



# THE METEOROLOGICAL MAGAZINE

HER MAJESTY'S  
STATIONERY  
OFFICE

July 1983

Met.O. 958 No. 1332 Vol. 112



# THE METEOROLOGICAL MAGAZINE

No. 1332, July 1983, Vol. 112

---

551.509.313:551.576.11

## **Analyses of moisture and convective activity from cloud, visibility and present weather reports**

By A. G. Higgins and P. R. W. Wardle

(Meteorological Office, Bracknell)

### **Summary**

Techniques have been developed to obtain analyses of the cloud water mixing ratio of stratiform clouds from cloud, visibility and present weather reports, and to identify and analyse convective activity. This paper describes two techniques and presents some examples of the analyses. One application of the work is in the enhancement of initial fields for the mesoscale numerical forecast model.

### **1. Introduction**

A mesoscale forecasting system is being developed in the Forecasting Research Branch of the Meteorological Office for short-range (6-24 hours) forecasting for the UK area. Although the forecast model has been in existence for some time as a research tool (Tapp and White (1976) and Carpenter (1979)) effort has recently been concentrated towards producing an operational system. The most notable change introduced in recent years has been the inclusion of moist processes, the original model being dry.

In order to obtain greater detail in the initial data analyses for the mesoscale model, research has concentrated on techniques of extracting information from some of the elements of surface observations hitherto unused in numerical forecasts and interpreting them in terms of model variables. At present, initial fields for the mesoscale model are interpolated from data for the new 15-level fine-mesh model recently introduced into operational use. The fine-mesh model has a grid length of about 75 km compared with the 10 km grid length of the mesoscale model. Whereas an array of only 12 x 14 grid points cover the UK on the fine-mesh grid, there are 90 x 100 points on the mesoscale grid, see Fig. 1. It is hoped that the use of up to 200 surface observations hourly should enable mesoscale detail to be added to the interpolated fields. One such technique is the enhancement of model fields of moisture by an analysis of present weather, cloud and visibility observations to infer information regarding cloud water mixing ratio of layer clouds. Another is the analysis of present weather and cloud reports to identify areas of convective activity. The model may then be 'forced' to convect in these areas with an intensity in keeping with what has been observed.



Figure 1. 90 x 100 grid for mesoscale analyses.

This article describes these two schemes and gives examples of the kind of output that they make available to the model, (or, if used operationally, to the bench forecaster). The schemes inevitably depend on a considerable degree of empiricism, but results obtained so far are encouraging.

## 2. Cloud water mixing ratio of layer cloud

Cloud water mixing ratio (CWMR) and humidity mixing ratio (HMR) are the moisture variables used by the cloud and rainfall parametrizations of the mesoscale model. Values of CWMR can be estimated from observations of cloud, present weather and visibility. Observations within the mesoscale model grid are first selected from a given hourly data set within the operational synoptic data bank. Observations of cloud amount, cloud base, visibility and precipitation rate are interpolated on to grid points using an analysis program devised by Purser and McQuigg (1982), described in Section 4. This process spreads the information from the observing stations on to the entire mesoscale grid in a controlled manner.

Cloud amounts are used directly as reported; cloud bases are converted to metres and the station height added on before analysis. For visibility, only values within fog limits (i.e. less than 1000 m) are of interest since above this limit the CWMR is very small. Observed visibilities are converted to CWMR using a relationship based on Eldridge (1971).

$$\log_{10} W = -1.55 \log_{10} V - 5.46$$

where  $W$  is CWMR in kilograms of liquid water per kilogram of dry air and  $V$  is the visibility in kilometres. A visibility of 100 m corresponds approximately to the CWMR of stratus type cloud.

Conversion of present weather into a dynamical rainfall rate is achieved by assigning mean precipitation rates to present weather code values that indicate dynamical rainfall, using extensions to the specification of rainfall rate from the *Observer's handbook* (Meteorological Office 1982). The rates are shown in Table I.

**Table I.** Mean precipitation rates for dynamical rainfall

Present weather code	Mean rate (mm h <sup>-1</sup> )
50,56	0.05
51	0.10
52	0.15
53,57,58,60,68,70	0.25
66	0.35
54,61,71,77,79	0.50
55	0.75
59,62,72	1.00
63,67,69,73	3.00
64,74	4.00
65,75	7.00

Then, using the formulation described below, a cloud depth is computed from the precipitation rates.

The stratiform rainfall scheme used in the mesoscale model may be written

$$-\frac{\partial P}{\partial z} = M(z) \left\{ \alpha + \gamma P(z) \right\} \left\{ 1 - e^{-(M/M_0)^2} \right\}$$

where  $P$  is the rainfall rate,  $M(z)$  is the CWMR and  $\alpha$ ,  $\gamma$ ,  $M_0$  are constants.

If this is discretized with constant  $\Delta z$ , and  $M$  is assumed independent of  $z$ , the total rate of rain at the bottom of a cloud may be written

$$P = \frac{\alpha}{\gamma} \left\{ (1 + \gamma \hat{M} \Delta z)^n - 1 \right\}$$

where  $\hat{M} = M \left\{ 1 - e^{-(M/M_0)^2} \right\}$ .

This formula may be inverted to give

$$H = \Delta z \frac{\log \left( \frac{P\gamma}{\alpha} + 1 \right)}{\log \left( 1 + \gamma \hat{M} \Delta z \right)}$$

where  $H = n \Delta z$ , as an approximate relationship between rainfall rate and cloud depth ( $H$ ). In the computations presented,  $\Delta z = 500$  m,  $M = M_0 = 0.5 \times 10^{-3} \text{ kg kg}^{-1}$ ,  $\alpha = 10^{-4}$  and  $\gamma = 1.0$ .

The next stage is to combine the four analyses (cloud amount, cloud base, visibility and rainfall rate) to produce a three dimensional picture of CWMR. The computer program checks each grid point in turn, looking first for a cloud amount of five oktas or more. If this criterion is not satisfied, the CWMR remains set at zero, at all model levels, for that particular grid point and the program moves on to the next point. However, if the cloud amount criterion is satisfied, the program goes on to examine the precipitation analysis.

If the rainfall rate is less than  $0.1 \text{ mm h}^{-1}$ , a CWMR value for non-precipitating layered cloud (see Table II) is assigned only to the nearest model level above the cloud base. If a value greater than  $0.1 \text{ mm h}^{-1}$  is found, the cloud depth is computed, from the formula above, and the CWMR value for precipitating layered cloud (see Table II) is then assigned to all model levels throughout the estimated depth of the cloud. The final stage is to add the contribution of CWMR from the visibility analysis to the bottom level of the model, completing the picture described above.

These techniques can be reversed so that, if forecast CWMR data are available, values of rainfall rates, visibility, cloud base and cloud tops can be output.

**Table II.** *Assigned CWMR values,  $\text{kg kg}^{-1}$*

No layered cloud/No precipitation/No poor visibility	Zero
Non-precipitating layered cloud	$5.0 \times 10^{-4} \times \text{cloud amount in oktas}$
Precipitating layered cloud	$5.0 \times 10^{-4}$

Examples of the output from this scheme are shown in Figs 3, 4, 6, and 7 described in Section 5.

### 3. Analysis of convective activity

The purpose of this analysis is to identify areas of convective activity, of different intensity, in much the same way as a bench forecaster might pick out areas of interest from an hourly chart. Convective activity is by its nature a local effect whereas dynamical layered cloud and precipitation are of a more widespread and continuous nature. Hence, a different approach is required from that in the previous section.

The scheme uses a short scale of intensities, from zero to five, defined in Table III. It examines reports of present weather and cloud (both main and subsidiary 8-groups) to allocate an intensity to each observation. An observation containing none of this information is discarded. A zero intensity does not imply no weather or cloud, simply that any reported weather is not of a convective nature.

**Table III.** *Convective intensity definitions*

Intensity	Definition	Indicator
5	Thunderstorm at time of observation	ww = $\geq 95$
4	Thunderstorm in last hour	ww = 29, 91–94
3	Moderate/Heavy/Violent shower at time of observation	ww = 81, 82, 84, 86, 88–90
2	Slight shower at time of observation	ww = 80, 83, 85, 87
	Adjacent showery activity	ww = 13–17
	Shower in last hour	ww = 25–27
	Cumulonimbus at time of observation	C = 9
1	No precipitation:	
	Altostratus reported	$C_M = 8$
	$\geq \frac{1}{8}$ cumulus reported	$N_S \geq 3$ when $C = 8$
0	Any other reports	Any other code figures

#### Notes

ww is Present weather code (Table 4677)

C is Cloud genus code (Table 0500)

$C_M$  is Cloud genus code for 'medium-level' cloud (Table 0515)

$N_S$  is Amount of cloud mass of genus C code (Table 2700) (World Meteorological Organization)

Observations are considered station by station and are first examined for the indicators described in Table III. An intensity value is then assigned to each observation. Where convective cloud is found, a cloud base height is also assigned, a background value of 4500 m being assigned where no information is available. When all observations have been examined the intensity field is analysed using Purser and McQuigg's scheme, as in the previous section, allocating a value to every grid point. These values represent a potential for convection, showing regions of activity, see Fig. 8. The next stage is to decide at which grid points, within a particular region of intensity, that type of convection, e.g. heavy showers, is actually occurring. To do this a statistical approach is adopted to introduce a random element into the distribution of showers.

