the evening and night to 12°C (53·6°F) around dawn on 20 August. Night skies were clear and winds from the west-north-west never rose above 5 kt. The midnight radiosonde sounding at Hemsby (52° 41′N, 1° 41′E), east of Leicester, shows an inversion of about 7 degC (13 degF) in the first 500 to 600 ft and stable conditions up to about 5000 ft. These conditions maintained a fairly strong heat-island.

Because of the several heat-exchange processes responsible for heat-islands over built-up areas[4] (p. 174), the temperatures recording in Leicester exceeded those outside by as much as 3·3 degC (6·0 degF) by 2315 GMT (Figure 2). The temperature difference between Westminster (St James's Park) in central London and Wisley in rural Surrey at this time was 2·8 degC (5·0 degF) ; temperatures in central north-east districts were probably about

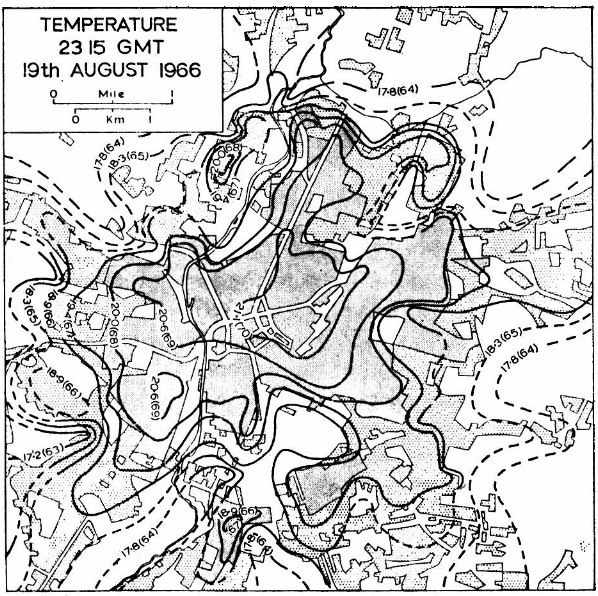

FIGURE 2—TEMPERATURE PATTERN FOR LEICESTER AT 2315 GMT, 19 AUGUST 1966
Isotherms are labelled in degrees Celsius and degrees Fahrenheit (in brackets).
Contours are drawn at 50-ft intervals. For explanation of shading see text above.

0·6 degC (1·0 degF) warmer. The heat-islands above Leicester and London were clearly of almost equal intensity in spite of the disparity in the sizes of the two cities. Thermograph readings at Westminster (St James's Park) and Wisley showed a constant temperature difference between 2200 GMT on the 19th and 0800 GMT on 20 August 1966, and it seems likely that this was also true of temperature conditions in Leicester.

Figure 2 shows a strong similarity between the form of the heat-island on the night of 19 August and the urban characteristics of Leicester. The margin of the warm air follows very closely the edge of the city with the sharpest thermal gradients in places where the city limits are most clearly defined more especially where compact urban development abuts against open country as in the north-east. In the south-east suburbs, built-up areas intermingle with open spaces at the city limit, giving a more diffuse edge to both the urban development and the margin of the heat-island. Locally, tongues of cold air may drain from open country into the urban fringes, sharpening the edge of the heat-island : this is what appears to have happened in east and south-west Leicester (Figure 2). Marginal winds blowing towards the centre of the heat-island may also have been present and these would help to shift the steepest thermal gradients nearer the centre of the city.[1] But the parallelism between the city's morphology and the heat-island above it goes beyond a simple conformity between the extent of the city and the area of warm air. The shape and spacing of the isotherms also reflects the varying density of urban development so that sharp thermal gradients are commonly found near the junction between dense and more open urban development with the highest temperatures of all in the very heavily built-up central districts (Figure 2).

