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Averages of earth temperature at depths of 30 cm and 122 cm for the United Kingdom 1931—60 (Met. 0.794).

The aim of this book is to provide earth temperature data for the use of workers in agriculture, horticulture, and the construction industries, and to aid research in climatology and other branches of geophysics. There are tables of averages and extremes of earth temperature at depths of 30 and 122 cm for many places in the United Kingdom. Monthly standard deviations and frequency tables of temperatures at a depth of 30 cm are also included for a number of places. Methods of measurement, site differences, diurnal and annual variation, variation with depth, snow and grass cover, notable winters and comparison with earlier averages are some of the subjects discussed and illustrated with diagrams. The tables are arranged in climatological districts to facilitate comparison but an alphabetical index and a map showing the position of places makes for ease of reference.
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THE CLIMATE OF INTERIOR OMAN

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Summary. Using fragmentary data, it is possible to deduce schematic patterns of low-level winds for each month over interior Oman. The southerly monsoon from July to September is little more than one kilometre deep on average, and is best developed in July. It spreads across the interior but is deflected to south-easterly by the Hajar Mountains. Its higher humidity contrasts with the dry north-westerlies dominating most of the region for the rest of the year. There is indication of an Oman convergence zone, where these north-westerlies meet either easterlies (November to January) or southerlies (February to June, and October). This zone becomes the intertropical convergence zone from July to September, when the north-westerlies meet southerlies from the southern hemisphere. Rainfalls are largely confined to the *seif* season (March to May); *kharif* (July to September) rains are very light, except over some mountainous areas. Average annual totals probably exceed 150 mm over the Hajar Mountains, but decrease to 30 mm or less over most of the interior.

Introduction. Our understanding of the climate of interior Oman, and of the Empty Quarter of Arabia in general, has been qualitative (e.g. Brice[1]), being based on fragmentary observations,[2] on travellers' accounts (e.g. Thesiger[3]), and on an extrapolation from neighbouring areas. By contrast, the climate of the Arabian Sea, Gulf of Oman and Persian Gulf has been mapped and described in some detail.[4,5] In recent years, as a result of the activities of oil companies and of the establishment of experimental farms, several series of records have accumulated which can be used to construct a more detailed account of the climate of interior Arabia. Dodd[6] made some estimates of temperature and rainfall, partly based on records kept by the Arabian American Oil Company. The following note discusses some further records available from interior Oman.

Records from Fahud. Petroleum Development (Oman) Ltd have kept an almost continuous daily record of temperature, humidity, wind and rainfall, either at their base camp, Fahud (22°15′N 56°30′E, altitude about 250 m), or at drilling sites nearby (Figure 1). By combining observations from these places, sequences covering periods of three to five years can be obtained. Table I gives a summary.

Monthly means of daily maximum temperature show an expected seasonal trend. January was coolest but June, not July, was hottest. The three months July to September were each a little cooler than might be expected from the trend shown by other months. Correspondingly, the 1000 h (0600 GMT)

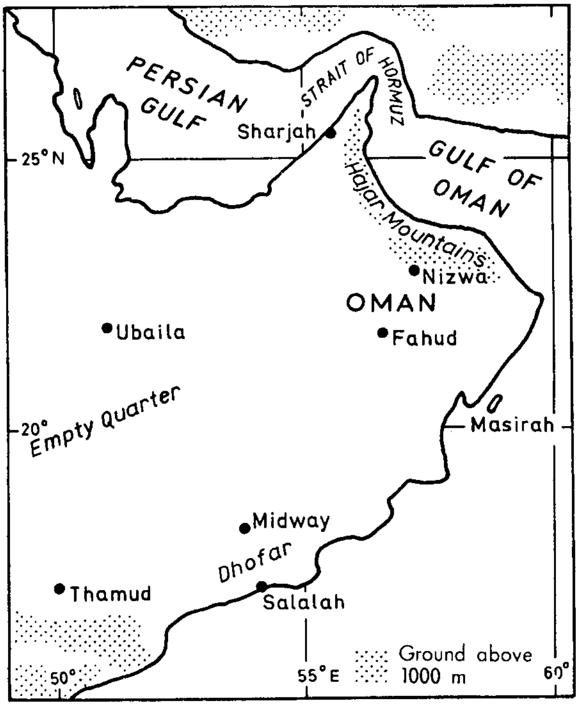

FIGURE 1—MAP SHOWING PLACES MENTIONED IN THE TEXT

TABLE I—CLIMATOLOGICAL DATA FOR FAHUD AND NIZWA

FAHUD. 22°15′N 56°30′E. Altitude about 250 m.
Period : 1963–67, with additional rainfall 1956–57.

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
*Temperature**														
Monthly mean of daily max. (°C)		25	28	34	36	41	45	44	43	40	37	32	26	36
Relative humidity														
Monthly mean of readings at 1000 h (per cent)		55	55	37	34	31	23	36	39	39	33	42	51	40
Rainfall														
Monthly means														
(a) Total (mm)		1	tr	9	9	8	tr	tr†	3	0	0	0	tr	30
(b) Rain days		<1	<1	1	3	1	<1	2	1	0	0	0	<1	10
Surface wind														
	N	5	14	6	15	6	8	2	1	0	2	1	7	5
Percentage	NE	11	0	2	3	1	1	0	3	7	11	13	0	4
frequency	E	11	4	7	5	13	7	8	15	18	9	4	2	9
of occurrence	SE	23	22	26	26	27	29	50	50	42	28	26	15	32
of different	S	6	14	10	18	11	6	6	10	13	13	9	17	11
directions	SW	0	0	0	5	3	2	3	1	4	4	2	0	2
at 1000 h	W	6	0	4	5	9	5	2	3	0	6	4	0	4
	NW	22	24	21	12	16	27	15	10	0	6	1	7	14
	Calm	16	22	24	11	14	15	14	7	16	20	39	51	19
No. of observations		112	93	101	117	120	110	155	144	83	93	84	58	1270

NIZWA. 22°55′N 57°30′E. Altitude about 450 m.
Period : 1963–67.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Rainfall													
Monthly means													
(a) Total (mm)	15	8	5	28	50	1	30	5	5	6	7	2	161
(b) Rain days	1	1	1	2	2	<1	2	1	<1	<1	1	<1	11

* Including observations at nearby drilling sites. Readings corrected to altitude of Fahud using a lapse rate of 10°C/km assuming that the potential temperature does not vary horizontally within the area of the drilling sites. This is probably true since the sites differ in height by 200 m at most, whereas the convective layer probably extends to 3–5 km above the ground.
† But 75 mm fell in July 1967.

relative humidity was higher for the same months. Thus, although maximum relative humidities occurred on average in January and February, there were minima in both June and October, separated by a secondary maximum in August/September. Closely similar trends were recorded in individual years.

It is natural to associate the cooler and moister months of July to September with the monsoon, blowing from the Arabian Sea. Monthly means of the percentage frequency of occurrence of wind directions observed daily at 1000 h (Table I) show south-easterlies were dominant in those three months. Such a direction may be considered to be a local distortion by the Hajar Mountains of the south to south-west monsoon. Indeed, throughout the year a local deflexion of the wind is suggested by a strong preference for directions from south-east and north-west. South-easterlies were usually dominant, but the two directions were about equally frequent from January to March, and in June. There were remarkably few south-west winds, at least at this time of day, whilst north-easterlies became important only in October, November and January.

Rainfall was also measured during 1956 and 1957, but the 7-year period of records is too short to yield any reliable averages, although a few general remarks can be made. The annual total appears to be about 30 mm, falling on about 10 days each year. Most of this total fell during the *seif* season (March to May), and the *kharif* rains (July to September) were very scanty. However, a phenomenal 75 mm fell in July 1967, mostly associated with an unusual disturbance that moved westwards from the Arabian Sea.

Five years' rainfall records are also available from the experimental farm at Nizwa (22°55′N 57°30′E, altitude about 450 m) on the southern slopes of the Hajar Mountains, and for much the same period as the observations at Fahud. The annual total at Nizwa was about five times that at Fahud. Again most of the rains fell during the *seif* season, but *kharif* rains accounted for about a quarter of the annual total. By contrast with Fahud, *kharif* rains fell each year at Nizwa.

Records from Midway, Dhofar. Three years' daily observations were taken by Dhofar Cities Service Petroleum Corporation from 1956 to 1958 at Midway (18°02′N 53°55′E, altitude about 450 m) in Dhofar province of Oman. Table II gives a summary. Monthly means of daily maximum temperature show a trend closely similar to that at Fahud. Again the period

TABLE II—CLIMATOLOGICAL DATA FOR MIDWAY, DHOFAR

MIDWAY. 18°02′N 53°55′E. Altitude about 450 m.
Period : 1956–58.

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Temperature Monthly mean of daily max. (°C)		25	28	32	35	39	41	37	38	38	34	30	27	34
Relative humidity Monthly mean of readings at 1000 h (per cent)		53	40	39	38	28	25	53	45	38	35	41	54	41
Surface wind	N	14	21	11	8	14	10	0	0	4	11	22	30	12
Percentage	NE	2	1	3	1	1	0	0	0	0	16	9	2	3
frequency	E	7	7	5	5	1	3	0	0	4	19	13	16	7
of occurrence	SE	2	4	1	1	0	0	0	0	1	5	3	0	2
of different	S	28	35	52	45	32	40	85	82	68	30	21	25	45
directions	SW	1	0	0	4	2	2	2	3	0	2	6	3	2
at 1000 h	W	7	7	0	3	17	7	8	2	1	6	8	9	6
	NW	16	6	1	11	8	8	0	0	1	2	8	1	5
	Calm	22	19	27	12	25	30	5	13	21	9	10	14	18
No. of observations		93	83	92	75	91	60	62	93	89	89	90	89	1006

July to September was relatively cool and moist. The monthly means of percentage frequency of occurrence of wind directions observed daily at 1000 h show that during these three months southerly winds blew, to the almost complete exclusion of other directions, reflecting the steadiness of the monsoon. Southerlies were common in most other months; from November to January they were about as frequent as north and north-west winds but from February to June they were dominant, being most frequent in March. There were remarkably few west or south-west winds. Easterlies or north-easterlies were significant only from October to December, but they became dominant in October, paralleling their increased frequency at Fahud at the same time of year.

Wind field, July to September. Tables I and II suggest that during the months July to September the monsoon spreads inland to reach at least as far north as Fahud, where it is deflected to a south-easterly, and where it is only occasionally interrupted by north-westerlies. These north-westerlies can be taken as a southward extension of the dominant north-westerlies over the Persian Gulf. The junction between the two streams is the inter-tropical convergence zone (ITCZ) if that is defined to include a region where trade and monsoon meet.