This random effect is produced by calling up pseudo-random numbers from a subroutine within the computer (RNDM (X)), the distribution of variables being from the uniform distribution in the range 0 to 1. By varying the value of a test statistic, different chances of an occurrence can be modelled thus reflecting the different expectancies of convective activity. Test statistics currently used are shown in Table IV.

As an example, consider an area of heavy shower activity within which area all grid points will have been allocated an intensity of three at the analysis stage. A random number is then called up for each grid point. If that number is greater than 0.875, the appropriate test statistic for heavy showers, then a heavy shower is deemed to be occurring at that point. If the number is equal to or less than 0.875, then there is no shower at that point.

The test statistic varies according to the intensity at the grid point being considered. Hence if the intensity is four or five, the test value used is 0.9. All grid points analysed as having an intensity value of one are used as such at the next stage of the scheme with no randomization.

**Table IV.** *Chances of occurrence of convective activity*

Intensity	Definition	Chance	Test statistic
5/4	Thunderstorms	1 in 10	RNDM(X) > 0.9
3	Heavy showers etc.	1 in 8	RNDM(X) > 0.875
2	Showers	1 in 4	RNDM(X) > 0.75
1	Non-precipitating convective cloud	—	Any

In due course, the separation and occurrence of showers, cumulonimbus, etc., may be taken directly from satellite and radar observations.

The scheme then goes on to assign a cloud depth to each grid point at which convection is deemed to be occurring according to the intensity at that point. An empirical approach is used, based on general convective theory; values are shown in Table V.

**Table V.** *Cloud depths*

Definition	Depth
	<i>metres</i>
Thunderstorms	8000
Heavy showers etc.	5000
Light showers	3000
Cumulus reported, no precipitation	2000

The final stage of the scheme involves the analysis of cloud base heights, these being converted to metres and station heights added before analysis. The analysed height and depth fields are then combined to give a cloud top field. All these analysed fields are then available to the mesoscale forecast model so that there may be a forcing of the model towards the intensity and depth of convection reported.

#### **4. Analysis scheme**

The analysis routine used by both these schemes is described in detail in Purser and McQuigg (1982) and was designed specifically for mesoscale analysis. It uses a successive correction technique in which modifications to an initially uniform field are obtained using recursive filters. These filters permit a detailed control of the scales present in the final analysis. They have a one-sided exponential decaying shape and are applied twice in each coordinate direction giving an approximately Gaussian spread of the information. The initial magnitude of the adjustment at each scan is obtained by bilinearly weighting each observation at the surrounding four grid points. The smoothing is then governed by a range parameter which is initially set large enough to define the large scale pattern in areas of sparse data and is then progressively reduced to a specified limiting value subject to there being sufficiently dense data to describe these scales. For 'rough' information like cloud observations, the initial range is set to seven grid lengths (70 km) and the limiting range is two grid lengths (20 km). The final analysis will then consist of scales greater than a minimum ranging from 20 km in data-rich areas to 70 km in areas of sparse data.

The analysis scheme also contains a quality control facility based on comparison of an observation with the latest scan. The prime intention of this process is to reject spurious data. However, the discontinuous nature of some of the variables being analysed, such as cloud amount data, has led us to accept all observations reaching the analysis stage.

#### **5. Output examples — 6 January 1983**

The situation chosen to demonstrate the output from the schemes is that for midday on 6 January 1983. A cold front lay north-east/south-west across the UK from roughly the Wash to Portland Bill, see Fig. 2. The front was quite a good example of a cold front with much of the rain occurring to the rear of the surface frontal position. It was moving south-east at about 20 knots.

A descriptive picture of the situation can be built up from the output. Fig. 3 shows the presence of layered cloud ahead of, and in, the frontal zone with a sharp cut-off well to the rear.

Only those reports with cloud amount greater than five oktas of layered cloud are used in the analysis of layered cloud heights, Fig. 4. It can be seen from Fig. 3 that there are very few non-zero reports in the north-west of the chart. Consequently, information from these few reports is spread over a large area by the height analysis routine. Hence, the cloud height field must be used in conjunction with the cloud amount field; i.e. a height from Fig. 4 should only be regarded as valid where there is a significant ( $\geq 5$  oktas) report of layered cloud. A point worth noting from the analysis is the low stratus in the warm air immediately ahead of the front and also in the Bristol Channel.

The analysis of convective cloud heights in Fig. 5 should also be used with care; a convective cloud height is only valid if there is convective activity at that point. The convective cloud height field is essentially flat, cloud base being quite uniform within the airstream, contrasting with the greater variability of the layered clouds.

Fig. 6 shows the analysis of rainfall rates. The frontal zone is well defined with pockets of moderate rain within a broad zone of slight rain. An observation of moderate continuous snow over the



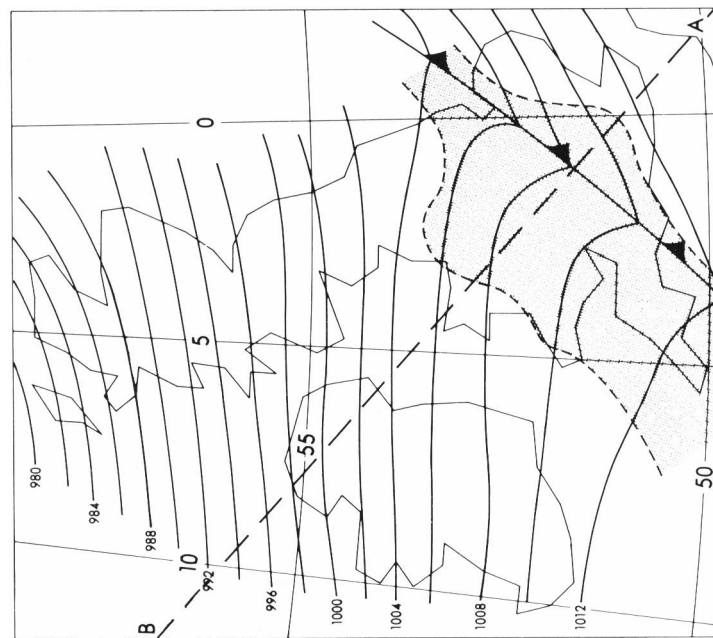


Figure 2. Synoptic situation, 1200 GMT 6 January 1983, with area of dynamic rain stippled. (For explanation of line AB see Fig. 7.)

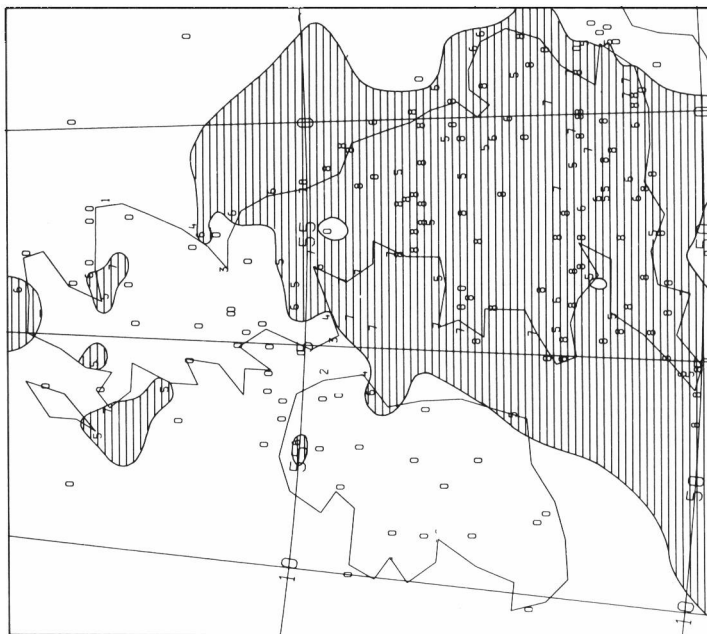


Figure 3. Analysis of layered cloud amounts for the lowest layer of five oktas or more, 1200 GMT 6 January 1983. (Cloud amounts plotted at observations.)

