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The use of anomaly maps in local forecasting

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Summary

Climatology provides an important input to local forecasting. This article describes the variation of mean daily values of meteorological parameters with 900 m wind direction. The spatial patterns of 'anomalies' reveal the airmass effects that usually accompany the directional changes and the local forcing by topographical and coastal effects that can occur.

1. Introduction

The greater availability of weather radar data has led to a wider appreciation of the local variability in, for example, shower activity and frontal sub-structure on the mesoscale. Some of these variations (such as orographic rainfall) may well be locally induced and detailed study of particular events can yield valuable information on the interaction of weather systems with hilly regions and coastal zones (Caughey and Partington 1983).

Other improvements in local forecasting skill, such as the prediction of fog and frost, depend on a detailed knowledge of local effects, many of which are related to topographical influences. It is in this area especially that climatological data can be used to reveal small-scale variations. Although observations from the climatological network are not available in 'real' time they contain much more detailed information than is routinely available to the forecaster.

When considered as a function of the 900 m wind direction climatological data can reveal the likely small-scale spatial variations in meteorological parameters within a region. These are due to the correlation between airmass type and wind direction, and influences from the underlying terrain. This paper describes the results of an investigation into climatic variability in Northern Ireland as a function of wind direction. The 'anomaly' maps produced enable forecasters to assess the likely ranges in meteorological variables across the Province, once the synoptic framework has been decided.

2. Available data

The distributions to be discussed were derived from data drawn from 37 climatological stations in Northern Ireland (see Fig. 1(a) and Table I). Mean daily values of the parameters considered are listed, as are the record lengths for each station. Departures (or anomalies) from the mean daily values (over the whole period of the records) were then derived as functions of the 900 m wind direction (in 30° sectors — a value of 060°, for example, includes wind directions from 045° to 075°). Maximum and minimum temperature anomalies were calculated on a seasonal basis, sunshine for the winter and summer 'half' years and rainfall for the whole year. Since topography has a major influence on anomalies the distribution of land above 1000 ft in Northern Ireland is given in Fig. 1(b).

A vector mean wind speed was derived for each day from the 00, 06, 12 and 18 GMT Long Kesh ascents. If the vector mean speed was less than 5 m s^{-1} the day was assigned to the light and variable category and is not considered further here (this resulted in rejection of from 10% to 28% of the available data, depending on the wind direction category). Otherwise the data were assigned to one of the 30° sectors. Ignoring the year-to-year variations in the quantities and the fact that different years and varying periods of records have been used for the various stations, the anomalies can be considered to reveal effects from airmass and local influences. To illustrate these the station anomalies have been drawn up in contour map form.

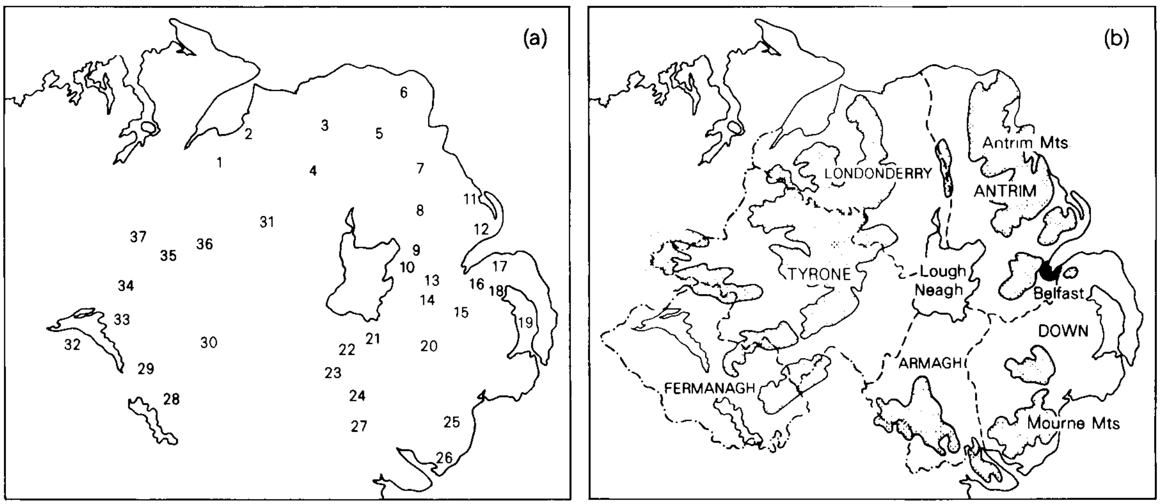

Figure 1. (a) locations of stations listed (and numbered) in Table I and (b) land above 1000 ft (shaded areas).

3. Rainfall

Rainfall distributions are strongly influenced by topography, hence only the behaviour of the annual daily averages is considered. A predominant process, which probably accounts for most of the increase of rainfall with height, is orographic enhancement. In this case hills force moist low-level air to rise forming 'cap' clouds which amplify pre-existing rain falling from higher-level frontal clouds. An important factor is the replenishment of liquid water in the cap clouds, so strong winds (>15 m s^{-1}) are required.

Table I. *Mean daily values of meteorological parameters (computed over the whole record length) for each station used in the analysis.*

Station Name	No.	Length of record (years)	Rainfall Mean daily amount Whole year averages (mm)	Minimum temperature Autumn (°C)	Winter (°C)	Maximum temperature Summer (°C)	Winter (°C)	Sunshine Daily averages Winter (hours)	Summer (hours)	Mean wind at 10 m as % of 900 m wind speed
Loughermore	1	9	3.1	5.4	0.2	16.7	5.8	-		-
Ballykelly	2	13	2.2	7.0	1.6	17.7	7.4	1.9	5.0	40
Ballymoney	3	6	2.6	6.3	1.3	17.7	6.9			
Garvagh	4	9	3.2	5.8	0.8	17.3	6.3			
Altnahinch	5	6	4.2	5.7	0.9	16.0	5.3	1.2	4.9	44
Ballypatrick	6	9	3.4	6.2	1.2	15.8	6.0			43
Parkmore Forest	7	11	4.4	5.5	0.3	16.4	5.3			
Lowtown	8	5	3.8	5.3	0.4	15.9	4.9	1.4	4.9	37
Greenmount	9	7	2.3	6.4	1.1	18.1	6.8		-	
Aldergrove	10	40	2.3	6.4	0.9	17.8	6.7	1.6	4.9	46
Larne	11	9	3.0	6.7	1.8	18.0	7.1		-	
Kilroot	12	7	2.4	6.8	1.4	17.4	7.3		-	
Divis	13	8	3.2	4.9	-0.2	15.4	4.5	-	-	
Black Mountain	14	7	3.0	5.3	0.3	15.8	4.9	-	-	-
Belfast (Malone)	15	5	2.5	6.7	1.4	18.4	7.1	-	-	-
Belfast (Stormont)	16	11	2.5	6.8	1.7	17.9	6.9	1.7	5.1	35
Helen's Bay	17	10	2.4	7.4	2.3	17.7	6.7	1.9	6.4	-
Creighton's Green	18	12	2.7	6.9	1.7	16.8	6.2	-		-
Reagh Island	19	10	2.0	7.4	2.0	17.9	7.0	1.9	5.1	-
Hillsborough	20	11	2.4	6.5	1.3	17.3	6.3	1.7	5.0	25
Lurgan	21	10	2.2	6.4	1.2	18.6	7.0			-
Portadown	22	16	2.2	6.2	1.2	18.7	7.2			-
Loughgall	23	11	2.2	5.9	0.6	18.1	7.0	1.8	4.9	16
Armagh	24	22	2.2	6.5	1.4	18.7	7.2	1.8	4.8	
Tollymore	25	10	3.3	7.1	1.8	17.8	7.1			
Kilkeel	26	14	2.7	7.9	2.5	17.6	7.7	2.1	6.4	53
Bessbrook	27	10	2.8			-		1.8	5.0	
Lisnaskea	28	6	3.2	6.0	1.1	18.4	7.1	1.6	4.5	
Pubble Forest	29	9	3.1	5.6	0.1	17.5	6.5		-	
Knockmany	30	9	2.9	5.1	-0.1	17.5	6.5		-	
Derrynoyd	31	9	3.4	5.8	0.8	17.8	6.4		-	
Lough Navar	32	9	3.9	5.8	0.3	17.2	6.2	-	-	
Castle Archdale	33	8	3.1	6.0	0.8	17.5	6.5	1.6	4.6	26
Lough Bradan	34	10	3.2	5.5	0.2	16.6	5.6	1.5	4.5	39
Carrigans	35	8	3.3	5.9	1.0	17.7	6.6	-		38
Lislap	36	11	3.5	5.0	0.0	16.9	5.9	-		-
Baronscourt	37	9	3.1	5.9	0.5	17.7	6.5	-		-

Fig. 2 shows the variation of the percentage of total rainfall (in the complete period of the records) as a function of wind direction for selected stations. This illustrates the influence that wind direction exerts on rainfall amounts and the difference between areas in the south-east compared to the north-west of the Province. Thus in the south-east of Co. Down 30% of the total rainfall occurs in the quadrant 090°–180° (075°–195°), whereas in the north-west (at Ballykelly) the corresponding figure is only 16%. On the other hand, from 230°–030° the average percentage at Ballykelly is much higher than in the south-east.

The anomaly maps (Fig. 3) show the percentage of the mean daily rainfall which falls when the wind direction is 060°, 150°, 210° and 300° respectively. For 060° the rainfall is everywhere well below average, a factor well known to local forecasters as screening from the upland areas of Scotland and northern England. As expected, the anomalies are most prominent in the west where less than half the mean daily amount can be expected. At 150° the pattern has altered markedly with a prominent area in the vicinity of the Mourne Mountains in the extreme south-east; here more than twice the mean daily amount is likely. Most of the Province has above average, except for the extreme north-west. The maximum in south-east Down is doubtless due to local orographic enhancement due to forced ascent of moist onshore winds.

At 210° the maximum in the south-east is still significant and now the values are above average everywhere. A large area (140%) to the west of Lough Neagh may be related to orographic effects in the hills of Co. Tyrone and Co. Fermanagh. Finally, for 300° conditions are wetter than average in the north (up to 120%) — probably owing to onshore shower activity — but the south-east is much drier. Although these anomaly maps represent averages over all synoptic types they nevertheless provide the forecaster with useful guidance in assessing the likely variations when the synoptic framework (and hence wind direction) has been established.

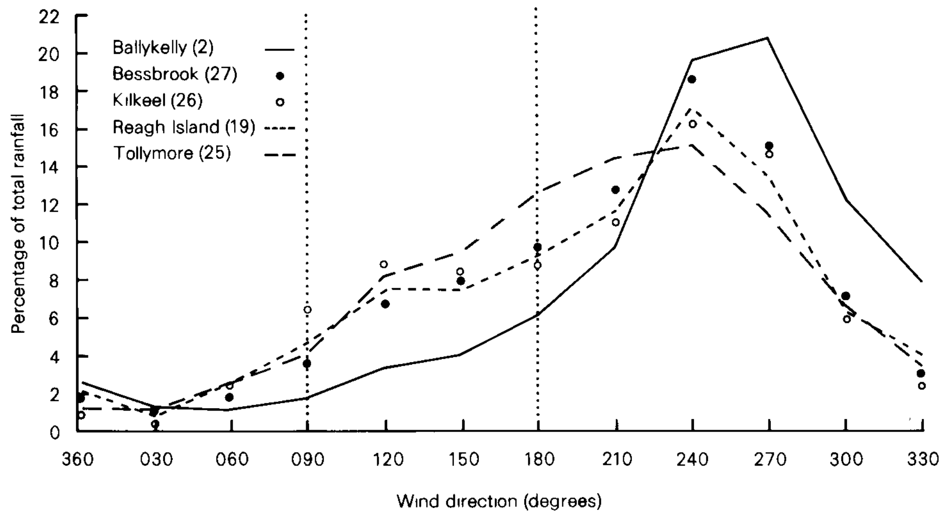

Figure 2. Percentage of total rainfall (in the complete record) as a function of 900 m wind direction for selected stations.

4. Temperature

(a) *Maximum temperature (summer)*

Because of the seasonal variations in the difference between sea surface and land temperatures it is considered more appropriate to compile the anomaly distributions on a seasonal basis. These should reveal (and quantify) the raising of night minima near coasts in winter as well as the lowering of day maxima in summer. Fig. 4(090°) does indeed demonstrate that onshore winds on the east coast reduce the day maximum by ca. 1 °C in south-east Down, whereas in the north-west continued diurnal heating over land results in increases of about the same magnitude. The highest temperatures in easterly winds are almost invariably reported from western counties of the Province. In settled sunny weather the anomalies in the north-west especially will be much greater.

Winds from 180° generally bring warmer conditions with temperatures up to 2 °C above the normal in the north-west but still a cooling of ca. 0.5 °C in the extreme south-east, where onshore winds are still

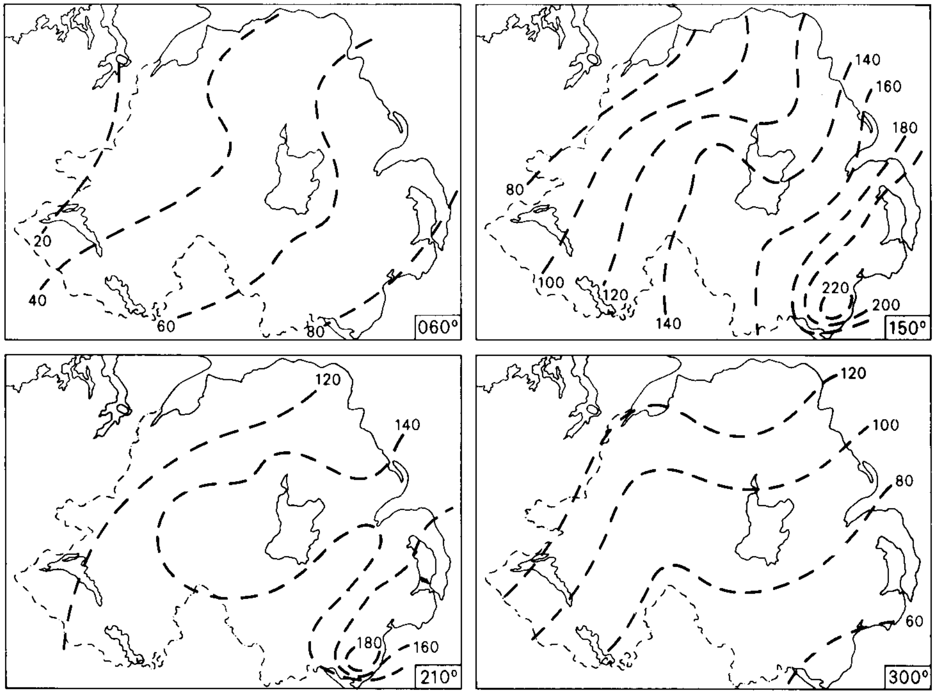

Figure 3. Anomaly maps drawn from the percentages of the mean daily rainfall at the various stations which occur for wind directions of 060°, 150°, 210° and 300°.

significant. At 270°, however, the eastern counties show a positive anomaly and the negative zone is transferred westwards to the region affected by onshore winds and probable increased cloudiness (see Fig. 9). As expected, northerly winds reduced day maxima to below average, except for a narrow coastal zone in the extreme south-east. In northern counties reductions of up to 2 °C are average and this value is doubtless markedly exceeded in cloudy polar airmasses.

