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WESTERLY-TYPE RAINFALL AND ATMOSPHERIC MEAN-SEA-LEVEL PRESSURE OVER ENGLAND AND WALES

By E. N. LAWRENCE

Summary. For days with a 'straight' westerly type (that is, not the anticyclonic-westerly or cyclonic-westerly types) of atmospheric circulation over the British Isles region, the long-term monthly and annual averages of the daily rainfall amount over England and Wales (combined) for 5-mb ranges of MSL pressure and the corresponding frequencies of these ranges were calculated for the period 1950–69 (20 years). The results were harmonically analysed for each range of pressure.

The results show that both the average daily rainfall amount and the amplitude of its annual variation increase with decreasing pressure; but with very low pressure there is a tendency for the daily rainfall amount to level off or even decrease. The date of the annual maximum daily rainfall amount varied from late November or earlier for well below average pressure, to December for higher pressure.

The frequency of days with 'straight' westerly-type circulation and the amplitude of its annual variation are largest when MSL pressure is about average. For low pressure the maximum frequency occurs mainly in winter, while with higher pressure the maximum frequency occurs mainly in summer and autumn.

The results are discussed in relation to sea temperature and land–sea orientation.

Introduction. An earlier project, to obtain synoptic-type daily rainfall averages over England and Wales,[1] showed that indirect estimates of total rainfall for individual months, based on these averages and on the register of daily synoptic types for the British Isles region,[2] fell short of the actual rainfall, or the so-called direct estimate of rainfall, for months which were extremely wet or extremely dry. The cause of these errors was attributed mainly to the loss of variance resulting from the use of averages for synoptic types with large frequencies, notably the 'straight' westerly type (that is, not the anticyclonic-westerly or cyclonic-westerly types[2]) of atmospheric circulation. To overcome this weakness in the procedure, as far as the 'straight' westerly type is concerned, days of this type were sub-classified according to atmospheric pressure at MSL.

The present work consists of the calculation of daily rainfall averages over England and Wales (combined) for varying ranges of pressure and the average frequencies of these ranges, for each calendar month and for the year for days of 'straight' westerly-type circulation.

Method. To ascertain objectively the daily pressure over England and Wales on 'straight' westerly-type days during the period of 20 years from 1950 to 1969, the pressure (to the nearest millibar) was read from the midday chart of the *Daily Weather Report** for the central point of 53°N 02°W.

For these days, the direct estimates of daily areal rainfall amounts for England and Wales[1] were processed to obtain for each calendar month the average daily rainfall amount for 5-mb ranges of pressure (e.g. 990–994, 995–999, 1000–1004 mb) and the corresponding average frequencies of the ranges (in days per month).

To eliminate irregularities arising from small samples, the average daily rainfall amount and average frequency, for each range of pressure separately, were adjusted by the use of a 1:2:1 weighting for each month together with its two adjacent months. The weightings were applied to rainfall totals, making due allowance for varying frequency. The resulting frequencies were slightly further adjusted, proportionally, to ensure that the total frequency for each month, for all values of surface pressure, remained the same as the initial frequencies given for the 'straight' westerly type.[1] The resulting values of the average daily rainfall amount and the average frequency, for each month separately, were then further adjusted by the use of a 1:2:1 weighting between consecutive five-millibar pressure categories. As before, the weightings were applied to rainfall totals, making allowance for varying frequency. This inter-pressure category weighting procedure was then repeated.

This repeated procedure of inter-pressure category weighting leads to two extra pressure categories at each extreme of pressure in each month. Such ranges of pressure did not actually occur within the 20-year period, either in the month indicated or in either of the two adjacent months. These 'theoretical' categories were eliminated by grouping the three pressure categories at each extreme of pressure, for each month separately. Results are shown in Table I.

Annual variation.

Daily rainfall amount. For days with a 'straight' westerly-type circulation, the average daily rainfall amount in each calendar month and for each of four alternate 5-mb ranges of pressure are shown in Figure 1, which shows also the first harmonic curves. The 'theoretical' categories, previously mentioned, are included in the plotted points of Figure 1 and also in the harmonic analysis whenever such categories occur. This procedure provides values in the pressure range of 990–994 mb in the summer months.

The harmonic coefficients, for various ranges of pressure, are given in Table II, using the notation :

$$R \text{ or } F = a_0 + \sum_{k=1}^{k=5} \left(a_k \cos \frac{2\pi k}{12} t + b_k \sin \frac{2\pi k}{12} t \right),$$

where $t = 0, 1, 2,$ etc. refer to January, February, March, etc. and R millimetres per day is the average daily rainfall amount for a given range of pressure and F days per month is the average frequency of the given range, for days of 'straight' westerly-type circulation. It can be seen from Table II that the

* London, Meterological Office. *Daily Weather Report.*

TABLE I—AVERAGES OF RAINFALL OVER ENGLAND AND WALES FOR GIVEN RANGES OF MSL PRESSURE AND FREQUENCIES OF THESE RANGES IN THE PERIOD 1950–69 FOR 'STRAIGHT' WESTERLY-TYPE CIRCULATION

		Pressure range (mb)											
		975–979	980–984	985–989	990–994	995–999	1000–1004	1005–1009	1010–1014	1015–1019	1020–1024	1025–1029	1030–1034
Jan.	*R*	4·4	4·8	4·8	4·9	5·1	5·0	4·5	3·9	3·3	2·8	2·1	1·2
	F	0·03	0·08	0·16	0·29	0·48	0·70	0·83	0·93	0·97	0·79	0·45	0·21
	RF	0·13	0·38	0·77	1·42	2·45	3·50	3·73	3·63	3·20	2·21	0·95	0·25
Feb.	*R*		4·1	3·8	3·8	4·2	4·3	3·9	3·2	2·5	2·0	1·5	0·8
	F		0·07	0·11	0·20	0·35	0·50	0·60	0·68	0·73	0·64	0·38	0·19
	RF		0·29	0·42	0·76	1·47	2·15	2·34	2·18	1·83	1·28	0·57	0·15
Mar.	*R*		3·8	3·5	3·8	4·1	4·0	3·4	2·6	2·1	1·6	1·2	0·6
	F		0·04	0·07	0·16	0·33	0·53	0·71	0·83	0·82	0·62	0·32	0·15
	RF		0·15	0·25	0·61	1·35	2·12	2·41	2·16	1·72	0·99	0·38	0·09
Apr.	*R*				3·6	3·8	3·5	2·9	2·4	2·1	2·0	1·7	1·1
	F				0·11	0·20	0·41	0·68	0·92	0·91	0·62	0·28	0·10
	RF				0·40	0·76	1·43	1·97	2·21	1·91	1·24	0·48	0·11
May	*R*				2·6	3·0	2·9	2·6	2·2	2·0	1·8	1·7	
	F				0·04	0·11	0·31	0·65	1·00	1·09	0·77	0·42	
	RF				0·10	0·33	0·90	1·69	2·20	2·18	1·39	0·71	
June	*R*					2·2	2·4	2·4	2·2	2·0	1·7	1·4	
	F					0·10	0·27	0·68	1·17	1·34	0·96	0·47	
	RF					0·22	0·65	1·63	2·57	2·68	1·63	0·66	
July	*R*					3·1	2·9	2·7	2·5	2·2	1·9	1·4	
	F					0·10	0·31	0·81	1·36	1·49	1·02	0·47	
	RF					0·31	0·90	2·19	3·40	3·28	1·94	0·66	
Aug.	*R*					4·5	4·1	3·6	3·1	2·7	2·2	1·6	
	F					0·16	0·43	0·94	1·40	1·39	0·88	0·41	
	RF					0·72	1·76	3·38	4·34	3·75	1·94	0·66	
Sept.	*R*					4·8	4·3	3·9	3·4	3·0	2·4	1·8	
	F					0·30	0·58	1·06	1·42	1·35	0·85	0·42	
	RF					1·44	2·49	4·13	4·83	4·05	2·04	0·76	
Oct.	*R*			8·9	6·1	5·1	4·5	3·9	3·5	3·0	2·5	1·8	
	F			0·04	0·12	0·35	0·70	1·09	1·36	1·28	0·85	0·47	
	RF			0·36	0·73	1·79	3·15	4·25	4·76	3·84	2·13	0·85	
Nov.	*R*	5·6	7·8	7·4	6·6	5·9	5·3	4·5	3·7	3·2	2·6	2·0	
	F	0·02	0·04	0·10	0·23	0·48	0·80	1·05	1·16	1·06	0·74	0·47	
	RF	0·11	0·31	0·74	1·52	2·83	4·24	4·73	4·29	3·39	1·92	0·94	
Dec.	*R*	4·7	6·1	6·1	6·0	5·9	5·5	4·9	4·1	3·5	2·9	2·2	1·3
	F	0·03	0·07	0·17	0·32	0·59	0·88	1·06	1·13	1·06	0·78	0·41	0·16
	RF	0·14	0·43	1·04	1·92	3·48	4·84	5·19	4·63	3·71	2·26	0·90	0·21
Year	*R*	4·75	5·20	5·51	5·07	4·83	4·38	3·70	3·08	2·63	2·20	1·71	1·00
	F	0·08	0·30	0·65	1·47	3·55	6·42	10·16	13·36	13·49	9·52	4·97	0·81
	RF	0·4	1·6	3·6	7·5	17·1	28·1	37·6	41·2	35·5	21·0	8·5	0·8

R = monthly or annual rainfall averages in mm/day
F = average frequencies of the pressure ranges in days/month or days/year
RF = product of *R* and *F* in mm.

TABLE II—HARMONIC COEFFICIENTS OF (a) THE ANNUAL VARIATION OF WESTERLY-TYPE RAINFALL AMOUNT AND (b) FREQUENCY OF WESTERLY TYPE FOR DIFFERENT RANGES OF MSL PRESSURE OVER ENGLAND AND WALES, 1950–69

Pressure range *mb*	Harmonic coefficients										
	a_0	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5
(a) Rainfall amount, *R*											
					millimetres/day						
990– 994	+4·363	+0·965	−1·535	−0·424	+0·006	−0·176	−0·388	+0·107	+0·104	+0·020	−0·047
995– 999	+4·309	+1·002	−1·039	−0·200	+0·069	−0·083	−0·423	−0·028	+0·091	+0·050	−0·030
1000–1004	+4·060	+0·988	−0·791	−0·032	+0·077	−0·013	−0·311	−0·091	+0·045	+0·040	−0·012
1005–1009	+3·594	+0·808	−0·710	+0·093	+0·062	+0·053	−0·193	−0·073	+0·003	+0·012	+0·000
1010–1014	+3·075	+0·576	−0·663	+0·130	+0·012	+0·117	−0·131	−0·006	−0·013	+0·004	+0·010
1015–1019	+2·622	+0·414	−0·573	+0·106	−0·053	+0·151	−0·126	+0·047	−0·010	+0·009	+0·017
1020–1024	+2·205	+0·295	−0·436	+0·045	−0·107	+0·153	−0·137	+0·062	+0·008	+0·007	+0·024
1025–1029	+1·761	+0·169	−0·286	−0·035	−0·153	+0·144	−0·130	+0·052	+0·041	−0·002	+0·033
(b) Frequency, *F*											
					days/month						
990– 994	+0·128	+0·141	−0·031	+0·025	−0·022	−0·005	−0·015	−0·004	−0·011	+0·001	−0·005
995– 999	+0·285	+0·211	−0·088	+0·001	−0·031	−0·010	−0·026	−0·007	−0·022	+0·002	−0·010
1000–1004	+0·536	+0·197	−0·171	−0·029	−0·030	−0·009	−0·043	−0·005	−0·033	+0·002	−0·015
1005–1009	+0·847	+0·015	−0·237	−0·037	−0·018	−0·005	−0·053	+0·007	−0·038	+0·001	−0·019
1010–1014	+1·114	−0·217	−0·238	+0·000	−0·020	−0·002	−0·041	+0·028	−0·044	+0·001	−0·021
1015–1019	+1·124	−0·268	−0·164	+0·062	−0·037	+0·003	−0·002	+0·039	−0·044	+0·001	−0·019
1020–1024	+0·794	−0·121	−0·072	+0·080	−0·038	+0·007	+0·027	+0·027	−0·027	+0·001	−0·014
1025–1029	+0·364	+0·018	−0·018	+0·047	−0·017	+0·008	+0·021	+0·011	−0·008	+0·001	−0·008