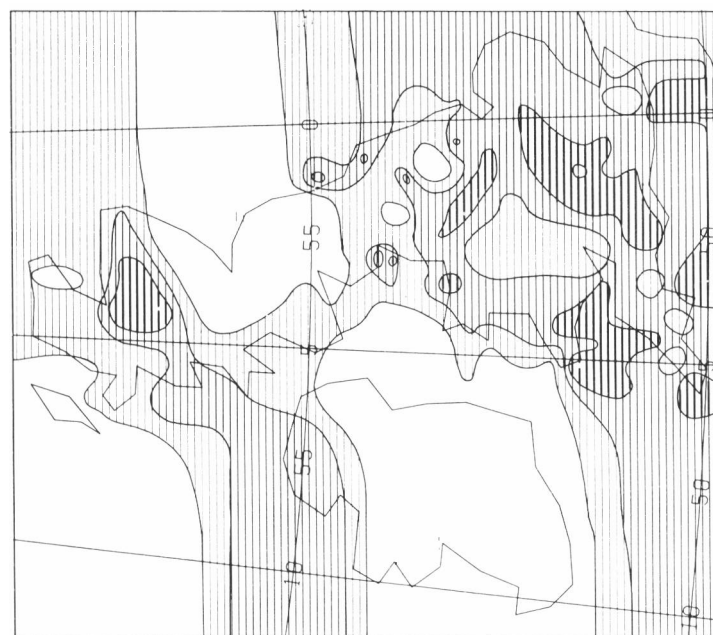


Figure 4. Analysis of layered cloud heights (metres) for the lowest layer of five oktas or more, 1200 GMT 6 January 1983. Dark: <400 m, Medium: 400-1200 m, Light: 1200-3200 m, No shading: >3200 m.

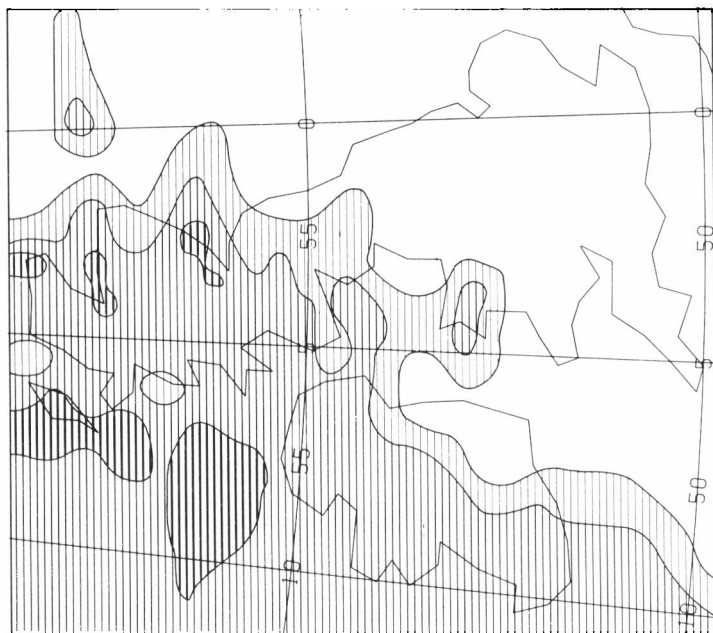


Figure 5. Analysis of convective cloud heights (metres), 1200 GMT 6 January 1983. Dark: <400 m, Medium: 400-1200 m, Light: 1200-3200 m, No shading: no convective cloud.

Cairngorms shows up as an area of dynamic precipitation with a rate greater than  $3 \text{ mm h}^{-1}$ . All neighbouring stations were reporting showers, highlighting the problem that these analyses are only as good as the observations on which they are based.

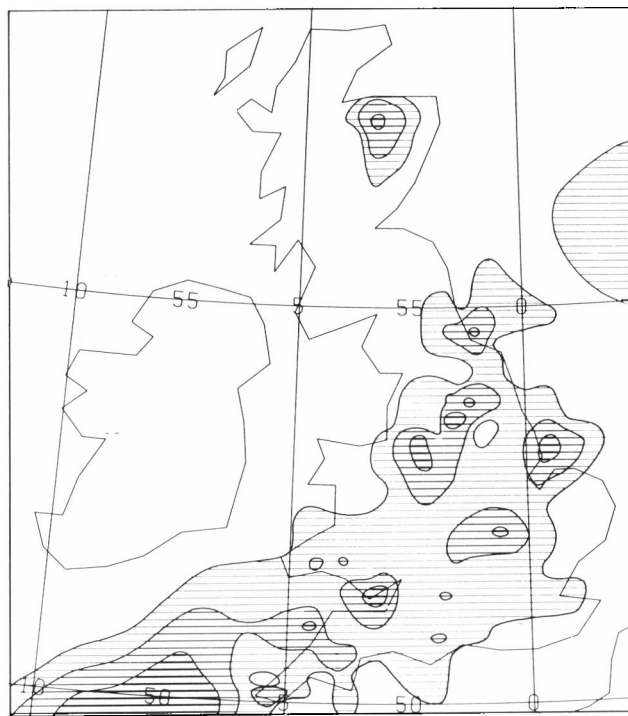


Figure 6. Analysis of hourly rainfall rates derived from present weather codes 50-79, 1200 GMT 6 January 1983. Dark:  $> 3 \text{ mm h}^{-1}$ , Medium:  $1-3 \text{ mm h}^{-1}$ , Light:  $0-1 \text{ mm h}^{-1}$ .

The vertical cross-section of CWMR Fig. 7 is a slice through the front and into the cold air, the line AB on Fig. 2. Thin non-precipitating layers are shown in the extreme south-east of England, thickening and lowering towards the frontal zone (grid points 65-70) and then thinning out to the rear of the front. There is a brief lowering of the cloud base over Shropshire before the cloud base lifts to medium and high cloud levels over the Irish Sea with no layered cloud reported in the genuine cold air over Ireland and westwards. This is a very good representation of the observations and it gives a good indication of the clearance of the upper cloud shield.

Fig. 8 shows the convective intensity analysis. The presence of quite widespread showers in the cold air is well illustrated as are areas of convection over high ground ahead of the main showery activity, North Wales and southern Pennines. Convection is just starting on the west coast of South Wales while that shown over Wittering is due to a report of four oktas of cumulus and slight continuous rain (with layered cloud above and below)! The shelter of the Cairngorms and Pennines is also illustrated.

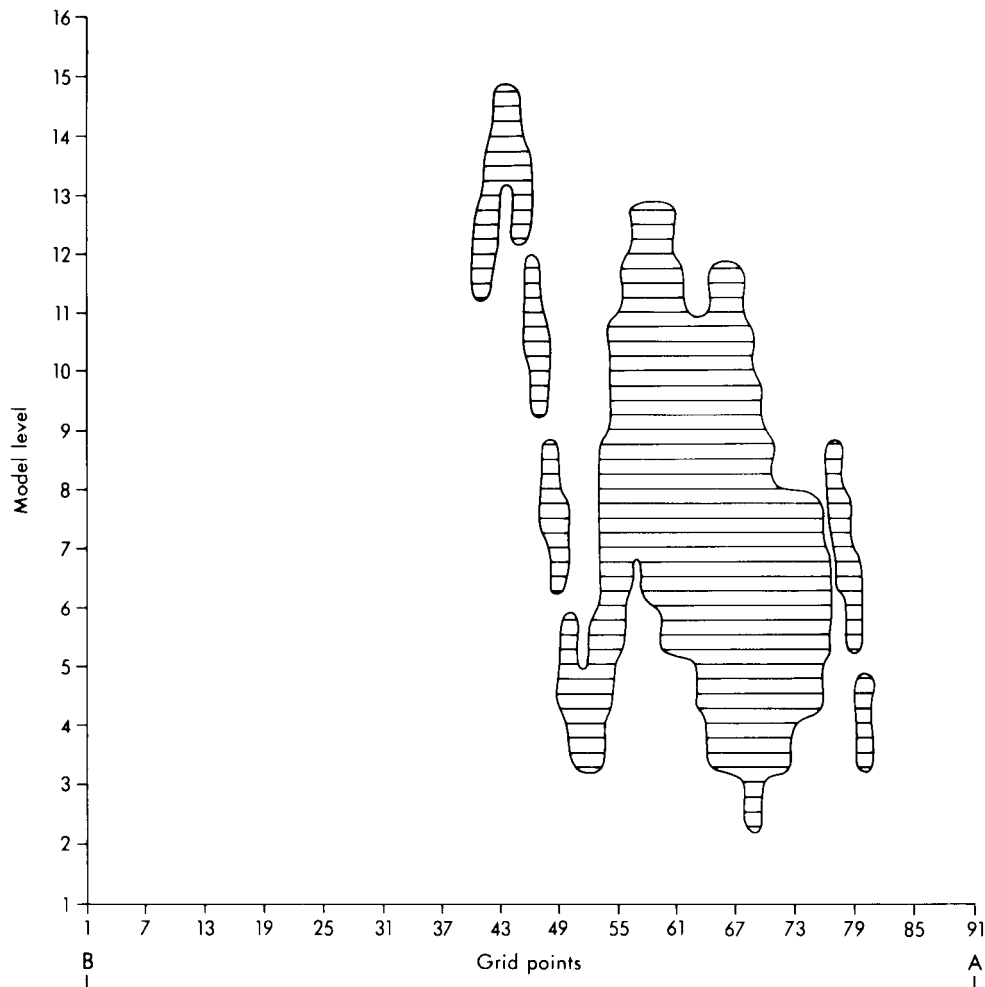


Figure 7. Analysis of cloud water mixing ratio, cross-section along AB — see Fig. 2.