(b) *Maximum temperature (winter)*

The surrounding sea in winter has an ameliorating effect on low day maxima. Easterly winds result in anomalies well below average inland, especially in the west and north-west and to the lee of the Antrim and Mourne Mountains. However, in the coastal zones of south-east Down temperatures are rather closer to average (see Fig. 5). With a 180° wind direction temperatures are everywhere above average by between 1–2 °C, but again the lower anomalies are found along the coasts, probably because sea temperatures are generally below airmass temperatures for this direction. At 270° the anomalies are again everywhere positive with the maxima as expected in inland areas. With northerly winds the pattern is entirely negative, with the greatest deviations away from the coasts. These can be as much as 2.5 °C below the winter average for all wind directions. Thus, for example, reference to Table I shows that with northerly winds at Armagh the average day maximum is reduced to 4.7 °C. In summary, therefore, the greater anomalies (positive or negative) tend to occur in inland regions with coastal regions remaining closer to the overall averages. As expected the sign of the anomaly is very sensitive to wind direction which emphasizes the correlation between this parameter and airmass type.

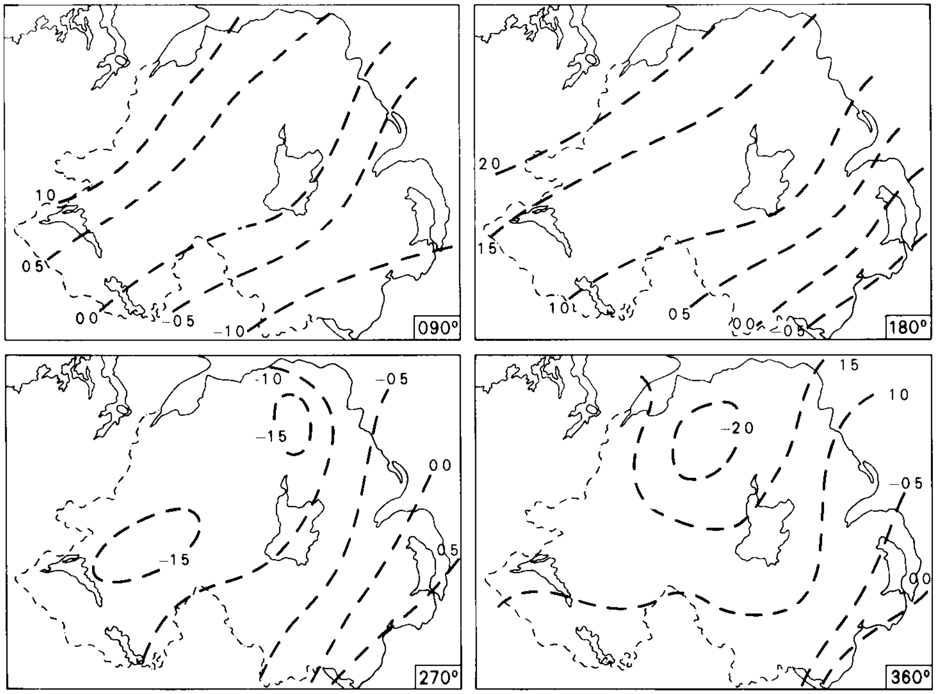

Figure 4. Anomalies of summer (June, July, August) maximum temperature (°C) for wind directions of 090°, 180°, 270° and 360°.

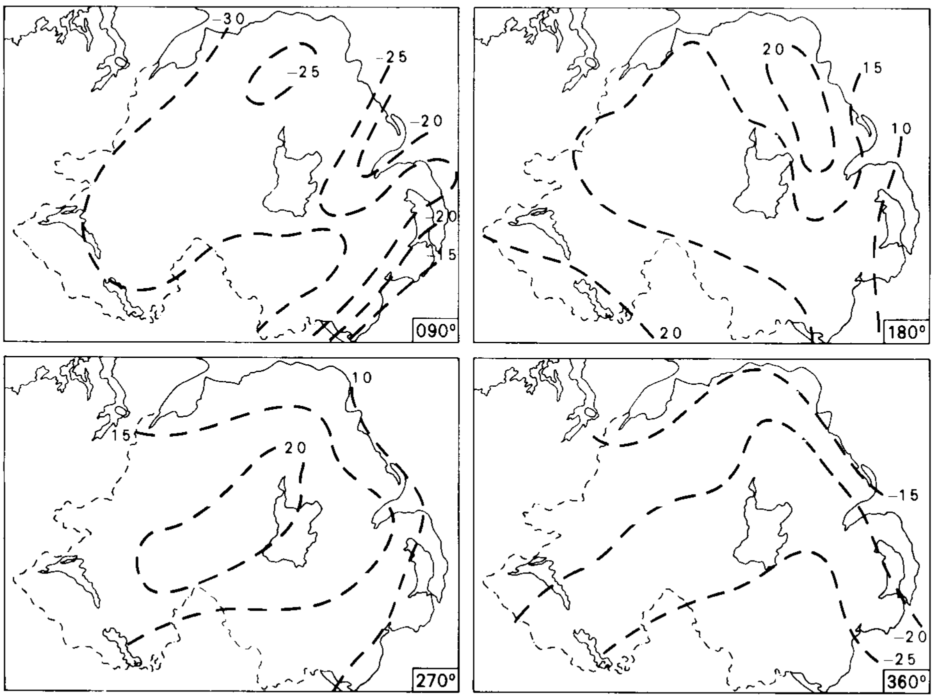

Figure 5. As Fig. 4, but for winter (December, January, February) maximum temperature.

(c) *Minimum temperature (autumn)*

Minimum temperature characteristics were felt to be most important in autumn and winter, so only these are considered here. The anomaly patterns for autumn are given in Fig. 6. For 090° a strong gradient in anomalies exists, with lowest values in the extreme west of the Province. Hence, for example, at Lisnaskea (Co. Fermanagh) the average minimum of 6.0 °C becomes 3.5 °C when winds are from 090°, and clearly ground frosts may be expected in sheltered places. At Kilkeel, on the other hand, the average autumn minimum is almost 5 °C higher, at 8.4 °C. With winds from 180° the pattern is much altered, with anomalies everywhere positive. The greatest values are again in the west, up to 3 °C — hence minima of around 9–10 °C may be expected. For 270° the anomalies are small. In northerly winds negative anomalies appear in all areas. As one would expect, the deviations increase in magnitude away from the north coast, to reach ca. 3.5 °C, in central and southern districts. At Aldergrove Airport, for example, the average night minimum of 6.4 °C is reduced to 2–3 °C in this wind direction, so that ground frost may again be expected.

(d) *Minimum temperature (winter)*

This is an extremely important category since Road Hazard Warnings are frequently issued in this period and a good appreciation for the location of regions particularly prone to low temperatures is vital. For 090° minimum winter temperatures (see Fig. 7) are below average, except for a narrow coastal strip in Co. Down and Co. Antrim. Thus at Lisnaskea in this wind direction the average night minimum would be −1 °C. With 180° the anomalies are everywhere positive, by up to 3 °C in the west, so air frost is much less likely with this wind direction. Similar considerations apply to 270°. However, with 360° all anomalies are again strongly negative reaching −3.5 °C in the south. The general distribution is very similar to autumn anomalies for this wind direction. The average minimum at Armagh during northerly winds is therefore expected to be −2.0 °C, and of course in 'favourable' synoptic types would be much lower.

(e) *Mean wind speed*

The main influence on near-surface wind speeds is from the reduced frictional drag over the sea compared to the land. Hence onshore winds at coastal sites are invariably a higher percentage of the 900 m wind speed than offshore winds. The values given in Fig. 8 are the percentage changes from the mean percentage that the 10 m wind speed is of the 900 m wind speed. Thus at Kilkeel, for example, the 10 m wind speed is, on average, 53% of the 900 m speed (see Table I) but for 090° (i.e. onshore winds) this increases by 140% to 75% of the 900 m wind speed. For westerly (offshore) winds, on the other hand, the percentage decreases from 53% to 45%. As expected, inland regions show much smaller variations from the average, since frictional effects vary much less with wind direction.

5. Sunshine

(a) *Winter*

With easterly winds in winter Co. Down is frequently affected by low cloud (formed by convection over the sea) which reduces sunshine amounts markedly. However, the shorter sea track to Co. Antrim results in values remaining near average. Less than 20% of the mean daily average is recorded in some places with a wind direction of 090° (see Fig. 9). In the north-west, however, the figures tend to be much

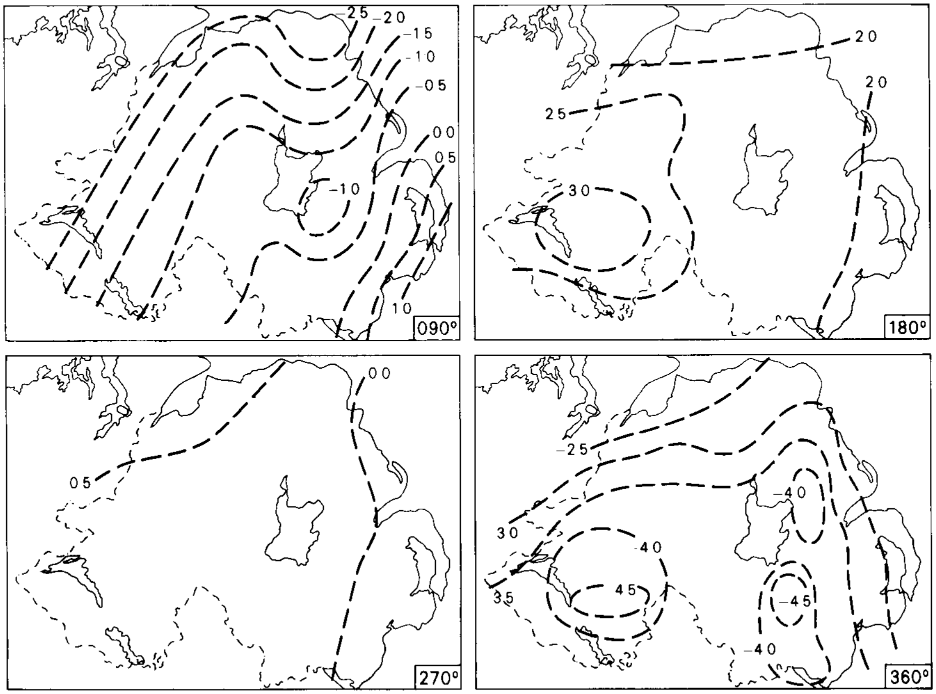

Figure 6. As Fig. 4, but for autumn (September, October, November) minimum temperature.

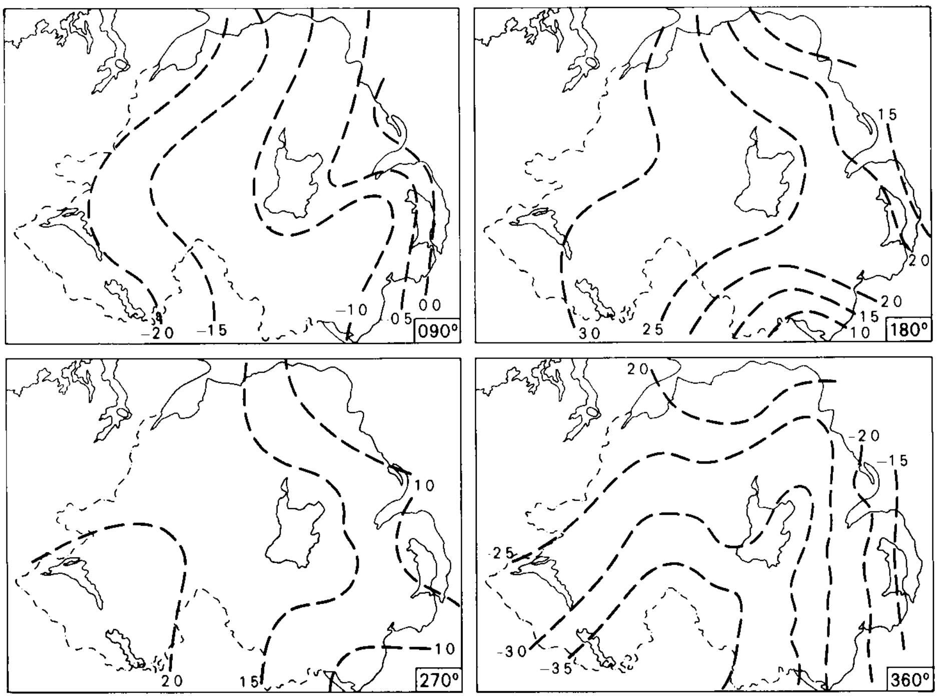

Figure 7. As Fig. 4, but for winter minimum temperature.

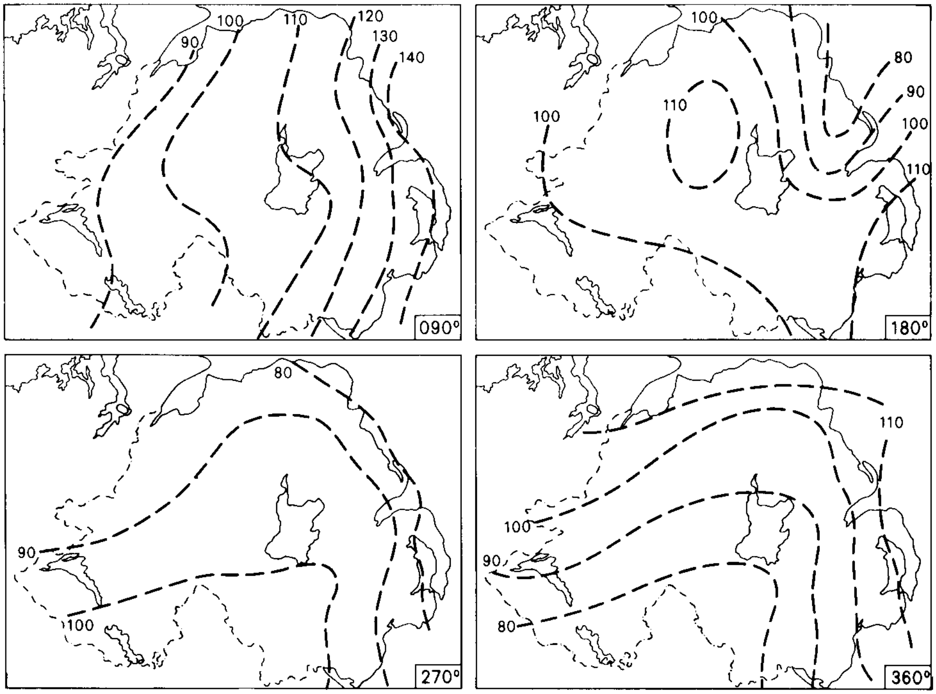

Figure 8. Percentage changes from the mean percentage that the 10 m wind speed is of the 900 m wind speed. The averages are taken over the complete record lengths without seasonal differentiation and are presented for 900 m wind directions of 090°, 180°, 270° and 360°

above average. At 180° the values are everywhere below normal so that this is a particularly cloudy direction in winter, probably because it is more frequently associated with cyclonic situations. As expected, with a wind direction of 270° the cloudier area now switches to the west of the Province, although values are also reduced in the north-east probably owing to orographic effects over the Antrim Plateau. The lowland areas of east and central Co. Down provide the only values above normal. For 360° the values range from about average on the north-west coast to 240% of average in the central and eastern regions, equivalent to about 4 hours of bright sunshine per day. This doubtless reflects greater convection over the relatively warm sea and the dissipation of cumulus or stratocumulus well inland where surface temperatures are low.

(b) *Summer*

In summer with a wind direction of 090° the coastal zones are now sunnier than inland regions, presumably owing to cumulus and stratocumulus convection over land (see Fig. 10). Values reach 140% of average, so at Reagh Island with this wind direction the mean daily amount is 7 hours. Unlike the winter period it seems that southerly winds in summer are associated with above average sunshine amounts, presumably because they are now more frequently anticyclonic. At 270° values tend to be below average, whereas for 360° they are everywhere above average especially in the Greater Belfast and north Down areas.