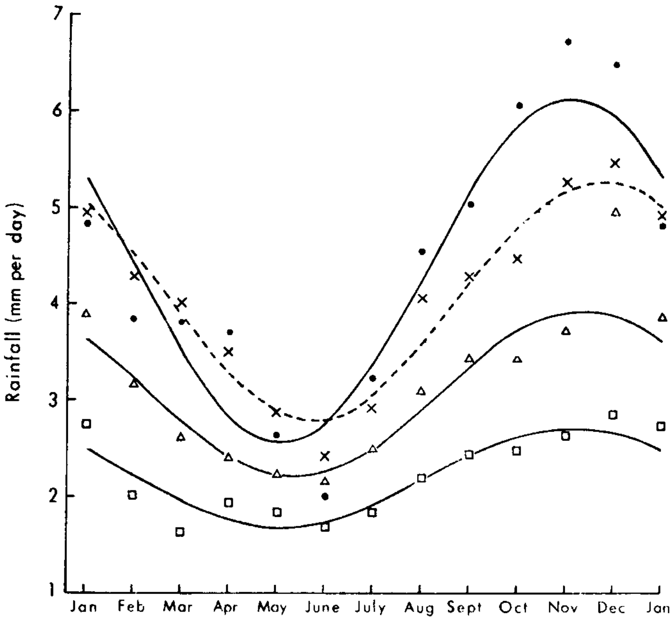

FIGURE 1—ANNUAL VARIATION OF THE AVERAGE DAILY WESTERLY-TYPE RAINFALL AMOUNT OVER ENGLAND AND WALES FOR DIFFERENT RANGES OF PRESSURE AT MSL AND THE FIRST HARMONIC CURVES, DURING THE PERIOD 1950–69

● ——— ● 990–994 mb X- - - - -X 1000–1004 mb
△ ——— △ 1010–1014 mb □ ——— □ 1020–1024 mb

first harmonic coefficients are the most important and that the second and third harmonics add significant contributions; the remaining harmonics can be regarded as 'noise'.

The first harmonic coefficients (Table II) were used to calculate, for each 5-mb range of pressure, the amplitude of the annual variation of average daily rainfall amount (Figure 2), and the first three harmonic coefficients

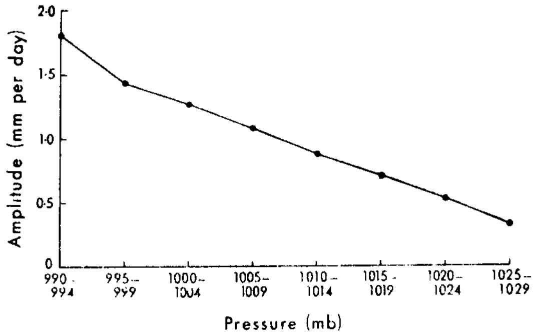

FIGURE 2—AMPLITUDE OF THE ANNUAL VARIATION OF THE AVERAGE DAILY WESTERLY-TYPE RAINFALL AMOUNT OVER ENGLAND AND WALES FOR DIFFERENT RANGES OF PRESSURE AT MSL, BASED ON FIRST HARMONICS, DURING THE PERIOD 1950–69

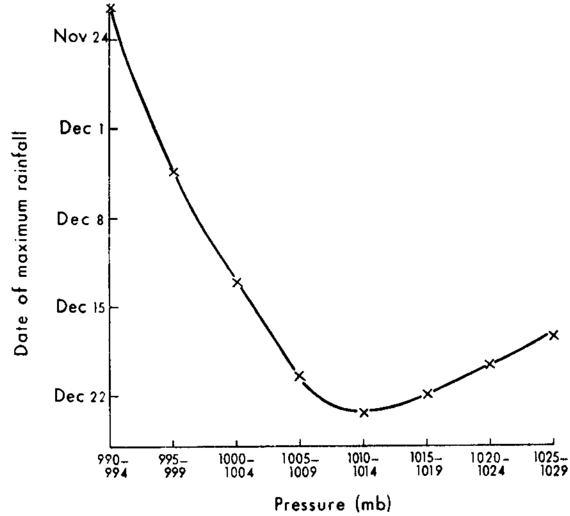

FIGURE 3—DATE OF THE ANNUAL MAXIMUM AVERAGE DAILY WESTERLY-TYPE RAINFALL AMOUNT OVER ENGLAND AND WALES FOR DIFFERENT RANGES OF PRESSURE AT MSL, BASED ON THE FIRST THREE HARMONICS, DURING THE PERIOD 1950–69

(Table II) were used to calculate the date of the annual maximum average daily rainfall amount (Figure 3) for the 'straight' westerly type. For each range of pressure in Figure 3 the estimated date of the maximum value of R was obtained from the formula :

$$R = a_0 + \sum_{k=1}^{k=3} \left\{ a_k \cos(30kt)^\circ + b_k \sin(30kt)^\circ \right\},$$

where t varies from 8·5 (beginning of October) to 0·5 (end of January) (the period which includes the maximum value of R), and where the values of a_0, a_k and b_k are obtained from Table II.

Frequency of westerly-type circulation. For days of 'straight' westerly-type circulation, the average frequency in each calendar month and for each of four ranges of pressure are shown in Figure 4, which shows also the first harmonic curves. The so-called 'theoretical' categories, previously discussed, were included in the plotted points and also in the harmonic analysis whenever such categories occurred.

The harmonic coefficients, for various ranges of pressure, are given in Table II, using the notation previously described.

The first harmonic coefficients were used to calculate, for each range of pressure, (a) the amplitude of the annual variation of average frequency (Figure 5) and (b) the date of the annual maximum average frequency (Figure 6) — for the westerly type. The equation of the first harmonic curve of the amplitudes of Figure 5 is :

$$F = 0{\cdot}209 + 0{\cdot}11 \sin(45p - 62)^\circ ,$$

where $p = 0, 1, 2$, etc. give F for 990–994, 995–999, 1000–1004 mb, etc.

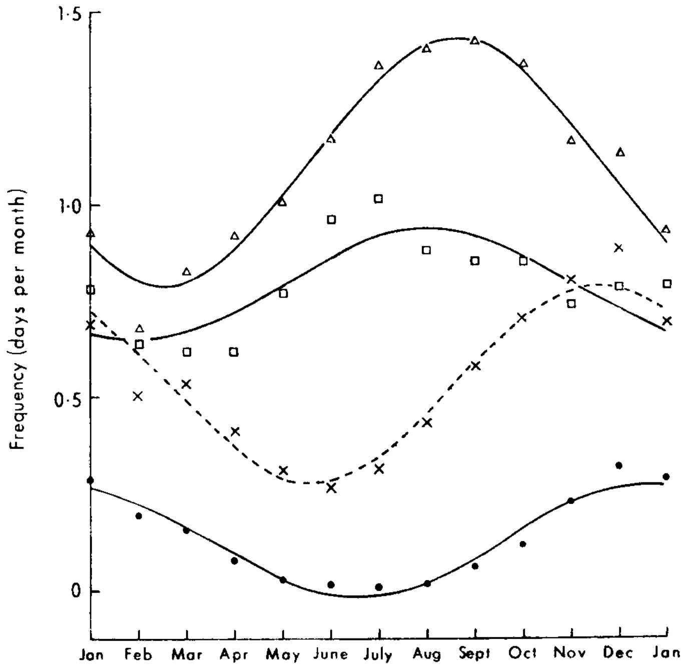

FIGURE 4—ANNUAL VARIATION OF THE AVERAGE FREQUENCY OF DAYS WITH WESTERLY-TYPE CIRCULATION OVER THE BRITISH ISLES REGION FOR DIFFERENT RANGES OF PRESSURE AT MSL AND THE FIRST HARMONIC CURVES, DURING THE PERIOD 1950–69

● ——— ●	990–994 mb	X- - - - -X	1000–1004 mb
△ ——— △	1010–1014 mb	□ ——— □	1020–1024 mb

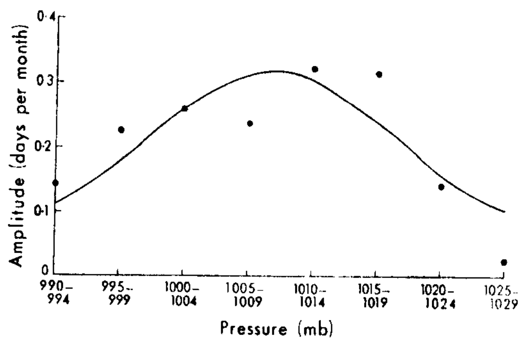

FIGURE 5—AMPLITUDE OF THE ANNUAL VARIATION OF THE AVERAGE FREQUENCY OF DAYS WITH WESTERLY-TYPE CIRCULATION OVER THE BRITISH ISLES REGION FOR DIFFERENT RANGES OF PRESSURE AT MSL, BASED ON FIRST HARMONICS, AND THE FIRST HARMONIC CURVE OF THESE AMPLITUDES, DURING THE PERIOD 1950–69

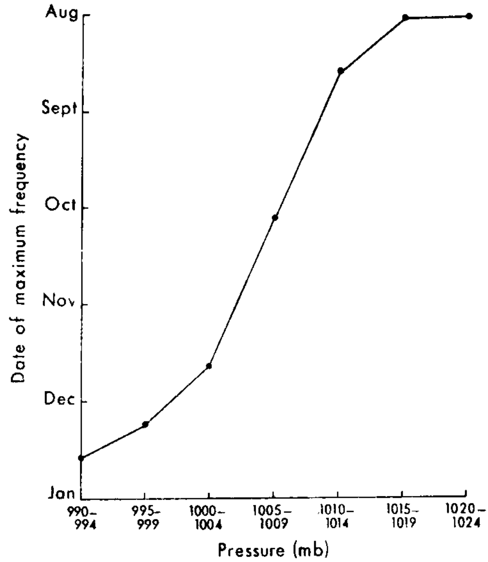

FIGURE 6—DATE OF THE ANNUAL MAXIMUM AVERAGE FREQUENCY OF DAYS WITH WESTERLY-TYPE CIRCULATION OVER THE BRITISH ISLES REGION FOR DIFFERENT RANGES OF PRESSURE AT MSL, BASED ON FIRST HARMONICS, DURING THE PERIOD 1950–69

In Figure 6, the point corresponding to the range of pressure, 1025–1029 mb is not plotted because the annual variation of frequency for this pressure range is small and shows no clear single annual maximum, as indicated by the non-dominant first harmonic coefficients of Table II. In Figure 6, the annual 'peak' dates of mid-January, mid-December, etc. correspond to phase angles of 90°, 120°, etc. in the first harmonic curves based on Table II data.