23 August 1966.—On 23 August 1966, the synoptic situation over Great Britain was dominated by a ridge of high pressure across north-west Europe from Scandinavia to the Azores. Skies which had been covered by six-eighths cumulus and stratocumulus cloud during the day cleared to less than a one-eighth stratocumulus cover during the night and there was little or no wind. Temperatures in both Leicester and London had risen to about 18°C (64·4°F) in the early afternoon of 23 August and fell to about 7°C (44·6°F) by dawn on the 24th. The midnight radiosonde sounding at Hemsby showed a surface inversion with a temperature rise of 4·0–5·0 degC (7·2–9·0 degF) in the first 500 ft. It was probably this which prevented the warm air of the heat-island lifting off the ground.

The heat-island above Leicester at 2345 GMT on 23 August had an intensity at its centre of 4·4 degC (8·0 degF) with peak values in the same closely built-up area as on the 19th and with the same conformity between the isotherm and the urban development patterns (Figure 3). Central north-east districts of London, with a similar urban form to central Leicester, were probably at this time, between 4·4 and 5·0 degC (8·0 and 9·0 degF) warmer than rural districts around the city. The temperature difference between Westminster (London) and Wisley at 2200 GMT was 4·4 degC (8·0 degF) and this was its peak intensity for the night. The author has, however, shown that night-time temperatures in London are normally highest a little north-east of the centre[4] (p. 155) so that on the night in question the heat-island above London is likely to have had an extreme intensity of about 5 degC (9·0 degF), that is,

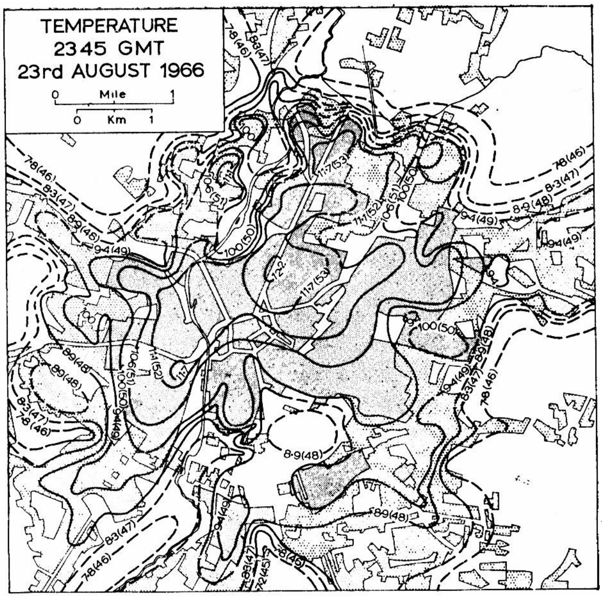

FIGURE 3—TEMPERATURE PATTERN FOR LEICESTER AT 2345 GMT, 23 AUGUST 1966
Isotherms are labelled in degrees Celsius and degrees Fahrenheit (in brackets).
Contours are drawn at 50-ft intervals. For explanation of shading see page 246.

almost exactly the same as the value for similar types of urban development in Leicester.

31 August 1966.— The third traverse was made during the night of 31 August–1 September with temperatures corrected to 2330 GMT on 31 August. England and Wales were then covered by a weak ridge of high pressure ahead of a frontal depression centred west of Ireland. Night skies in central and south-east England were rather cloudy ahead of a warm front approaching south-west Wales and Cornwall, and at midnight there was a seven-eighths cover of cumulus and stratocumulus cloud above Leicester and a six-eighths cover of cirrostratus cloud above London. Winds were calm in Leicester but a south-westerly wind of about 6 kt blew on the margins of London : the wind in the centre can be estimated at about 7 kt[4] (p. 73). Temperatures in both Leicester and London reached a maximum of 19°C (66·2°F) on 31 August and fell during the night to a minimum of 11°C (51·8°F) around dawn on the following day. The 0000 GMT temperature sounding at Hemsby showed no surface inversion. Clearly, the lapse rate was unsuitable for an intense heat-island to develop, but quite apart from this, the overcast skies reduced radiation heat losses from both town and country and the heat-island above Leicester at 2330 GMT on 31 August 1966 was, in consequence poorly developed (Figure 4). This was in spite of the relatively light winds and weak eddy diffusion in the boundary layer. In London on the night of 31 August, the heat-island reached its maximum intensity of between 1·7 and 2·2 degC (3·0 and 4·0 degF) at 2200 GMT (as deduced from the thermograph records at Westminster and Wisley). In spite of the slightly stronger winds in London, the clearer skies would roughly compensate for this difference between meteorological conditions over London and Leicester as controls of their respective heat-islands[4] (p. 178) and it is therefore interesting to