Some indication of the average northward extent of the southerlies can be found in the winds observed at Sharjah. There is a strong diurnal variation of surface wind at that place[7] associated with the sea-breeze, but at an altitude of 1000 m the wind as measured by pilot balloons at 0900–1000 h probably indicates a broader-scale flow. Table III shows monthly means of percentage frequency of occurrence of wind directions at 1000 m observed almost daily

TABLE III—MONTHLY MEANS OF PERCENTAGE FREQUENCY OF WIND DIRECTIONS AT SHARJAH AND MASIRAH

(*a*) SHARJAH. Winds at 1000 m at about 1000 h. Period 1961–65

Direction ranges *degrees*	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
350–010	1	2	1	5	5	2	0	2	1	7	1	1	2
020–040	4	1	3	3	1	1	1	2	4	5	7	4	3
050–070	3	0	2	4	2	1	2	3	5	7	6	7	4
080–100	8	6	1	1	4	3	4	4	7	6	7	9	5
110–130	4	3	2	0	2	3	6	7	11	3	10	4	5
140–160	4	1	1	3	2	3	4	9	7	6	5	5	4
170–190	5	9	11	8	4	6	17	12	7	3	5	4	8
200–220	7	11	8	7	9	6	9	9	2	3	4	5	7
230–250	5	6	11	11	5	11	12	6	5	1	1	7	7
260–280	16	14	13	8	12	11	7	6	5	6	7	7	9
290–310	20	19	27	27	15	20	9	9	11	10	15	13	16
320–340	7	5	4	9	17	12	5	1	7	10	5	7	7
Calm or <5 kt	16	23	16	14	22	21	24	30	28	33	27	27	23
No. of observations	153	140	152	149	119	147	153	155	149	155	150	155	1777
Missing observations	2	1	3	1	5	3	2	0	1	0	0	0	18

(*b*) MASIRAH. Winds at 500 m at about 1000 h. Period 1961–65

Direction ranges *degrees*	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
350–010	1	1	1	1	0	1	0	0	0	4	3	3	1
020–040	5	4	2	1	1	0	0	0	0	4	8	14	3
050–070	22	16	4	1	1	1	3	2	0	9	27	37	10
080–100	13	9	5	2	1	1	2	0	0	3	10	8	5
110–130	7	4	3	0	2	0	0	3	1	1	2	2	2
140–160	5	5	5	2	3	0	1	0	3	0	0	1	2
170–190	2	3	7	9	9	3	6	8	6	3	1	0	5
200–220	3	4	9	20	13	24	17	22	22	4	3	1	12
230–250	2	7	14	24	35	32	29	33	30	16	3	1	19
260–280	3	5	11	9	18	19	21	11	7	9	3	1	10
290–310	7	9	1	9	5	6	7	6	0	5	3	5	6
320–340	3	3	4	2	1	1	4	0	0	1	3	4	2
Calm or <5 kt	27	31	24	20	11	12	10	15	31	41	34	23	23
No. of observations	113	109	148	148	148	139	107	90	94	115	119	147	1477
Missing observations	11	3	7	2	7	11	17	34	36	9	1	8	137

from 1961 to 1965. From July to September, south-west to south-east winds were dominant, but north-westerlies were more frequent than as Fahud. These southerlies were not deep, however, for at 2000 m north-westerlies were strongly dominant.

Thus, on many days the monsoon reaches at least as far north as Sharjah, as a current between one and two kilometres deep. At the surface, night-time winds at Sharjah usually blow from between east and south,[7] directions to be expected with a monsoon modified by a land-breeze.

Some indication of the depth of the monsoon along the south-east coast of Oman can be found from pilot-balloon winds at Salalah and Masirah. Frequent low cloud at Salalah leads to few observations at 1000 m, so the calculated frequencies are unlikely to be representative of the true flow at that altitude. However, the very presence of clouds is indicative of lifting of the moist monsoon current. This low cloud is confined to coastal waters and the adjacent hills that rise to a general altitude of 1000 m, but it is deep enough to give drizzly rain.[5] Spillage of the monsoon over these hills probably leads to the remarkably persistent southerlies at Midway. The evidence suggests the monsoon is between one and two kilometres deep over Salalah, and this depth agrees well with that measured[8,9] over the adjacent sea during the International Indian Ocean Expedition. At Masirah, although there is less low cloud, frequencies of 1000 m winds are still likely to be biased towards days with fair weather, particularly those with little cloud and light winds. However, at 500 m there are considerably fewer missing observations, and these winds (Table III) probably indicate the broad-scale flow largely undisturbed by sea-breezes. From July to September, south-westerlies are strongly dominant, with an almost complete exclusion of directions other than those between south and west, again demonstrating the steadiness of the monsoon.

Above the monsoon, winds are mostly north or north-west. In the interior, day-time convective mixing might therefore be expected to transfer northerly momentum downwards to the surface. At Midway, winds measured at 1600 h show a small increase in the frequency of northerlies compared with 1000 h, more so in September than in August, suggesting not only that a vertical exchange of momentum does occur but also that the monsoon becomes more shallow as the season progresses. This further implies, by analogy with the Sudan and West Africa, where the depth of the monsoon decreases northwards,[10,11] that the ITCZ is furthest north in July. No afternoon observations were available from Fahud, but data for July and August 1964 from Thamud (17°20′N 49°55′E, altitude about 600 m) confirm an increase in the frequency of northerlies during the afternoon (1700 h) compared with the morning (0900 h). In both months, afternoon north to north-east winds were about as frequent as south to south-easterlies, suggesting that on average the ITCZ lay close to Thamud in the afternoon and therefore, again by analogy with Sudan and West Africa, about 200 km to the north-west in the morning.

Combining these fragmentary observations it is possible to obtain a coherent pattern of the average, low-level (up to an altitude of 1000 m) monsoon flow over Oman. For July, this is shown schematically in Figure 2*(a)*. Southerlies are deep enough to cross the coastal hills east of about 50°E, subsequently flowing across the relatively flat interior, but being deflected by the Hajar Mountains. After crossing the coast of Trucial Oman, these southerlies will be warmer than, and should therefore ride above, north-westerlies flowing in contact with the relatively cool sea surface of the Persian Gulf. Approaching the mountains of Iran, it is likely that the flow is deflected to the east. Over the Gulf of Oman, westerlies prevail[5] except for a thin surface film of easterlies that meet winds from the Persian Gulf in the Strait of Hormuz.

The position of the ITCZ as shown in Figure 2*(a)*, although further north than is commonly believed, agrees closely with one suggested by Flohn.[12] Further support comes from observations at Ubaila (22°00′N 50°55′E), in the northern Empty Quarter, which Dodd[6] considers to be near the northern limit of the monsoon.

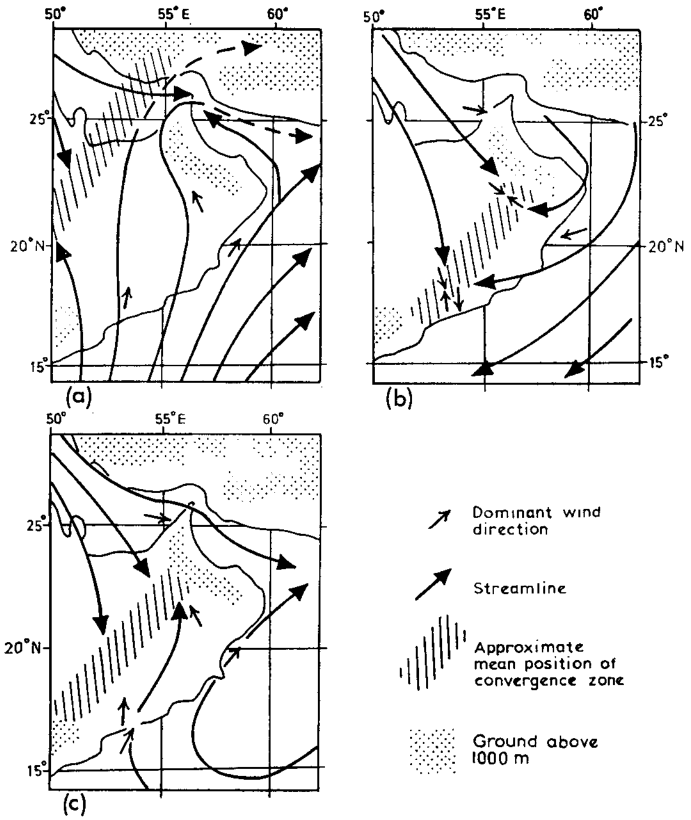

FIGURE 2—SCHEMATIC PATTERNS OF WIND FLOW AT 1000 HOURS IN THE LOWEST KILOMETRE OF THE ATMOSPHERE OVER OMAN

(a) July *(b)* January *(c)* April

The flow patterns are based on observations at various heights (see Tables I–III), and it is assumed that wind direction does not change with height through the layer. Streamlines are broken where winds from the land flow above a thin surface film of air moving from a different direction.

The shallowness of the monsoon, with a consequently restricted source of low-level moisture, is probably responsible for the rarity of rain over Oman from July to September. Possibly the only two exceptions are the Hajar mountains and the hills behind Salalah. About 50 mm probably fall on favoured places in the former mountains, and somewhat more on the latter.

However, heavy rains have occurred elsewhere — for example 12 mm at Sharjah[13] on 26 July 1956, and 30 mm at Masirah in July 1967, the latter in association with the 75 mm fall at Fahud. Such rains are probably related to unusual travelling disturbances accompanied by a deepening of the monsoon and a northward surge of the ITCZ.

Above the monsoon, the north-westerlies probably acquire their warmth and low relative humidity partly as a result of subsidence, particularly that associated with the right-exit region of the so-called 'tropical easterly jet' with its axis in the high troposphere[14] near 15°N, and partly because of intense insolation under clear skies over the Near East and Iran.

Wind field, November to January. During this season, the south-west monsoon over the Arabian Sea has been replaced by the north-east trades. Considering 1000 h winds, at 500 m over Masirah (Table III), the dominant direction is east-north-east with a weak secondary maximum from the north-west, but at 1000 m over Sharjah north-westerlies dominate with east-north-easterlies forming a secondary maximum. North-west winds develop in the rear of disturbances moving across the area, and their leading edge is often marked by a cold front ahead of which winds usually blow from between south and east. The presence of north-westerlies at Masirah suggests that some of these fronts can cross the south-east coast of Oman, buton most occasions the north-westerlies fail to reach the coast so that a semi-permanent zone of convergence probably exists in this season over interior Oman, separating north-westerlies from the trade wind. This can be called the Oman convergence zone (OCZ). Some indication of its position can be found in the observations at Fahud, where in January north-west winds are about as frequent as south-easterlies. This is consistent with the OCZ lying, on average, close to that place in January. In November and December, dominant south-easterlies at Fahud and north-westerlies at Sharjah place the OCZ further to the north-west. Some indication of its orientation can be found in the Midway observations. With northerlies about as frequent as southerlies there from November to January, the OCZ would be approximately as shown in Figure 2*(b)*, i.e. with an orientation similar to that of the ITCZ in July. The OCZ has some characteristics of a lee convergence zone, where north-westerlies from the Near East meet north-easterlies from West Pakistan in the lee of the Iran mountains.

Wind field, February to June, and October. At Masirah during February, 500-m south-westerlies increase in frequency at the expense of east-north-easterlies of previous months, and by March they are dominant. Throughout the season, southerlies are dominant at Midway, forming part of a broad-scale flow from the Arabian Sea before the monsoon sets in, usually some time during June. This change from east or north-east winds to south or south-west is probably a response to the increasing difference between air temperatures over land and sea as the year advances. A similar change occurs along the east coast of India. In both areas, anticyclonic cells appear over the ocean in March and April, leading to south-westerlies along eastward-facing coasts, but the cells fade as the monsoon develops. Similar weak cells appear fleetingly in October. Thus, the south-westerlies can be looked upon as local distortions of the trade flow. Nevertheless, they are continuous in time with the monsoon south-westerlies flowing from the southern hemisphere during the period June to September.