Discussion. Table I and Figures 1 and 2 show the expected result that for 'straight' westerly-type circulation over the British Isles the average daily rainfall amount and the amplitude of its annual variation both increase with decreasing pressure; the annual mean and the amplitude decrease almost linearly with pressure from 995 to 1029 mb (Table I and Figure 2); in this range of pressure, the ratio of the amplitude to the mean also decreases steadily, from 0·33 to 0·19; but with very low pressure, there is a tendency for the daily rainfall amount to level off or even decrease. This latter result may be caused by a greater *cyclonic* curvature over the North Atlantic when pressure is lower, and hence by an influx of drier air masses; also, because very low pressures may indicate that the depression 'associated' with the westerlies is at or near its maximum depth, a large part of England and Wales may be well away from active fronts and have drier and colder air aloft, associated with the 'cold pool' stage of cyclonic development. A decrease of rainfall with very low pressure may result also from a decrease of orographic rainfall associated with decreased gradients.

The date of the annual maximum rainfall amount changed from late November (or earlier) to late December as the pressure increased from 990–994 mb (or below) to 1010–1014 mb, but with further increase of pressure to 1025–1029 mb, there was a tendency for the date of daily maximum rainfall amount to become slightly earlier again, that is, to change to about mid-December (Figure 3). A possible explanation of these results is that the various pressure ranges are associated with different isobaric curvatures over the North Atlantic and so with different air-mass sources namely :

(1) 990–994 mb from the region between Iceland and Greenland (cyclonic curvature),
(2) 1000+ mb from the Davis Straits region (slight cyclonic curvature) or the Newfoundland region (small mean curvature), and possibly also
(3) 1015–1024 mb from the south-west of the North Atlantic, south and east of Newfoundland (slight anticyclonic curvature).

The annual variation of British rainfall could thus depend on the annual variation of meteorological factors, notably sea surface temperature, in these regions.

The association of anomalous sea surface temperature gradients with greater cyclonic development or other anomalous meteorological factors is alleged or suggested by a number of authors.[6,7,8] In particular, a maximum daily rainfall amount in November, with pressure of 990–994 mb may be associated with a November maximum in the sea surface temperature gradient in region (1). In this region unpublished sea-temperature data[3] for ocean weather station (OWS) A (62° 00′N, 33° 00′W) for the period 1951 to 1960 together with published data[4] for OWS C (52° 45′N, 35° 30′W) for the same period show a November maximum in the north–south gradient of sea surface temperature, though published data for OWS A[5] together with data for OWS C[4] show only that the north–south gradient was greater in November than in December.

The area of maximum sea surface temperature gradient may well move south to region (2) by December and thus lead to a December maximum in British rainfall for air masses originating in this region. Certainly monthly averages of sea surface temperature, as evidenced by OWS B (56° 30′N, 50° 00′W),[4] show a decrease through the autumn and winter, presumably associated with an increasing tongue of cold surface water of the Labrador current.

The tendency for the date of maximum rainfall to become earlier again (moving from late December to mid-December) for pressures in the range of 1015–1024 mb may well be due to an association of such pressure values with air masses originating partly in region (3). In this region, data[4] for OWS C and OWS D show a maximum sea surface temperature gradient in November.

According to this sea-temperature hypothesis as the explanation of the annual variation in the date of the daily maximum rainfall amount (Figure 3), the results in general suggest that the area of cyclogenesis relevant to British rainfall may include all these regions and so extend well beyond the region to the south of Newfoundland.[8]

An alternative explanation of the small annual pressure-dependent shift in the date of the maximum average daily rainfall amount with the 'straight' westerly-type circulation is based on the pattern of annual variation in *overland* thermal convection. Rainfall resulting from such convection may be greater when there is (a) more direct polar air, that is, more cyclonic curvature over the North Atlantic, presumed to be associated with lower pressure or (b) smaller pressure gradients overland, associated with high and low extremes of pressure. Since both synoptic situations (a) and (b) are in general more likely to produce thermal convection rainfall at times of the year when insolation is greater, a shift of the annual rainfall maximum from December to November or earlier could occur with the more extreme values of pressure or at least with the lower extremes.

The importance of the annual variation of both overland thermal convection and sea temperature in explaining the annual variation of synoptic-type average daily rainfall amount is suggested by the results of an earlier investigation.[1]

Table II and Figures 4 and 5 show the expected result — that the frequency of days with 'straight' westerly-type circulation and the amplitude of its annual variation are largest when pressure is about average. Figure 6 shows that the annual maximum frequency with low pressure occurs mainly in winter, while the maximum frequency with higher pressure occurs mainly in summer and autumn, presumably reflecting the seasonal displacement of the Azores anticyclone.

Concluding remarks. The 'straight' westerly-type circulation over the British Isles has a frequency and daily rainfall amount which change systematically with atmospheric MSL pressure. These results reflect the significance of the calculated rainfall and frequency averages.

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EXTREME WEATHER CONDITIONS OVER CYPRUS DURING APRIL 1971

By R. BOAST and J. B. McGINNIGLE

Summary. The island of Cyprus experienced extreme weather conditions during April 1971. The statistics are presented and the synoptic situations which were the cause of the extreme weather are identified and examined in detail. Broad-scale synoptic features are considered and compared with relevant statistics.

Introduction. The island of Cyprus lies at the eastern end of the Mediterranean Sea at about latitude 35°N. The month of April is within the 'transition' period during which winter conditions give way to the hot, dry summer. Statistically, April is shown to be a pleasant month, with day-time temperatures rising to the low twenties (°C). Average rainfall is 15–20 millimetres in most low-lying areas[1] with 'wet days' (≥1 mm/24 hours) likely to occur only three times during the month.

By the middle of April 1971, it was apparent that the island was experiencing an exceptionally wet month. Examination of records for Nicosia, in the centre of the island, and Akrotiri on the south coast (Figure 1), revealed that the previous maximum rainfall totals for the month had already been exceeded. By the end of the month, more new records had been set. New extreme figures for the greatest rainfall in a day and for the number of wet days in a month had been recorded at both Nicosia and Akrotiri. Nicosia had also recorded its lowest April sunshine duration and the maximum wind gust previously recorded had been equalled.

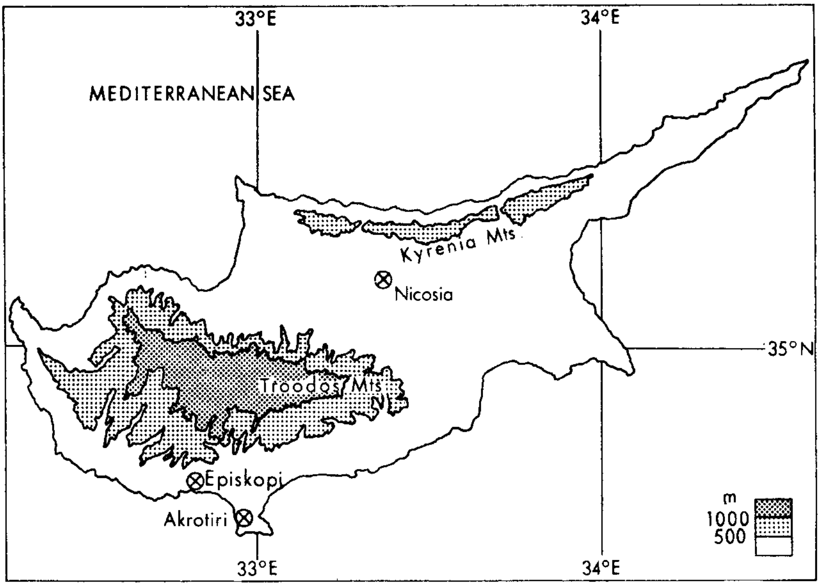

FIGURE 1—MAP OF CYPRUS

Further examination of the statistics for the month showed that although both Nicosia and Akrotiri had experienced a record number of wet days, the record rainfall totals were mainly due to several days on which large amounts of rainfall were recorded. Nicosia recorded 91 per cent of its rainfall for the month during the 24-hour periods (06–06 GMT) of the 3rd, 12th, 16th, and 23rd, while Akrotiri recorded 95 per cent of its total on the 3rd, 12th, 14th, and 15th.

Statistics. Table I shows previous means and extremes of temperature, rainfall, surface wind and sunshine for April, at Nicosia and Akrotiri, together with the values recorded during April 1971. Dates and years of previous extremes have been omitted except where new records were set during April 1971. No sunshine records are available for Akrotiri.

Table II shows the rainfall distribution for April 1971 at Nicosia and Akrotiri. Rainfall is measured each day at 06 and 18 GMT (08 and 20 local

TABLE I—COMPARISON OF MEANS AND PREVIOUS EXTREMES WITH APRIL 1971 VALUES

	NICOSIA Means and previous extremes for April	NICOSIA April 1971	AKROTIRI Means and previous extremes for April	AKROTIRI April 1971
Temperature (°C)				
Mean maximum	23·1(1)	21·0	21·3(3)	20·8
Mean minimum	10·1(1)	9·1	13·1(3)	12·2
Highest maximum	39·5(2)	30·5	33·0(4)	27·8
Lowest maximum	12·8(2)	13·1	14·7(4)	16·4
Highest minimum	21·9(2)	15·0	21·4(4)	19·7
Lowest minimum	2·8(2)	5·2	5·2(4)	7·3
Rainfall (mm)				
Mean monthly total	17·3(1)		14·5(3)	
Highest monthly total	47·3(2) 1957	105·4*	39·5(4) 1965	78·5*
Lowest monthly total	2·0(2) 1959		1·5(4) 1964	
Highest daily total	31·7(2) 1968	39·4*	14·1(4) 1969	31·3*
Mean No. wet days†	3 (1)		3 (3)	
Highest No. wet days†	8 (2) 1948	9 *	7 (4) 1965	8 *
Wind (kt)				
Highest hourly wind	41 (2)	26	32 (4)	24
Highest gust	56 (2) 1964	56 *	55 (4)	39
Sunshine (hours)				
Mean monthly total	281·0	221·9	—	—
Highest daily mean	11·30	—	—	—
Lowest daily mean	8·06	7·40*	—	—

Figures in brackets give period covered: (1) 1943–68, (2) 1945–70, (3) 1957–66 and (4) 1957–70. * New extreme values. † Wet day > 1·0 mm/24 hours (06–06 GMT).