## 6. Conclusions

Two areas of development of analyses on the mesoscale have been described. It is recognized that there are deficiencies in the schemes, not least of which is the problem of inconsistencies in reporting, but it is felt that the limitations imposed by these problems are greatly outweighed by the advantages of increased detail from the majority of accurate observations.

The work is relatively new and has yet to be incorporated into the mesoscale model, itself some way from an operational state. Further analyses, of such elements as pressure, temperature, winds, etc., can also be carried out using Purser and McQuigg's analysis scheme. It is hoped that as new sources of observational data become available, these too may interact with the model analyses. Satellite and

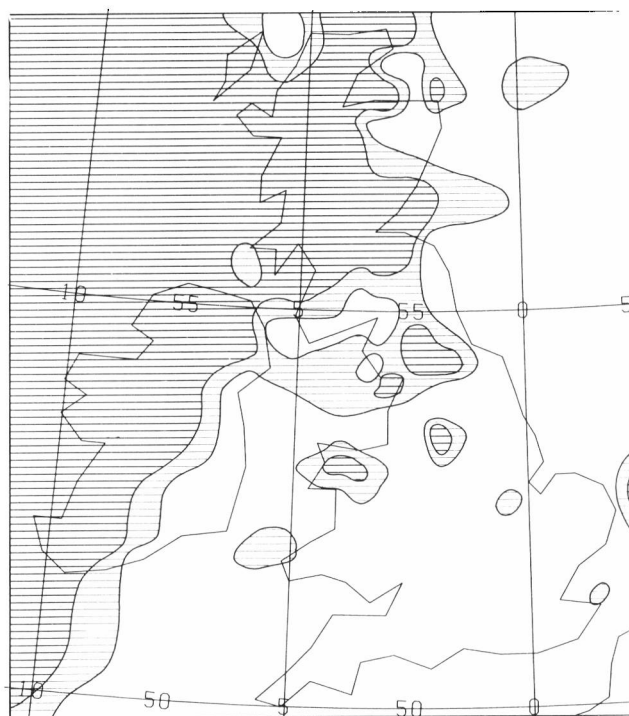


Figure 8. Analysis of convective intensity, 1200 GMT 6 January 1983. Light: non-precipitating convective cloud, Dark: showery.

radar data immediately come to mind for identifying more precisely cloud edges, cloud tops, individual thunderstorm cells, rainfall rates, etc. Only after testing and further improving these schemes within the full mesoscale model can their true usefulness be assessed.

### Acknowledgements

We would like to thank Dr B. Golding for his help and guidance during the period of these projects.

### References

- |                                   |      |   |
|-----------------------------------|------|---|
| Carpenter K. M.                   | 1979 | An experimental forecast using a non-hydrostatic mesoscale model. <i>Q J R Meteorol Soc.</i> <b>105</b> , 629-655.  |
| Eldridge R. G.                    | 1971 | The relationship between visibility and liquid water content in fog. <i>J Atmos Sci.</i> <b>28</b> , 1183-1186.   |
| Meteorological Office             | 1982 | Observer's handbook, London, HMSO.  |
| Purser R. J. and McQuigg R.       | 1982 | A successive correction analysis scheme using recursive numerical filters. (Unpublished, copy available in the National Meteorological Library, Bracknell.) |
| Tapp M. C. and White P. W.        | 1976 | A non-hydrostatic mesoscale model. <i>Q J R Meteorol Soc.</i> <b>102</b> , 277-296.   |
| World Meteorological Organization | 1974 | Manual on codes, Vol. I, Geneva, WMO No. 306.   |

## Global solar radiation measurements on 6 August 1981. A day of midday darkness

By R. J. Armstrong

(Meteorological Office, Bracknell)

### Summary

This article describes the effect on the solar radiation of the severe storms that hit southern England on 6 August 1981. The feature that distinguished this day from other days of violent thunderstorms, and made front page news, was the darkness that beset many areas, including London, in the middle of the day. From the solar radiation values provided by twelve sites the movement and intensity of the storms across southern and eastern England can be identified.

### Introduction

August 6 was the first of three successive overcast days which followed the hottest spell of the 1981 summer, the fine weather being broken down by a series of organized thunderstorms. As a result of the intensity of these storms, 6 August 1981 has been designated as a day of meteorological importance for which various branches of the Meteorological Office are providing detailed reports on the different aspects of the weather. Other accounts and observations have been presented in the journals, such as Bader *et al.* (1983) Nicholson (1982), Elston (1982), Crane (1981), Austin (1981) and Goethuys (1982), as well as in many of the national daily newspapers. Previous storms that caused large reductions in the solar radiation have been described by Helliwell and Blackwell (1955) and Gildersleeves (1962).

The synoptic situation during this period can be regarded as ideal for thunderstorm development. After two days of convective activity over France and increasing moisture content over the Bay of Biscay, an upper trough developed and moved in from the Atlantic. The situation by the morning of the 6th was that of a pronounced upper trough near south-west England and a surface low over northern France (see Fig. 1). At 700 mb an area of moist air, with a relative humidity greater than 75%, stretched from northern France to cover most of England. The active storms crossed the south coast at about 0500 GMT on the 6th and moved north-east across south-east England and the east Midlands while earlier storms died away leaving a large area of persistent, but less intense, rain over the Midlands and northern England.

### Measurements

Twelve stations (see Fig. 5 and Table I) were able to supply radiation data for the area of interest ranging from continuous records to hourly integrations. Four of these are Meteorological Office

**Table I.** *The location of the 12 sites that provided radiation data for this article*

Site	Latitude	Longitude	Site	Latitude	Longitude
Bracknell	51° 23'N	00° 47'W	Grendon Underwood	51° 54'N	00° 01'W
Brooms Barn	52° 14'N	00° 34'E	Hemsby	52° 41'N	01° 41'E
Crawley	51° 05'N	00° 13'W	London	51° 31'N	00° 07'W
East Malling	51° 17'N	00° 27'E	Rothamsted	51° 48'N	00° 21'W
Garston	51° 42'N	00° 23'W	Silsoe	52° 01'W	00° 25'W
Grafham Water	52° 17'N	00° 19'W	Wallingford	51° 36'W	01° 10'W

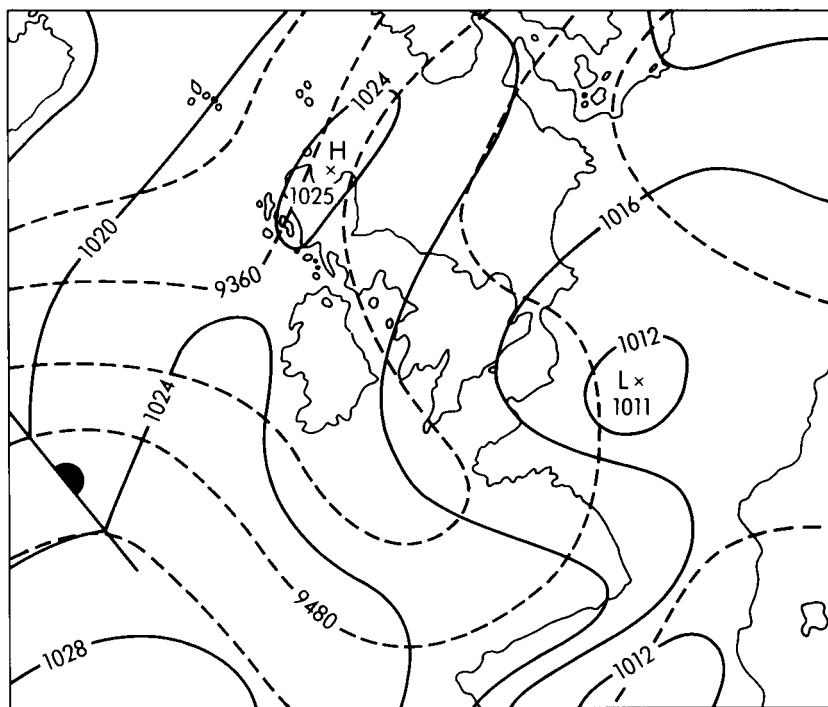


Figure 1. The synoptic situation for 1200 GMT, 6 August 1981. Mean-sea-level pressure (solid lines) in millibars, 300 mb geopotential (dashed lines) in geopotential metres.

stations, viz. Bracknell, Crawley, London Weather Centre and Hemsby, the rest being under the authority of other government departments or private research institutes, though forming part of a current network of 37 stations regularly supplying radiation data to the Meteorological Office.