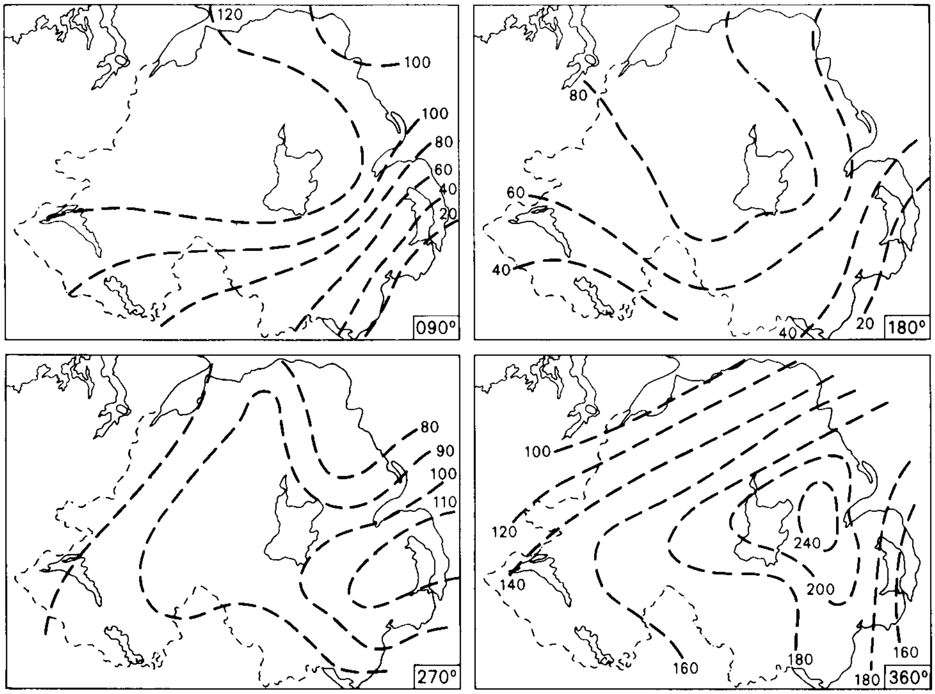

Figure 9. Percentage of the mean daily value of winter (December, January, February) sunshine for wind directions of 090°, 180°, 270° and 360°

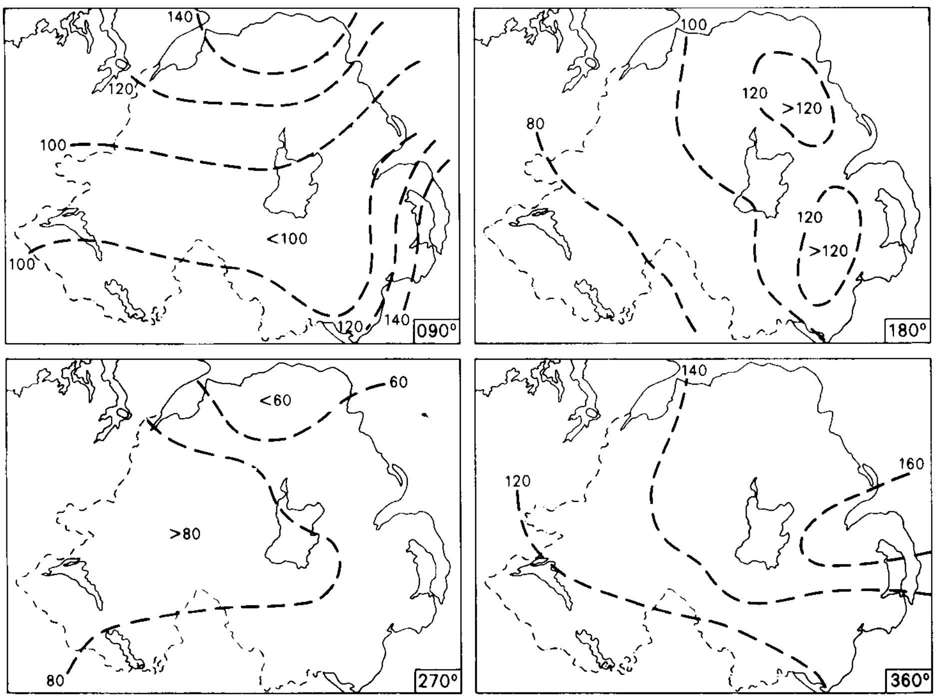

Figure 10. As Fig. 9, but for summer (June, July, August) sunshine.

Concluding remarks

This study could be further refined and extended by including, for each wind direction segment, a weather-type classification. Indeed, such an investigation has been reported for rainfall in south-east England (Stone 1983). However, in the present case further subdivisions of the number of observations in each category would not be practicable. Nevertheless, the foregoing 'anomaly' values can be exaggerated or reduced, in a subjective way, once the synoptic framework has been decided upon. The general characteristics of the patterns may be taken as giving reasonably good guidance on where, for example, the coldest or warmest regions may be expected and the 'typical' contrasts that are observed.

Acknowledgement

Thanks are due to Mr K. Grant, Met O 9 (Special Investigations Branch), for writing the computer program and processing the data from the Northern Ireland stations.

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551.521.11:551.521.12(41-4)

The accuracy of estimates of daily global irradiation from sunshine records for the United Kingdom

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Summary

Daily and monthly totals of global solar irradiation on a horizontal surface are estimated from records of duration of bright sunshine by Cowley's method for an independent sample of 21 stations within the United Kingdom, and the estimates compared with measured values. The accuracy of the estimate is given as a percentage and the frequency distribution of daily errors is explored. Root-mean-square (r.m.s) errors of daily and monthly estimates lie in the ranges 15–20% and 3–9% when averaged over the year but there is a marked seasonal variation.

The use of sunshine values from a location 50 km away typically increases the r.m.s. errors of daily irradiation estimates from 14% to 22% in summer.

Individual daily global irradiation is more accurately estimated from local sunshine observations than by assignment from nearby radiometric stations if these are more than about 20 km away; for monthly totals the critical distance is about 30 km.

1. Introduction

The daily total of global solar radiation received on a horizontal surface is important in a variety of meteorological applications, including the determination of evapotranspiration rates for hydrometeorological use and surface energy budget calculations for solar energy and agricultural requirements. Currently the United Kingdom solar radiation network comprises 40 stations which measure daily or hourly global irradiation of wavelength 0.3–3.0 μm using Kipp and Zonen pyranometers; a description of the network can be found in Richards (1980). The geographical distribution of stations is insufficient to give an adequate spatial resolution for all applications, and estimation of global irradiation from the much more numerous measurements of sunshine duration is widely employed. There are 370 stations in the United Kingdom which report sunshine.

A simple linear relation between global irradiation and bright sunshine duration, measured by Campbell-Stokes recorders, was established by Ångström (1925). The estimation technique for daily totals was improved by Cowley (1978) who divided days into two groups — sunless and those with some sunshine — and argued that these constitute two distinct statistical samples, giving an estimated daily global irradiation, G_E, in the form:

$$G_E/G_0 = a + bN/N_0 \quad \text{for } N>0 \quad \ldots \quad (1)$$

$$G_E/G_0 = a' \quad \text{for } N = 0 \quad \ldots \quad (2)$$

where G_0 is the extraterrestrial daily global irradiation on a horizontal surface, N is the duration of bright sunshine measured by Campbell-Stokes recorders and N_0 is the astronomical daylength. The empirical coefficients a, a', b were calculated at 10 sites from data for the period 1966–75. Maps of coefficients covering the United Kingdom were interpolated by Cowley: a and a' were assumed constant throughout the year but monthly maps of b were produced, giving 14 coefficient maps in all.

This paper examines the accuracy of Cowley's method in an independent data sample for both daily and monthly totals. Since the error in estimated irradiation is unlikely to be completely random, the frequency distribution of errors was also investigated.

An extra source of error arises when an estimate of irradiation is required for a location at which no sunshine measurement is available, and it is necessary to assign sunshine observations from a nearby site. The accompanying loss of accuracy was explored by comparing irradiation estimates obtained from sunshine recorded at neighbouring stations.

A common problem is encountered when an estimate of irradiation is required for a location at which only sunshine is recorded, but radiation measurements are available from a station at a small distance: which estimate is superior, the value given by Cowley's equations or the assigned radiation measurement? This question was examined by calculating the differences in measured irradiation within the network as a function of the separation between stations.

2. Preparation of data

Measurements within the solar radiation network are co-ordinated by the National Radiation Centre at Beaufort Park, the section of the Meteorological Office which is responsible for the calibration of radiation instruments against international reference standards. Observations of sunshine duration and irradiation are subjected to a package of quality control checks before being archived: data with major inconsistencies are labelled 'unreliable'. Daily global irradiation on a horizontal surface, G_M, taken from the controlled data is assumed to be correct for this analysis, although it should be noted that the measured values themselves have an inherent inaccuracy arising from a number of sources, with calibration and angular response errors being of particular importance. The principal causes of error have been studied by a number of workers, e.g. McGregor (1983), from which the r.m.s. (root-mean-square) error of individual hourly measurements is considered to be about 5% for the United Kingdom network, which is in agreement with results from a study of the Canadian solar radiation network (Hay and Wardle 1982). This study also quoted r.m.s. errors for daily and monthly integrated measurements, giving average figures of 3½% and 2½% respectively, but with a seasonal dependence; similar errors are expected to apply to United Kingdom network instruments.

The actual error of the estimate quoted in the present paper is $G_E - G_M$, with the percentage error being defined as $100(G_E - G_M)/G_M$, for each individual measurement. In general these calculations will underestimate the differences from the 'true' radiation field, as obtained from a hypothetical network of ideal instruments. However, since only a fraction of the measurement error can be considered to be systematic and common to the entire network, the additional error will not be as large as the figures given in the previous paragraph.

All errors given in the following sections are averages for the period 1976–82, with a minimum sample of at least 100 days for each monthly set of results. Only days with 'reliable' measurements of sunshine and radiation are used, i.e. when there is a complete record or when data are missing for only a small fraction of the day and pass the quality control checks. Similarly, each monthly total of global irradiation is required to contain at least 20 days with data. These restrictions reduce the number of stations used in this study to 21: details of each site are listed in Table I and the geographical locations are shown in Fig. 1.

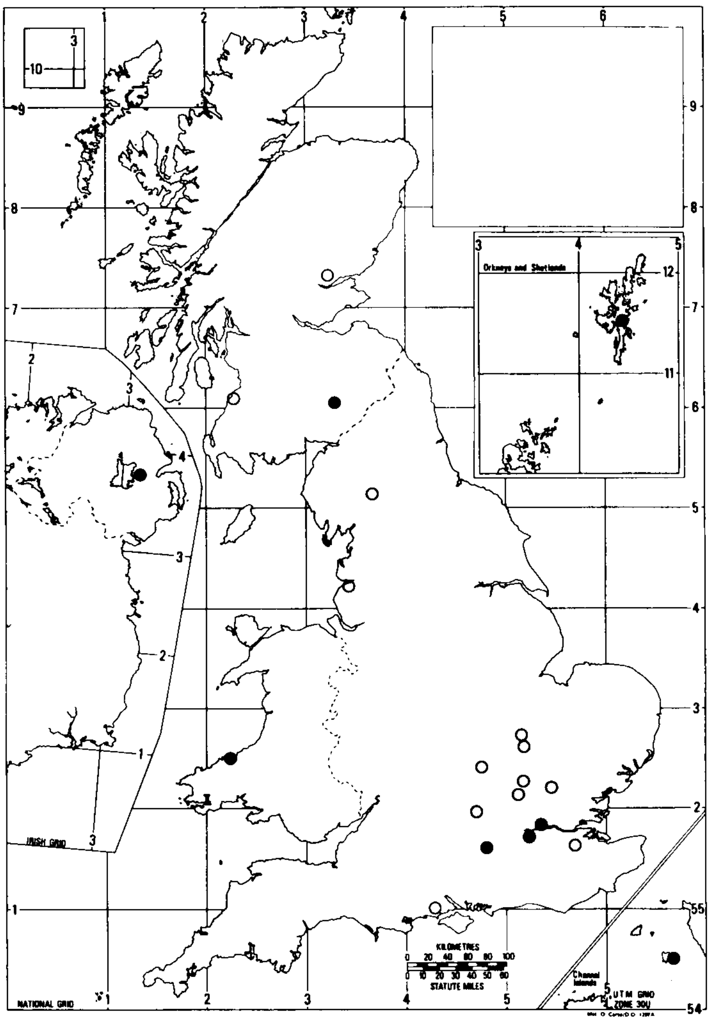

Figure 1. The geographical positions of stations used in the analysis, which measure both daily global irradiation and sunshine duration. The stations which were also included in the derivation of the empirical coefficients by Cowley (1978) are labelled by ●; other sites are labelled ○.

Table I. *Details of stations used in the analysis*

Station	Height	National grid reference		Type	Used in Cowley calculation of a, a', b 1966–75	Notes
	metres	E	N			
Silsoe	59	5.08	2.38	co-op	no	
Moor House	562	3.75	5.32	"	no	
East Malling	37	5.70	1.57	"	no	
Efford	16	4.30	0.93	"	no	(a)
Fairfield	24	3.42	4.34	"	no	(b)
Garston	77	5.11	2.01	"	no	
Lerwick	82	4.45	11.38	Met O	yes	
Eskdalemuir	242	3.24	6.03	"	yes	
Kew	5	5.17	1.76	"	yes	
Bracknell (Beaufort Park)	73	4.84	1.66	"	yes	
Aldergrove	68	1.29	5.34	"	yes	
Aberporth	133	2.25	2.51	"	yes	
Cardington	28	5.08	2.46	"	no	
London Weather Centre	77	5.30	1.81	"	yes	
Jersey	85	3.87	-0.79	co-op	yes	
Mylnefield	30	3.34	7.29	"	no	
Auchincruive	45	2.38	6.24	"	no	(b)
Grendon Underwood	70	4.67	2.23	"	no	
Rothamsted	128	5.13	2.13	"	no	(a)
Hoddesdon	47	5.38	2.11	"	no	
Wallingford	49	4.58	1.89	"	no	

Notes: (a) Radiation records are from 0900–0900 GMT.
(b) Radiation and sunshine records are from 0900–0900 GMT.
All other records refer to the period 0000–2400 GMT.
co-op : co-operating station
Met O : Meteorological Office station.
The national grid has been extrapolated to include Jersey and Aldergrove.

The maps of coefficients a, a', b were interpolated by Cowley on to a grid of resolution 40 km × 40 km covering most of the United Kingdom. The estimate of global irradiation for each day, G_E, is calculated from equations (1) and (2) using the daily duration of sunshine at each station and the coefficients found by linear interpolation from the four closest grid points. However, three sites (Lerwick, Aldergrove and Jersey) are outside the grid region and values of a, a', and b derived for the period 1966–75 at each site were used.

Those days for which the error exceeded 50% were discarded; these few outlying values constituted less than 1% of the sample, i.e. one or two days in each set of seven months' data, and were confined to the winter months. These errors mostly occurred on days of anomalously low measured irradiation, for which recording or instrument deficiencies are a likely cause. The inclusion of such days would have distorted the calculation of r.m.s. errors for the few samples in which they were present.