TABLE II—NICOSIA/AKROTIRI RAINFALL DISTRIBUTION FOR 06–18, 18–06 AND 06–06 GMT FOR APRIL 1971

Date	NICOSIA 06–18	NICOSIA 18–06 *millimetres*	NICOSIA 06–06	AKROTIRI 06–18	AKROTIRI 18–06 *millimetres*	AKROTIRI 06–06
3	13·7	4·6	18·3	31·2	0·1	31·3*
7	0·0	0·0	0·0	Trace	0·0	Trace
11	0·0	2·4	2·4	0·0	0·6	0·6
12	13·8	25·6	39·4*	6·6	9·5	16·1
13	2·3	0·0	2·3	0·1	Trace	0·1
14	0·2	0·9	1·1	3·2	9·5	12·7
15	1·0	Trace	1·0	8·8	6·1	14·9
16	15·1	0·0	15·1	0·9	1·6	2·5
17	0·1	0·0	0·1	0·1	0·2	0·3
18	0·1	0·0	0·1	0·0	0·0	0·0
21	Trace	0·0	Trace	0·0	0·0	0·0
22	3·0	0·0	3·0	0·0	0·0	0·0
23	22·6	0·0	22·6	0·0	0·0	0·0
26	0·0	0·0	0·0	Trace	0·0	Trace

* New records for the month.
Trace = <0·1 mm.

time). The daily total shown for each day is that measured between 06 GMT on that day and 06 GMT on the following day. The daily totals are also shown in histogram form in Figure 2. In order that the combined Nicosia and Akrotiri rainfall can be studied, Figure 2 uses a common abcissa with the Akrotiri histogram columns inverted. Thus it can be seen that the combined rainfall amounts on the 3rd and the 12th were similar but the distribution at the two stations was reversed on these dates. Reasons for this time/space distribution will be discussed in the later sections of this paper.

Table II and Figure 2 show that the rainfall for the month fell during four distinct periods covering the 3rd, the 11–13th, the 14–17th and the 22–23rd. The first three periods affected both stations but the fourth affected only Nicosia.

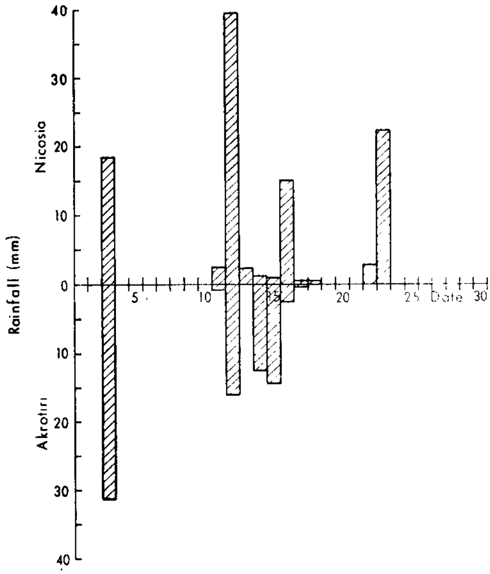

FIGURE 2—DAILY RAINFALL DISTRIBUTION FOR NICOSIA AND AKROTIRI FOR APRIL 1971

Synoptic analysis.

Central and eastern Mediterranean. An examination of the April 1971 chart series for this area showed that Cyprus had been affected by four surface depressions during the month. The periods during which these depressions were adjacent to Cyprus were coincident with those already identified from the rainfall statistics.

These four depressions have been examined in detail in the four subsections below. In each case, surface and 300-mb continuities are presented and composite surface/1000–500-mb thickness/300-mb contour charts, for both developing and developed stage, are reproduced.

(a) *Depression 1 (1–4 April 1971).* This 'Saharan depression'[2] was first identified at 00 GMT on 1 April when it was centred over western Libya. It moved east along the North African coast, with only diurnal changes in its central pressure, until 12 GMT on the 2nd (Figure 3). During the next 12 hours, an upper trough moving from the north-west (Figure 3) produced a tightening south-westerly thermal gradient over the depression, causing it to develop and move north-east (Figure 4). It passed over Cyprus on the 3rd as a fully developed frontal depression (Figure 5).

Continuous rain began at Akrotiri during the late morning (3rd) and was heavy at times. The extensive rain area of the depression

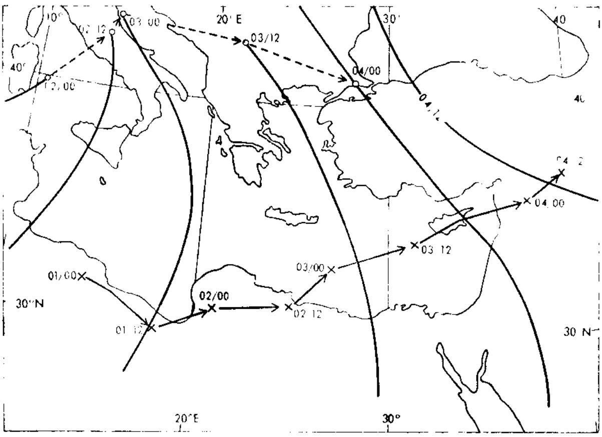

FIGURE 3—MOVEMENT OF SURFACE CENTRE AND 300-mb CENTRE AND TROUGH FROM 00 GMT ON 1 APRIL UNTIL 12 GMT ON 4 APRIL 1971

o – – – o Track of 300-mb centre ———— 300-mb trough
x —— x Track of surface centre
Times are shown in the form: date/time (GMT)

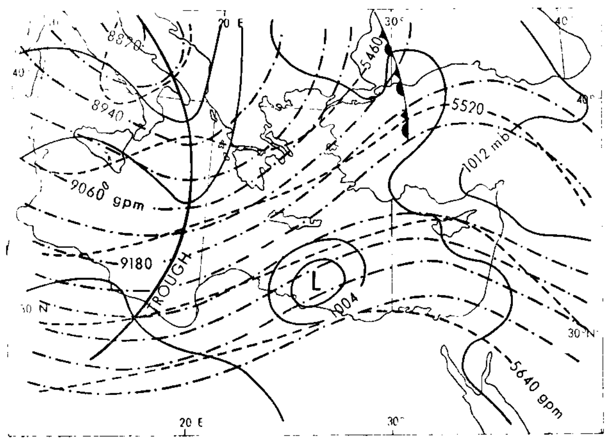

FIGURE 4—SURFACE AND UPPER AIR PATTERNS FOR 00 GMT ON 3 APRIL 1971

———— Surface isobars — · — 300-mb contours
– – – 1000–500-mb thickness lines

combined with Akrotiri's position on an exposed coast, resulted in a new maximum daily rainfall being recorded. At Nicosia, precipitation began during the early afternoon but ceased for a time as the centre of the depression passed almost overhead between 17 and 18 GMT. During the onset of the north-westerly surface winds west of the centre, a gust of 56 knots (1 kt ≈ 0·5 m/s) was recorded, equalling the previous record for April.

After crossing Cyprus, the depression continued to move north-east towards Syria. Once over the land, it quickly lost its momentum and became slow moving over the Syrian/Turkish border by 12 GMT on the 4th.

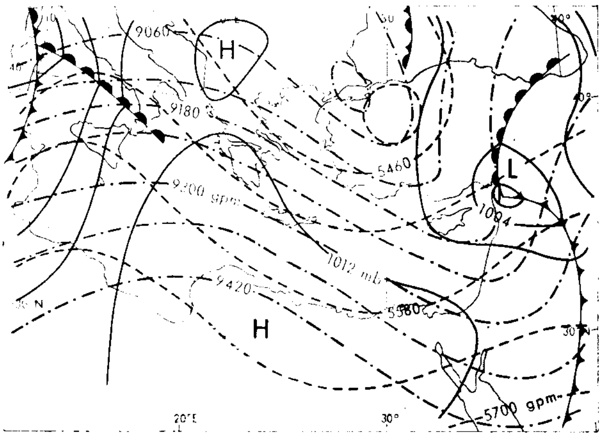

FIGURE 5—SURFACE AND UPPER AIR PATTERNS FOR 00 GMT ON 4 APRIL 1971

——— Surface isobars —·— 300-mb contours
– – – 1000–500-mb thickness lines

(b) *Depression 2 (10–14 April 1971).* This was another 'Saharan depression' situation, though more complex than the previous one. At 00 GMT on 10 April, two depressions were identified, one over Libya and the other over Saudi Arabia. At the same time the 300-mb contour chart showed a slow-moving low centre over Sicily, with weak troughs extending south from the centre. During the next 24 hours, the situation changed rapidly.

The weak 300-mb trough intensified and moved quickly east increasing the thermal gradient over the Libyan depression and causing it to move quickly north-east (Figure 6). At the same time, the Saudi Arabian depression moved west under the influence of a

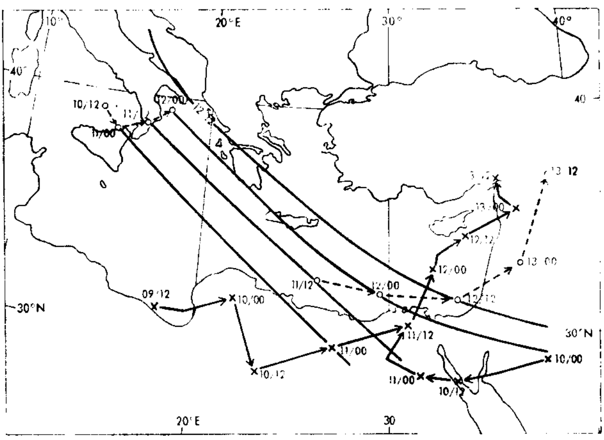

FIGURE 6—MOVEMENT OF SURFACE CENTRES AND 300-mb CENTRES AND TROUGH FROM 12 GMT ON 9 APRIL UNTIL 12 GMT ON 13 APRIL 1971

o – – – o Track of 300-mb centres ——— 300-mb trough
x —— x Track of surface centres
Times are shown in the form: date/time (GMT)

light easterly thermal gradient on the north side of a weak cold pool over Saudi Arabia. The two depressions subsequently combined to become one feature (Figure 7) in an area of thermal diffluence on the cold side of the westerly jet which extended across the Sahara to Saudi Arabia. The combined depression deepened and then moved north-east as a south-westerly thermal flow was established over its centre. The depression passed close to Cyprus on the 12th (Figure 8).

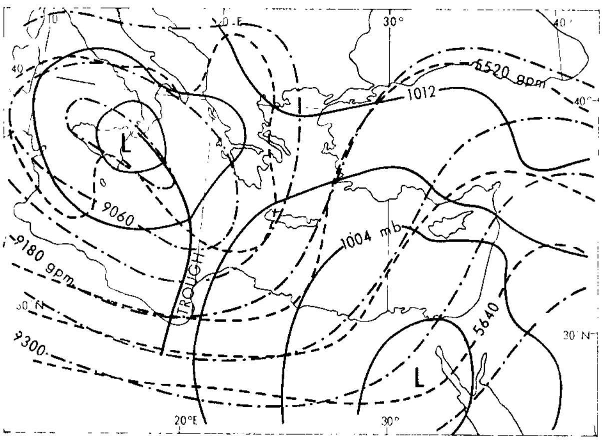

FIGURE 7—SURFACE AND UPPER AIR PATTERNS FOR 00 GMT ON 11 APRIL 1971

——— Surface isobars — · — 300-mb contours
– – – 1000–500-mb thickness lines

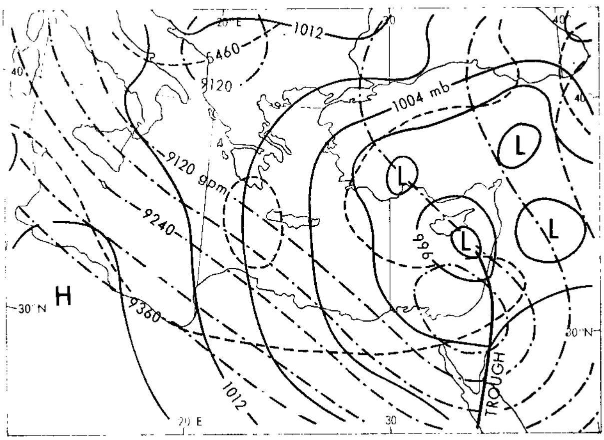

FIGURE 8—SURFACE AND UPPER AIR PATTERNS FOR 12 GMT ON 12 APRIL 1971

——— Surface isobars — · — 300-mb contours
– – – 1000–500-mb thickness lines

On this occasion it was Nicosia, being exposed to the east and south-east, which recorded a new maximum daily rainfall total. Akrotiri experienced a marked decrease in precipitation close to the centre of the depression.