Although southerlies are dominant from February onwards at Midway, south-easterlies at Fahud only slowly become more frequent than north-westerlies, suggesting a slow seasonal displacement of the OCZ north-westwards (Figure 2*(c)*). Indeed, in June the OCZ seems to return temporarily to near Fahud. Throughout this season the OCZ is less like a lee convergence zone; it shows more the character of the trade front *(front alizé)* of north-west Africa. Thus, there appear to be progressive seasonal changes in the OCZ, not only of its position but also of its character, for by July it has evolved into the ITCZ with the south-westerlies coming from the southern hemisphere. During October, when trades replace the south-westerlies, the OCZ is re-established over interior Oman as a lee convergence zone.

A synoptic pattern associated with rainy days, particularly during the *seif* season but also more generally from November to May, is the presence in the upper tropospheric westerlies of a cold trough extending southwards to 20°N or even lower latitudes. Divergent flow is to be expected in the south-westerlies ahead of such a trough, leading to widespread ascent and sometimes to the formation of extensive cloud sheets in mid-troposphere. Local outbreaks of rain can then occur, especially if potential instability is released. If, at the same time, there is advection of moisture from the Indian Ocean by lower tropospheric winds ahead of the accompanying cold front, together with day-time heating over land, then such a pattern would favour the development of deep convection clouds and heavy rain. Deep convection can also be expected on infrequent occasions in the rear of a cold front particularly during the coldest months. This would occur near the axis of the associated upper cold trough,[15] where winds are west to north-west throughout much of the troposphere, and where heat and moisture have been added from the Persian Gulf or the Gulf of Oman.

Tropical cyclones can also lead to heavy and extensive rains. However, these disturbances are uncommon — one approaches the Arabian coast about once in three years[16] — and they are largely confined to the transition months preceding and following the monsoon, May–June and October–November. Even so, tropical cyclones contribute a quarter of the annual rainfall at Salalah, but only about five per cent at Masirah. Over interior Oman, their contribution is probably less, although occasional heavy falls with flooding do occur, for example[17] in October 1948. Heavy rains sometimes fall in each of several successive rainy seasons. As an example we may note the cyclonic rains of November 1966, the *seif* rains of March–April 1967, the monsoon rains of July 1967 and the rains of January–February 1968.

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RAINFALL AT BURAIMI OASIS IN JULY 1969

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Summary. A description is given of a storm in July 1969 at Buraimi Oasis, on the border of Abu Dhabi territory with Muscat, during which 6·4 mm of rain fell. Some data for dewfall in the area in July 1969 are also given, as well as monthly rainfall data for the Oasis for the period November 1965 to July 1969.

The oases in the Buraimi group are at a height of 280 m above sea level and are situated at the northern end of Jebel Hafit (Figure 1). They lie partly in Abu Dhabi territory and partly in Muscat territory and are about 120 km from the Persian Gulf. The Hajar Mountains are about 20 km to the east and separate Buraimi from the Gulf of Oman.

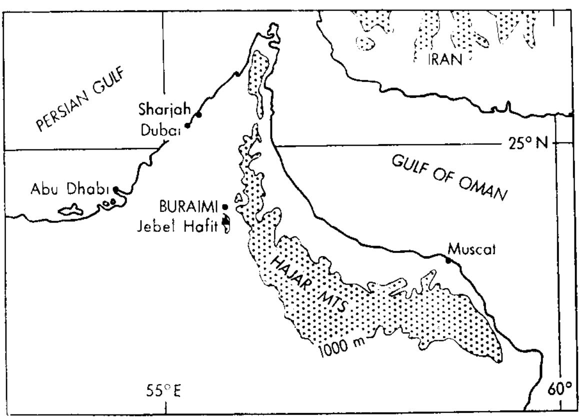

FIGURE 1—MAP OF THE BURAIMI OASIS AREA

The usual meteorological instrumentation is lacking at Buraimi apart from a single rain-gauge at Jahili Fort (Trucial Oman Scouts), which was established in autumn 1965. Dew-gauge readings are also available for a period in July 1969. Rainfall data are given in Table I and it is clear that scattered showers are not unusual during the summer months. However, July 1969 was considered abnormal by the local inhabitants on account of the frequency of humid days, whilst there was a heavy rainstorm on 7 July.

TABLE I—RAINFALL AT BURAIMI OASIS

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total
						millimetres							
1965					Gauge not installed						Nil	Nil	
1966	Nil	37·5	Nil	Nil	Nil	1·0	1·0	Nil	Nil	Nil	Nil	Nil	39·5
1967	Nil	Nil	6·4	5 9	Tr	Nil	2·5	Nil	Nil	Nil	Nil	Nil	14·8
1968	5·0	69·8	Nil	2·5	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Tr	77·3
1969	33·5	1·3	Nil	4·3	Nil	Nil	6·4						46·7 (Jan.–July)

During the summer months, the climate of the oasis area is mainly influenced by the low-pressure area centred over southern and central Iran. June and July are the months of the 'shamal', a persistent north-west wind, whilst the monsoonal circulation does not generally reach as far north as Buraimi. During July 1969, the effects of the monsoon were felt further north than is usual.

The shift in the monsoonal pattern was probably reflected at Buraimi by the frequency of humid days which were invariably followed by a dewfall (Table II). The dew-gauge was sited at ground level on a grass plot *(Cynodon dactylon)* in a walled garden. The most humid days were 7, 10, 13, 19, 24, and 30 July and on three of these days (7th, 24th and 30th) rain fell at Buraimi. On the other days, and also on the 16th and 27th, towering cumulonimbus were observed over the Hajar Mountains in the afternoon and it seems likely that there was some rainfall.

TABLE II—QUANTITATIVE EQUIVALENTS OF DUVDEVANI DEW-SCALE NUMBERS AT BURAIMI, JULY 1969

	Dewfall *mm*		Dewfall *mm*		Dewfall *mm*
July 6	nil	July 15	nil	July 24	(Rain)
7	0·15	16	Tr	25	0·075
8	0·15	17	nil	26	nil
9	nil	18	0·02	27	Tr
10	0·02	19	0·075	28	nil
11	nil	20	nil	29	0·02
12	nil	21	nil	30	0·15
13	0·02	22	nil	31	0·15
14	nil	23	0·045		

The storm on 7 July 1969 was regarded by the local inhabitants at Buraimi as the worst summer storm in living memory. At 1630 h local time, an isolated thunderstorm with visible lightning passed about 8 km north of Buraimi, moving in a westerly direction. By 1720 h the persistent light wind, west-north-west, the local equivalent of the 'shamal', which had blown throughout the day had strengthened and commenced to veer. This was accompanied by a duststorm which, at its most intense phase, reduced visibility to about 50 m, the wind blowing from the north. Rain started to fall at 1750 h and it rapidly became heavy with the peak intensity being reached about 10 minutes later when hailstones up to 6 mm in diameter fell. During this time the wind had strengthened to gale force (estimated speed 100 km/h) and was blowing from the north-east quarter. The heavy rains and wind ceased at 1820 h, though a light drizzle continued for a further 20 minutes. During the storm 6·4 mm of rain were recorded, though this is probably an underestimate since much of the rain and hail was driven almost horizontally by the high winds, and there was enough rain to cause some of the wadis to flow for a short time. Considerable damage was caused to the new low-cost houses, walls were pitted by the hailstones, almost all the 'barasti' huts were blown down, and numbers of palm trees were uprooted. The storm was succeeded by a very humid and calm evening whilst a thick fog, with visibility down to 50 m in places, occurred on the following morning, not dispersing until about 0800 h.

Rainfall on 24 July was much lighter and the amount that fell was not measurable in the gauge at Jahili Fort. The rain was brought about by the movement north-eastwards of the intertropical convergence zone (ITCZ) which was almost directly over Buraimi, whilst the seasonal low pressure over southern Iran had extended southwards. In contrast to the other two days on which rain fell, precipitation did not occur until 2300 h.

At the end of July, the main centre of low pressure over central Iran was reinforced and induced a strong 'shamal'. The light rain that fell was possibly the result of a convection storm developing over the mountains. Although only a few drops of rain fell on 30 July at Buraimi, heavy falls were recorded in neighbouring parts of Muscat territory. Although no temperature records are available, the 30th, like the other days on which rain fell, appeared to be hotter than average. The incidence of a strong 'shamal' and the increased heating of the rocks would provide additional uplift over the Hajar Mountains to the moister air from the Arabian Sea monsoon, resulting in the development of a convection storm.

It is considered that a number of factors contribute to summer rainfall in the Buraimi area. These include :

(i) *The presence of moist unstable air.* Tephigrams showed that on the days that rain fell at Buraimi there was moist unstable air over both the Persian Gulf and the Arabian Sea.

(ii) *Rainfall from middle-level ITCZ cloud.* Such rainfall is usually light and brought about by strong advection.

I should like to acknowledge the information and help provided by Mr K. W. J. Wood, Meteorological Officer, R.A.F. Sharjah, and by Mr J. P. Dixon, R.A.F. Muharraq, as well as the helpful advice of Dr K. Smith.

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MAPPING SPATIALLY SMOOTHED RAINFALL

By D. J. HOLLAND and JENNIFER M. NOAD

Summary. In the course of verifying numerical forecasts of rainfall, the details of rainfall within a square of side about 100 km have to undergo spatial averaging in order to obtain a grid-point value representing the rainfall over the square. Rainfall for 24 h starting at 0900 GMT are available for a close network of stations over Britain and a set of values can be estimated (subjectively or by computer) at points on a subgrid of grid length 10 km. These estimates can then be averaged over the larger squares of an 'interpretation grid' of grid length 100 km. The average of each square is then allocated to the central grid point.

In practice there is a requirement for mapping rainfall for, say, 24 h starting at 0000 GMT (i.e. 'civil day' rainfall). Measurements are available from autographic records for such 24-h totals but only from a sparse network of stations. However, the ratio *(CD/RD)* of 'civil day' rainfall to 'rainfall day' rainfall, for instance, has a fairly smooth pattern which can be interpolated despite the sparse network. Each measurement of *RD* can then be converted to a *CD* measurement by multiplying by the interpolated *CD/RD* ratio, and a detailed map can be produced for 'civil day' rainfall.
The causes of some discrepancies are discussed.

Introduction. In the course of interpreting numerical predictions of weather in general, and of rainfall in particular, it is necessary to think in terms of values for grid points or grid squares, bearing in mind that the computations implicitly treat the numbers as if they behaved like grid-square averages.

When dealing with patterns of pressure it is usual to gloss this over, because even on a plotted chart of 'actual' sea-level pressure the 'noise', i.e. the ups and downs on subgrid scales, is filtered out by the conventional free-hand drawing of isobars. Much the same is true of isobaric contour heights, layer thicknesses and temperatures, whether drawn by hand or objectively analysed by machine.

Rainfall, however, has hitherto tended to be viewed differently, its fluctuations on the subgrid scale being too big and too interesting either to be dismissed as mere 'noise' or to be filtered out in practice by free-hand drawing. Here the grid-square discipline is new and unfamiliar. A numerical forecast of rainfall, nominally for a grid point, is really telling us something about the spatial mean over quite a big area around, and in the course of relating this to the actual events we must get to know both how the spatial mean rainfalls organize themselves on synoptic scales and how they tie up with the subgrid details. In particular, in the course of research and development in this context, subgrid details of actual 24-hour accumulations of rainfall in the region of the British Isles have had to undergo accurate spatial averaging over unit squares of a grid with a grid length of about 100 km. Although future work of this kind may become computerized, it has been pioneered by hand with procedures whose achievement in quality control is probably unique. These procedures are the subject of this article.