3. Results

(i) *Daily errors*

The mean and r.m.s. percentage errors of estimated daily global irradiation were calculated for each station in the analysis, averaged for each month of the year. The errors for Bracknell, which is considered to give typical results for the network, are listed in Table II. Average errors at each station for

Table II. *Error statistics for Bracknell, including the mean daily global irradiation*

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Units
Mean G_M		797	1270	2354	3587	4746	4826	4708	4055	3016	1727	949	613	W h m^{-2}
Daily percentage error	r.m.s.	20.0	17.8	16.3	14.4	13.9	13.2	11.2	12.8	13.0	16.7	17.7	20.5	%
	mean	-4.5	-1.1	2.5	3.3	5.0	0.7	0.7	2.8	0.1	0.3	-1.6	- 3.2	%
Daily actual error	r.m.s.	134	190	315	411	499	512	428	402	297	219	135	102	W h m^{-2}
	mean	-49	-31	56	94	148	12	-8	59	-36	-10	-33	-32	W h m^{-2}
Percentage of days with modulus (error) exceeding threshold:	100 W h m^{-2}	41	48	72	80	83	83	79	81	78	58	42	32	%
	500 W h m^{-2}	0	2	11	23	31	32	26	23	9	3	1	0	%
	1 kW h m^{-2}	0	0	0	1	4	5	2	1	0	0	0	0	%
	20%	33	22	22	14	14	12	5	10	15	19	25	30	%
Monthly percentage error	r.m.s.	7.2	3.2	4.1	3.7	4.3	2.1	1.7	2.5	2.7	2.1	4.0	5.9	%
	mean	-6.0	-2.5	2.5	2.7	3.3	0.3	-0.1	1.5	-1.2	-0.7	-3.3	-5.4	%

the entire sample of 7 years are shown in Fig. 2, where the abscissa is the northerly component of the national grid reference, with one unit denoting 100 km (national grid co-ordinates are extended to include Aldergrove and Jersey in this work). The r.m.s. percentage errors are similar at each site and mostly fall within the range 15–20%, including those stations involved in the original derivation of empirical coefficients (these are identified in the figure); there appears to be a small systematic increase in error northwards. Mean errors lie between ± 6% and seem to be randomly distributed.

The percentage error for all 21 stations combined is shown in Fig. 3 to indicate the way in which the daily error varies with each month of the year. It can be seen that there is a strong seasonal dependence, with considerably less accurate estimates (by percentage) in winter. In terms of the actual error, this seasonal dependence reverses owing simply to the large variation in solar radiation received on a horizontal surface during the year at United Kingdom latitudes. This is illustrated for Bracknell in Table II.

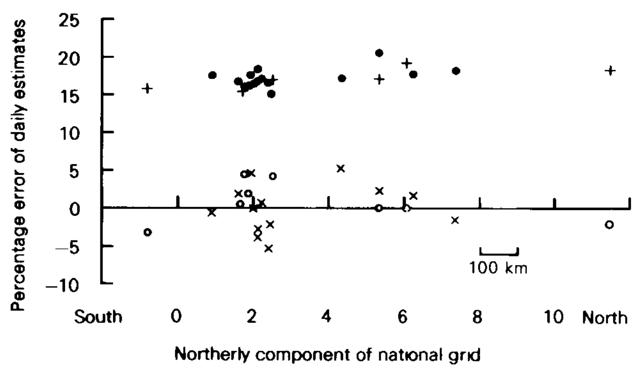

Figure 2. Mean and root-mean-square (r.m.s.) percentage errors of daily estimates of global irradiation as a function of the north component of the national grid reference for each station, averaged over the 7-year sample period. The r.m.s. and mean errors of stations included in the original derivation of empirical coefficients are labelled by + and O respectively; r.m.s. and mean errors of the remaining sites are labelled by ● and ×.

The accuracy of estimation is more completely determined if the frequency distribution of errors is known. A simple statistical method can be applied to test for a normal distribution. First, the null hypothesis is assumed: that percentage errors are normally distributed. Then the cumulative error distribution is subdivided into categories and the χ^2 test for significance at the 5% level is applied. The results for Bracknell data, with six categories, are shown in Table III, from which it can be seen that the hypothesis is accepted for 7 out of 12 months. Hence the error distribution approximates to a normal form for most, but not all, months.

A useful criterion of accuracy is given by the percentage of occasions on which the magnitude of the percentage error exceeds a threshold value. A threshold of 20% provides a rough guide to the usefulness of daily estimates of global irradiation: values for Bracknell are given in Table II, which indicates the relatively poor estimates obtained in winter months. These values can also be predicted from the mean and r.m.s. percentage errors, if a normal distribution is assumed. Table IV shows the observed and predicted percentage of occasions exceeding an error of 20% at East Malling. The good agreement obtained indicates that the assumption of a normal distribution is adequate for this purpose.

It may be noted that a 20% daily error corresponds to about 900–1200 W h m^{-2} in summer and to about 50–140 W h m^{-2} in winter, depending upon location. To assist the comparison of errors at different times of the year the percentage of occasions for which the actual error exceeds, 100, 500, 1000 W h m^{-2} are listed in Table II for Bracknell.

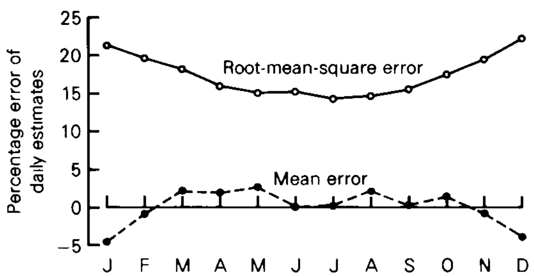

Figure 3. Mean and r.m.s. percentage errors of daily estimates averaged for all stations for each month of the year (for a 7-year sample).

(ii) *Representative sunshine measurements*

When an estimate of global irradiation is required for a location where sunshine measurements are not performed, the local sunshine duration must be obtained from neighbouring sunshine stations. An attempt to assess the importance of this source of error was made by considering the estimation of daily irradiation at a single station, with empirical coefficients appropriate for that location, but replacing the measurements of sunshine with those recorded at other sites. This gives an indication of the error introduced by the assignment of sunshine recorded at a distance. Fig. 4 shows the r.m.s. error for January and July as a function of the separation of each site from Silsoe, which is chosen as a suitable example of a 'base' station since it is located in the densest part of the network. It can be seen that there is a steady increase of error with increasing distance, particularly for July when a separation of 50 km increases the r.m.s. error from 14% to about 22%. At large distances (greater than about 400 km) the errors exhibit a wide range of values.

A similar relation between errors and the separation of sites was found for other stations and it is expected that these results are typical of lowland areas of the United Kingdom.

Table III. *Calculated χ^2 values for Bracknell with decisions of tests for a normal distribution of percentage errors. (Critical value at 5% significance for χ^2 is 7.815.)*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Calculated from error frequency distribution	19.9	6.5	4.7	4.7	32.6	5.8	7.0	15.3	35.6	15.4	2.6	1.8
Acceptance of null hypothesis	No	Yes	Yes	Yes	No	Yes	Yes	No	No	No	Yes	Yes

Table IV. *The percentage of days on which the modulus of the percentage error exceeds 20% at East Malling, both as observed and as predicted from the mean and r.m.s. errors assuming normal (Gaussian) statistics*

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Daily percentage error	r.m.s.	20.8	18.7	17.8	15.2	13.9	15.5	13.0	12.4	13.6	17.2	18.9	23.4
	mean	1.1	0.9	5.6	3.9	3.0	−0.2	2.3	1.8	−0.1	3.0	−0.5	3.7
Percentage of days with modulus (error) exceeding 20%	observed	32	28	22	17	12	18	11	10	12	21	29	39
	predicted	34	28	26	19	15	20	12	10	14	24	29	38

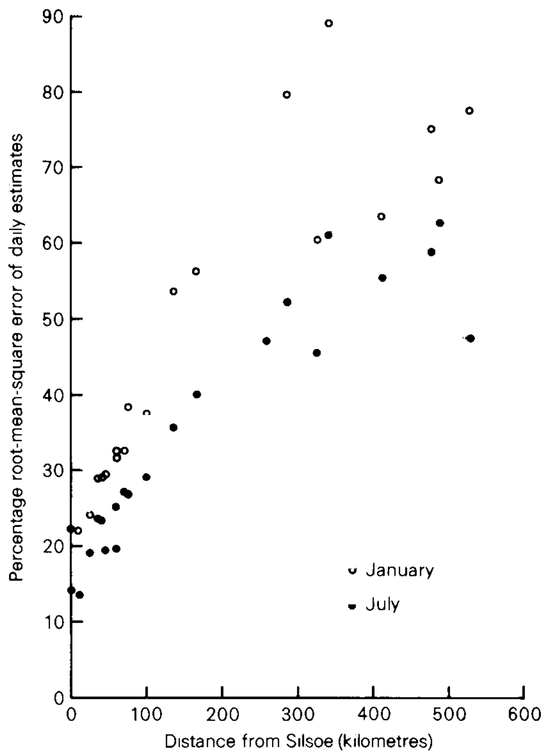

Figure 4. The r.m.s. percentage error of daily estimates for Silsoe, using sunshine recorded at other sites, for January and July, versus the distance of these sites from Silsoe.

(iii) *Monthly errors*

The preceding results apply only to daily totals of global radiation. The estimation of individual monthly totals is also of interest: Figs 5 and 6 show the dependence of mean and r.m.s. monthly errors on the geographical position and season respectively, corresponding to Figs 2 and 3 which displayed daily errors. As expected, there is a reduction in error from daily to monthly totals which is associated with the removal of part of the random error. However, the reduction is not as large as that predicted for a normal population, i.e. by dividing the square root of the number of days in a month (ca. 5.5), since the deviations of individual days making up the monthly sum are related, owing to the persistence of weather conditions for more than one day. The importance of systematic errors for monthly integrated estimates can also be seen: deficiencies in the specification of empirical coefficients are responsible for a significant proportion of the r.m.s. error.

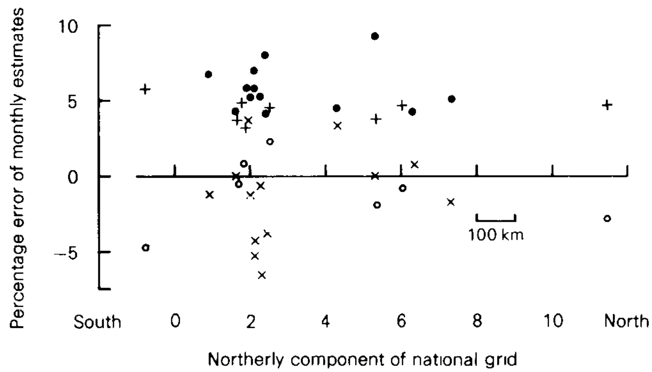

Figure 5. As Fig. 2, but for monthly estimates.

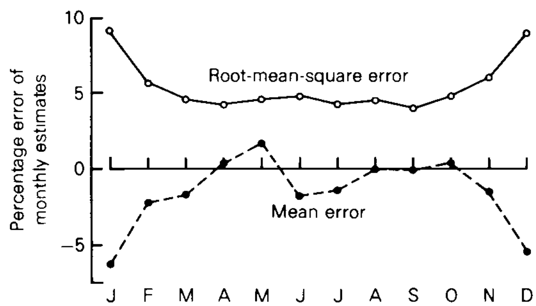

Figure 6. As Fig. 3, but for monthly estimates.

A comparison of Figs 2 and 5 indicates that mean daily and monthly errors are not identical — since errors are given in percentage terms the errors in estimated monthly totals are weighted towards days of high measured global irradiation. For example, the estimated irradiation for a day of strong sunshine may have only a small percentage error but this could amount to a significant contribution to the monthly error if other days in the month are of low irradiation. In general there is a tendency for daily mean errors to be more positive than monthly mean errors: a detailed examination of the results at several stations indicated the cause to be that high irradiation days are underestimated more often than low irradiation days. However, the data sample for monthly figures is small, with a maximum of 7 months (and a minimum of 5), and may not be characteristic of a longer period.

(iv) *Estimation: assignment of irradiation measurements or local regression from sunshine?*

A problem frequently encountered when practical estimates of global irradiation are required for a particular location is whether to assign the irradiation measured at the nearest radiometric station or to derive values from sunshine recorded locally, using the Cowley coefficients. The accuracy of the latter has already been discussed; the accuracy of estimates using assigned measurements of irradiation (i.e. equated to the nearest station) can be explored by calculating the differences between simultaneous observations within the radiation network.

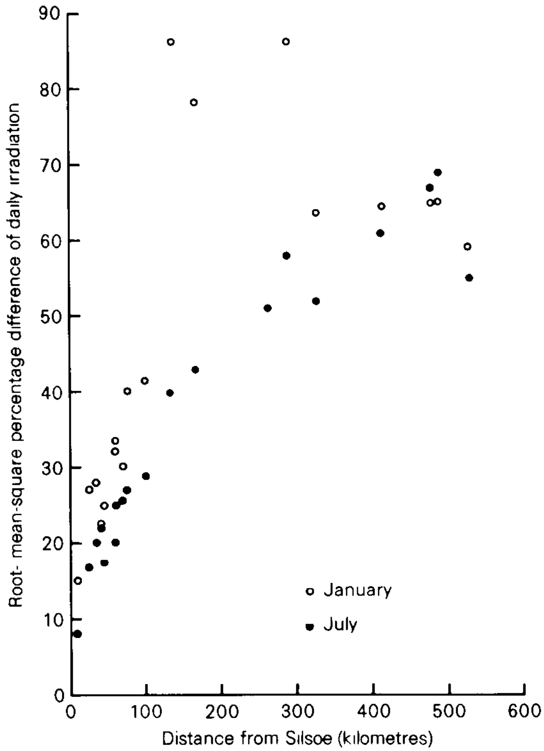

Figure 7. The r.m.s. percentage differences in daily global irradiation measured at Silsoe and at other sites as a function of their distance from Silsoe, for January and July.

Fig. 7 shows the r.m.s. percentage differences in measured daily global irradiation between station pairs, which can be regarded as errors in this context, as a function of the distance of each site from Silsoe, which is again taken to be the reference station, for January and July. These differences can be compared with the r.m.s. error of estimation from local sunshine records at Silsoe which were found to be 22% and 14% for January and July respectively (see Fig. 4). The limited number of irradiation differences and their large spread of values preclude the derivation of an explicit relation between irradiation difference and station separation. However, for both months it can be seen by inspection of the envelope of points in Fig. 7, that the r.m.s. error from assignment is larger than that from the Cowley method when the assignment distance exceeds about 20 km. Hence it can be inferred that, for the relatively homogeneous region of the United Kingdom under consideration, the estimation of individual daily global irradiation from local sunshine records is more accurate than if measured irradiation values are assigned from a single site at a distance greater than about 20 km from the desired position. Similar results are obtained for other reference stations but the scarcity of closely spaced pairs of sites allows only a very rough estimate of this limit.

The relative accuracy of the estimation methods for individual monthly totals and for the entire sample in each month of the year can be examined similarly. However, the increase in the r.m.s. percentage difference of irradiation with increased station separation, as defined above, is less pronounced for monthly sums of global radiation, partly because of the relatively small sample, but mostly because of the dominating contribution of climatological differences. In other words, r.m.s. monthly differences between measured irradiation at different stations depend mainly on the difference between the climatological average irradiation at each site, which can be fortuitously small, even when they are far apart and within quite separate radiation regimes. Fig. 8 shows the magnitude of the difference between the mean daily irradiation measured at Silsoe and at other stations for January and July, averaged over the 7-year sample period and expressed as a percentage of the Silsoe mean irradiation. Clearly there is some increase in irradiation differences with distance, but this is much less marked than in Fig. 7. For each station and for each month of the year the daily irradiation can be estimated by the Cowley method, and then averaged over the 7-year period, in a simple extension of the daily results described earlier: it is found that the errors (expressed as a percentage of the measured irradiation for the same period) vary widely from station to station. The modulus of these errors, averaged over all stations, approximates to the average error of estimating climatological mean irradiation by Cowley's method; for January and July the values are 5% and 3% respectively (for comparison with Fig. 8). Using this criterion of the error of estimating climatological irradiation, it can be seen from Fig. 8 that, on average, estimation by Cowley's method is more reliable than the assignment of mean irradiation from a single location at a distance further than a few tens of kilometres (say, roughly 30 km) from the desired position.