This depression lost its momentum after crossing the Syrian coast and became slow moving over approximately the same area as the first one.

(c) *Depression 3 (14–17 April 1971).* At 00 GMT on 14 April, a slack upper circulation, residual from the previous depression system, was slow moving over the eastern Mediterranean and a trough at 300 mb was lying north-east–south-west over southern Italy. At the surface, a northerly airstream over Turkey was causing a marked lee trough over the Cyprus area. A shallow depression was identified, on the axis of this trough, centred over south-west Turkey. A cold front lying north-east–south-west over the Black Sea was moving south with very cold polar continental air behind it. During the 14th the cold front continued its southward movement (Figure 9) until its central portion became slow moving close to the centre of the lee depression (Figure 10). The 300-mb trough moved steadily east and a

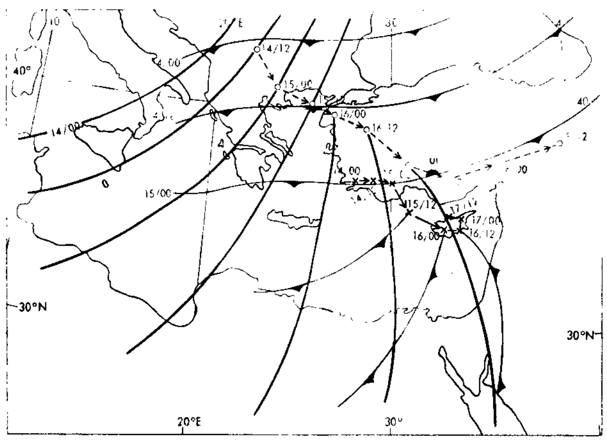

FIGURE 9—MOVEMENT OF SURFACE CENTRE AND FRONT AND 300-mb CENTRE AND TROUGH FROM 00 GMT ON 14 APRIL UNTIL 12 GMT ON 18 APRIL 1971

o – – – o Track of 300-mb centre ———— 300-mb trough
x —— x Track of surface centre
Times are shown in the form: date/time (GMT)

circulation developed on its axis over northern Greece (Figure 9). This situation caused shower activity over Cyprus but significant rainfall was confined to exposed coastal districts. During the 15th the western part of the cold front moved south-east and, as the very cold air was fed around the surface depression, it began to develop. The slow moving part of the front became unidentifiable over Turkey and the cold front was reanalysed to extend from the depression centre, which by this time was moving south-east towards Cyprus. As before, shower activity over the island was mainly confined to exposed coastal areas.

During the 16th the continued eastward movement of the 300-mb trough produced a backing in the thermal gradient over the depression (Figure 11), causing it to cease its eastward movement and begin to

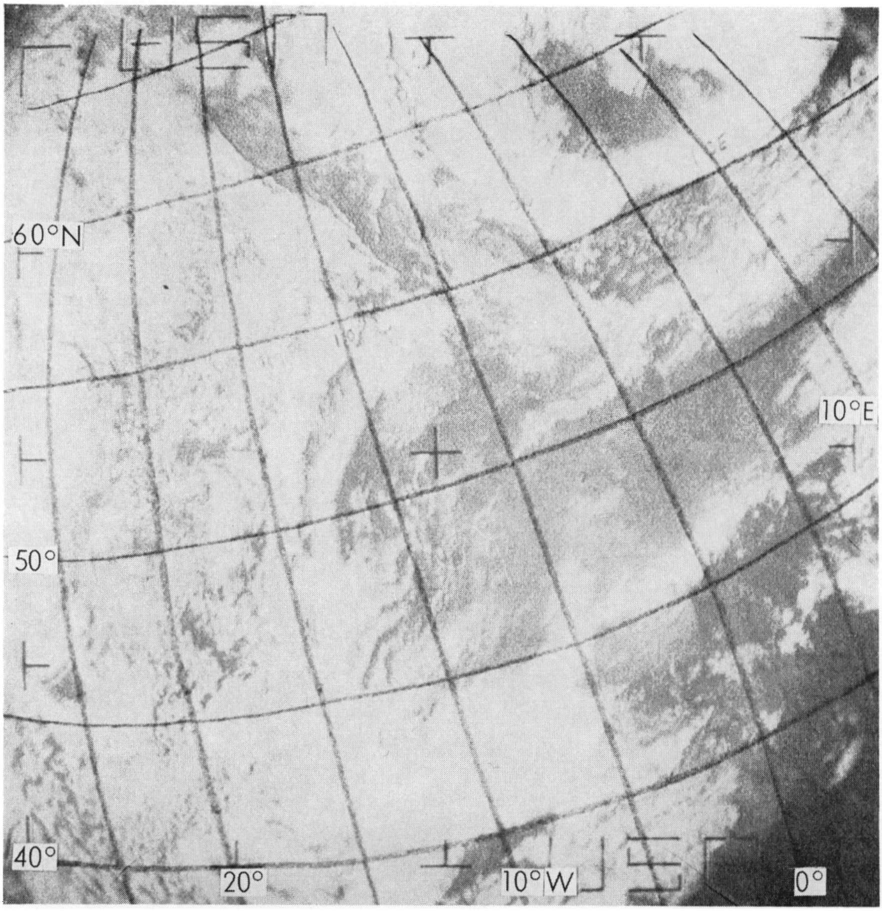

PLATE I—ESSA 8 SATELLITE PICTURE FOR 1117 GMT ON 17 JULY 1971

See page 153.

Photograph by D. R. Hindley

PLATE II—YORKSHIRE COAST SHOWING CONVECTION CLOUD DEVELOPING INLAND ON 17 JULY 1971

See page 155.

Photograph by D. R. Hindley

PLATE III—YORKSHIRE COAST SHOWING CLEAR CORRIDOR BETWEEN CONVECTION CLOUD FORMING INLAND AND THAT FORMING OUT TO SEA, 17 JULY 1971

See page 155.

Photograph by D. R. Hindley

PLATE IV—CONVECTION CLOUD DEVELOPING OUT TO SEA OFF THE YORKSHIRE COAST ON 17 JULY 1971

See page 155.

To face page 145

Photograph by Mrs J. V. Hurst

PLATE V—EROSION OF VEGETATION BY WIND AND SALT ON THE COAST SOUTH OF TRIPOLI, LEBANON, APRIL 1966

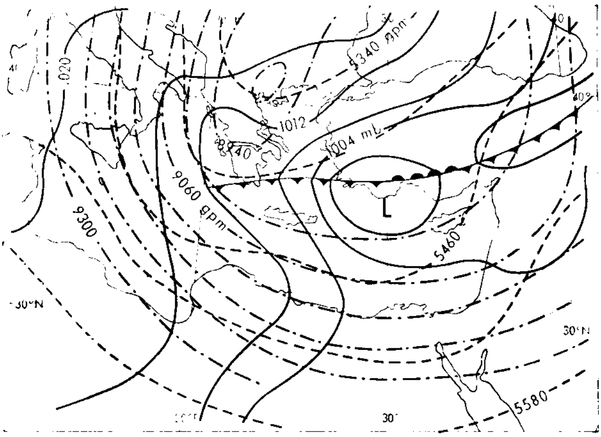

FIGURE 10—SURFACE AND UPPER AIR PATTERNS FOR 00 GMT ON 15 APRIL 1971

——— Surface isobars —·— 300-mb contours
– – – 1000–500-mb thickness lines

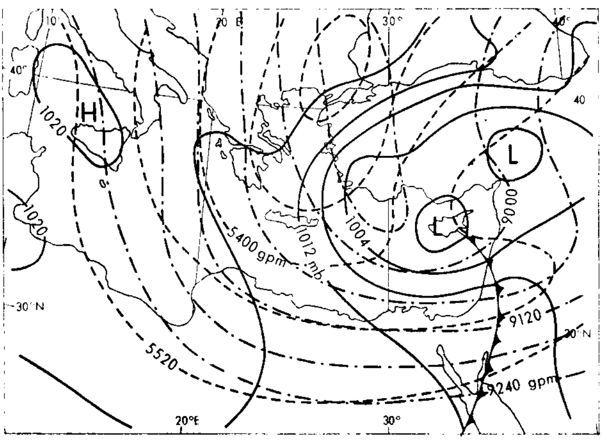

FIGURE 11—SURFACE AND UPPER AIR PATTERNS FOR 12 GMT ON 16 APRIL 1971

——— Surface isobars —·— 300-mb contours
– – – 1000–500-mb thickness lines

move north. With the depression centred over Cyprus and the upper trough approaching from the west, shower activity was more general during the 16th, with widespread thunderstorms. During the 17th the upper trough relaxed as its associated centre filled and the surface depression lost its identity. Isolated showers continued to affect Cyprus until the 18th.

(d) *Depression 4 (20–24 April 1971)*. This was another case of the lee trough over the Cyprus area becoming more intense. During the 20th a low centre at 300 mb moved south-east over the western Black Sea while its associated trough moved south-east over western Turkey (Figure 12). At 12 GMT on the 21st a shallow surface depression was identified, lying below the upper trough. During the next 24 hours this depression moved south-east with the upper trough (Figure 12).

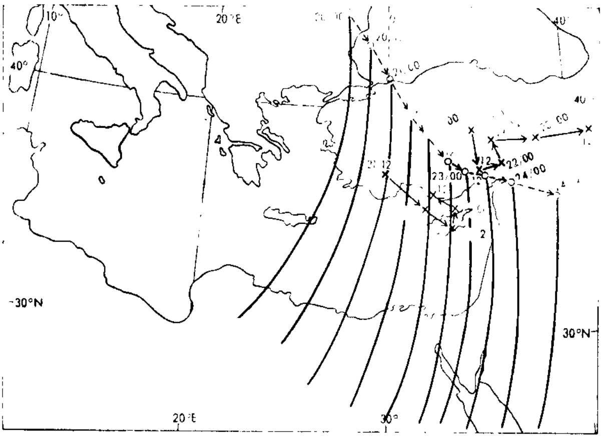

FIGURE 12—MOVEMENT OF SURFACE CENTRES AND 300-mb CENTRE AND TROUGH FROM 00 GMT ON 20 APRIL UNTIL 12 GMT ON 24 APRIL 1971

o - - - o Track of 300-mb centre ——— 300-mb trough
x —— x Tracks of surface centres
Times are shown in the form: date/time (GMT)

Although the depression did not develop greatly (Figure 13), day-time heating was sufficient to set off scattered thunderstorms over central Cyprus during the 22nd. No vigorous convection was observed over the sea. During the 23rd the depression became slow moving over Cyprus as the upper centre began to fill (Figure 14). Again, day-time heating set off thunderstorms and Nicosia recorded 22·6 mm of rain in 1·6 hours during one of them.

By 12 GMT on the 24th the upper centre had moved away east and no circulation was identifiable over the Cyprus area.