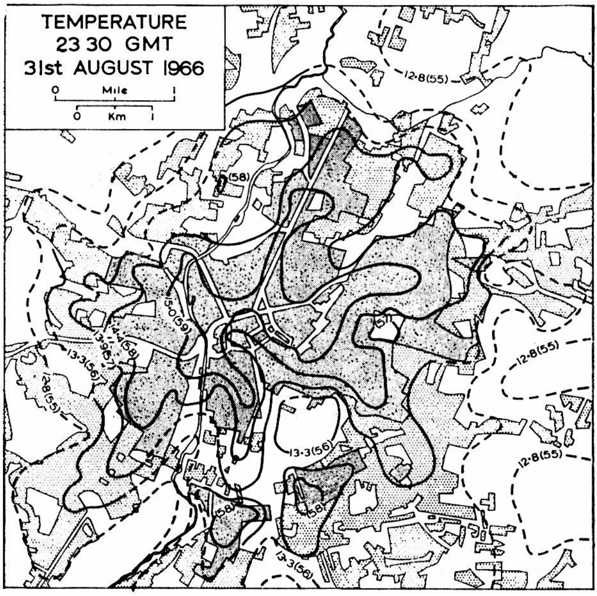

FIGURE 4—TEMPERATURE PATTERN FOR LEICESTER AT 2330 GMT, 31 AUGUST 1966
Isotherms are labelled in degrees Celsius and degrees Fahrenheit (in brackets).
Contours are drawn at 50-ft intervals. For explanation of shading see page 246.

note that, as on previous occasions, the heat-island above London on this night had a comparable intensity to that above Leicester, a smaller city but with development densities at its centre comparable to those in central north-east London.

Conclusions.—It is clear that the intensities of the heat-islands above Leicester on the nights studied corresponded very closely with those for areas of similar housing density in London. The disparity between the size of the two cities seems to have had little effect.

The heat-islands on these occasions were probably about 150–250 ft deep at their centres and the wind profile within this layer can reasonably be assumed to have become adjusted to the urban roughness parameter soon after the air had crossed the city boundary (Davenport,[3] p. 68) so that eddy diffusion rates in the lower atmosphere would not be materially affected by the much smaller size of Leicester which is about 5 miles across as compared with London's 25 miles. The heat contribution from the burning of various fuels within the city would be small in August and much would, in any case, be diffused vertically and laterally during unstable and turbulent day-time conditions. There would be relatively little combustion during the night. Clearly the heat-island is generated mainly by the thermal and wind effects of buildings, more especially their high thermal capacity and surface area and their group geometry. Differences in albedo and evaporation between cities and their rural surrounds are probably of secondary importance and differences in pollution levels, cloud amounts and fog frequencies are likely to be of only occasional significance.

The remarkable conformity between the pattern of night-time temperatures and the form of the city on clear, calm nights when meteorological conditions are most conducive to the development of heat-islands suggests the importance of nearby urban densities (and thereby thermal capacities) and the shape of the buildings and intervening spaces in the maintenance of high urban temperatures. The thermal lag of the urban fabric helps to produce the greater intensity of night-time heat-islands whilst the nature of the wind profile above the city[3] (p. 87) and the virtual trapping of air between buildings are clearly of the utmost importance in the maintenance of city warmth. The very strong heat-islands associated with clear, calm nights contribute very heavily, of course, to average intensities.

The conclusion from the present comparative studies in Leicester and London is, that city size is not, in itself, very relevant to the intensity of heat-islands, and it follows that city growth is not necessarily correlated with greater urban warmth[5], although an expansion of the urban area may well be indirectly relevant through considerations of the depth and intensity of eddy diffusion and thereby the fetch over which the wind profile becomes adjusted to the urban roughness parameter.