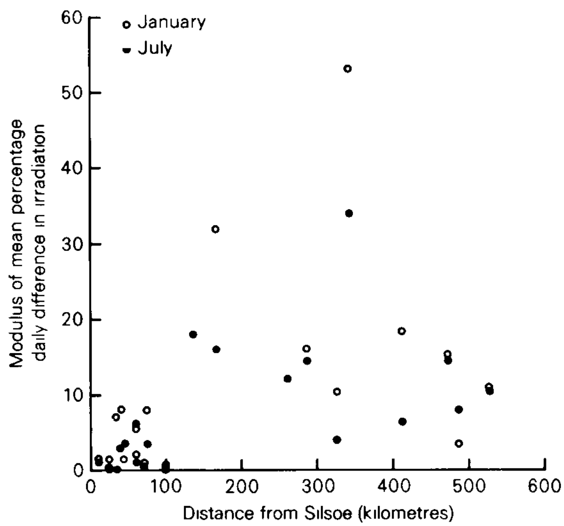

Figure 8. The modulus of the long-term mean percentage daily differences in irradiation measured at Silsoe and at other sites as a function of their distance from Silsoe, for January and July.

4. Discussion

The relation used by Ångström and Cowley ignores the detailed physical causes of variations in global irradiation at the earth's surface. These arise from changes in the composition of the atmosphere, particularly the aerosol and water vapour content; from the complex scattering and absorbing properties of water drops and ice particles within different thicknesses and configurations of clouds; and from changes in the albedo of the underlying surface. The equations only take account of a single measure of the optical characteristics of cloud, i.e. the duration of bright sunshine, and have to be derived on a climatological basis; therefore it is not surprising that large errors may be generated when they are applied to single days. Also, the measurement of bright sunshine by Campbell–Stokes recorders is known to have a number of deficiencies (Painter 1981), particularly overestimation in periods of intermittent sunshine, and these are implicitly included in the specification of the empirical coefficients.

The estimates of global irradiation are poorest for days when little or no bright sunshine is recorded — the cloud type and thickness govern a wide possible range of fractional transmission through cloudy atmospheres. There have been a number of attempts to calculate the fraction of solar radiation transmitted through various cloud species, e.g. Haurwitz (1948), Lamb (1964), and more recently Cotton (1978), and this approach may offer an improvement in accuracy when cloud information is available. In general, the daily estimate of Cowley is more reliable for sunny days than for overcast days since there is a greater variability in global irradiation due to clouds than that due to turbidity. Apart from changes in cloud cover due to variations in climate, the duration of bright sunshine is dependent on the solar altitude because of geometric effects. When the sun is low in the sky there is a greater probability that the direct beam will be intercepted by broken cloud (Davis *et al.* 1979); also the incident energy can be reduced below the burn threshold by the attenuation of a longer atmospheric path, especially when thin cloud is present or there is a large aerosol content. The average solar altitude decreases from south to north and from summer to winter, so that less accurate estimates are expected in the north compared to the south and in winter compared to in summer, quite apart from large-scale and seasonal changes in atmospheric conditions; this is consistent with the trend of errors shown in Figs 2 and 3.

Examination of the original data on which Cowley based the determination of a, a', b reveals that, strictly, a and a' as well as b should be provided as monthly rather than just constant values, since the month by month changes in a and a' are comparable to those of bN/N_0. However, this would be unwieldy to implement in practice since the coefficients are not independent, which complicates the process of obtaining consistent maps of these parameters. The inexact relationship between sunshine and irradiation does not justify an extension to a higher order polynomial for mapping throughout the UK, although some authors, e.g. Hay (1979), have used such a form for specific sites.

The importance of assigning representative measurements of sunshine duration in estimating irradiation by Cowley's method is emphasized by the results shown in Fig. 4, where the use of sunshine measurement sites away from the point of estimation leads to errors which increase roughly linearly with distance. This is most pronounced for estimates during summer (illustrated by the July results) when there is a greater variability in sunshine over small horizontal scales, which is probably due to the seasonal pattern of convective activity. Local cumuliform clouds are more prevalent over the United Kingdom mainland in summer than in winter and these can lead to considerable differences in sunshine recorded at neighbouring positions; stratiform cloud conditions seem more likely to give rise to a relatively homogeneous geographical distribution of sunshine.

The results concerning both the representativeness of sunshine measurements and the choice of estimation of irradiation presented earlier are relevant to the problem of estimation at a distance from a single measuring station. In practice it is usually possible to derive values from a number of sites, particularly for sunshine, using interpolation procedures of varying elaboration. Hence the increase in error with increasing distance from the measurement position is an overestimate of what may be achieved with a closely spaced network of stations. However, it should also be noted that these results apply only to the relatively homogeneous lowland terrain of south-east England, this being the only area with a sufficient density of radiation stations. It is expected that coastal and highland regions exhibit greater horizontal variability in the irradiation field; consequently there will be a larger increase in error with increasing distance from the measurement position. It is possible that the limiting distances quoted in previous sections are seasonally dependent but the uncertainty of the values deduced from Figs 4, 7 and 8 is too large for this to be adequately resolved.

5. Conclusions

The accuracy of estimation of daily and monthly totals of global irradiation from bright sunshine records using the method of Cowley (1978) has been investigated for 21 stations around the United Kingdom. The calculations, which are based on a sample which is independent of that used to derive the empirical coefficients, provide the following results:

The r.m.s. errors of daily estimates, averaged throughout the year, are in the range 15–20%, with mean errors within ±6%. The r.m.s. errors averaged over all stations vary from about 15% (or 600 W h m^{-2}) in summer to 25% (or 150 W h m^{-2}) in winter. The r.m.s. errors of monthly estimates are in the range 3–9% which are larger than would be inferred from assuming that each daily error is independent. The mean monthly errors are similar, but not identical, to the mean daily errors and constitute an important proportion of the total monthly error.

The number of individual days for which the error exceeds 20%, or other chosen levels, can be approximated by assuming a normal distribution of errors. The accuracy of estimation of daily global irradiation is dependent upon the representativeness of the measurement of bright sunshine duration. The use of sunshine recorded at a distance of 50 km from the location at which the irradiation estimate is required typically increases the r.m.s. error in summer from 14% to about 22%.

The estimation of global irradiation by Cowley's method, for a particular location which has sunshine but not radiation measurements available, has been compared with the assignment of measured values from a neighbouring radiometric site. For the relatively homogeneous terrain of south-east England it is found that more accurate estimates of individual daily global irradiation are obtained by regression from local sunshine records than by the assignment of irradiation measured at a station more than about 20 km distant. Similarly, long-term average global irradiation is more reliably estimated from local sunshine than by an assignment of measured irradiation more than about 30 km from the required position.

A high proportion of the day-to-day errors are due to the simplicity of the estimation scheme which ignores the detailed physical causes of changes in global irradiation at the earth's surface. However, this method provides readily obtainable estimates with sufficient accuracy for many applications and constitutes an important source of irradiation data which is supplementary to those of the solar radiation network. It is expected that a considerable amount of effort would be required to provide estimates using existing data which are significantly more accurate and can be applied throughout the UK. One obvious possible extension involves the use of observations of cloud type and cover, to improve estimation of totally overcast days.

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551.542.1:551.553.1(564.3)

Diurnal and seasonal trough-induced surface pressure gradients and winds over Cyprus

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Summary

Average values of monthly mean sea level pressure at three-hourly intervals were used, firstly, to describe purely diurnal pressure gradients and winds and, secondly, in combination with a model of the seasonal/lee pressure trough, to describe resultant pressure and flow patterns, by 'day' and 'night', and at times when no thermally induced pressure gradients exist. Results are found to agree with observed surface flow phenomena.

Data and normalization

Values of average mean sea level pressure at three-hourly intervals (00, 03, 06, etc., GMT), each month, were tabulated for five locations in Cyprus as follows: Nicosia, Paphos and Morphou, 1951–55; Cape Apostolos Andreas, 1951–54; and Akrotiri, 1957–71. The Paphos and Cape Apostolos Andreas data for 00 and 12 GMT were compared, for each month in 1951, and the simple empirical factors obtained were applied to the averages for the latter station to allow for the non-inclusion of 1955 data therein. The changes made were small. The Akrotiri data, being for a longer but non-overlapping period, were adjusted to give estimates of 1951–55 values by simple relationships of monthly average mean sea level pressures. The 1957–71 monthly averages at Akrotiri were replaced by the monthly means of the Paphos and Morphou 1951–55 averages.

Determination of sense of pressure gradients between coastal stations and Nicosia and resulting airflow

Monthly mean curves were drawn to the three-hourly average pressure data for all stations, locating maxima at or near 10 and 22 hours Zone Time (GMT + 2 h) and minima at or near 04 and 16 hours. Curves for Morphou and Paphos were superimposed on those for Nicosia by registering pressure scales. Curves for Akrotiri were superimposed on those for Nicosia by registering revised monthly averages with corresponding values on the Nicosia scales. The times when relatively falling Nicosia average pressures equalled those at the coastal stations (A) and when relatively rising Nicosia average pressures once again equalled those at the coastal stations (B) are shown in Table I. The A-value for Akrotiri in September is, presumably, a quirk of the crude normalization and should be 08 or 09. Times of sunrise and sunset on the 15th day of each month (1982) are shown for comparison.

In the absence of a synoptic-scale pressure gradient the June to September relationships imply actual pressure gradients normal to coastlines, with inflow from A to B hours, and outflow from B to A on most days. From December to March the average pressure patterns and values reflect a good deal of cloudiness and, presumably, underestimate the time-span A–B on sunny days. In other months there is, presumably, some underestimation of time-span A–B on sunny days.

B is considerably later than sunset in some months and hence sea-breezes would be expected to persist into darkness, an observed phenomenon forecasters have been reluctant to predict without physical support. Relationships between average pressures at Nicosia and Cape Apostolos Andreas were not studied because of the extreme geographical location of the latter. A- and B-times are well related to the duration of land- and sea-breezes and to the occurrence of mountain- and valley-induced (anabatic and katabatic) winds.

Table I. *Times (GMT + 2 h) when average (1951–55) mean sea level pressures for three coastal stations became* (A) *greater than and* (B) *less than average pressures at Nicosia.*

Month	Times of intersection of coastal station monthly average mean sea level pressure curves with corresponding curves for Nicosia						35°N, 33°E 15th day of month	
	Morphou		Akrotiri		Paphos		Sunrise	Sunset
	A	B	A	B	A	B		
Jan.	–				–		0656	1658
Feb.	10	16	11	18	11	17	0637	1728
Mar.	10	18	11	18	11	17	0559	1755
Apr.	08	18	09	18	09	18	0518	1819
May	07	20	07	19	08	20	0446	1844
June	07	20	07	20	07	20	0433	1904
July	09	19	08	19	07	20	0446	1902
Aug.	09	18	08	19	09	19	0508	1837
Sept.	09	17	07	19	09	18	0530	1757
Oct.	09	17	09	19	09	18	0553	1715
Nov.	11	17	12	16	11	17	0623	1642
Dec.	11	15				–	0649	1638

Determination of resultant pressure gradients when a synoptic-scale pressure system covers Cyprus

Meteorological Office (1962) gives monthly, average, mean sea level pressure maps for an area including the Mediterranean. The seasonal trough is dominant from June to August, appears weakly in May and is a fading feature in September. In summer this trough is both an extension of the Asian summer low and a result of the lee effect due to the Turkish mountains. At other times the trough is purely a lee effect. The average pressure difference over the length of Cyprus (west–east), along or near which direction the axis of the trough is usually found, is of the order of 1 mb (Meteorological Office 1962). A simple template was made (see tops of Figs 1–5) to enable the trough axis and isobars at 0.5 mb intervals to be drawn, quickly and accurately, on maps of the scale of those in Figs 1–5. The small numbers (1–28) are those of the wind sampling points used by the writer in a simple wind-tunnel study (Wales-Smith 1984) and are included here to facilitate comparisons. The five stations used here are Nicosia, slightly west of 21 (Nicosia Town), Morphou, just north of 9, Paphos 4, Cape Apostolos Andreas 16, and Akrotiri 1. Five positions (see tops of Figs 1–5) were chosen for the trough axis.

The monthly, average diurnal pressure curves for the five stations were studied and values of pressure change from afternoon minimum to evening maximum were extracted. These values, averaged over the period June to September only, were halved to give estimates of deviation from an assumed, neutral, state when pressure gradients were only those of the seasonal trough (see tops of Figs 1–5). These half-values were: Nicosia, 1.0 mb; Cape Apostolos Andreas, Akrotiri and Paphos, 0.3 mb; and Morphou, 0.5 mb. It was decided, therefore, to use the value 0.3 mb for most of the coastline.

The half-values were subtracted from and added to values in the top sections of Figs 1–5 to yield estimated afternoon and late evening patterns of pressure (centre and bottom parts of Figs 1–5, respectively). It is unfortunate that only one inland station could be included but there is no reason to doubt that summer changes inland are much larger than on the coast. The estimated isobars have been drawn so as to leave the seasonal trough pattern undisturbed except near and over land. No attempt has been made to allow for differences in pressures on north- and south-facing slopes. The study was not extended to the period including the early morning pressure minimum and the forenoon maximum as the difference can not be related, simply, to thermal changes of the sort analysed in this section.

If, following Haurwitz (1947), it is accepted that the 'day' (central) flow patterns of Figs 1–5 are not balanced over the land and if balance is also assumed to be lacking in the 'night' (lower) patterns, cross-isobar flow (or, at least, a large cross-isobar component) would be expected. If, however, the 'neutral' patterns are regarded as being associated with more or less balanced flow then, ignoring the effects of flow over and around mountains and hills, surface winds might be as shown by arrows (Vrb standing for calm or variable).

A noticeable feature of the 'night' patterns is the well-known, nocturnal north-west wind experienced at Larnaca Airport. If this wind were solely katabatic in origin it would be expected to blow from only slightly north of west. The conjectural patterns also suggest that the weakest sea-breezes on the south

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Figures 1–5

Top sections: Surface isobars at ½ mb intervals of a symmetrical trough over Cyprus with axis where shown.

Centre sections: Surface isobars obtained by subtracting the following quantities from pressures indicated in the top sections: Nicosia, 1.0 mb; Morphou, 0.5 mb; Cape Apostolos Andreas, Akrotiri and Paphos, 0.3 mb.

Bottom sections: Surface isobars obtained by adding the following quantities to pressures indicated in the top sections: Nicosia, 1.0 mb; Morphou, 0.5 mb; Cape Apostolos Andreas, Akrotiri and Paphos, 0.3 mb.

Notes: Estimated isobars in centre and bottom sections are drawn so as to leave the basic (top section) trough patterns undisturbed except near and over land. Contours are at 200 m, 500 m and 1000 m.