The 12 stations concerned measure a range of solar radiation elements, though all record the global irradiance on a horizontal surface (i.e. the rate at which the radiant energy falls on a unit area of a horizontal surface) for the waveband 0.29 to 3.0  $\mu\text{m}$ . The global solar radiation consists of two components: the diffuse or scattered radiation (measured at the four Meteorological Office stations and Silsoe); and a direct component (only recorded at Bracknell) measured normal to the sun's rays by a tracking pyrheliometer. Bracknell also measures the global solar irradiance on vertical surfaces facing north, east, south and west. These are of particular interest to engineers concerned with the heating of buildings. For the purpose of this article, the global solar radiation on a horizontal surface is the only variable considered.

The stations record radiation data by different methods: Meteorological Office stations use MODLE 3 (Meteorological Office Data-Logging Equipment, Mark 3) which logs values at one minute intervals on a magnetic tape. After computer processing the data are produced in graphical form. Two other stations (Rothamsted and East Malling) supplied a continuous chart record of the day's radiation. The remaining stations use voltage-time integrators which print the total at the end of each hour (except at Grafham Water where half-hour totals are printed). Additionally, Wallingford and Grendon Underwood supplied the times when their solarimeters did not record any radiation, and Garston

provided a small chart record of the day that indicates changes in the radiation level, but could not be quantified in absolute units. The minute values from the four Meteorological Office sites are processed in local apparent time (LAT); the difference between LAT and GMT depends on astronomical factors as well as the longitude of the station (solar noon or 1200 LAT is when the sun is due south of the station). For the purpose of this study the difference is small enough (i.e. less than 10 minutes) to be ignored.

### Observations

Table II shows the daily totals of global irradiation on a horizontal surface (in  $\text{W h m}^{-2}$ ) for the 12 sites with the long term means for August (based on up to ten years data). Each percentile (1%, 5%, 99%) indicates the number of occasions on which the given daily totals are not exceeded. Hence for Bracknell, Wallingford, Grendon Underwood and Garston the daily total on 6 August 1981 represents one of the three lowest radiation days to be expected in a ten-year period in August.

**Table II.** Daily totals of global solar radiation ( $\text{W h m}^{-2}$ ) for the 12 sites together with the long term means for August (based on up to ten-years data). Each percentile (1%, 5%, 99%) indicates the number of occasions on which the given daily totals are not exceeded

Site	Daily total for 6 August 1981	1%	August percentiles 5%	99%	August average	Number of days used
Bracknell	603	702	1406	6843	4095	277
Crawley	1087	937	1614	6485	4074	61
London	1047	920	1502	6313	3929	211
Hemsby	1997	942	1435	7140	4136	31
Wallingford	310	591	965	6229	3722	186
Grendon Underwood	560	675	1072	6189	3731	186
Rothamsted	706	628	1141	6592	3742	278
Silsoe	956	577	1170	6738	3984	309
East Malling	2679	804	1399	6559	4012	307
Garston	650	680	1248	6477	3847	245
Grafham Water	1150	520	1148	6569	3652	155
Brooms Barn	2844	755	1147	7065	3688	62

Fig. 2 shows the mean hourly irradiances for the 12 sites. The extent of the storm clouds can be seen from the radiation values with periods of very low global irradiance (less than  $5 \text{ W h m}^{-2}$  on a horizontal surface) lasting for more than an hour at many of the sites. Such low levels of irradiance for such a long period indicate that the cumulonimbus must have been both very thick and horizontally extensive. Bracknell recorded only four minutes of direct irradiance greater than  $10 \text{ W m}^{-2}$ .

Fig. 3 shows the diurnal global irradiance curve for Bracknell. Evidence of a first storm can be seen by the irradiance values being below the level of detection between 0718 and 0733 LAT. Low values of irradiance continued until a second and more intense storm arrived at 0936 LAT, lasting for over an hour until just before 1100 LAT. Superimposed on Fig. 3 are the long term means for August (based on data from 1972–1981) represented by the 1%, 5% and 99% percentiles described above, as well as the 1972–1981 average for each hour.

Fig. 4 shows the diurnal irradiance curves for two other Meteorological Office stations. The two peaks in the morning at 0914 LAT at Crawley and 0953 LAT at London Weather Centre represent a clear spell between two storms, not clearly evident on the Bracknell output.



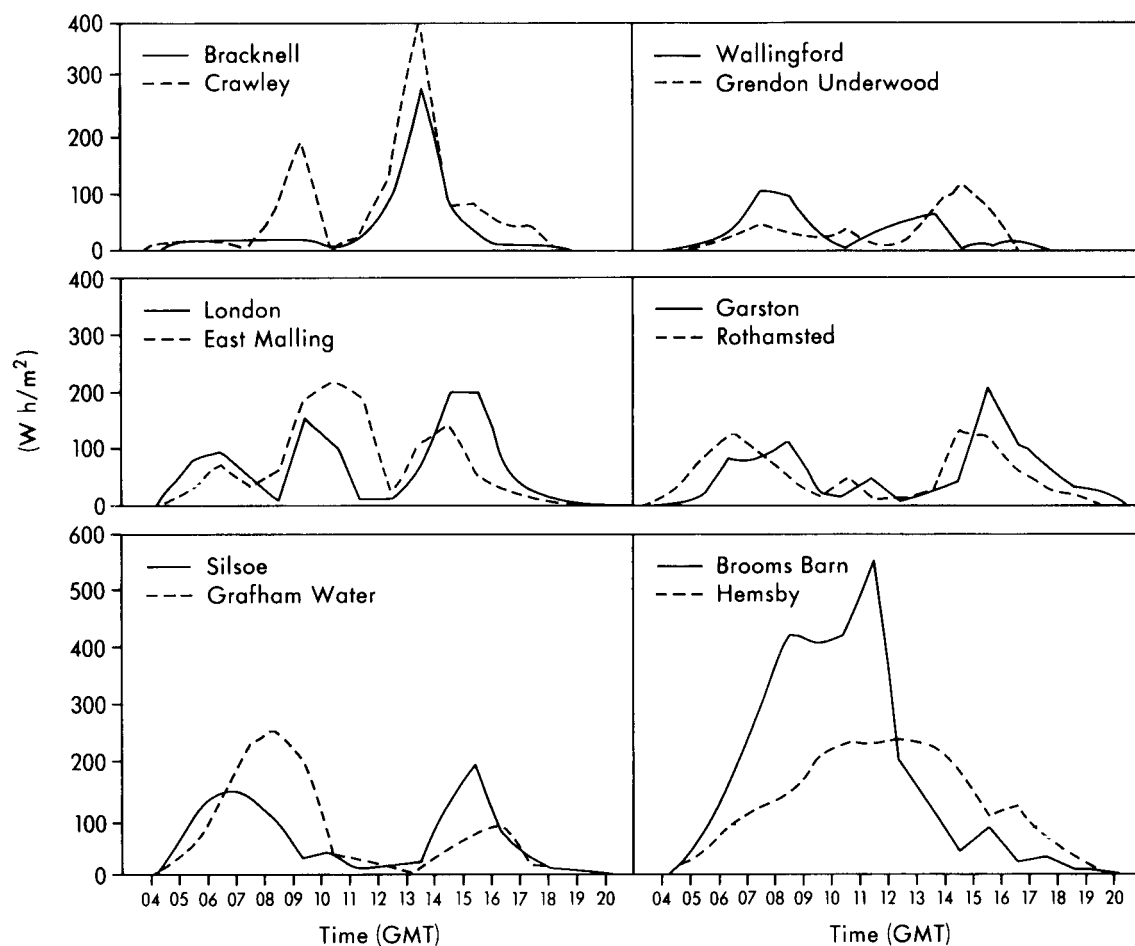


Figure 2. Hourly irradiations for selected sites on 6 August 1981.