Some particular requirements. A particular project will now be described in order to make clear what is entailed in dealing with spatially smoothed rainfall. The grid framework was already laid down and the manner in which it lay obliquely across the country is clear from, for example, Figure 2. Rainfall figures were required for as many of the squares as would be compatible both with a high standard of quality control of the rain data and with ready access to a quality-controlled version of the data in a form handy for mapping. Moreover, the squares chosen were to suffice for several 24-hour periods, most of which happened to be 'civil days', i.e. starting at 0000 GMT, whilst two started at 1200 GMT. Figures for the corresponding 'rainfall days', starting at 0900 GMT, might serve as intermediaries but were not called for as end products.

In respect not only of quality control and of spatial profusion but also of ready access, the rain-gauging network of the United Kingdom ousted all others from practical consideration. Since its processing by computer is adequately described by Bleasdale and Farrar,[1] no elaboration is required, apart from emphasizing that the taped data are nearly all 'rainfall day' totals, as there are as yet comparatively few tapes with rain data in other time steps. Even when only 24-hour totals are required, autographic records are needed whenever the starting time differs substantially from 0900 GMT. Quality-controlled tabulations from autographic records are readily available but only from a sprinkling of stations, a sparse network by U.K. standards. Because of the starting time of 0000 GMT or 1200 GMT for the selected occasions, recourse would at some stage have to be made to this sparse network; and, in the absence of a full set of tapes, even for this network it would be necessary to some extent to work direct from hand-written tabulations.

The sparseness of this network presented a problem because much of the subgrid detail, particularly in the uplands, slips through such a network unnoticed. Only the 'rainfall day' network picks up this kind of detail and so a procedure had to be designed that would exploit the resolving power of the main network whilst geared in time to the sparse one.

The link that was used was simply to compare, at each station of the sparse autographic network, the recorded rainfall for the 24 hours from 0000 GMT (or, on two of the occasions, from 1200 GMT) with that for the 24 hours from 0900 GMT. It was anticipated that this 'civil day' to 'rainfall day', or *CD/RD*, ratio would not in general be very sensitive to the orography or to the subgrid-scale structure of the rainfall but would reflect rather broadly the time sequence of the rainfall's development, and that on a map this would give the ratio a fairly smooth pattern that could be interpolated despite the sparseness of the network. In particular, of course, if the rain all fell within the 15-hour overlap period, the ratio would be exactly 1, while on the noon-to-noon occasions the ratio would duly be 1 wherever the rain all fell in the 21 hours from noon. Corresponding interpolation on the *RD* or main-network map would, meanwhile, be quite good because of the network's profusion and so the sparsely-gauged *CD* map could be filled in by multiplying the *RD* value for the required position by the *CD/RD* ratio interpolated for that position. This multiplication, strictly speaking, ought to precede the spatial averagings and provision was made for operating in this way now and then, as for example in the Devon area on the specific occasion discussed later. In general, however, it was considered acceptable to do the spatial averagings before the multiplying.

In the absence of rain-gauging at sea, the only eligible grid squares would be those lying largely or wholly inland. In interpreting the word 'largely' no formal pass level was set because the reliability of offshore extrapolation would naturally vary with synoptic situation and with how much of the inland rainfall pattern was effectively orographic, e.g. being better in westerlies over the Thames estuary than over the Bristol Channel and Irish Sea. The 19 fully outlined grid squares that are shown on the maps represented the most that could qualify in general on this understanding, the south-easternmost being acceptable on most occasions despite going quite far out to sea. A few squares that extended comparably far out to sea in the west were to be taken into consideration later but were rated lower in reliability because even if offshore extrapolations across them could sometimes be good, there would often be situations in which they could not. These squares are shown in Figure 2 with pecked lines defining their western edges.

A specific occasion. One of the occasions dealt with, i.e. the 24-hour period from 0000 GMT on 8 September 1965, will now be used to illustrate the procedures which were evolved for obtaining the rainfall in the required form.

The original purpose of the work was to verify precipitation forecasts for grid points of the polar-stereographic grid of the 10-level atmospheric model described by Bushby and Timpson.[2] It was decided that each grid point should be made the centre of a square in a new grid called the 'interpretation grid' (see, for example, Figure 2) which is therefore virtually the same as the polar-stereographic grid except that it is displaced by half a grid length in each direction.

Each interpretation-grid square was subdivided into about 100 cells by subgrid points, 10 km apart, of the National Grid of the Ordnance Survey or of the Irish Grid in the case of Northern Ireland. Owing to differences between the two grids the number of National Grid points in an interpretation-grid square varies from 100 in Scotland to 93 in southern England.

The unsmoothed *RD* rainfall data were plotted on 1 : 625000 Ordnance Survey 'Ten Mile' maps of Great Britain. A similar map was plotted for Northern Ireland. To facilitate plotting, the data were printed out by computer complete with the National Grid References of the stations. Key maps of 'computer areas' were used as a check on the position of each station.

The plotted maps having been drawn up (Figure 1), an estimate was made for each subgrid point in every interpretation-grid square. These estimates were averaged in interpretation-grid square blocks, each such block average being the spatially smoothed rainfall for the square (see Figure 2). This value refers to the 'rainfall day'. As 'civil day' rainfall totals were required, a conversion was necessary, as indicated on page 41. To facilitate this, autographic data were used. Rainfall totals for the 'rainfall day' and 'civil day' were extracted from data of 78 autographic stations in the United Kingdom. The *CD*/*RD* ratio was computed for each station and plotted (Figure 3). The mean value of the *CD*/*RD* ratio was then estimated for each interpretation-grid square. In general, this was multiplied by the spatially smoothed *RD* rainfall for the square (Figure 2) to yield the spatially smoothed *CD* rainfall (Figure 4). A rough guide was provided by an auxiliary map of the *CD* rainfall for the 78 autographic stations. Big discrepancies occasionally occurred, however, for which there were two main causes :

(i) The autographic stations are usually found on relatively low ground, so that the amount of rainfall over a grid square containing mountains is often underestimated by the auxiliary map.

(ii) If there are places where the rainfall on the 'civil day' does not dominate that on the 'rainfall day', e.g. because heavier falls occur between 0000 GMT and 0900 GMT, the product of the averages of *RD* rainfall and *CD*/*RD* ratio can be misleading. The auxiliary map can help, though care is needed in judging the part played by (i). On 8 September 1965 the usual procedure markedly overestimated the *CD* rainfall over the Devon grid square. On this, and on other similar occasions, the grid square was subdivided and each subdivision was

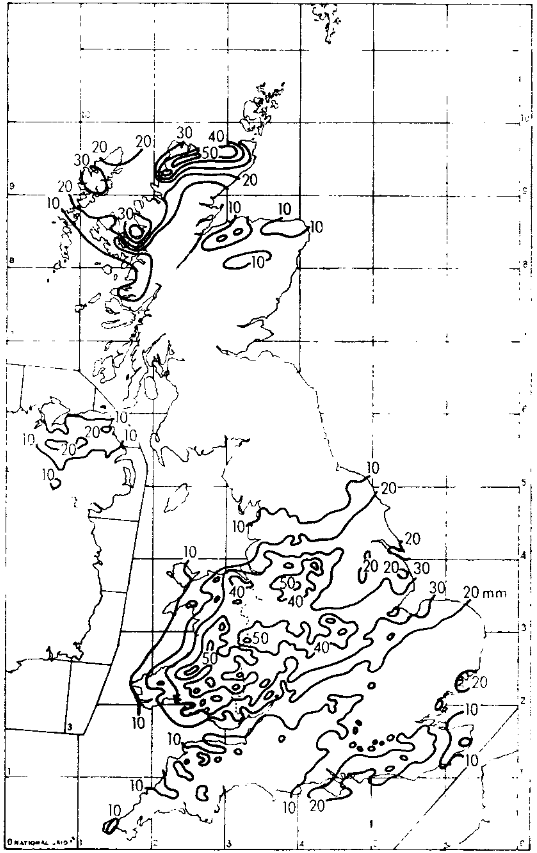

FIGURE 1—ISOHYETS OF THE UNSMOOTHED RAINFALL FOR 24 HOURS FROM 0900 GMT ON 8 SEPTEMBER 1965

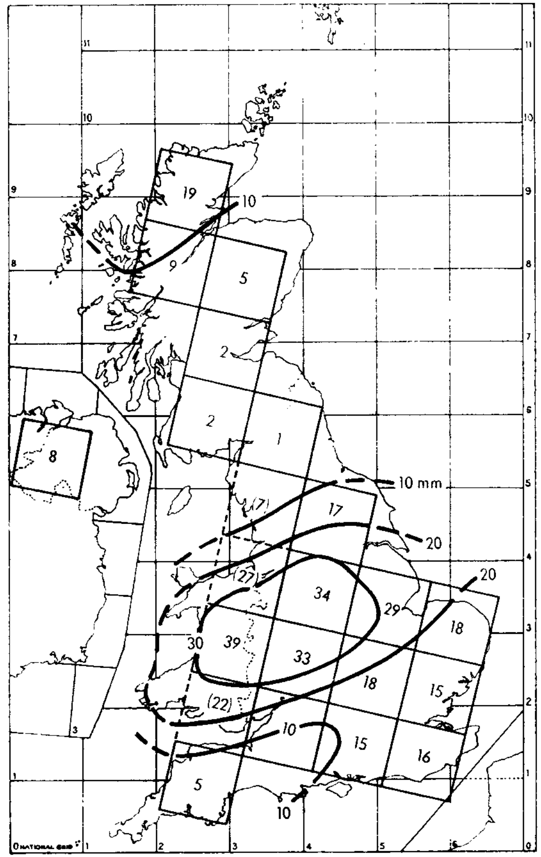

FIGURE 2—RAINFALL FOR 24 HOURS FROM 0900 GMT ('RAINFALL DAY') ON 8 SEPTEMBER 1965 AVERAGED SPATIALLY OVER INTERPRETATION-GRID SQUARES

Isohyets are of spatially smoothed 'rainfall day' rainfall. Values in squares are in millimetres.

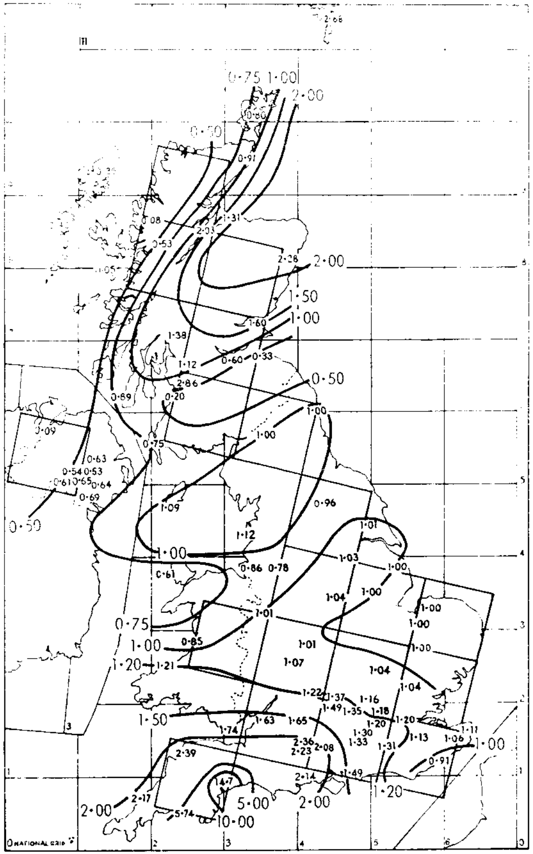

FIGURE 3—RATIO OF 'CIVIL DAY' RAINFALL TO 'RAINFALL DAY' RAINFALL ON 8 SEPTEMBER 1965

'Civil day' rainfall is for 24 hours from 0000 GMT on 8th and 'rainfall day' rainfall is for 24 hours from 0900 on the 8th.