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REVIEWS

Solar-activity forecasting, by Yu. I. Vitinskii. $9\frac{1}{2}$ in × 7 in, pp. iv + 129, *illus.*, (translated from the Russian by the Israel Program for Scientific Translations, Jerusalem), Oldbourne Press, 1–5 Portpool Lane, London EC1, 1965. Price: 54*s*.

Variable solar activity has effects, some of which are well known, upon the high atmosphere; and indeed it entirely controls the physical state of the outermost layers. The effects include (in descending order of height) variation in the drag of the outer atmosphere on satellites, disturbances in the ionosphere which are liable to disrupt radio communication, polar lights (aurorae), and a large percentage variation of the amount of ozone produced in the stratosphere. Disturbances of the earth's magnetic field, magnetic storms and inhibition of the cosmic ray flux from elsewhere in the galaxy also result from certain solar outbursts. Some of these effects are of immediate practical importance, and in consequence possible methods of forecasting the course of solar disturbance some days, months and years ahead have had to be explored.

Because the sun is the source of the energy that heats the earth's surface, evaporates moisture from it and drives the winds, any variation of this energy supply — even by a fraction of one per cent — might be expected to influence weather and climate. However, the difficulties of measuring the strength of the solar beam impose a wider error margin than the range of any likely variations. And such is the variety and complexity of the energy transformation and transmission processes in the lower atmosphere that the early hope for simple sun–weather relationships came to nothing — or almost nothing. That phase of research was brought to an end with a rude shock when an apparently strong positive correlation between the levels of the African lakes and sunspot number, found by C. E. P. Brooks,[1] broke down after the 1927 maximum. The initial data series had, of course, been far too short. The fact that since 1927 the lake levels have been high twice in each '11-year' sunspot cycle, around the maximum and minimum years, may now suggest that the matter was dropped too hastily. But in the 1920's another supposed relationship — a negative correlation between mean surface temperatures in the tropics and sunspot number[2] — also appeared to weaken and then change phase. This could mean that the two phenomena had rather similar, but not identical, natural periods and were unconnected. After this, a whole generation of meteorologists, particularly in Great Britain, refused to waste time and effort in such a treacherous field. Moreover, prejudice against the existence of any real relationships between sunspots and weather was aroused when the topic became the special preserve of cranks and those whose enthusiasm in the search for easy answers was only matched by their lack of criticism of the evidence.

Signs are not lacking, however, that the subject of solar disturbance affecting weather and climate must receive serious attention once more, despite its acknowledged difficulty. As often in science, interesting new results have come from new types of observational material and new techniques — in this case, from the world-wide network of upper tropospheric wind and pressure data and from the working up of long series of observations, including derived data on solar disturbance, atmospheric radiocarbon and surface temperature over many centuries. The $\pm$ (2 to 4) per cent variation over rather long periods in the quantity of radioactive carbon in the carbon dioxide in the atmosphere, a substance which depends on the cosmic ray flux for its production and is subject to decay at a known (exponential) rate, is of special interest as a physical marker susceptible of sufficiently precise laboratory measurement today.

Suess[3,4] and others have established the history of radiocarbon variation over the last 1500 to 3000 years and have noted the appearance of a strong negative correlation with the 50-year average temperature values derived by Lamb[5] over the last thousand years. Bray[6] has also established a relationship between the length of the '11-year' sunspot cycles (or, better, the cycle interval between maximum and maximum) and the intensity reached at maximum: proceeding from this he has noticed (in data quite other than the radiocarbon and temperatures mentioned above) that the intensity of solar disturbance century by century shows an inverse relationship with the extent of Arctic sea ice and of glaciers since A.D. 300 and a positive correlation with tree growth near the thermal limit of trees in north-west Canada. On a much shorter time-scale, Baur's forecasts of summer and winter weather character in Europe based on indications of enhanced vigour of the circumpolar westerlies about the middle of the rising and descending phases of the '11-year' sunspot cycles have attained a remarkably high degree of verification over many years. Moreover, Baur's assumption about the course of circulation vigour has been upheld by a preliminary study of the long series of January mean pressure maps since 1750 produced in the Meteorological Office.[7]

Sazonov[8] has noted a strong association between intense rises of 500 mb height between 35 and 70°N and days when a large group of sunspots pass the sun's central meridian. He has also pointed out that the positions of intense anticyclone centres formed in the upper troposphere are concentrated in a ring of constant geomagnetic latitude. This ring lies parallel to the zone of maximum frequency of aurora and passes over Britain, Scandinavia, the Siberian Arctic coast and Alaska, from where it runs south-east to the subtropical zone near Bermuda.