## Discussion

From the data provided by the twelve sites it has been possible to detect the periods of 'zero' radiation (i.e. global irradiance of less than  $5 \text{ W m}^{-2}$  on a horizontal surface), though for those stations that report hourly integrations, only approximate times could be estimated. The evidence suggests that two major storm systems moved south-west to north-east across south-eastern England and the east Midlands on 6 August 1981. The positions of the front edge of the main storm clouds, as defined by the time that the irradiance reached 'zero', have been plotted (Fig. 5(a)) for each hour: 0700 to 1000 GMT for the first storm and 0900 to 1600 GMT for the second storm, although beyond 1400 GMT the analysis is based on limited data. (See also Table III.)

The radiation data can provide information about the intensity (as inferred from the darkness) and extent of the storms. The first system was most intense over Crawley and London, lasting for a shorter period over Bracknell, while Wallingford showed no decrease in the radiation trace, this indicating the north-western extent. East Malling reached a minimum of  $12 \text{ W m}^{-2}$  in the radiation trace, suggesting the first storm was not as intense there as further west and this probably indicated its south-eastern

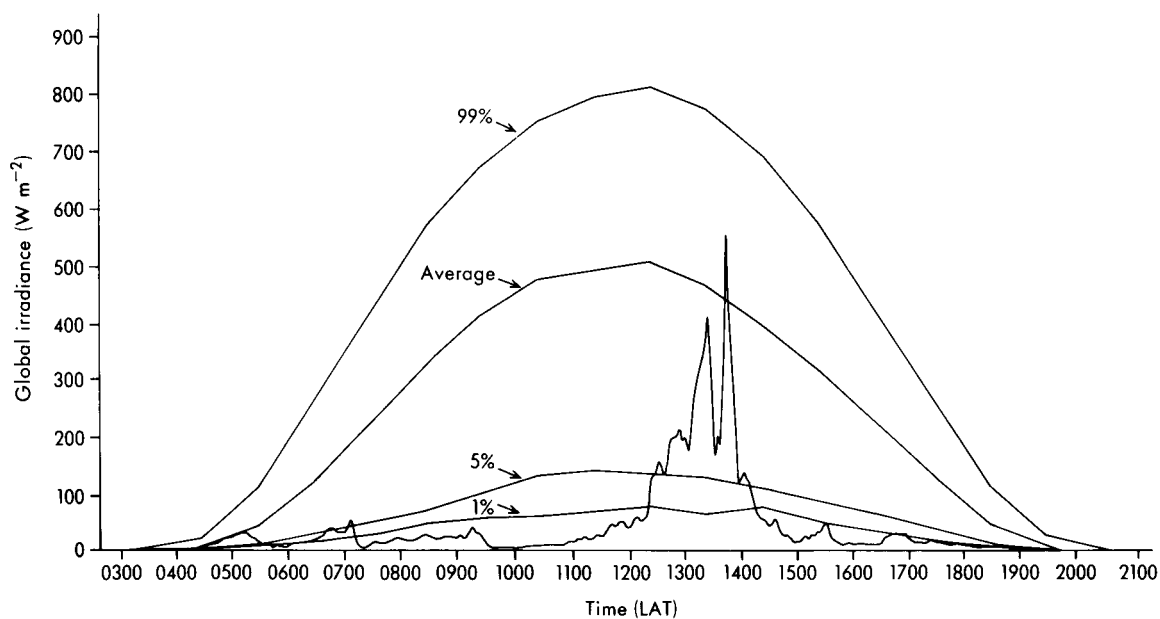


Figure 3. Diurnal radiation plot of Bracknell MODLE data for 6 August 1981 together with the average, 1%, 5% and 99% percentiles for August.

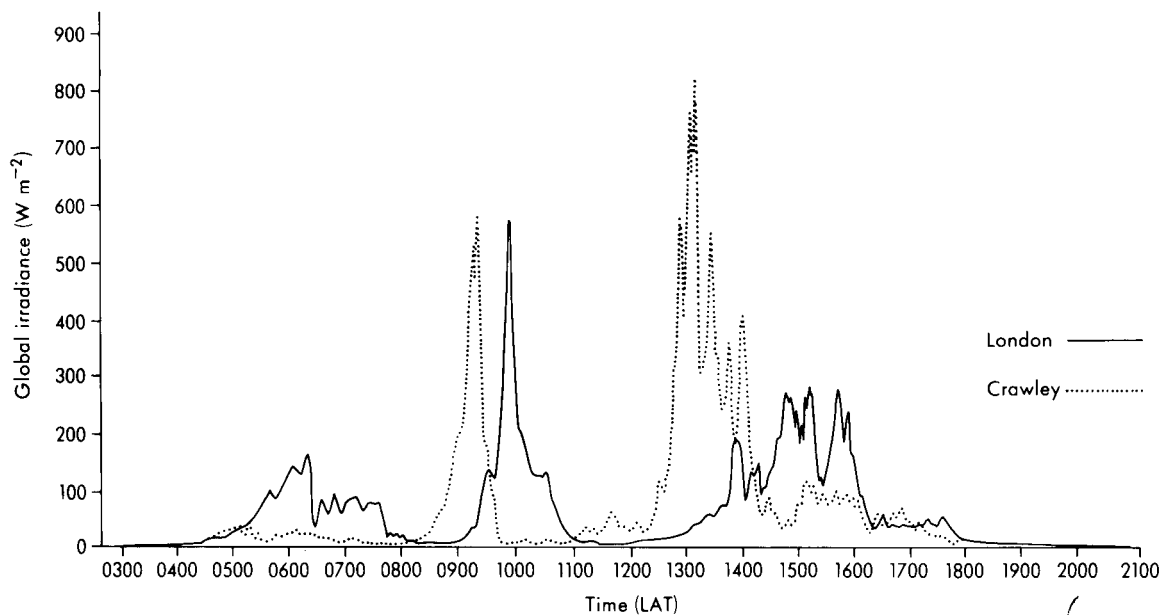


Figure 4. Diurnal radiation plots for two of the MODLE stations.

boundary. The darkness at Garston and Rothamsted lasted for about an hour, but by the time the storm reached Grafham Water the band of darkness was reduced in scale and there was no indication of significantly low values of irradiance at Brooms Barn. The period before the second system showed two distinct patterns: Crawley, London and East Malling had a relatively clear spell between the storms when it is obvious that the clouds broke for a short while, though no 'bright sunshine' was recorded at London or Crawley by Campbell-Stokes sunshine recorders; and Bracknell where the irradiance remained low all the time, never rising above  $50 \text{ W m}^{-2}$  until the end of the second storm.

The movement of the second and more intense storm system, lasting for more than an hour at over half the stations, was easier to detect, but because it affected all 12 sites the lateral extent could not be judged. It was still producing low irradiance values, though for a much shorter time, as it crossed East Anglia late in the afternoon, with Hemsby showing a pronounced dip in the irradiance trace for five minutes from 1548 GMT.

The Hydrometeorological Section of the Meteorological Office have studied the rainfall during this day and from radar data have been able to draw an outline of the main radar-echo area. Fig. 5(b) shows the outline at 0900 and at 1200 GMT. The shape of the echoes at 0900 looks rather like a semicolon; the lower part (comma shaped), which was more than 100 km long and less than 50 km wide, lies north-west to south-east. The most active area of the round part of the radar echo was near the eastern edge which moved northwards, just to the west of London about 0900 GMT, expanding in size to approximately 100 km across.

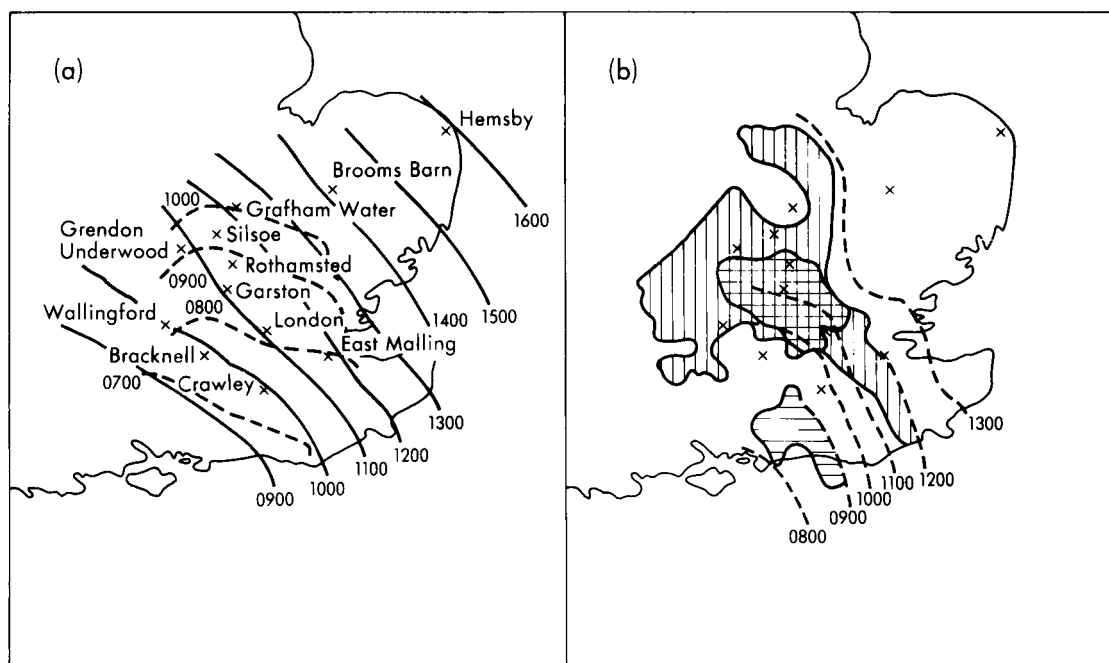


Figure 5. (a) The positions and times of the leading edge of the first storm system (dashed lines) and the second storm system (solid lines) as derived from radiation data. (b) The outline of the radar echo area at 0900 (horizontal lines) and at 1200 (vertical lines). The dashed lines show the positions and times of the leading edge of the second system as indicated by radar. All times are GMT.