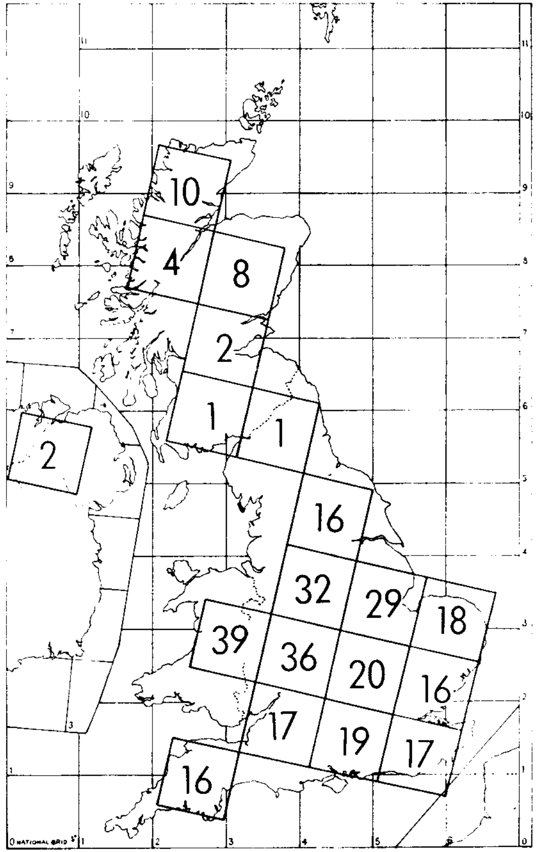

FIGURE 4—APPROXIMATE RAINFALL FOR 24 HOURS FROM 0000 GMT ('CIVIL DAY') ON 8 SEPTEMBER 1965 AVERAGED SPATIALLY OVER INTERPRETATION-GRID SQUARES

Values in squares are in millimetres.

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PLATE I—MAJOR AND MRS K. J. GROVES WITH WINNERS OF THE 1969 L. G. GROVES AWARDS

SAC Rogers and Squadron Leader H. E. B. Mayes are to the left and Dr K. A. Browning and Mr B. R. Kerley are to the right of Major and Mrs Groves (see page 57).

Photograph by R. K. Pilsbury

PLATE II—CIRRUS AND ALTOCUMULUS LENTICULARIS

Eight of these cirrus bands were formed to the north-west of Bracknell, Berks., on 25 April 1969 and they persisted from 1815 to 1900 GMT. Below six of the bands, small pieces of altocumulus lenticularis formed. The northern end of the bands was obscured by cirrocumulus which exhibited a billows structure at right angles to the bands.

Photograph by R. K. Pilsbury

PLATE III—WAVE IN CONDENSATION TRAIL

This trail, taken with the camera facing towards north-west from Bracknell, Berks., at 1800 GMT on 4 April 1967, was moving southwards and long thin streaks of cirrus formed behind it to the north. In this cirrus can be seen an extensive wave structure parallel to the trail.

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Photograph by R. K. Pilsbury

PLATE IV—WAVE CLOUDS

This display, to the west of Bracknell, Berks., was part of a very extensive wave system to the south and west of the area. It began to form around 1100 GMT, 20 August 1968, and persisted for at least an hour. There were fairly rapid changes in cloud shape to the west but to the south several complete waves similar to a sine curve persisted for some time.

assessed separately. If the technique is to be applied on a computer, or otherwise objectively, some method of picking out such areas will be required.

Comment. Not only does this system serve in checking numerical forecasts but it introduces a new form of rain-map interpretation which may be of interest to hydrologists, particularly as interpolation of rainfall to grid points is likely to be used increasingly in computer handling of rainfall data.

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551.588.6

THE EFFECT OF A SMALL UPLAND PLANTATION ON AIR AND SOIL TEMPERATURES

By K. SMITH
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Summary. Some data were obtained to assess the moderating influence of forest cover on local temperatures. By using resistance thermometers continuous measurements of air temperatures at screen level (1·2 m) and of soil temperatures (at depth of 10 cm) were made during 1968 at a plantation site and at a neighbouring open site in County Durham.

Mean air temperatures (averages of the mean daily maximum and minimum) over the year or month showed little difference between the sites. The range of air temperature from mean monthly maximum to mean monthly minimum was less under forest cover than in the open. Soil temperatures at 10 cm at 0900 GMT under forest cover were higher in winter than those at the open site, and lower in summer. The mean diurnal range of soil temperatures was small but was less under forest cover than at the open site.

Introduction. One of the most important changes in rural land use during the present century has been the spread of upland afforestation in Britain, and there is now almost as much land under forest as there is land in the built-up areas.[1] It is frequently admitted that both afforestation and urbanization necessarily modify the local climatic conditions, and Chandler,[2] for example, has summarized the largely inadvertent consequences of the continuing expansion of Greater London. On the other hand, much less is known about the modification of rural topoclimates[3] by the spread of a forest cover. Some attention is now being devoted to the nature of the forest water budget, but the thermal implications of afforestation continue to attract relatively little interest.

Although some of the pioneer work in Europe on the climate of small areas was concerned with the broad temperature influence of forests,[4] this theme was never really taken up in Britain. Recent investigations, such as those of Hurst,[5] have dwelt on the air temperature stratifications developed below screen level in lowland plantations. Somewhat divergent views appear to be held about the overall thermal effect of mid-latitude forests as indicated by standard instrumentation. Thus, whilst it is generally accepted that afforestation reduces the range of air temperatures, some workers[6] claim that the mean monthly and annual values are also depressed relative to comparable sites in the open, and attention has been drawn[7] to conflicting evidence presented by experiments in the U.S.A. and Switzerland on the effect of afforestation on the range of variation of maximum and minimum temperatures.

There are few published studies available for Britain, and the work of Coutts[8] in upland Aberdeenshire, for example, is typically concerned solely with the forest environment rather than with local differences observed in relation to standard sites. In view of these deficiencies, it was decided to make some preliminary observations of air and soil temperatures under a small plantation in the northern Pennines.

Site and records. Continuous measurements of air and soil temperatures were made during 1968 at two adjacent sites located on a south-facing slope at an altitude of some 450 m above MSL in upper Weardale, County Durham. Site A was established near the centre of a small but compact plantation of Scots Pine *(Pinus sylvestris)* which covers an area of 0·03 km². During the period of the measurements the trees were mature, but the canopy had been thinned in places by wind-blow. Site B was set up some 80 m away with a fairly open aspect and 25 m distant from the southern edge of the plantation.

At both sites air temperature was measured in a standard screen 1·2 m above ground, whilst soil temperatures were recorded at a depth of 10 cm. The data were obtained as a chart trace using resistance thermometers and a Cambridge multi-point recorder, which was installed in September 1967. The thermometers were calibrated against a NPL (National Physical Laboratory) certificated thermometer, and the calibration was checked regularly during the period of observation since only small temperature differences were expected between the two sites.

Air temperature. Mean air temperatures (calculated as the averages of the mean daily maximum and minimum temperatures) were identical at 6·6°C for both sites during 1968. This reflects a similar coincidence for the individual monthly means, and it was only during October that the monthly values differed by as much as 0·5 degC. For four months of the year the plantation was colder than site B but, as shown in Table I, there were also equivalent periods of time when it was warmer than or at the same mean temperature as site B, and there was thus no evidence to suggest that forest values are consistently lower than those obtained from standard sites.

TABLE I—MEAN MONTHLY SCREEN TEMPERATURES

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
							degrees Celsius						
Site A													
Maxima	3·8	1·2	5·6	8·9	9·8	15·9	14·6	15·4	13·6	12·1	5·5	2·6	9·1
Minima	−0·4	−2·9	1·2	2·1	3·4	8·2	8·9	9·5	8·7	8·3	2·6	−0·6	4·1
Mean	1·7	−0·8	3·4	5·5	6·6	12·1	11·8	12·4	11·1	10·2	4·0	1·0	6·6
Site B													
Maxima	4·1	2·2	6·3	9·8	10·3	16·5	15·3	16·0	13·9	12·0	5·4	2·5	9·5
Minima	−0·7	−3·1	1·0	1·7	2·8	7·7	8·3	9·1	7·8	7·5	2·1	−1·1	3·6
Mean	1·7	−0·4	3·6	5·7	6·6	12·1	11·8	12·5	10·8	9·7	3·7	0·7	6·6

When mean monthly maxima and minima are considered, however, it is clear that the tree canopy does suppress the temperature range at site A. From Table I it can be seen that minima were higher at the plantation site in all months, and maxima were lower except for the last three months of the year. As might be expected, the largest differences in maxima and minima between the two sites occurred during the summer half-year, but there was no direct relation with the warmest months since these differences took place in April and September. The difference between minimum temperatures at the two sites averaged 0·5 degC through the year, and was slightly more marked and persistent than the discrepancy in maximum values. Nevertheless, this resulted in only minor variations in the incidence of screen frost as indicated in Table II.

TABLE II—NUMBER OF DAYS WITH AIR FROST

	Jan.	Feb.	Mar.	Apr.	May	June–Oct.	Nov.	Dec.	Year
Site A	16	28	11	10	4	0	3	15	87
Site B	16	29	11	10	4	0	5	18	93

Soil temperature. A comparison of soil temperatures at 10 cm depth revealed quite different characteristics since, for much of the year, there was relatively little diurnal variation at either site; the diurnal range was smaller in the plantation. The cumulative influence of altitude, low evaporation and frequent precipitation, which totals some 1650 mm per year, often produced waterlogging in the soil irrespective of vegetative cover. Under these conditions a surface water gley has developed at both sites, and it is likely that the thermal régime of this soil is as conservative as that of upland peat soils.[9] Consequently, it was considered more meaningful to compare 0900 GMT values of soil temperature rather than daily maxima and minima.

As with air temperatures, the annual averages were identical, but a clear seasonal difference emerged when mean monthly data were compared as in Table III. This shows that the plantation was warmer than the standard

TABLE III—MEAN MONTHLY SOIL TEMPERATURES

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
							degrees Celsius						
Site A	2·6	1·7	2·9	4·4	5·8	10·1	10·8	11·8	10·5	9·6	5·2	3·0	6·5
Site B	2·6	1·4	3·2	5·4	6·9	11·5	11·2	11·9	9·8	8·3	3·8	1·5	6·5

site in winter and cooler in summer, with the largest differences occurring in December (1·5 degC) and June and November (1·4 degC). This seasonal variation resulted in a distinction in the phasing of the growing season at the two sites, with an earlier start at site B which was compensated by the prolongation of growing temperatures into November in the plantation as shown in Table IV.

TABLE IV—NUMBER OF DAYS WITH MEAN SOIL TEMPERATURES GREATER THAN 6°C

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Site A	0	0	0	11	10	30	31	31	30	31	4	0	178
Site B	0	0	1	14	19	30	31	31	30	26	0	0	182

In periods of settled weather the discrepancy between mean soil temperatures at the two sites commonly reached between 3 degC and 4 degC on individual days, and it was during dry spells in summer that the largest diurnal fluctuations also took place. This can be illustrated by the mean hourly values of soil temperature for the anticyclonic week from 13 to 19 June, which have been plotted in Figure 1 together with the corresponding air temperatures at site B. Apart from the greater diurnal range of the air temperature and the overall relative warmth of the soil at site B, where afternoon temperatures were almost 6 degC higher than in the plantation, the most striking feature of Figure 1 is the difference in amplitude between the soil temperature curves. Thus, the mean diurnal range of soil temperature at site A was less than half the 4·6 degC recorded at the standard site, whilst, somewhat surprisingly, the daily temperature cycle at site A appears to be phased about one hour earlier than at site B.