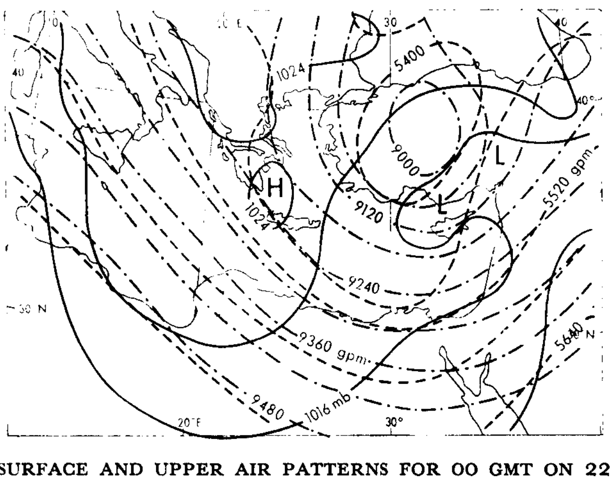

FIGURE 13—SURFACE AND UPPER AIR PATTERNS FOR 00 GMT ON 22 APRIL 1971

——— Surface isobars —·— 300-mb contours
- - - 1000–500-mb thickness lines

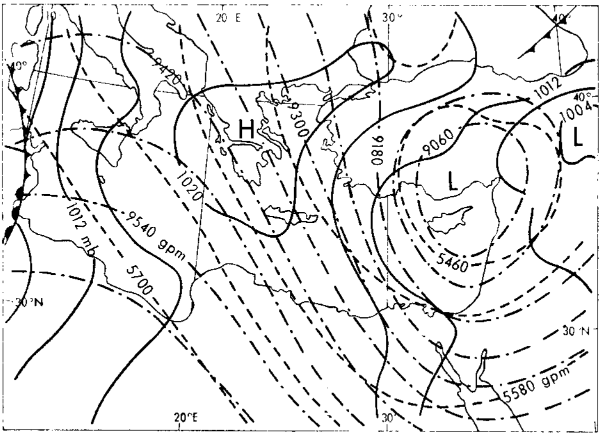

FIGURE 14—SURFACE AND UPPER AIR PATTERNS FOR 12 GMT ON 23 APRIL 1971

——— Surface isobars —·— 300-mb contours
– – – 1000–500-mb thickness lines

The previous sections have described the four depressions which were responsible for the severe weather conditions over Cyprus during April 1971. The first two were developments of 'Saharan depressions', whose origins were over the Sahara desert south of the Atlas Mountains. The first of these was a classic case as defined.[2] The second, though clearly still a 'Saharan depression' development, was more complex as a result of the amalgamation of the original Atlas low with a depression which originated over Saudi Arabia. The combined total rainfall at Nicosia and Akrotiri was similar in each of these cases but the spatial distributions varied because of the difference in the depression tracks. The first depression had a relatively long sea track, precipitation was mainly from layer cloud and no thunderstorms were observed. The second depression had a shorter sea track but was accompanied by thunderstorms which intensified the associated rainfall.

The other two depressions were both 'Cyprus depressions'[3] which formed near Cyprus. Both were formed when lee troughs (south of the Anatolian plateau (Turkey)) were intensified by the introduction of cold continental air into their circulations. Rainfall from depressions formed in this way is usually much more marked in the autumn than in the spring because of the higher sea temperatures which produce widespread convection. The cold air associated with the first of the 'Cyprus depressions' was, however, sufficiently cold to cause widespread convection. The second depression was less marked than the first and no significant convection occurred over the sea, but daytime heating was sufficient to produce thunderstorms over inland areas.

Broader-scale considerations. A broad-scale appreciation of synoptic movement and development for the whole month was carried out. The area considered was from the eastern Atlantic to central Russia and from Scandinavia to the Tropic of Cancer (information in south permitting).

Three distinct synoptic régimes for the month were identified.

(a) *1 to 10 April.* This period was notable for a predominantly meridional flow over the eastern Atlantic with a zonal flow over the Mediterranean and little significant movement or development over Europe. The cold airflow to north-west Africa was interrupted three times during the period as the northern part of the mid-Atlantic ridge system moved east and became cut off. The first two occasions resulted only in a 24-hour interruption of the cold airflow. The third cut-off, which occurred on the 10th, resulted from a major extension of the mid-Atlantic ridge. After this cut-off had occurred, the original ridge quickly collapsed as a zonal upper flow became established between 30° and 40°N. An anticyclone developed over the United Kingdom with a consequent cold air feed to Europe on its eastern side.

(b) *11 to 22 April.* Throughout this period, a quasi-stationary trough/ridge/trough pattern persisted from the eastern Atlantic to eastern Europe. This situation caused progressively colder air to be fed to the eastern Mediterranean region during the 11th to the 17th, after which the cold air supply was cut off until the 21st when it was re-established.

(c) *23 to 30 April.* The trough/ridge/trough pattern quickly became more mobile and flattened. A split zonal flow over the Atlantic and a broad zonal flow over Europe became established and persisted until the end of the month.

The broad-scale synoptic pattern identified during the first period (1st to 10th) was favourable for the formation of 'Saharan depressions' and their subsequent movement to the Cyprus area. The almost continuous supply of cold air to the area south of the Atlas Mountains provided ideal conditions for the formation of 'Saharan depressions' and the zonal upper flow over the Mediterranean provided the mobility necessary for them to reach the Cyprus area.

The synoptic situation during the second period (11th to 22nd) was favourable for the formation of 'Cyprus depressions' as it provided a good supply of cold air to the eastern Mediterranean.

During the period 23rd to 30th, mobility over central Europe confined all significant weather well to the north of Cyprus.

Comparison with synoptic statistics.

300-mb winds. The average 300-mb wind chart for April[4] indicates that the flow is zonal over the eastern Atlantic/Europe/North Africa area, with the stronger winds over Egypt and the Red Sea. The 22 days during which meridional patterns were persistent over the eastern Atlantic and Europe indicate that April 1971 was significantly different from the average.

Vector mean winds and standard vector deviations for Malta and Episkopi (Cyprus) were calculated in order to compare April 1971 with the average values over the central and eastern Mediterranean area. The comparison is shown in Table III.

TABLE III—COMPARISON OF AVERAGE 300-mb WINDS* WITH THOSE OF APRIL 1971

	Malta	Episkopi (Cyprus)
Monthly average wind (degrees/kt)	270/37	270/33
Standard vector deviation (kt)	38	37
April 1971		
Vector mean wind (degrees/kt)	275/49	285/37
Standard vector deviation (kt)	32	33

* 1947–50 inclusive.

It can be seen that both Malta and Episkopi had significantly stronger 300-mb vector mean winds during April 1971, with the direction in each case veered from the average. The standard vector deviations are smaller in each case, showing a smaller-than-average spread of individual vectors.

This comparison clearly reflects how the meridional blocking patterns which were a feature of northern latitudes for most of the month, concentrated greater-than-normal mobility along the central and eastern Mediterranean Sea.

Depressions. The frequency and tracks of depressions which have affected the Cyprus area have been compiled[6] and these are shown in Figure 15 in respect of 'Saharan depressions'. The statistics are for a period March–May inclusive and from these it can be inferred that the number of 'Saharan depressions' which affected Cyprus during April 1971 was by no means unusual.

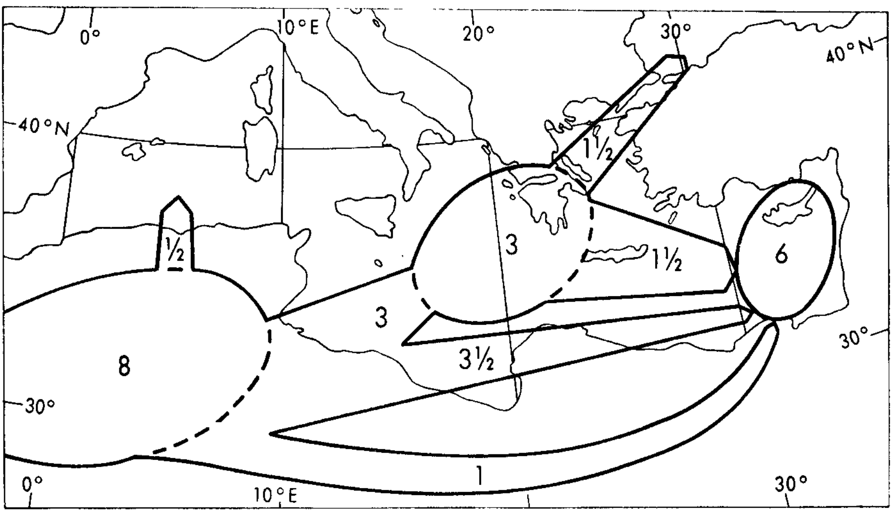

FIGURE 15—AVERAGE TRACKS AND AVERAGE FREQUENCIES OF OCCURRENCE OF 'SAHARAN DEPRESSIONS' FOR THE PERIOD MARCH TO MAY INCLUSIVE

From the statistics,[5] it has been stated that, during the same period (March–May), an average of only one depression forms over the Cyprus area. The two occasions identified and discussed in this paper therefore give a frequency higher than average.

The number of depressions which originate in the western Mediterranean and subsequently enter the Cyprus area is given as $5\frac{1}{2}$ during the three-month period. No such depressions affected Cyprus during April 1971.

In comparison with these depression statistics, the frequency of 'Saharan depressions' was normal, the frequency of 'Cyprus depressions' was higher than average while no depressions originating in the western Mediterranean affected the area. The total of four depressions during April 1971 would appear to be an approximate average for the month, although the origin distribution is unusual.

Concluding remarks. It is therefore concluded that the extreme weather conditions experienced over Cyprus during April 1971 were due to :

(a) The occurrence of two persistent broad-scale synoptic régimes of a meridional type, which are sympathetic to the development and movement of two significant weather-producing Cyprus situations, the developed 'Saharan depression' and the developed 'Cyprus depression'.

(b) The strong development patterns which produced these situations and the effects, on a smaller scale, of track and associated air-mass character.

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THE TROWAL, AN IMPORTANT FEATURE OF FRONTAL ANALYSIS

By R. M. MORRIS

One of the best-known modifications of the original Bjerknes frontal model was developed by Canadian meteorologists during the post-war years. The three-front model[1] was conceived to take account of upper air data which revealed a more complex structure than was envisaged by Bjerknes. A fundamental feature of the three-front model was a recognition of the trowal; the trowal is located on synoptic maps as a surface trough beneath a thermal ridge. The trowal is essentially an upper frontal zone but it is also associated with a discontinuity in weather elements observed from the ground. Usually the passage of a trowal marks a change from typical pre-frontal continuous precipitation to a more showery type with well-broken cloud. In other words the trowal appears to exhibit the characteristics of both a warm and cold front together but there is not necessarily any significant change of temperature at the surface. Since the trowal is associated with a relatively strong thermal wind aloft, it is also identified as a discontinuity in the thermal advection field. Such a discontinuity has dynamical significance, particularly in regard to the diagnosis of vertical motion.

In a recent paper[2] it was shown how a qualitative estimate of vertical motion could be assessed from synoptic charts by making use of the omega equation. The relevant equation (1*a*) in that paper is restated as follows :

$$\omega \approx -\frac{\partial}{\partial p}(\mathbf{V}.\nabla Q) - \nabla^2(\mathbf{V}.\nabla h_{TT}). \qquad \ldots (1)$$

Thus ascending air (ω negative) occurs in association with relatively strong positive (cyclonic) vorticity advection aloft and/or a maximum of warm-air advection in the layer. If the equation is applied to the 1000–500-mb layer the mean vertical velocity in the layer depends upon the difference between the vorticity advection at 500 mb and at 1000 mb and the advection of the thickness by a mean wind in the layer.