**Table III.** *Estimated times (GMT) over each site for the two major storms, with minimum values of irradiance ( $W m^{-2}$ ) recorded*

Site	First storm	Minimum	Second storm	Minimum
Bracknell	0727 to 0742	0	0945 to 1108	0
Crawley	0721 to 0816	1	0951 to 1109	1
Wallingford	—	—	1005 to 1130	0
London	0811 to 0905	0	1111 to 1217	1
East Malling	0755 to 0840	12	1200 to 1240	0
Garston	0845 to 0945	0*	1110 to 1230	0*
Grendon Underwood	0830 to 0930	20*	1040 to 1130	0
Rothamsted	0850 to 0948	8	1112 to 1248	6
Silsoe	0830 to 0930*	20*	1130 to 1230*	4*
Grafham Water	1000 to 1100*	10*	1245 to 1345	5*
Brooms Barn	—	—	1330 to 1445*	30*
Hemsby	—	—	1548 to 1552	2

\* indicates that only an approximation could be made

The bright period between the storms at Crawley, London and East Malling can be explained by the passage of the northern part of the echo being followed by a gap, and then the comma-shaped part as it moved north-east. It was the comma-shaped storm that gave the heavy rainfall to places such as London at midday. Bader (personal communication) has plotted the leading edge of the radar echo associated with this storm as it moved across south-east England at each hour from 0800 to 1300 GMT (Fig. 5(b)) and this shows very good agreement with the position of the second storm as derived from the radiation data and shown in Fig. 5(a). The speed of the comma as estimated from the rainfall data was  $25 \text{ km h}^{-1}$  which again is in agreement with the calculated speed from the time at which the start of the 'zero' values were recorded at Crawley and then at East Malling. The speed of the top part of the semicolon was between  $35$  and  $40 \text{ km h}^{-1}$ . However, the speed calculated from the first 'zero' values at Bracknell and then at Rothamsted was slightly higher at  $43 \text{ km h}^{-1}$ . This could be explained by the fact that the storm was increasing in size during the morning of the 6th.

To achieve 'zero' values of global irradiance suggests that the clouds must have been both very thick and extensive. For example, the atmospheric transmission of solar energy at 1030 LAT, given by the ratio of the observed global irradiance ( $5 \text{ W m}^{-2}$ ) to the 'clear day' global irradiance (i.e. the 99% level) would be less than about  $5/750$  or  $0.7\%$ . This is a much smaller value than the average observed overcast fractions (e.g. Haurwitz (1948) gave a figure of  $10\%$  for complete coverage by nimbostratus). It is also a much smaller transmission than for most models of radiation transfer through clouds; for example Liou (1976) gave a figure of  $3\%$  for a cumulonimbus cloud  $4.5 \text{ km}$  thick and Stephens (1978) formed parametrization relations for cumulonimbus clouds, the largest optical thickness ( $\tau_N$ ) considered being in the order of  $5 \times 10^3$  which gave a transmission factor of  $1\%$ . He noted that if the sun's disc is not visible through a cloud then  $\tau_N$  must be greater than  $10$  and gave the approximate relation of

$$\tau_N \approx 1.5W r_e^{-1}$$

(assuming uniform extended water clouds) where,

$W$  = total liquid water content in a vertical path in  $\text{g m}^{-2}$ , and  
 $r_e$  = effective radius of droplet distribution in  $\mu\text{m}$ .

Therefore, if  $r_e \approx 10 \mu\text{m}$ , a typical figure for cumulonimbus,  $W$  must exceed  $3 \times 10^4 \text{ g m}^{-2}$  if the transmission is to be less than 1%. The total liquid content, calculated from the Crawley 1200 GMT ascent with a wet-bulb potential temperature of  $18^\circ\text{C}$  and a parcel of air cooled along a saturated adiabat to 8 km, was  $W = 3 \times 10^4 \text{ g m}^{-2}$ , which agrees with the relation above. However, this calculation is an extreme simplification of the problem of determining the transmission of radiation through cloudy atmospheres and ignores many of the complications arising from multiple scattering, absorption and non-spherical ice particles.

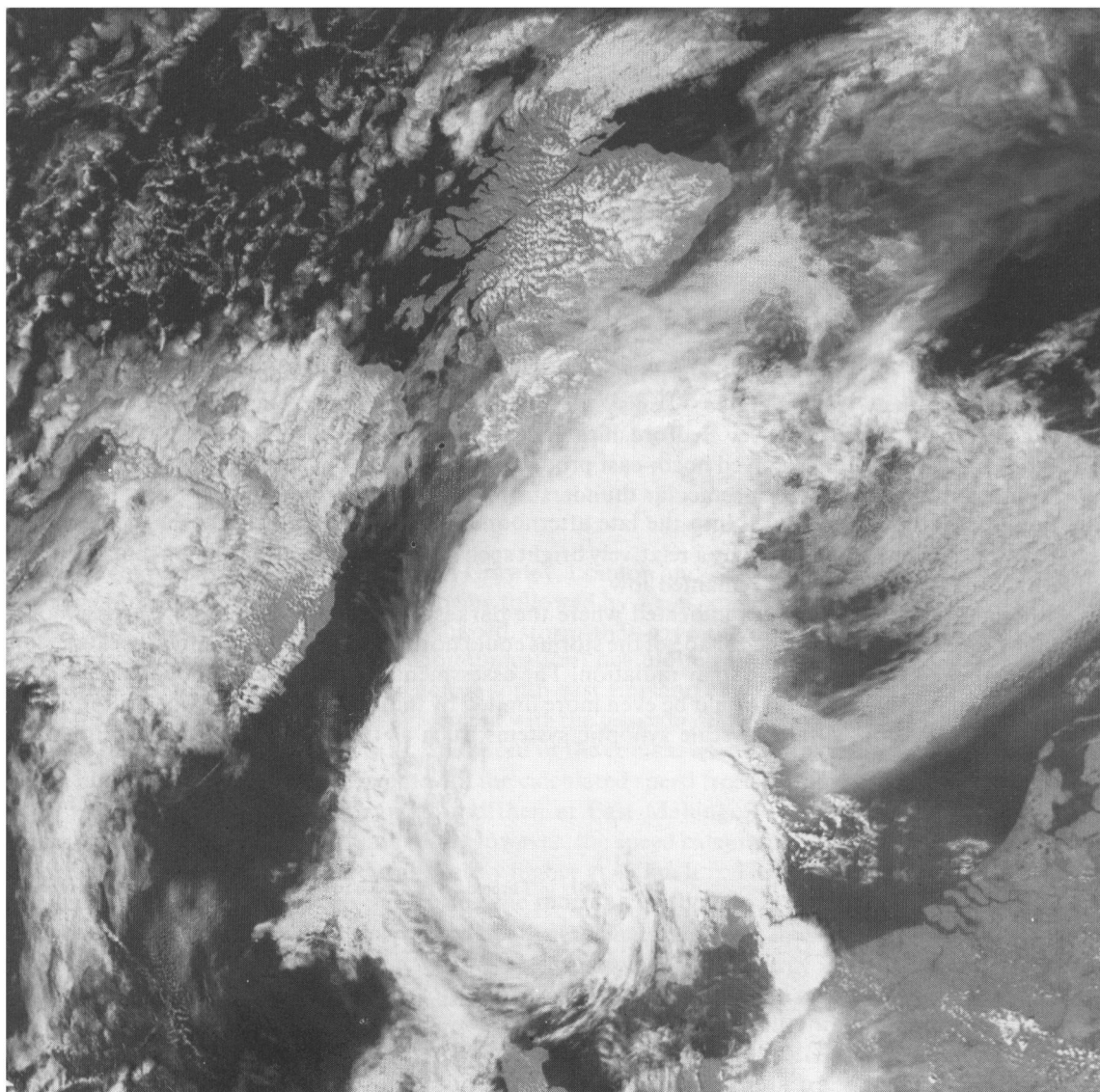
## Conclusions

The storms of 6 August 1981 were of exceptional darkness and duration, which resulted in solar irradiance levels of less than the 1% percentile and rainfall intensities with return period of over 100 years in many places in south-eastern England. From the evidence provided by the radiation values of twelve sites there were two major storm systems: the first arrived at Bracknell at about 0730 GMT, moved north and weakened over Bedfordshire and Cambridgeshire. The second system arrived at Bracknell at 0945 GMT and moved north-east producing lower values of global radiation than the first and being associated with the spectacular thunderstorms and blackness of the sky widely reported in the Press. The storms lasted well into the late afternoon and probably dissipated over the North Sea after sunset. They were separated by a relatively bright spell in the east (e.g. East Malling) but in the west (e.g. Bracknell) the irradiance remained low.