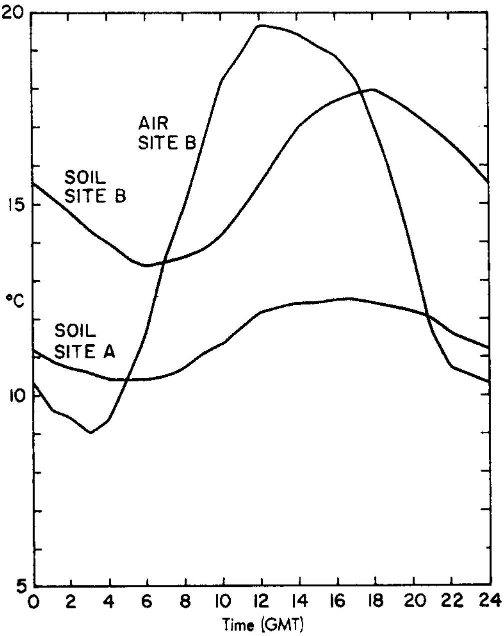

FIGURE 1—MEAN HOURLY SOIL TEMPERATURES AT SITES A AND B AND AIR TEMPERATURE AT SITE B FOR 13–19 JUNE 1968

Discussion. The evidence from this limited investigation suggests that despite the undoubted influence of a woodland cover in reducing the diurnal range of air temperature the suppression of soil temperature fluctuation is much more important and operates on a seasonal as well as a daily scale. This assumption was confirmed by employing the Kolmogorov-Smirnov test on the 366 daily values. It was found that, whilst no statistical significance could be attached to the differences in either maximum or minimum air temperatures between the two sites, the difference in mean daily soil temperatures reached the 0·99 level of significance.

In view of the growing interest in the land-use potential of the British uplands, it is becoming more and more necessary to have quantitative climatic data on which future policies may be based. This is especially so in the case of afforestation where more investigations are required, not only to determine the environmental limits for successful planting but also to assess the moderating influence which the forest cover exerts on the local climate.

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OCTOBER DAILY PRESSURES AND PRESSURE PATTERNS NEAR ICELAND RELATED TO TEMPERATURE QUINTILES OF THE FOLLOWING WINTER IN CENTRAL ENGLAND

By R. F. M. HAY

Summary. Daily data for October (1873–1962) suggest that mean pressures near Iceland over the period 11 to 15 October are significantly higher in that locality before extremely cold winters in central England than they are before extremely mild winters. Through the whole period for which daily records are available (going back to 1779, though with some gaps in the record), cold winters in central England have tended to be preceded by high pressure in Iceland during 11 to 15 October.

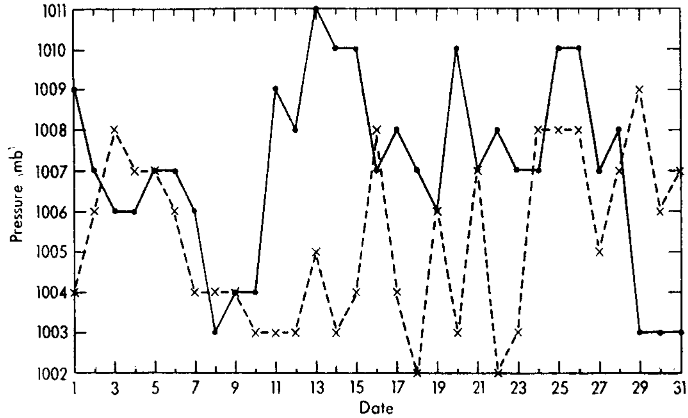
Cold winters in central England are also significantly associated with those preceding Octobers (1873–1962) in which anticyclone centres were formed on at least three days in a defined area near Iceland. A study of the day-to-day movements of anticyclonic patterns in October indicates an association between westward-moving patterns and very cold winters.

Introduction. In a previous paper[1] a relation between the occurrence of high monthly mean pressure near Iceland in October and very cold (T_1*) winters following in central England, was found for the period of blocked circulation which prevailed during 1873–95 and 1941–63. This note describes some results obtained by using daily sequences of pressure (instead of monthly mean pressures) near Iceland mainly for the Octobers between 1873 and 1962. The intention was to find whether the differences already found between mean October pressures before cold and mild winters in central England could be reasonably attributed to the incidence of one or more 'singularities' of the type described by Brooks[2] and others. It was considered possible that such a singularity might be disclosed by a tendency for it to recur at about the same period in October in a majority of the autumns preceding cold winters; whereas its absence or reversal at such time might be an indicator of a mild winter to follow.

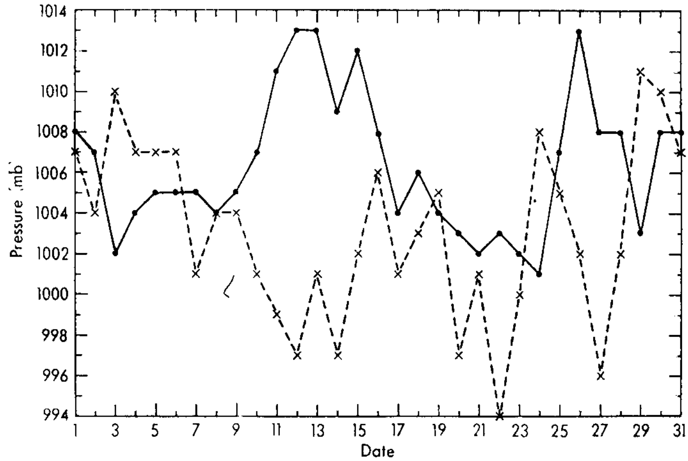
Daily mean pressures in October near Iceland. Daily pressures for the position 65°N 20°W were extracted from *Daily Weather Reports* for each day of October in the years 1873 to 1962 inclusive. From these data, mean values of pressure for each day of October were obtained separately for the groups of years associated with each quintile of winter temperature in central England. The same procedure was applied to the very coldest and very mildest winters, defined here as winters in the lowest (D_1) and highest (D_{10}) temperature decile, respectively.

Figures 1*(a)* and 1*(b)* show the variation of mean daily pressures in Octobers preceding T_1 and T_5, and D_1 and D_{10} winters respectively. The difference between the mean pressures for 11 to 15 October in the two groups of years

* The symbols T_1, T_2, etc., refer to quintiles 1, 2, etc., of winter temperature ranging from T_1 (very cold) to T_5 (very mild). Similarly D_1 and D_{10} refer to deciles of winter temperatures where D_1 is the low temperature decile and D_{10} is the high temperature decile.



(a) In Octobers preceding winters with temperatures in quintiles 1 and 5.
•——• Q_1 (17 years) x - - x Q_5 (19 years)



(b) In Octobers preceding winters with temperatures in deciles 1 and 10.
•——• D_1 (9 years) x - - x D_{10} (9 years)

FIGURE 1—MEAN DAILY PRESSURE AT 65°N 20°W IN OCTOBERS PRECEDING SPECIFIED WINTERS IN CENTRAL ENGLAND

associated with T_1 and T_5 winters in central England is not significant at the 5 per cent level using Student's *t*-test. However, a similar test using the two (smaller) groups of years associated with the extreme winters (D_1 and D_{10}) of the period just reaches significance at the 5 per cent level.*

The daily standard deviations (σ) were determined for 1, 16, and 31 October. The standard deviation of the difference of two means each formed from N independent values is $\sigma\sqrt{(2/N)}$. The standard deviations of differences of these means for the case where $N = 18$ (corresponding to 18 years in a quintile) were found for the same dates in October; the procedure was repeated making $N = 9$ (corresponding to 9 years in a decile).

* For 5 per cent level with 16 degrees of freedom, t should equal or exceed a value of 2·05.

Figure 2 shows the daily values of the differences between the means of daily mean pressure for years in D_1 and D_{10} (refer to Figure 1*(b)*). Dotted lines show the limits for values exceeding twice the standard deviation of differences of means, which by definition might be expected to occur by chance on 5 per cent of occasions, that is on about 1½ occasions in a month. It was found that daily values of differences between T_1 and T_5 winters did not reach the relevant limits; Figure 2, however, shows that for a difference between D_1 and D_{10} winters the limit is closely approached on at least four consecutive days, and exceeded on one of the days in this series.

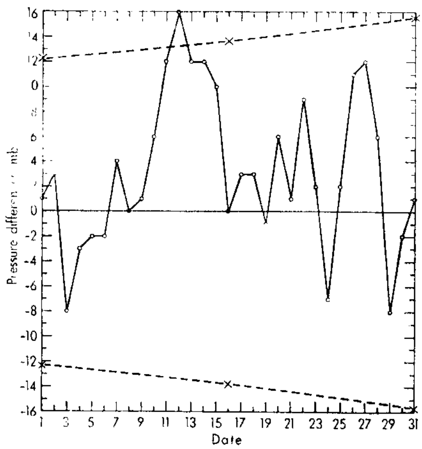


FIGURE 2—DIFFERENCES BETWEEN OCTOBER DAILY PRESSURES AT 65°N 20°W MEANED FOR OCTOBERS PRECEDING UNUSUALLY COLD WINTERS (D_1) IN CENTRAL ENGLAND AND THOSE MEANED FOR OCTOBERS PRECEDING UNUSUALLY MILD WINTERS (D_{10})

X Value of twice the standard deviation of differences of pressure means on 1 October (12·32 mb), 16th (13·73 mb) and 31st (15·69 mb).

Test on independent data. The results just described, supported by a further scrutiny of the data for the Octobers from 1873 to 1962, suggest the existence of a simple relation such that when mean pressure for 11 to 15 October is in the quintile P_5 of high pressure relative to the whole series† of these means for 1873–1962, then a very cold winter (T_1) is likely to follow in central England. Since independent data in the form of daily pressures for Iceland[4] are available for the periods 1779–84 and 1823–36, it was possible to compare these with temperatures for central England in the winters following, and so to test the validity of the relation described above. Freeman's method,[3] currently used in long-range forecasting at the Meteorological Office, Bracknell, was used for this purpose. For the long period 1873–1962 his methods yielded a score of +0·5, while for the two earlier short periods combined a

† The relevant quintile boundaries for this series are : P_5 ≥1015 mb, P_4 1006–1014 mb, P_3 1000–1005 mb, P_2 995–999 mb, and P_1 ≤994 mb.

score of +0·8 was obtained.* Both these scores rate as 'moderate agreement' between forecast and actual winter temperatures. Moderate agreement covers a range of scores from +1·4 to 0·0.

Although these results inevitably depend upon rather small samples (nine cases in the long period and five in the combined early short periods) they deserve to go on record because they imply that the relation just described, i.e. P_5 in Iceland for 11 to 15 October is likely to be followed by T_1 winter in central England, may well have been a stable one for at least the past 180 years.

The remaining period of independent data from 1963 to 1967 included no occasion when mean pressure at 65°N 20°W for 11 to 15 October was P_5. Hence it was not possible to test the validity of the relation during this short period.