Much further work is needed to establish the meteorological and related facts securely.[9] In the meantime, certain rules for long-range weather forecasting have been formulated[10,11,12] which presuppose an ability to fix the date of the next sunspot maximum or minimum.

The appearance of this book should therefore be welcomed both as a manual for those, meteorologists and others, who must make some estimate of the future course of solar disturbance and as a guide to the present state of the subject. What one finds in this regard is admittedly far short of satisfactory: a set of empirical statistical relationships, some very insecure, others probably firm, some based on extremely short runs of observations, others resting on 200 years' data or more. The contribution of solar physics does not so far go beyond certain alternative, and very generalized theories of the nature and origins of the disturbances seen on the sun's face. The author, Vitinskii, has been a contributor to the subject himself and appears well read in the western as well as the Soviet literature. He states the position fairly, even if circumstances have forced him and those he quotes to squeeze the last drop of juice and more (!) from the observations available. There is a serious need for better indices of solar behaviour and the setting up of observation routines that will monitor the relevant emissions from the sun over long periods into the future.

Among the characteristics of solar behaviour so far identified are different relationships between the lengths of the rising and falling phases of the '11-year' cycle in intense and weak cycles, relationships between the solar latitude of the first spots in a new cycle and the intensity of disturbance, relationships between successive cycles (especially the pairs within each 22-year cycle) and the occurrence of some longer-term variations for which time-scales around 90 and 178 years are suggested. On this sort of basis the various forecasts of the current '20th cycle' available so far agree in expecting a maximum sunspot number not much over half that attained in the last two cycles, and in expecting a longer period-length, thus placing the probable maximum between 1968 and 1970. Those concerned should read this book.

H. H. LAMB

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NOTES AND NEWS

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Satellite experts at the Fifth World Meteorological Congress

Mr A. Johnson and Dr M. Tepper, United States satellite experts, presented lectures on 'The use of satellite data in weather forecasting' and 'The future of meteorological satellites' to the 400 delegates at the Fifth World Meteorological Congress in Geneva during April.

Mr Johnson of the National Environmental Satellite Centre reviewed the short history of satellite meteorology from the first experimental TIROS satellite in 1960 to the present TIROS operational satellite system (TOS) which was further advanced in April by the launching of ESSA V. From a height of 887 miles (1419 km) ESSA V views weather all over the earth once every 24 hours, photographing a given area at the same local time each day.

Mr Johnson illustrated his lecture with varied examples of the satellite meteorologist's art, demonstrating how many types of meteorological phenomena, from cyclones, thunderstorms, snow and ice to jet streams and frontal systems can be identified in satellite data, particularly in cloud photography, and how additional information such as wind speed and direction can be inferred.

It was the impact of satellite data upon conventional weather analysis and forecasting which led originally to the development of the idea of a World Weather Watch, the form and future of which were further discussed at the Fifth Congress.

Mr Johnson referred to the first Applications Technology Satellite, (ATS-1) which is an earth-synchronized satellite, rotating at the same speed as the earth and therefore appearing to be stationary at a height of 27,000 miles (43,200 km) over the equator south of Hawaii. This satellite photographs the same area covering nearly one-third of the earth's surface every 20 minutes during daylight. A motion picture compiled from ATS-1 photographs, shown publicly for the first time, dramatically illustrated the variations in cloud systems during one day. Delegates were given an excellent opportunity of studying initial exercises in the evaluation of cloud movement, storm formation and optimum frequency of observations.