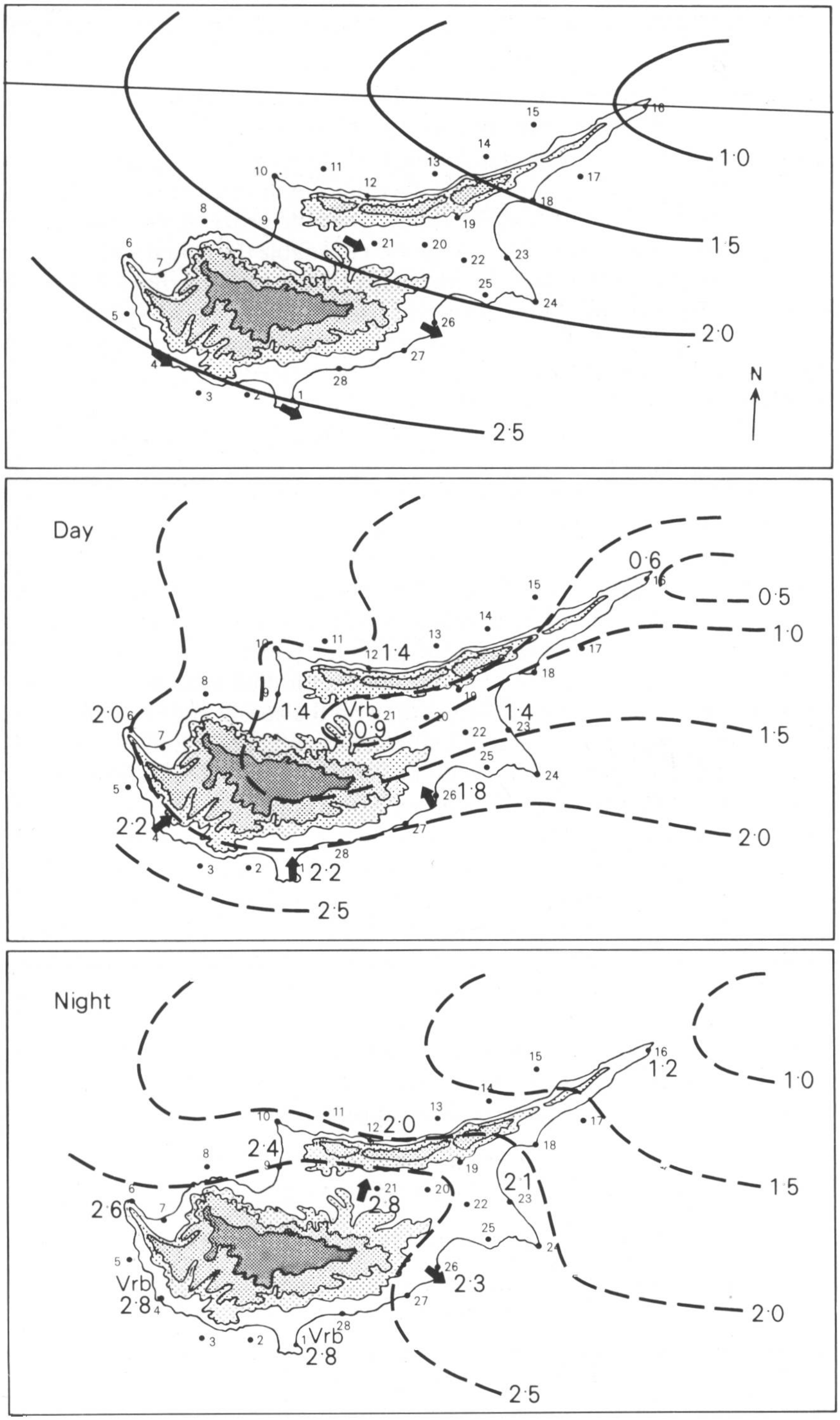

Figure 1. Local flow over Cyprus due to synoptic-scale trough. See page 201.

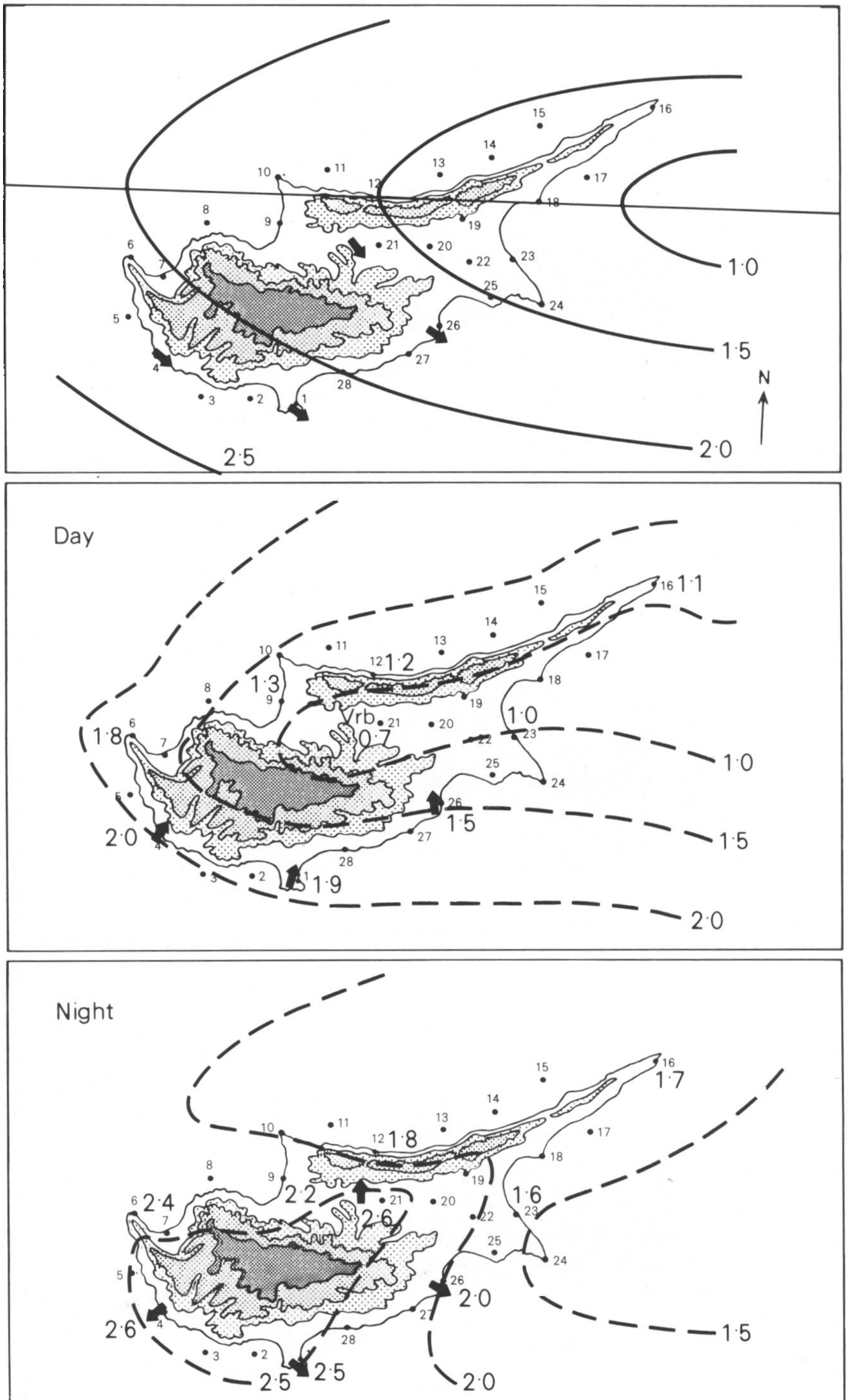

Figure 2. Local flow over Cyprus due to synoptic-scale trough. See page 201.

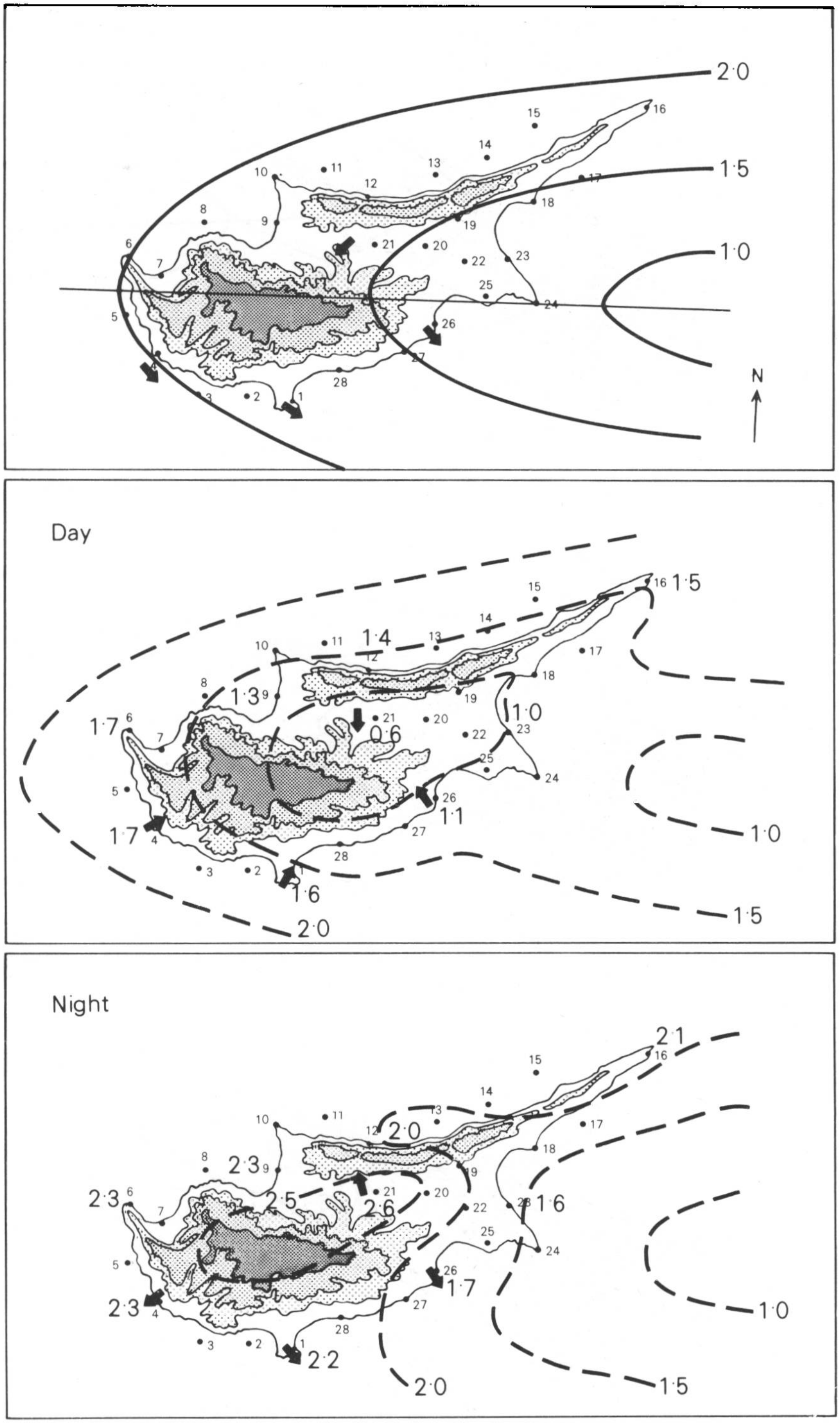

Figure 3. Local flow over Cyprus due to synoptic-scale trough. See page 201.

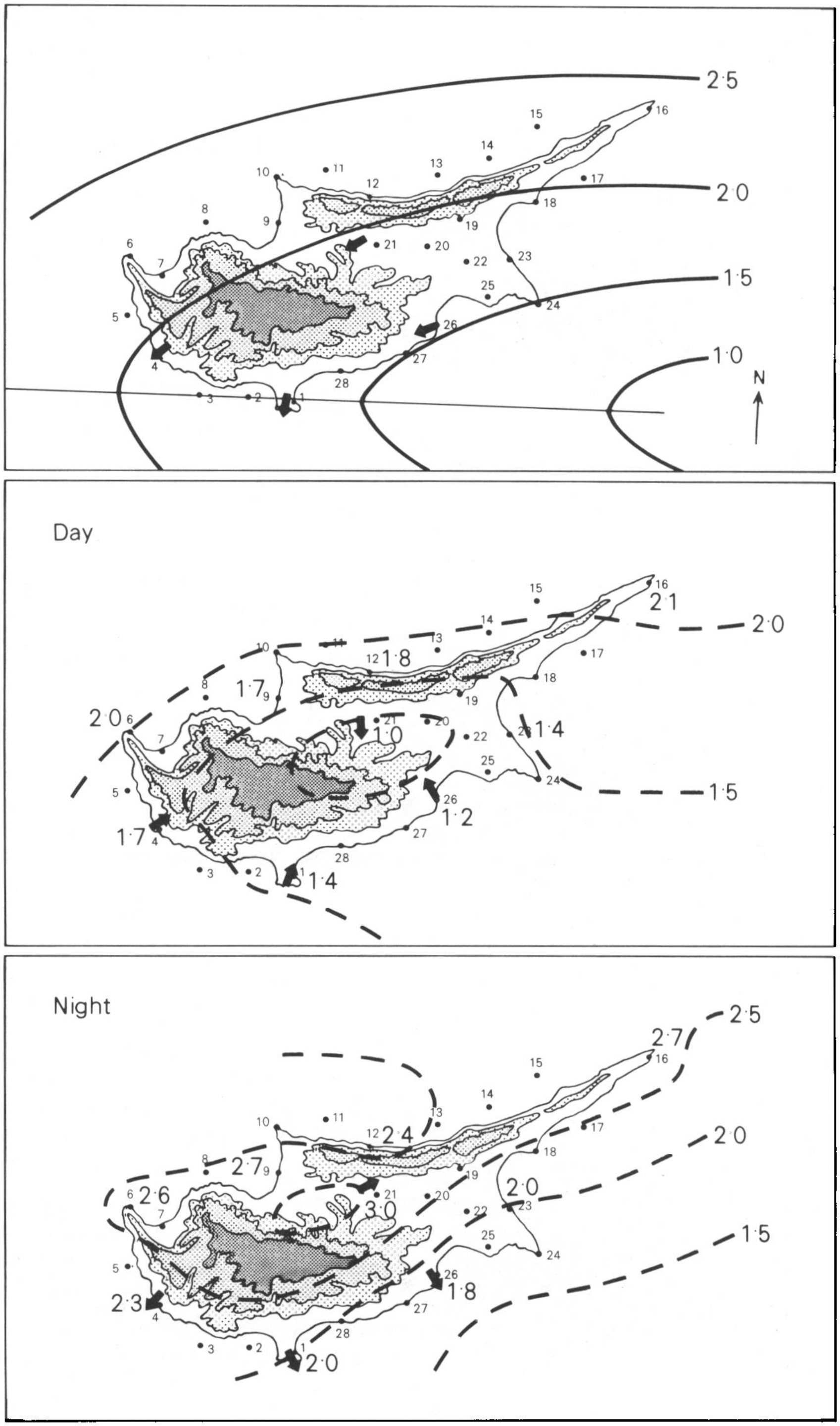

Figure 4. Local flow over Cyprus due to synoptic-scale trough. See page 201.