Movements of centres of anticyclones near Iceland. The incidence and daily movement of anticyclones near Iceland during October were investigated in relation to the winters following in central England for the period 1874 to 1963. The procedure adopted was to note the daily positions and intensities of all anticyclone centres and ridges with pressure 1016 mb or more which lay within an area (Figure 3) defined by latitudes 60° and 70°N and longitudes 5° and 35°W. This information was then used to determine the day-to-day directions of movement of anticyclone centres and of ridges for all these cases. The incidence of directions of movement, related to winter temperatures following in central England, is shown in Figure 4*(a)* and *(b)*.

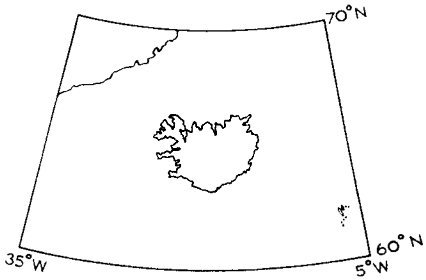


FIGURE 3—AREA NEAR ICELAND USED FOR MOVEMENTS OF ANTICYCLONES AND RIDGES

The bold numbers in Figure 4*(b)* indicate that the occurrence of anticyclone centres in the vicinity of Iceland in October is much more frequent

* In these early periods the number of forecasts of T_1 winters in the various categories of success was :

Category	Forecasts of T_1
A (no serious discrepancy)	2
B (good agreement)	1
C (moderate agreement)	0
D (little agreement)	2
E (no real resemblance)	0

The two winters with forecasts T_1 in category *A* were both extremely cold (D_1), one being the only T_1 winter (also D_1) during the period 1823–36.

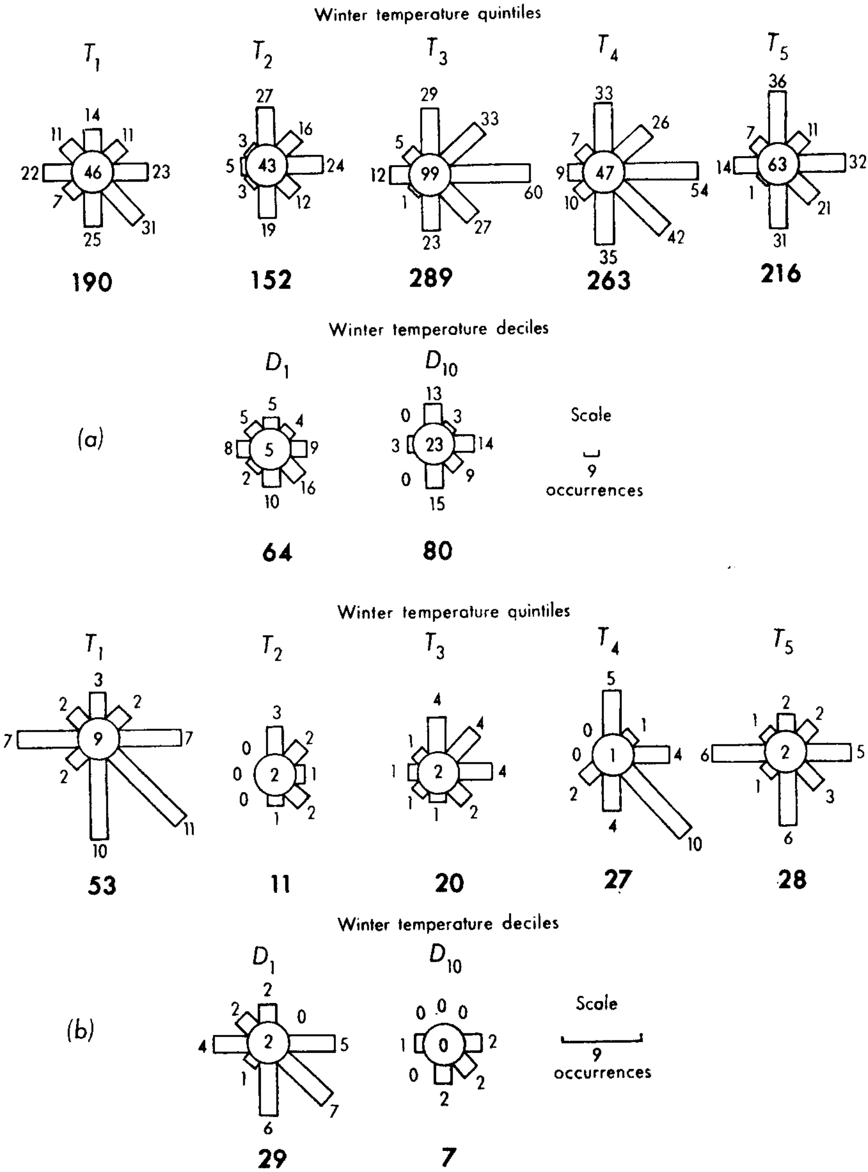


FIGURE 4—THE NUMBER OF DAYS OF OCCURRENCE OF MOVEMENTS OF ANTI-CYCLONIC PATTERNS NEAR ICELAND IN OCTOBER CLASSIFIED ACCORDING TO TEMPERATURE QUINTILES AND DECILES IN THE WINTER FOLLOWING IN CENTRAL ENGLAND

(a) Centres and ridges (top 2 rows) *(b)* Centres (bottom 2 rows)

The roses show the number of day-to-day movements in October of the anticyclonic patterns towards each direction. The central figures show the number of days when the patterns were stationary and the bold figures refer to the total number in each category.

before T_1 winters than before T_2, T_3, T_4 and T_5 winters. The contrast between D_1 and D_{10} winters is still greater in this respect.

The directions of movement of anticyclone centres and ridges can next be considered by extracting actual frequencies of day-to-day westward movements (i.e. towards south-west, west and north-west) and of day-to-day movements of all anticylonic patterns in all other directions, and relating them to the five temperature quintiles of the following winters as shown in Table I. A chi-square test applied to this 5×2 contingency table shows significance at the 0·1 per cent level, although this level is probably fictitiously high because of correlation between successive days of anticyclonic patterns in the Iceland area. Nevertheless this relation, implying a strong bias towards westward-moving anticyclonic patterns before T_1 winters, has a definite predictive value; it is not, however, easy to apply in practice because of the variation in the actual number of days of westward-moving anticyclonic patterns in October. The number can vary between 0 and 9 in Octobers before T_1 winters for example, with an average number of days of only 2·5. Other quintiles of winter temperature have even lower mean numbers of days with westward-moving anticyclonic patterns (2·5, 0·6, 0·9, 1·4 and 1·2 days in T_1, T_2, T_3, T_4 and T_5 winters respectively).

TABLE I—NUMBER OF DAYS IN OCTOBER WHEN ANTICYCLONIC PATTERNS MOVE TOWARDS SPECIFIED DIRECTIONS AND ARE FOLLOWED BY WINTER TEMPERATURES IN A GIVEN QUINTILE, 1873–1962

Direction of day-to-day movement of anticyclonic patterns*	Winter temperature (quintiles) 1	2	3	4	5	Totals
Towards SW, W and NW	40	11	18	26	22	117
All other directions	150	141	271	237	194	993
Total	190	152	289	263	216	1110

* Anticyclonic patterns include anticyclone centres together with ridges.
$\chi^2 = 29{\cdot}95$, which is significant at better than the 0·1 per cent level.

Also, from Figure 4*(a)* it can be seen that the main contrast between frequencies of day-to-day westward movements (i.e. towards south-west, west and north-west) of anticyclones and ridges near Iceland in October lies between Octobers preceding T_1 and T_2 winters in central England. Since contrasts between similar frequencies before T_1 and T_5 winters, and before T_1 and T_4 are less than the contrast between T_1 and T_2 winters, the T_1–T_2 contrast is of limited value as a forecasting tool. For frequencies of anticyclone centres only, Figure 4*(b)* shows broadly similar results.

There is some value in grouping stationary anticyclones along with those which showed day-to-day movements towards south-west, west, north-west, north and south, because such anticyclones are broadly associated with the incidence of the majority of large-scale blocking patterns in the northern Atlantic. Figure 4*(b)* readily shows that anticyclonic movements of this type occurred on 33, 6, 10, 12 and 18 days respectively before T_1, T_2, T_3, T_4 and T_5 winters, and on 17 and 3 days respectively before D_1 and D_{10} winters.

Table II shows the number of winters (central England) in each temperature quintile when anticyclone centres were found near Iceland during the previous October on at least 3 days, on 2, on 1 and on 0 days in the previous October.

TABLE II—NUMBER OF WINTERS IN EACH TEMPERATURE QUINTILE RELATED TO SPECIFIED NUMBERS OF DAYS OF OCCURRENCE OF ANTICYCLONE CENTRES NEAR ICELAND IN THE PRECEDING OCTOBER, 1873–1962

Winter temperature quintile	Number of days with anticyclone centres in October ≥3	≤2	2	1	0	Totals
5	4	15	1	9	5	19
4	5	13	1	1	11	18
3	2	17	2	6	9	19
2	2	15	1	3	11	17
1	11	5	1	1	3	16
Totals	24	65	6	20	39	89

A chi-square test shows that when Octobers having at least 3 days with anticyclone centres near Iceland (4, 5, 2, 2 and 11 cases in T_5, T_4, T_3, T_2 and T_1 respectively) are compared with Octobers having 2 or fewer days (15, 13, 17, 15 and 5 cases in T_5, T_4, T_3, T_2 and T_1 respectively), that is in the form of a 5×2 contingency table, the differences in the frequencies are significant at the better than 0·5 per cent level. Thus, Octobers with 3 days or more with anticyclone centres are strongly associated with T_1 winters to follow in central England.

Conclusions.

(i) Statistical tests made upon daily mean pressure values near Iceland for Octobers preceding anomalous winters during the period 1873–1962 (i.e. those having temperatures in the highest and lowest quintiles and deciles) show that daily pressure values in the period 11 to 15 October before extremely cold (D_1) winters in central England are significantly higher than those daily values found for the same period before extremely mild (D_{10}) winters. This result is also probably true for daily pressure values found for 11 to 15 October before T_1 and T_5 winters, but the available evidence is less conclusive.

(ii) Examination of daily data for Iceland from early years (1779–85 and 1823–36) suggests that high pressure (P_5) over Iceland during 11 to 15 October can be expected to be followed by a T_1 winter and that this relationship may have been stable during at least the past 180 years.

(iii) Anticyclone centres occur in the vicinity of Iceland on individual days in October much more frequently before T_1 winters than before T_2, T_3, T_4 and T_5 winters. The contrast between D_1 and D_{10} winters is still greater in this respect.

(iv) While day-to-day movements of anticyclonic patterns occurred towards all directions in October, westward movements were frequently followed by T_1 winters.

(v) Octobers having at least three days with anticyclone centres near Iceland are significantly associated with T_1 winters.

Acknowledgement. The writer wishes to thank Mr R. Blair for his assistance with processing the data.

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COLLOQUIUM ON THE SPECTRA OF METEOROLOGICAL VARIABLES

By C. J. READINGS

About 50 scientists from various disciplines attended a colloquium arranged by the Inter-Union Commission on Radio Meteorology and dealing with the spectra of meteorological variables. It was held in June 1969 just on the outskirts of Stockholm in a residential castle called Hässelby Slott. All the local arrangements were supervised by the Swedish National Committee of the International Union of Radio Science and the Committee must be complimented on the efficient manner in which both the conference and the social functions were organized. The latter included a boat trip round the Archipelago of Stockholm and an evening at the Drottningholm Court Theatre — quite apart from a cocktail party and a banquet.