The ATS-1 is also demonstrating the efficiency and speed of meteorological satellites as telecommunications devices. Both original data and processed data such as weather analyses are relayed by ATS-1 from the Washington World Centre to centres, such as the Melbourne World Centre, which are equipped for reception of automatic picture transmission (APT).

Dr Tepper of the National Aeronautics and Space Administration described how the U.S. Meteorological Satellite Programme will develop, test and check satellite sensors, instrument sub-systems and techniques and combine with increasingly sophisticated high-speed electronic computers to establish the satellite as the key observational tool in the World Weather Watch system.

Under the current TOS system, two separate satellites are used to obtain daylight global cloud data and direct local read-out of data to ground receiving stations, now installed in over 40 countries. Night-time information is largely derived from radiation measurements made by NIMBUS infra-red radiometers. A forthcoming research satellite, TIROS M, planned for early 1969, will provide global and local, day and night cloud data.

Techniques for obtaining more continuous observations on the mass, wind and moisture fields at various atmospheric levels will provide atmospheric structure data and, within a few years, may extend predictions from 1 to 2 days to more than 2 weeks ahead. Three additional ATS flights are planned to start in 1967. A NIMBUS satellite to be launched in 1968 and another in 1970 will be used to test a special system for interrogating, locating and recording other observational devices such as constant-level balloons, automatic weather stations and oceanographic buoys.

A series of experiments is being considered for flight aboard an Apollo-type spacecraft in late 1969. This satellite will be manned and will thus benefit from human observation and judgement. Because of greater capacity it will be able to carry heavier and more complex equipment than can be carried by the TOS, ATS or NIMBUS satellites.

Retirement of Mr A. L. Maidens

Arthur Leonard Maidens retired from service with the Meteorological Office on 30 June 1967, having entered the public service as an Observer at the National Physical Laboratory (NPL) in 1926. He served in the Aerodynamics Branch, working on model experiments which must have been quite advanced for their time, since words such as 'flaps' and 'slots' appear in the titles of reports of which he was co-author. Whilst at the NPL he studied for and passed the Special B.Sc. degree of London University and in April 1930 joined the Meteorological Office as a Junior Professional Assistant. The salary, offered, presumably attractive to Honours Graduates at the time, was £175 per annum.

His first work in the Office was in the Headquarters Forecasting Branch M.O.2, and from 1934 to 1938 he was a forecaster at Croydon, the London Airport of the day. After a year forecasting for the RAF at Mildenhall he was posted in April 1939 to Malta, where he was called up for service in the Meteorological Section of the RAF Reserve in late August. He left Malta in December 1939 on posting to the Air Component of the Expeditionary Force in France and was promoted to the acting rank of Squadron Leader in March 1940. The card which records his personal history next bears the laconic note 'returned to U.K. 18.6.40'. The journey home was neither direct nor comfortable. Then after a spell in Northern Ireland, he went for three years to Gibraltar, where he received acting promotion to Wing Commander rank. He ended his war service at Prestwick, and remained there as a civilian until 1948. In this year his long connexion with weather forecasting was broken ; he was posted to Dunstable to take charge of the branch concerned with upper-air observations. In 1957 he was promoted to the grade of Senior Principal Scientific Officer as Assistant Director in charge of Instrument Development, the post from which he has now retired. He was able to play a considerable part in the planning of the laboratory facilities at the new Bracknell Headquarters of the Office, and it was no fault of his that the otherwise excellent plans have proved inadequate for the numbers who now wish to use them — he foresaw more clearly than most the probability of expansion and the need for space.

Leonard Maidens is gifted with an unusual degree of patience and the facility of seeing all sides of controversial issues. We, his colleagues, will miss his sometimes garrulous good humour. We wish him clear roads for his caravan, and many fine summers in which to enjoy them.

G. D. ROBINSON

AWARD

We note with pleasure that the International Meteorological Organization Prize for outstanding work in meteorology and international collaboration has been awarded for this year to Professor Cyril J. Kondratiev (U.S.S.R.) by the Executive Committee of the World Meteorological Organization during its 19th session.

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