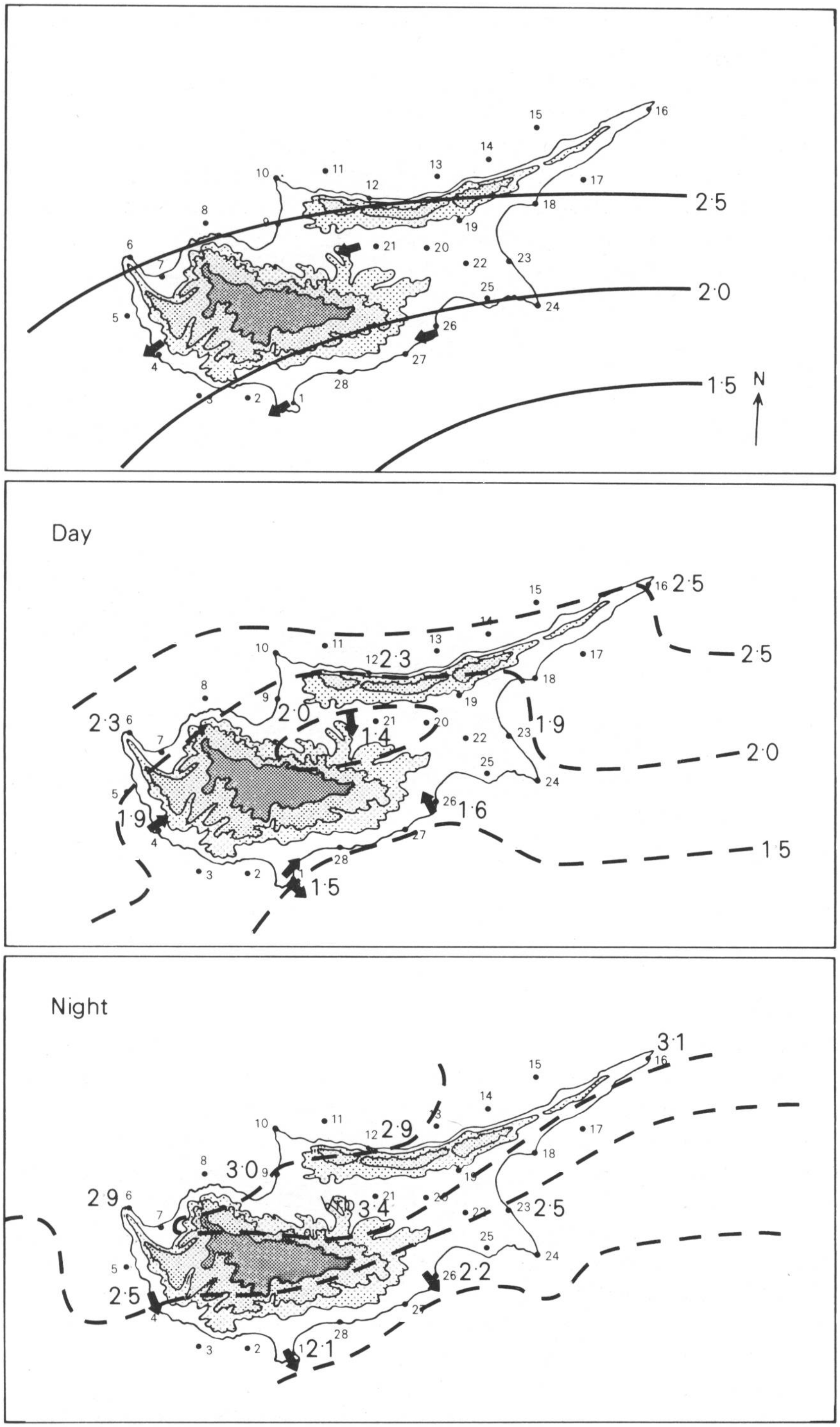

Figure 5. Local flow over Cyprus due to synoptic-scale trough. See page 201.

coast should occur when the axis of the trough is well south of the centre of the island and vice versa, modelled results which accord with experience.

No attempt has been made to study conjectural flow patterns involving other types of synoptic-scale pressure systems because of the uncertainties involved.

It is suggested that this very simple technique can be used as a contribution to understanding diurnal surface wind components wherever three-hourly average mean sea level pressure data are available from sufficient locations for the same period of years. It is probably most suited to studies of large islands and peninsulas but there seems to be no good reason why it should not be applied to areas including continental coastlines.

Acknowledgement

The writer acknowledges, with gratitude, the tedious data-extraction and arithmetic performed by his, unknown, colleagues without whose efforts this study would not have been carried out so easily.

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551.507.362.2:551.510.42:551.575.5(430.1)

Advection of fume and smog (scanned by satellite) over hundreds of kilometres

By H. Schulze-Neuhoff

(German Military Geophysical Office, Traben-Trarbach)

Poor visibility in the vicinity of emission sources is well known, for example Krames (1981). During autumn 1983 several examples have been evaluated in surface observations showing industrial haze (fume) in relatively small but long belts, similar to roads, downstream of the 'Ruhr area' (see Fig. 1) or other industrial centres. The fume is not visible in satellite pictures normally, but on 7 November 1983 a 'smog road' was shown by a low stratus cloud belt extending from Magdeburg towards Hanover (see Figs. 2 and 3). A secondary, smaller and more diffuse, belt parallel to this primary phenomenon and spreading west-north-westwards seems to be originated by the industrial area near Salzgitter.

Fig. 4 shows the synoptic chart from the Interactive Graphical System at the German Meteorological Geophysical Office (Gemein *et al.* 1982). The smog road from Magdeburg towards Hanover and the fume road from Hanover towards Emden is indicated by weather observations and visibility. One hour later the small low stratus belt had dissolved by insolation.

Smog is assumed here as being defined by visibility less than 1 km, primarily produced by industrial particles and secondarily by meteorological facts like radiative cooling and a subsidence inversion over wet ground.

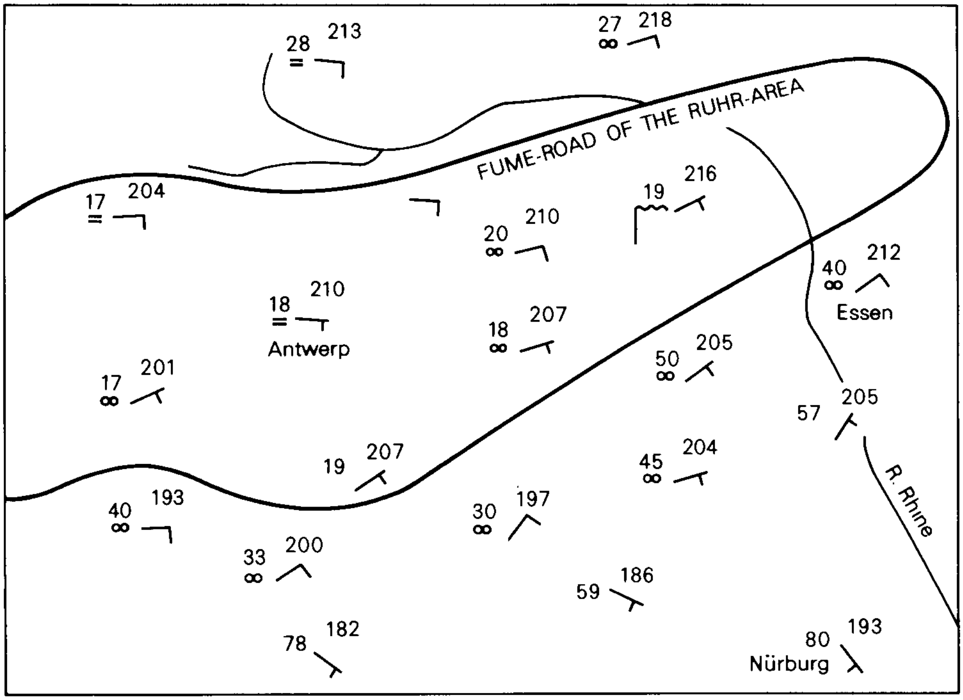
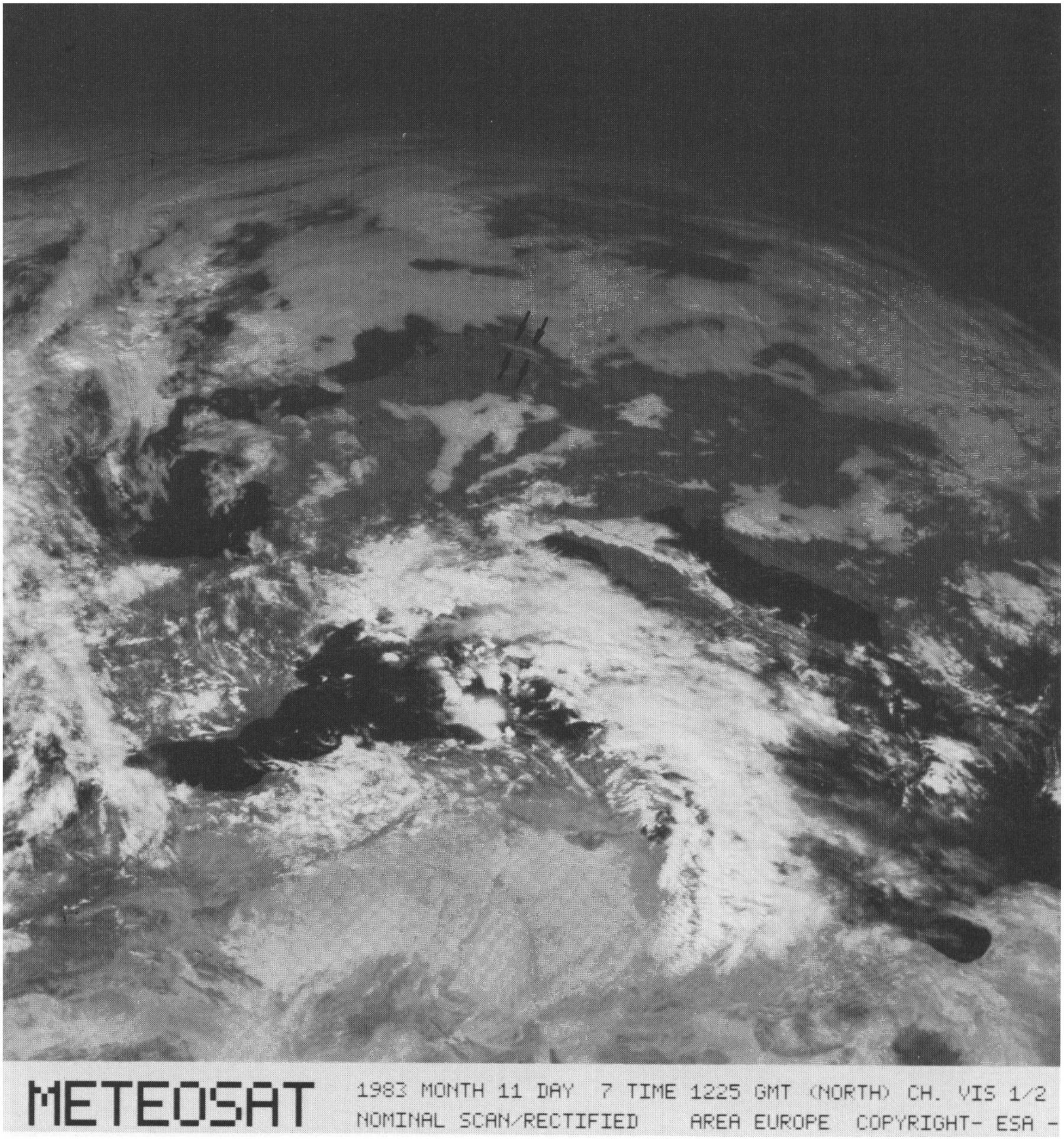


Figure 1. Surface observations (pressure, wind and visibility) for 1300 GMT 28 September 1983. The 'fume road' is shown by observations of visibility equal to or less than 2 km.

References

Gemein, H. P., Engel, M. and Schiessl, D. 1982 An operational interactive graphics system. Fachliche Mitteilungen Nr203. Herausgeber Amt fur Wehrgeophysik, Traben-Trarbach.

Krames, K. 1981 Auswirkungen von Emission auf die Flugsicht (Consequences of emissions to the flight visibility.) *Promet*, **4'81**, 16–19.



Photograph by courtesy of European Space Agency

Figure 2. Satellite (Meteosat 2) visual photograph for 1230 GMT 7 November 1983. The 'smog road' extending from Magdeburg to Hanover is marked.

Figure 3. Satellite (NOAA 7) visual photograph for 1257 GMT 7 November 1983. (The grey scale used in the picture is non-linear optimized to maximum contrasts.)

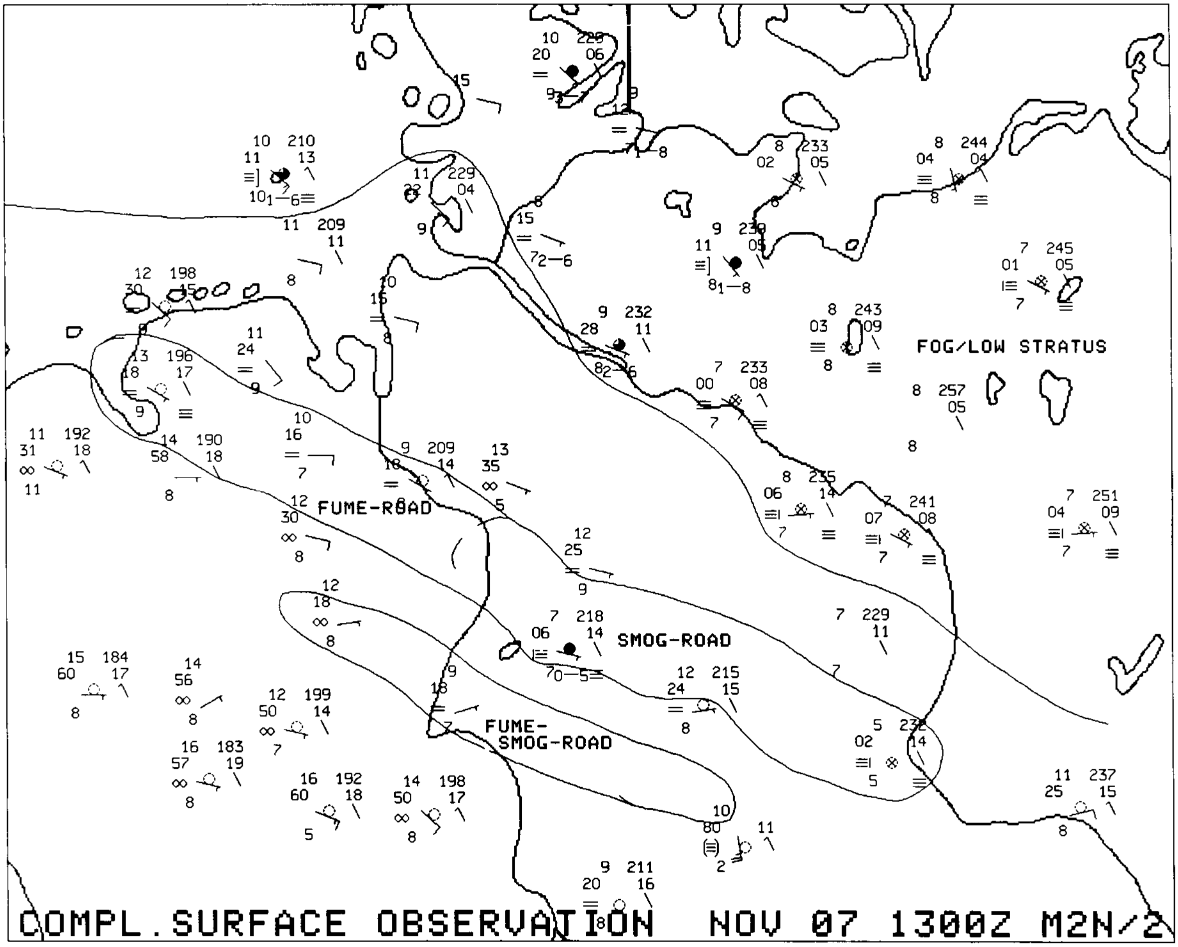


Figure 4. Plotted observations for 1300 GMT 7 November 1983 as produced by the Interactive Graphical System at the German Meteorological Geophysical Office, Traben-Trarbach.

Reviews

Introduction to environmental remote sensing (second edition), by E. C. Barrett and L. F. Curtis. 185 mm × 245 mm, pp. xiii + 352, *illus.* Chapman and Hall Ltd., London, 1982. Price £12.95.

The field of remote sensing has undergone an explosive growth in the last decade. Even in 1976, the year of the first edition, the attempt to encapsulate a wide-ranging and fast-moving subject in a book such as this must have been a bold one. By the time of the second edition, the field had grown and changed in such a way that the authors' attempt to provide 'a balanced and integrated introduction for the relative newcomer' was bound to be, at best, a partial success. There are now so many aspects to the principles, practice and application of remote sensing that it is very difficult to provide a summary of each facet which is both balanced in emphasis and up to date.

The book contains 19 chapters grouped in two main parts: 'Remote Sensing Principles' followed by 'Remote Sensing Applications'. Part I, however, deals not only with the scientific principles involved (which should require little updating) but also with the instruments and data interpretation techniques used, where continuing advances in sensor technology and data processing capability have opened up new avenues of exploration. Part II attempts to catalogue the applications grouped roughly according to scientific discipline.