The purpose of this note is to illustrate the diagnosis of a trowal that was present on the synoptic chart at 00 GMT on 20 March 1970. As in the previous case,[2] use is made of computer-analysed charts and comparisons are made between the objectively derived vertical-motion field and subjective assessments based upon equation (1).

Figure 1 depicts the 1000–500-mb thickness and superimposed 1000-mb contour-height flow. The essential features are clearly evident; there is a well-marked thermal ridge beneath which there is an equally prominent trough in the 1000-mb flow. Figure 2 depicts the 500-mb contour flow with superimposed isopleths of thickness advection ($\mathbf{V}.\nabla h_{TT}$) calculated from Figure 1. The 500-mb flow consists of a rather ill-defined ridge-axis lying approximately north–south across the British Isles and a south-westerly stream to the west within which there appears to be a very low-amplitude undulation.

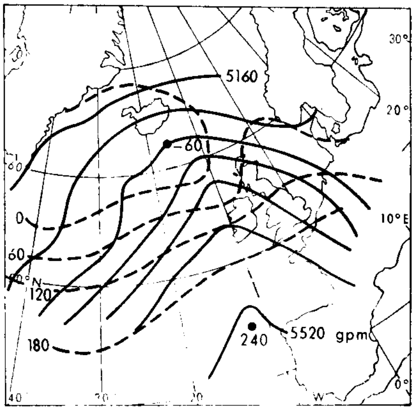

FIGURE 1—1000–500-mb THICKNESS AND SUPERIMPOSED 1000-mb CONTOUR-HEIGHT FLOW AT 00 GMT ON 20 MARCH 1970

——— 1000–500-mb thickness — · — 1000-mb contours

It is instructive to assess the balance of terms in equation (1) on each side of the trowal axis. East of the trowal there is cyclonic vorticity advection at 1000 mb beneath cyclonic vorticity advection at 500 mb (region just upwind of the ridge axis) north of 55 degrees latitude. South of 55° the 1000-mb flow curvature is weak whilst the 500-mb flow curvature is roughly constant in the ill-defined ridge. Thus the magnitude of the vorticity advection term (equation (1)) is probably weak in the whole region because it depends upon the relative magnitude of two like terms in the north and because only small amounts of vorticity advection are present in the south. The thickness advection field shows a pronounced maximum of warm-air advection extending

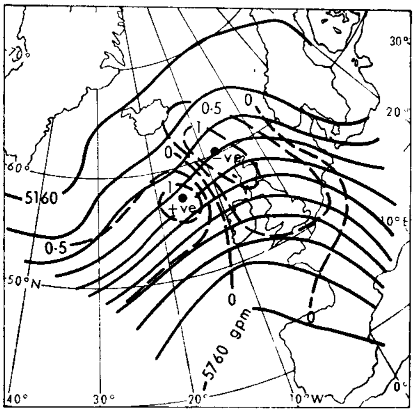

FIGURE 2—500-mb CONTOURS WITH SUPERIMPOSED ISOPLETHS OF THICKNESS ADVECTION AT 00 GMT ON 20 MARCH 1970

——— 500-mb contours — — — — Isopleths of thickness advection

from south-east Iceland across Scotland. It appears that on the basis of equation (1) there will be ascending motion in the region between south-east Iceland and central Britain, due largely to the thermal advection term. West of the trowal the curvature at both 1000 mb and 500 mb is small so that the vorticity advection term is probably very small too. On the other hand, the thermal advection field contains a prominent maximum of cold air advection. On the basis of equation (1) there will be descending air north-west of Ireland associated with the thermal advection field.

Figure 3 depicts the distribution of mean vertical velocity in the 1000–600-mb layer, as produced by the computer. The similarity between the pattern of vertical velocity and thickness advection distribution is very clear.

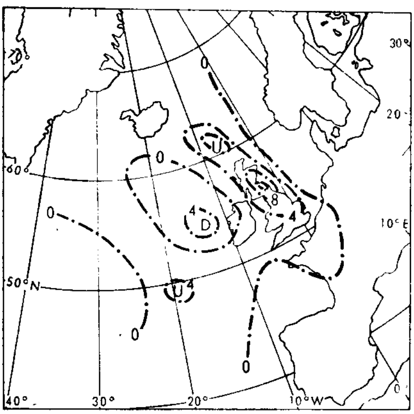

FIGURE 3—DISTRIBUTION OF MEAN VERTICAL VELOCITY IN THE 1000–600-mb LAYER, AS PRODUCED BY THE COMPUTER, 00 GMT ON 20 MARCH 1970

— · — Mean vertical velocity at intervals of 4 mb/h
U = up D = down

Ascending air coincides with the maximum of warm-air advection and descending air almost coincides with the maximum of cold-air advection. Furthermore, the isopleth of zero vertical velocity is closely identified with the isopleth of zero thickness advection.

The recognition of trowals supplements the more familiar frontal concepts. Trowals occur sufficiently frequently to deserve a separate classification, although they do not occur as frequently as other frontal features. The essential point to note is that each frontal feature has a distinctive thermal and dynamical structure. Thus the cold and warm fronts are associated with a zone of strong thermal wind and cold- and warm-air advection fields respectively. The trowal is associated with a strong thermal ridge and both warm- and cold-air advection fields. On the other hand, the occlusion is a composite system in which the upper frontal trough is usually displaced horizontally from the position of the surface trough.

Finally it must be remembered that the emphasis on upper fronts in no way reduces the importance of low-level air-mass analysis which is often concerned with shallow layers not closely related to the flow structure aloft. These surface fronts have important secondary effects, e.g. low cloud, surface convection, ice factor, etc., but they are not identified with deep vertical-motion fields except in association with upper fronts.

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1. GALLOWAY, J. L.; The three front model: its philosophy, nature, construction and use. *Weather, London*, **13**, 1958, pp. 3–10.
2. MORRIS, R. M.; A case study of the spectacular developments and movement of a February storm. *Met Mag, London*, **100**, 1971, pp. 14–27.

551.553.11

SEA-BREEZE FRONT NEAR THE SOUTH COAST OF ENGLAND

By K. ROWLES

A satellite photograph taken by ESSA 8 on 17 July 1971 at 1117 GMT is reproduced in Plate I. It shows a prominent belt of convective cloud along the south coast, extending from Cornwall to Kent.

The synoptic situation at 09 GMT (Figure 1) shows an area of high pressure to the west of the British Isles with an associated ridge extending eastwards across Wales and the southern half of England. This maintained light winds between north and east along the south coast. A sea-breeze had set in along the south coast by 11 GMT, at which time air temperatures inland had risen to 18°C. Five-day mean (15–19 July 1971) sea surface isotherms, which have been superimposed on the 12 GMT chart (Figure 2), show that the sea surface temperature was between 15°C and 16°C. Land temperatures were therefore some 2 degC to 3 degC higher than those over the sea at the time of the onset of the sea-breeze. A streamline analysis of the surface wind flow shown on the same chart reveals a zone of convergence parallel to the coast, and some 10 to 20 miles inland.

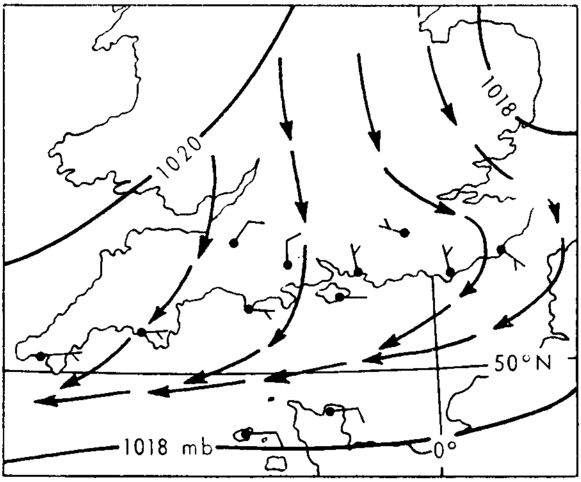

FIGURE 1—SYNOPTIC SITUATION AT 09 GMT ON 17 JULY 1971
Arrows denote streamlines.

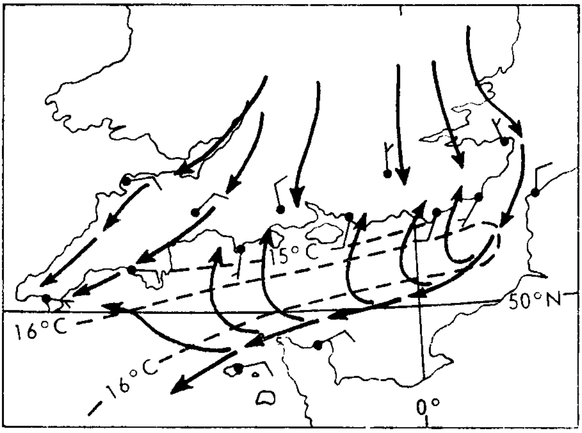

FIGURE 2—SEA SURFACE ISOTHERMS AT 12 GMT ON 17 JULY 1971
Arrows denote streamlines.

By 15 GMT there was a small pressure trough lying from Bournemouth to the Thames Valley; this was about the time of maximum development of the sea-breeze circulation. As the land surface cooled during the evening so the trough filled and disappeared, and by 21 GMT the circulation was reversed, with a light north-easterly flow re-established along the south coast.

The 12 GMT Crawley radiosonde ascent indicated a shallow layer of instability from the surface to an inversion based at 800 mb (6500 ft). This allowed shallow cumulus to form with a general base at 6000 to 7000 ft (2 km) and isolated tops to 8000 ft. Cloud bases of between 4000 and 5000 ft were indicated for air inland. Along the sea-breeze front, however, where there was an influx of moister air from the Channel, bases were as low as 2000 to 3000 ft.

The satellite picture was useful in confirming the continuity of the front along the south coast and the existence of individual convection cells.

551.526.6:551.558.1

THE IMPORTANCE OF LOW SEA SURFACE TEMPERATURES IN INHIBITING CONVECTION ALONG THE NORTH SEA COAST IN SUMMER

By D. R. HINDLEY

Summary. An example is given of the way in which convection cloud is prevented by the relatively low sea surface temperatures occurring in a belt off the coast of north-east England. It is suggested that this should be taken into account in forecasting for the coastal belt.

There have been a number of occasions in the past, during summer, when with unstable north-north-westerly flow along the east coast of England, the coastal belt has been free of showers and has enjoyed long hours of sunshine.

There was such an occasion on 17 July 1971, when a cool showery day was expected. The national and area forecasts included 'showers being moderate or perhaps heavy at times near the east coast'. In the event, convection was markedly damped down along the coastal belt.

The nature of the air mass along the east coast is shown by the Shanwell 00 GMT ascent (Figure 1). With an air-mass dew-point of 7°C, a temperature of 13·5°C was required (over land or sea) to initiate formation of convection cloud. By 12 GMT air temperatures had reached 16 to 19°C in inland areas. Along the coastal strip of sea off north-east England they were 11 to 12°C. Further east over the North Sea, they were 13 to 15°C.