As the participants were drawn from several disciplines (principally fluid dynamics, meteorology and wave-propagation) the first part of the conference was devoted to a series of reviews given by leading authorities in their fields and scientific sessions in which current work was described. During this part of the conference about 50 papers were presented. The topics considered were as follows :

(i) Experimental studies of atmospheric structure and spectra (both near the ground and higher up in the atmosphere).
(ii) Fine-scale structure deduced from wave-propagation experiments using radio, lidar, radar as well as acoustic and optical techniques.
(iii) Experimental and theoretical fluid dynamical aspects of turbulence and waves.

Most of the papers (and the reports of the working parties referred to later) will appear in the December 1969 issue of *Radio Science* (published in Washington D.C.).

A scientific visit to 'Kvarnberget' (a field station run by the Swedish National Research Institute to investigate radio propagation by tropospheric scatter) took place towards the end of this part of the conference. Amongst several interesting exhibits were some laser equipment for accurate survey work and an acoustic anemometer.

As the result of the discussions that took place between the delegates the following list of 'topics of interest' was drawn up :

(i) Intermittency of small-scale structure.
(ii) The spectral gap.
(iii) Fossilized turbulence.
(iv) The anisotropy of the fine structure.
(v) The boundary between laminar and turbulent flow.
(vi) Waves versus turbulence.
(vii) Heat, moisture and momentum fluxes in the boundary layer.
(viii) The budgets of kinetic energy and mean-square temperature fluctuations.

Each of these was allocated to a working group which continued the discussion during the next few days, and finally drafted a report summarizing findings and possible avenues of research. The final part of the conference was devoted to a detailed consideration of these reports by the whole assembly.

Attendance at this conference was a most rewarding experience for all the participants, as not only was a great deal of very interesting material presented but there was much invaluable discussion between scientists of different disciplines. However, it would perhaps have helped if the review sessions had been a little more introductory in nature.

AWARDS

L. G. Groves Memorial Prizes and Awards

The L. G. Groves Memorial Prizes and Awards for 1969 were presented at the Ministry of Defence, Whitehall, on 21 November 1969. Air Marshall Sir Peter Fletcher presided and the presentations were made by Major K. J. Groves, who was accompanied by Mrs Groves. (See Plate I.)

The Aircraft Safety Prize was won by Senior Aircraftman B. Rogers of Royal Air Force, Wildenrath. The citation reads :

> 'SAC Rogers has designed a standard personal survival pack which could replace the greater proportion of the twenty-odd different types of survival pack in current use. In addition, it would eliminate many of the unsatisfactory features which are present in existing equipment.
>
> SAC Rogers' design, the result of three years of research, will need careful evaluation under realistic service conditions and further development may be required. Nevertheless, the principle has been accepted and could well lead to much-needed standardization and greater simplicity in the servicing and training uses of future survival equipment for aircrew.'

The Meteorology Prize was awarded to Dr K. A. Browning, Principal Scientific Officer, Meteorological Office, with the following citation :

> 'In recognition of his work in determining the structure of the cloud and wind systems accompanying meteorological fronts and other rain and thunderstorms. By his effective use of a wide range of radar techniques and other systems for sounding the atmosphere, Dr Browning has been able to establish, for the first time, a comprehensive self-consistent description of the air motion in rain-producing clouds, and to relate this to the observed distribution of rain and hail. From the insight so obtained he has derived models of meteorological systems which will form the starting point for a comprehensive understanding of atmosphere disturbances with dimensions 10 to 100 km and thus form important benefits to aviation meteorology and forecasting.'

The Meteorological Observers' Award was given to Mr B. R. Kerley, Scientific Assistant, Meteorological Office, with the following citation :

> 'In recognition of the very high standard of observing which he has maintained during the flights by the Meteorological Research Flight which have often been arduous. Mr Kerley has been an observer with the Meteorological Research Flight for over four years and has flown over 350 hours on meteorological observer duties. In particular, Mr Kerley was observer on two flights conducted during project Scillonia in March 1968 and January 1969 when flying conditions were extremely bad, but

despite the physical difficulties Mr Kerley completed a set of observations which were required for the success of this unique project for the study of cloud systems.'

The Second Memorial Award went to Squadron Leader H. E. B. Mayes of Royal Air Force, Luqa, the citation reading :

'Since its introduction into service in 1960, the Canberra PR9 has been subject to frequent fuel pump failures which could lead to hazardous situations on long flights. Squadron Leader Mayes has applied himself with great diligence and perseverance to the problem. As a result of his investigations he recommended three modifications to improve the reliability of the fuel system and to remove the hazardous aspects. In directing his energies towards solving the problem, and by providing evidence in support of his proposals sufficient to prove their validity, Squadron Leader Mayes has made a direct and valuable contribution to flight safety.'

REVIEW

Aerology of the polar regions by S. S. Gaigerov. 247 mm × 177 mm, pp. viii + 280, *illus.* (translated from the Russian by the Israel Program for Scientific Translations, Jerusalem), Oldbourne Press, 1–5 Portpool Lane, London EC1, 1967. Price: 92*s*. 6*d*.

This important addition to the meteorological literature of the polar regions is one of the early fruits of the International Geophysical Year (IGY). The book is large in scope and deals in detail with most aspects of the polar circulations. Each chapter has separate sections dealing with the Arctic, then the Antarctic, followed by a brief comparison and summary.

Starting with a chapter on the development of aerological research in the polar regions there is a slight but natural bias towards Russian developments which shows an early and continuously active record in the Arctic during the 1930s when North American commitment was very limited. A balanced account of international development in the Antarctic concludes this section. The next section on the special features of investigation of the free atmosphere is a very interesting account of radiosondes, rockets and techniques used by the Soviet Union, which should be read by anyone involved in polar operations. The launching tower developed at Mirnyi is well worth investigation if, as is claimed, successful launches have been made on occasions when surface wind speeds were in excess of 35 m/s. Problems of hydrogen generation and balloon performance are also sensibly discussed.

From this point on, discussion of the polar circulation is developed. First comes a chapter on synoptic processes in the troposphere which begins with an account of investigations to 1962 and then goes on to discuss general physical, climatic and orographic influences and ends with a summary of seasonal processes. A full chapter is devoted to the vertical structure of depressions, anticyclones and fronts and it is interesting to note that the Fifth Soviet Antarctic Expedition (1960) deliberately organized chains of temporary stations to examine certain frontal features. A useful discussion on the contrasting thermal and wind regions of the Arctic and Antarctic follows.

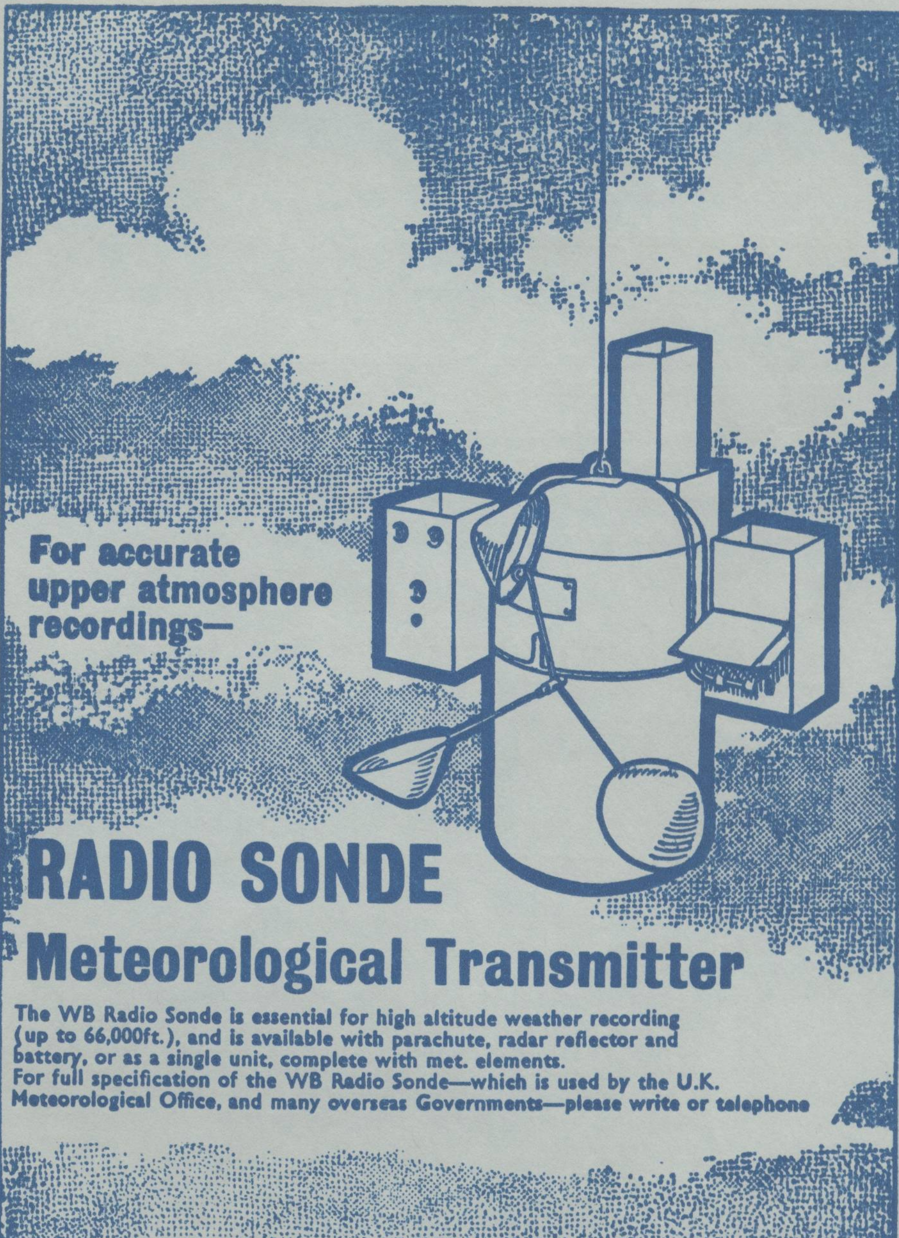
The final extensive chapter deals with the stratosphere and includes a summary of the possible causes of the ozone distribution in polar regions and of the theories of radiational balance of the stratosphere and mesosphere. The inclusion of a limited amount of rocket data to 48 km for Kheysa (Hayes) Island in Franz Josef Land is most welcome. Analysis of IGY and post-IGY data leads to the conclusion that the lower Arctic stratosphere is strongly influenced by the troposphere with radiation control being restricted to the stratosphere above 30 km. Consequently the asymmetry of the Arctic troposphere extends well into the stratosphere in comparison with the Antarctic where radiation control is dominant and leads to a more symmetrical stratospheric circulation.

There is an extensive and wide-ranging bibliography of 418 references, the first 248 of which are to Russian publications. Four appendices of Russian Antarctic upper air statistics complete the volume. The translation is fairly good with a few lapses into quaintness which lead to obscurity of meaning, e.g. 'from up downward' (from above downward), 'from down upward' (from below upward), 'temperature course' (the variation of temperature), 'lowland snowstorms' (drifting snow*). The print is clear but the illustrations leave much to be desired, especially the photographs which are very poor. Frequently longitude and latitude markings are omitted from diagrams and the vertical cross-sections tend to be confusing.

The fairly comprehensive contents list heading the book is useful but it is a pity that there is no alphabetical index. This and the other shortcomings are minor blemishes in such a useful and comprehensive survey which should prove to be a standard reference for several years to come.

D. W. S. LIMBERT

* See : World Meteorological Organization, International meteorological vocabulary, WMO No. 182, TP 91, Geneva, 1966.



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