After a preliminary chapter which introduces a few commonly used terms and discusses briefly the economics of remote sensing, Chapter 2 tackles the physical bases of remote sensing. It attempts to be fairly complete with discussions of the electromagnetic radiation and its spectrum and of the basic processes of emission, scattering, absorption, refraction, reflection and transmission of radiation. It is a disappointing chapter in that it contains several erroneous and misleading statements in an area of well-established theory where the fast-moving nature of remote sensing in general cannot serve as an excuse. For example, the Rayleigh–Jeans limit of the Planck function is incorrectly presented as a special case of Stefan's law. Also the discussion on the concept of emissivity neglects to mention its potential variation with wavelength and so misstates the definition of a 'grey' body. Consequently this chapter does not provide a very clear introduction to radiation theory.

Chapter 3 is considerably better and gives a brief but balanced overview of the spectral characteristics of the atmosphere, clouds and the earth's surface. The next chapter gives, again, a balanced and generally accurate introduction to the types of sensors used, including photographic and vidicon cameras, infra-red radiometers and spectrometers, active and passive microwave sensors and lidars. Chapter 5 gives a brief account of the different potential platforms for remote sensing devices, ranging from ground-based platforms, aircraft, balloons and rockets to satellites in different types of orbit. This is followed by a more detailed description of the Landsat system and of Spacelab and Shuttle.

Chapters 6 to 9 turn to the subject of data. Firstly, the collection of *in situ* data is covered, and its use in the interpretation of remote sensing data is discussed. The need for good quality 'surface truth' data is stressed. Also the use of satellite-borne data collection systems for relaying *in situ* data from remote sites is described. Turning to remotely sensed data, some important concepts are introduced: the difference between photographs and images, and between analogue and digital data. This is followed by a more detailed discussion of photographic processing and enhancement techniques and the conversion between optical and digital data. Chapter 8 covers the manual analysis and interpretation of data including methods of photo-interpretation and photogrammetry. Chapter 9 tackles the area of numerical data processing and analysis. In view of the growing importance of this field, this chapter is perhaps too brief and consequently makes some sweeping generalizations which are not valid for all satellite data types. The introductions to quantitative feature extraction and classification techniques are good in so far as they go, but one feels that the authors might have included a discussion of the concepts of information content and retrieval.

Part II starts with two chapters on 'weather analysis and forecasting' and 'global climatology' which are, perhaps, the areas to which most readers of this review would hope to look with interest. The first chapter is disappointing. Although the updating required to reflect recent satellite developments has been performed in some areas, in other places the description still refers to the status at the time of the first edition. A more important failing, however, is the discussion of applications, which does not reflect the current balance in the use of satellite data. A disproportionate amount of space is devoted to the art of manual nephanalysis, without mentioning that the growth of this practice was largely as a substitute, reflecting the past inability to provide forecasters with a good quality satellite image (or, in many cases, with any image at all). The chapter on global climatology is better balanced but suffers from a lack of infusion of recent material, the most recent reference in the section on radiation budget being 1971. This chapter also discusses briefly other aspects of global climatology under the headings atmospheric moisture (water vapour, clouds, rainfall), wind flows and air circulations, synoptic weather systems, and the middle and upper atmosphere. The emphasis is on the techniques used rather than on their role in understanding climate.

Chapter 12 provides an interesting review of 'water in the environment': radar monitoring of precipitation, ice and snow monitoring and evaporation estimation, followed by surface hydrology, hydrogeology and oceanography. The last of these covers water (surface) temperature and circulation patterns, water quality and salinity assessments, together with a description of the oceanographic satellite, SEASAT. This is quite comprehensive, although the description of sea surface temperature measurement is in need of updating.

The chapters on 'soils and landforms' and 'rocks and mineral resources' provide an interesting introduction for the non-earth scientist. Similarly, Chapters 15 and 16 on 'ecology, conservation and resource management' and 'crops and land use' are very readable. One impression which emerges from these sections is the degree to which remote sensing of these very complex land systems relies on empirical methods to a greater extent than in the disciplines of meteorology and climatology.

Chapter 17 covers the built environment and highlights some of the problems peculiar to monitoring urban areas. This is followed by a short review of 'hazards and disasters' which is mainly devoted to meteorological applications. The final chapter, 'problems and prospects', contains a plea, which will be echoed by all satellite data users, for the controlling agencies to keep the data cheap and accessible if they wish to see effective exploitation of the large investment in satellite hardware.

Throughout the book the standard of illustration is high with numerous images (both monochrome and colour) and diagrams. Indeed the problem of fitting in all the illustrations often leads to their separation from the relevant text — a minor irritation well worth bearing. Less helpful is the 'bibliography'. This is in fact a list of references cited in the text. Because this is an introductory work which often tempts the reader to inquire beyond the brief discussion possible on any particular subject, it would have been most useful to have provided a list of more detailed review papers in each area to which the reader could refer as a gateway to the relevant literature.

At the outset, the authors state as their target 'a realistic introductory survey of environmental remote sensing for students, scientists and decision makers'. With the exception of Chapter 2 and deficiences in some areas caused by lack of appropriate revision, the book largely succeeds in reaching this goal. In particular it provides a window on to the diverse range of disciplines in which remote sensing is now poised to make a significant contribution.

J. R. Eyre

Satellite microwave remote sensing, edited by T. D. Allan. 160 mm × 245 mm, pp. 526, *illus*. Ellis Horwood Limited, Chichester, 1983. Price £45.00.

This book is a collection of papers on the European contribution to the verification and use of SEASAT data. This research was co-ordinated by the SEASAT Users' Research Group of Europe (SURGE), through the European Space Agency (ESA). The flyleaf informs us that its intended readership is 'marine scientists, meteorologists, offshore operators, geodesists, military planners and those interested in all aspects of satellite technology at research, undergraduate, postgraduate and professional level... those involved in marine resources and transport'. Has anyone been left out?

SEASAT was an experimental polar orbiting satellite launched in June 1978, failing suddenly after three months. It carried five sensors, four of them operating at microwave frequencies: a scatterometer to measure wind-vectors over the ocean, an imaging radar, a radar altimeter and a microwave radiometer. The fifth instrument was a conventional visible/IR imager. SEASAT was the first satellite dedicated to oceanographic applications and its suite of microwave sensors allowed continued coverage by day or night, in cloudy or clear conditions. There was great European interest in this American venture, and under the wing of ESA, the UK tracking station at Oakhanger was modified to receive SEASAT telemetry. The SURGE members have used data from this source for their validation of SEASAT products over Europe and the Atlantic. It was a coincidence that the Joint Air–Sea Interaction (JASIN) experiment took place during the lifetime of SEASAT: the surface data measured by the ships and buoys have been used extensively to validate the wind and wave data as deduced from SEASAT.

The book is divided into six parts. These deal in turn with a review of SEASAT and the background to the European contribution, followed by papers on each of the four microwave sensors. It ends with a review of the European oceanographic satellite, ERS–1, which will carry the next generation of similar instruments. There is a total of 31 chapters, each written by an expert in their field: most of the contributors are from Europe, but some were invited from the United States and Canada. Often this approach can lead to overlapping of material or missing information which each author has assumed will be covered by another. In this case, however, the Editor has done an excellent job in ensuring that while each paper can be read as a complete entity (thereby making this work handy as a reference book), there is a minimum of repetition. Every chapter is liberally sprinkled with diagrams (and imagery where appropriate) and has individual reference lists. There are several colour plates and a comprehensive index.

By far the largest section deals with the Synthetic Aperture Radar (SAR), with several chapters devoted to various theoretical topics of SAR imaging mechanisms. Others discuss image content over sea and land, and wave spectra deduced from ocean images. The second largest topic is the Radar Altimeter and the assessment of the satellite tracking accuracy, ocean geoid and wave measurements. The remaining two instruments, the wind scatterometer (SASS) and microwave radiometer (SMMR) have only two chapters each, detailing the derived product accuracies with JASIN measurements. It is a pity that these instruments do not have a more extensive discussion of their potential use. Can it be coincidence that data from the SASS and SMMR would be of most interest to the operational meteorologist? The book is very biased towards research applications of the SEASAT payload, probably reflecting general European interest, through SURGE, in the SEASAT project. (The Meteorological Office, although greatly interested in the SASS, was not a member of SURGE.)

In conclusion, if any of the previously mentioned readership were to obtain this book, most of them would find something of interest. It is a book that can be used as a reference work, or to gain an understanding of the capabilities of the types of instrument carried by SEASAT (and by several future satellites now being planned) or just as an introduction to microwave remote sensing.

D. Offiler

Introduction to climatology for the tropics, by J. O. Ayoade. 152 mm × 230 mm, pp. xv + 258, *illus.* John Wiley & Sons, Chichester, New York, Brisbane, Toronto, Singapore, 1983. Price £6.95 paperback, £14.95 cloth.

The author's stated aim is to provide a basic text on the fundamental principles of climatology for students or teachers of geography and related environmental sciences in the tropics. It is probable that readers new to the subject would be disturbed by the numerous (over 300) errors that have unfortunately escaped the attention of the referees and proof-readers. Many of these errors are trivial and repetitive; for instance, none of the isotherms over Antarctica in the mean chart for July has a negative sign attached to its value, the wind speeds on the hodograph are misplaced by five knots, and some of the heights and saturated humidity mixing ratio values on the tephigram are wrong. Such slips may cause only a momentary hesitation in the student's reading, but a succession of them will undoubtedly cause him to lose confidence in the author. Some of the mistakes, however, are a little more fundamental and may lead to misunderstanding. Examples of these are the statement that a tropical cyclone consists of two vortices separated by a central calm area, the omission of two separate zeros leading to '50' mb being approximated to '560' m above mean sea level, and the uncritical copying of Stepanova's mistranslation of Budyko's radiation units, which are reproduced on many occasions as kg cal/cm^2 instead of kcal/cm^2.

A basic fault in the layout of the book is the placing of the chapter on atmospheric moisture after those on atmospheric circulation and weather-producing systems. One of the results is that the student will find himself comparing the properties of stable and unstable air masses before knowing what these words mean.

Despite the inaccuracies Dr Ayoade has covered most of the ground necessary to reach his objectives. He has included a fuller examination of the radiation budget than may be found in most books at the same level, and this is a great asset. His treatment of climatic change is slightly more extensive than usual, which is also valuable, but he seems to have been drawn by an excess of enthusiasm into a longer dissertation on the relative merits of different climatic classification schemes than is perhaps warranted in a work of this size.

The book is clearly printed and great care has been taken to ensure that the diagrams and tables are as close as possible to the portion of text which refers to them. Equations (which some geographers might be apprehensive about) are well set out and all the variables are fully defined. I think that the book does fill a somewhat awkwardly shaped slot, and I hope that there will be a second (extensively revised) edition.

B. N. Parker

From weather vanes to satellites: an introduction to meteorology, by Herbert J. Spiegel and Arnold Gruber. 210 mm × 275 mm, pp. xi + 241, *illus.* John Wiley & Sons, New York, Chichester, Brisbane, Toronto, Singapore, 1983. Price £12.20.

Any author who sets out to simplify a science, endeavouring to put a complex subject into language that a non-scientist can understand, immediately lays himself open to much criticism. He either has to oversimplify fundamental concepts and risk the scorn of his colleagues, or spend most of the text explaining technical jargon as well as the processes involved and thus obscure an overall view of the subject. Messrs Spiegel and Gruber have largely overcome these problems by steering a course between the two extremes and have produced a well thought out guide to the subject. The reader is taken on a logical progression of topics in attractively laid out chapters, each preceded by a list of objectives which a student would find quite helpful.

There are, however, several things wrong with the text and these must be weighed against the book's good points. Some are no doubt typographical errors which are mere irritations to someone who is familiar with the subject but which could be quite misleading for anyone who is learning new things. For example, on page 87, 'counterclockwise' instead of 'clockwise' for winds around a high-pressure system: page 114, Figure 10–9a, isobar 1018 should be 1008; page 175, under tropical cyclone, 'density' should read 'intensity'.

A few major errors also appear. For example, on pages 46 and 47 the explanation of stability and instability using Figure 4–10 comes out the wrong way round and this, coupled with a misleading guide to instability assessment in Exercise 9 (page 216), means that the readers' concept of instability will be very inadequate. It so happens that Exercise 9 has already come to grief owing to an error in the upper-air temperatures given in the text.

There is a real need for a book of this sort to be checked thoroughly before it is released, otherwise the people it is supposed to help are in fact misled.

It is unfortunate that a book published in 1983 should still use the old synoptic code — the new code was introduced in January 1982.

Also British readers (at least the younger among us) who have become used to SI units will be frustrated by the American predilection for 'English units'. The authors note in the preface that there is a 'national trend toward the metric system' but at present the reader is still left in a quagmire of different units.

Most of the diagrams are clear and helpful, although one or two could be misleading. For example, Figure 10–2 certainly illustrates the point that windflow in an anticyclone is divergent but it also suggests that the winds blow perpendicularly to the isobars. Also the computer-drawn charts, especially in chapters 12 and 13, leave much to be desired.

The main section of the book is followed by a series of exercises which help the reader to assimilate some of the ideas put forward in the text. This is a worthwhile item in a textbook of this sort.

There is a useful glossary that includes most of the technical words used in the text, although a few of the explanations are rather too short. However, the whole is rounded off by, what is essential in a book of this kind, a very good index.

The book has many good features. It provides a basic course in meteorology suitable for educated non-scientists. A teacher who could eliminate the errors could base a sixth form or college course upon it, although he would need to prepare his own material on air masses affecting the British Isles.

J. R. Grant

Books received

Hydrodynamic instabilities and the transition to turbulence, edited by H. L. Swinney and J. P. Gollub (Berlin, Heidelberg and New York, Springer-Verlag, 1981. DM 96) is volume 45 in Topics in applied physics and is a collaboration between physicists, mathematicians and fluid dynamicists, each of whom is a recognized leader in the field. The various chapters include: introduction to the relationship between dynamical systems theory and turbulence; a review of hydrodynamic stability and bifurcation theory; three case studies — convection, rotating fluids, and shear flows; a review of the many types of instabilities that occur in geophysics; and a discussion of instabilities and chaotic behaviour in non-hydrodynamic systems.

Mountain weather and climate, by Roger G. Barry (London and New York, Methuen, 1981) provides a comprehensive study of meteorological and climatological phenomena in the mountain areas (some 30% of the land surface of the earth) of the world. After an introductory chapter there are chapters on: geographical controls (latitude, altitude and topography) of mountain meteorological elements; circulation systems; and the climate characteristics of mountains. These are followed by case studies of selected mountain climates; a chapter on human bioclimatology, weather hazards and air pollution; and the book finishes with a chapter devoted to changes in mountain climates.

Climate from tree rings, edited by M. K. Hughes, P. M. Kelly, J. R. Pilcher and V. C. LaMarche Jr (Cambridge, London, New York, New Rochelle, Melbourne and Sydney, Cambridge University Press, 1982. £18.50) is based largely on material presented at the Second International Workshop on Global Dendroclimatology, Norwich, 1980. The detailed findings of the Workshop have been presented in the Report and recommendations (Hughes *et al.* 1980). Instrument records of climate variables are sparse before the beginning of the 20th century. Tree growth, and in particular tree rings, records responses to a wide range of climate variables, over a large part of the earth, going back several centuries.

The Guinness book of weather facts and feats, by Ingrid Holford (Guinness Superlatives Ltd, Enfield Middx, 1982. £8.95) is the second edition of this book first published in 1977. This second edition has been comprehensively updated, revised, redesigned, and almost totally reillustrated with nearly 200 black and white photographs and 16 pages in full colour. A new topic, micro-climate, has been introduced and more detail included about weather satellites and forecasting methods.

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