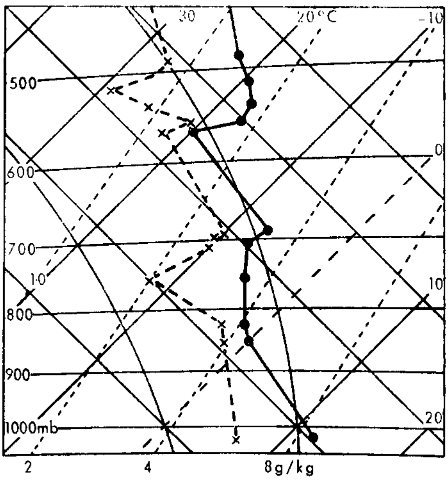

FIGURE 1—SHANWELL ASCENT FOR 00 GMT ON 17 JULY 1971

——— Temperature - Dew-point

The author was in a position to photograph the cloud formations near the east coast, and Plates II to IV were taken near Scarborough at about 12 GMT.

Plate II, looking north-north-west along the coast shows convection cloud developing a few miles inland. Plate III, looking due north, shows a clear corridor between the convection cloud inland and the convection cloud forming over the sea some miles out from the coast. Plate IV, facing north-east to east shows the cloud out to sea.

The explanation lies in the distribution of temperature along and off the coast. Figure 2 gives the five-day mean sea surface temperatures over the North Sea. The sea surface temperature distribution is a persistent feature. It is cool relative to the day-time temperatures normally reached inland at this time of year. It is also cooler than the sea surface over the shallower waters further east towards the Dogger Bank.

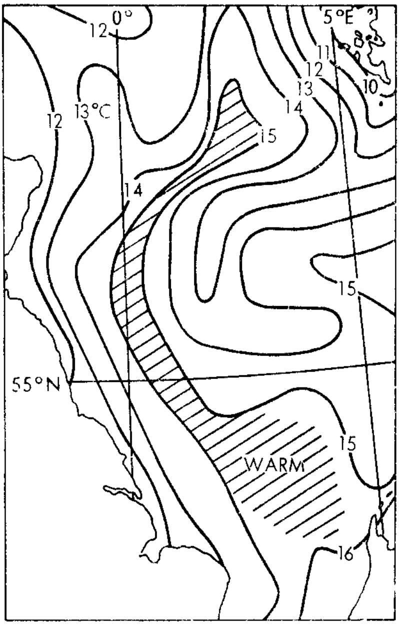

FIGURE 2—FIVE-DAY MEAN SEA SURFACE TEMPERATURES OVER THE NORTH SEA

It is clear that this is an instance of the coastal strip being free of cloud because of the cool coastal waters. These were effective in preventing the convection temperature being reached. Long sunshine hours were experienced at the coastal stations, varying between 10·3 hours at Scarborough and 14·1 hours at Kilnsea. From the increasingly important tourist industry point of view, the sunshine amount is of great significance. Provided the wind speed is not too strong, sunshine may be more important than temperature.

It is considered that rather more optimistic forecasts could be made for the coastal belt in the type of case illustrated in this note. It is suggested that a forecast of little or no cloud, and consequently 'dry and sunny', could be made for the coastal belt when the following criteria are satisfied :

(a) No major troughs or fronts are expected during the forecast period.

(b) Dew-points in the air mass are at least 3 degC below the sea surface temperatures (hence fog or low stratus are not in prospect).

(c) The geostrophic wind direction is along the coastline, i.e. 330–350 degrees. The geostrophic wind speed does not exceed 25 kt (stronger winds bring an excessive chill factor).

(d) The expected maximum air temperature along the coastal strip is less than the convection temperature shown by the 00 GMT Shanwell ascent.

NOTES AND NEWS

Retirement of Mr K. H. Smith

Mr K. H. Smith who, since 1968, has been the Assistant Director responsible for publications and training, retired from the Meteorological Office on 17 April 1972. After graduating in physics at London University followed by a spell as a schoolmaster, he joined the Office in 1938 and was assigned to forecasting duties, first at the flying-boat base at Calshot and then at Uxbridge which was the headquarters of No. 11 (RAF) Group and which became the main Air Traffic Control Centre in the United Kingdom.

In 1948 'KH', as he was widely known, was posted as an instructor to the Meteorological Office Training School. For the remainder of his career he was to be concerned with staff, either in their training or in their administration. From time to time postings appear to be haphazard, not least to the victim, but occasionally a flash of lightning illuminates the scene and certainly Mr Smith's transfer to the Training School in 1948 was quickly recognized as one of the best postings the Office has ever made. In 1952 he became Head of the Training School and two years later became Head of Met.O.10, the personnel branch, a post which he occupied for 14 years and left on promotion to Assistant Director when training once again became his principal responsibility. In these latter years one of his major projects, now successfully concluded, was the transfer of the Training School from Stanmore to Shinfield Park and its transformation into a residential college with more extensive and more varied training programmes.

For the past 24 years all members of the staff must have had personal dealings with KH not once but several times. As an individual, therefore, he was one of the best known in the Office and indeed we should widen the circle and bring into the reckoning the hundreds of overseas meteorologists who have taken our training courses. All of us will remember him as in every sense a guide, philosopher and friend. He had a wide and deep knowledge of his subject, an unusual degree of balanced judgement and whenever necessary he could stand back and take a detached view. No-one came to him in vain for advice and invariably the advice was seen to be helpfully inspired.

KH was admired in many ways but above all he will be remembered for that divine gift of humour which was so lavishly bestowed upon him. Samuel Johnson said that the gaiety of nations passed away with David Garrick. In the Meteorological Office we are somewhat more restrained in our praise but there can be no doubt KH's humour eased many a difficult situation and added to the harmony of his colleagues. We wish him and Mrs Smith a long and happy retirement.

P. J. M.

OBITUARY

It is with regret that we have to record the death of Mr C. C. Chapman (Scientific Officer) on 2 January 1972.

REVIEW

Weather and animal diseases, WMO Technical Note No. 113, by L. P. Smith. 275 mm × 213 mm, pp. iv + 49, *illus.*, Secretariat of the World Meteorological Organization, Geneva, Switzerland, 1970. Price: Sw.Fr. 10.

This publication was prepared at the request of the WMO Commission for Agricultural Meteorology, to review recent progress in applying standard meteorological data to forecasting the incidence and intensity of animal diseases, and to survey the techniques involved. The request reflects the considerable advances being made in this field and the interest which has been generated in the last 10 years, and this bulletin fills a very real gap in the literature.

The effect of climate on disease is widely recognized as a general phenomenon, but the detailed examination of the quantitative relationship between weather and specific diseases is at present restricted to a relatively small number of conditions for which sufficient data are available, and consideration is restricted to these. In the first section they are grouped as wind-borne diseases (particularly foot-and-mouth disease and fowl-pest), environmental and nutritional stress conditions, parasitic and fungal diseases and fertility problems. In each case the weather factors thought to influence the condition are briefly discussed and the correlation examined to identify those characteristics on which a positive forecast could be based. It is surprising to find that insufficient data are available on hypomagnesaemia to permit its inclusion in this section.

In the second part of the review the technical details of forecasting methods for specific diseases which are in use or in development in the United Kingdom are described, including work which has not been published elsewhere. While the first section will be of general interest to many workers in veterinary science and agriculture, this second section summarizes a great deal of information in a clear and concise form, and will be of great value to serious students of the subject. Particular attention is paid to foot-and-mouth disease, which has attracted considerable attention because of the disastrous epidemic of 1967–68.

The bibliography lists over a hundred references, but of necessity this is only a selection of the relevant published work, which is widely scattered through the biological, veterinary and meteorological literature. However, it provides a sound basis for further reading and as such is extremely useful. The review copy contains an annoying printing error in that 17 of its 50 pages are not numbered, and the author shows a rather carefree attitude to singular and plural nouns as, for instance, in 'advances has emanated' and 'snowfalls is very efficient'. Generally, though, errors are few and this is a very readable and informative introduction to a subject which is only now beginning to receive the attention it deserves.

R. J. THOMAS

LETTER TO THE EDITOR

551.507.362.2:551.521.12(548.82):551.576.3

The effect of cloud on solar radiation receipt at the tropical ocean surface

I was interested to read Mr D. E. Parker's paper in the August 1971 issue.*

Mr Parker's results could be used to calculate total solar radiation received at the ocean surface during one day (or a few days), but if any investigator wishes to do this, I think that in the tropics it would be simpler to work directly with daily totals and mean daily cloud amounts. In the tropics on a large majority of days the cloud is predominantly convective, and from a limited investigation which I made some years ago using Dar-es-Salaam data, it appears that there is a good linear correlation between daily totals (Q) and mean cloud amount $\overline{C}$ (excluding the few days with large amounts of As or Ns) provided $\overline{C} > 2$ oktas. For values of $\overline{C} < 2$ oktas, Q is virtually constant.

As an example, I attach a scatter diagram (Figure 1) relating daily totals of solar radiation to mean amount of cloud (low plus medium) for the hours 08–17 EAST at Dar-es-Salaam during May 1964. The 26 points marked x are occasions when the cloud was predominantly of convective origin, the 5 points marked o are occasions when large amounts of As were reported, with

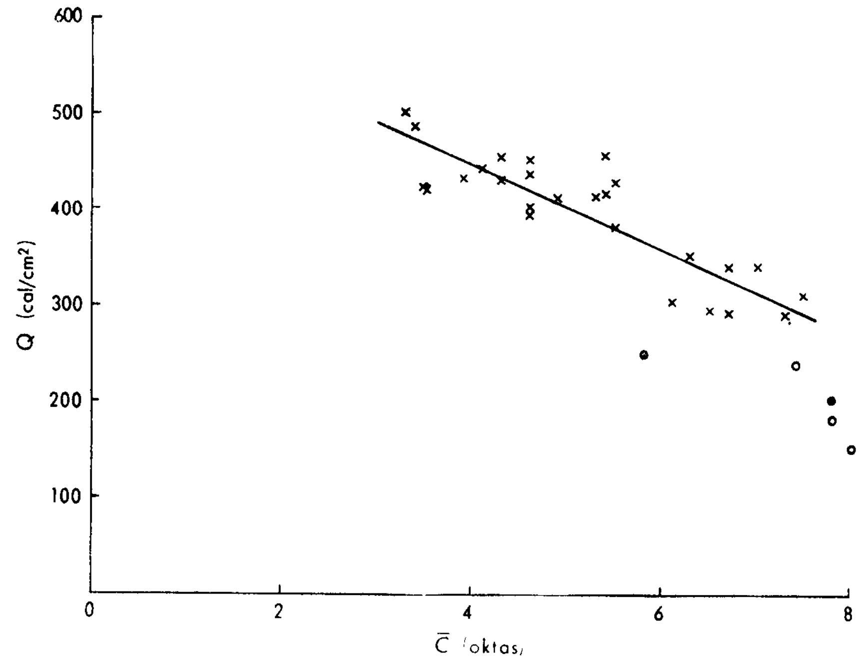

FIGURE 1—SCATTER DIAGRAM RELATING DAILY TOTALS OF SOLAR RADIATION TO MEAN CLOUD AMOUNT FOR 08–17 EAST AT DAR-ES-SALAAM DURING MAY 1964

* *Met Mag, London*, **100**, 1971, pp. 232–240.

variable amounts of low cloud. The straight line $Q = 628 - 44 \cdot 6\ \overline{C}$ gives a good fit to the x points ($r = 0 \cdot 77$) for values of $\overline{C}$ between 3 and 7·5 oktas. The occasions with thick medium cloud need separate treatment.

Regional Meteorological Training Centre,
East African Community, Nairobi

F. E. LUMB

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