Although the radiation values indicated where the darkest areas of the storms were, agreeing well with the rainfall data, the detailed shape of the storms could not accurately be determined because of the small number of sites recording solar radiation. The assessment of global radiation patterns in areas away from south-east England would be even more limited by the sparsity of the network, although the variation of radiation with large scale synoptic systems, such as fronts, could still be determined.

## References

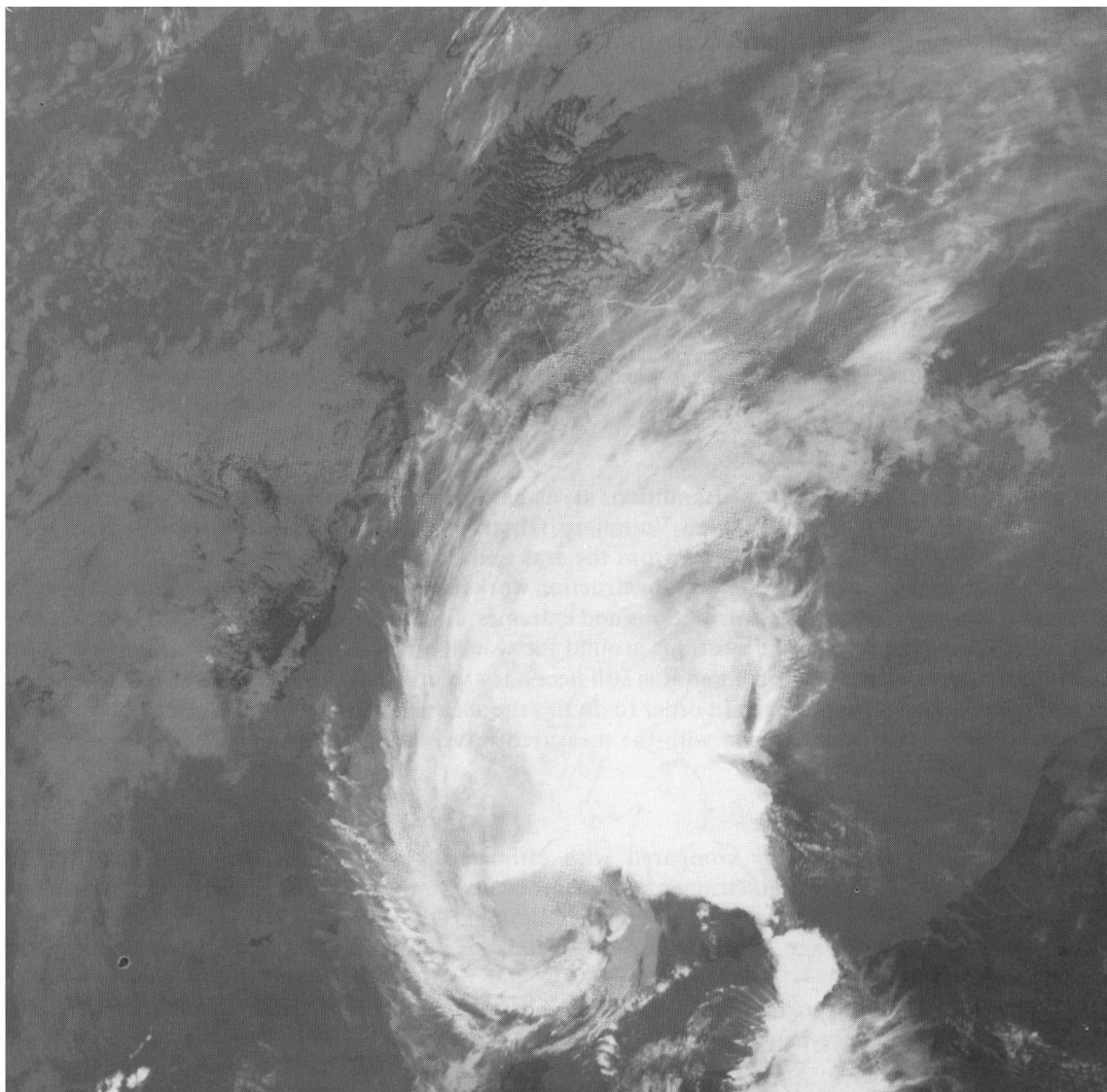
- |  |      |  |
|--|------|--|
| Austin, A.                                   | 1981 | Three days of gloom in August 1981. <i>J Meteorol Trowbridge</i> , <b>6</b> , 330.   |
| Bader, M. J., Collier, C. G. and Hill, F. F. | 1983 | Radar and rain-gauge observations of a severe thunderstorm near Manchester: 5/6 August 1981. <i>Meteorol Mag</i> , <b>112</b> , 149–162. |
| Crane, A. J.                                 | 1981 | Thunderstorms of 6 August, 1981. <i>Weather</i> , <b>36</b> , 267.   |
| Elston, C. H. J.                             | 1982 | Thursday, 6 August — Thor's day. <i>Weather</i> , <b>37</b> , 93–94.   |
| Gildersleeves, P. B.                         | 1962 | A contribution to the problem of day-darkness over London. <i>Meteorol Mag</i> , <b>91</b> , 365–369.                                    |
| Goethuys, J. P.                              | 1982 | Thunderstorms of 6–7 August 1981 in Belgium. <i>J Meteorol Trowbridge</i> , <b>7</b> , 22–23.  |
| Haurwitz, B.                                 | 1948 | Insolation in relation to cloud type. <i>J Meteorol</i> , <b>5</b> , 110–113.  |
| Helliwell, N. C. and Blackwell, M. J.        | 1955 | Day-time darkness over London on January 16, 1955. <i>Meteorol Mag</i> , <b>84</b> , 342–348.  |
| Liou, K. N.                                  | 1976 | On the absorption, reflection and transmission of solar radiation in cloudy atmospheres. <i>J Atmos Sci</i> , <b>33</b> , 798–805.       |
| Nicholson, G.                                | 1982 | Thursday, 6 August — Thor's day. <i>Weather</i> , <b>37</b> , 93.  |
| Stephens, G. L.                              | 1978 | Radiation profiles in extended water clouds. II: parameterization schemes. <i>J Atmos Sci</i> , <b>35</b> , 2123–2132.                   |



*Photograph by courtesy of Dundee University*

(a)

Satellite (NOAA 7) photographs taken at 1402 GMT on 6 August 1981 (a) visual (b) infra-red. The horizontal boundary of the highest and thickest cloud, which caused the cut-off in radiation at the surface discussed in the paper by R. J. Armstrong on p 200, is clearly shown in the infra-red photograph. There is also a suggestion of a minor circulation at lower levels over Dorset; surface observations, however, showed only a minor trough.



*Photograph by courtesy of Dundee University*

(b)

## Wave heights estimated by the Voluntary Observing Fleet compared with instrumental measurements at fixed positions

By Anne E. Graham

(Meteorological Office, Bracknell)

### Summary

Measured wave heights from twelve locations are compared with visual estimates made by the deck officers of merchant ships adjacent to the site. The methods of measurement and estimation are discussed together with the difficulties encountered in comparing the two different types of wave heights produced and in deriving extremes.

### 1. Introduction

For many years estimates of wave conditions at sea have been made by the deck officers of merchant ships. These merchant ships form the Voluntary Observing Fleet (VOF) which provides valuable meteorological and climatological data from the seas and oceans of the world.

In recent years the increase in offshore construction work has produced a need for knowledge of wave conditions including frequency distributions and extremes. Instrumentally measured wave heights are now available from a number of locations around the world, but generally these records are for short and often incomplete periods only and it is still necessary to utilise the many years of estimated data already archived on a global basis. In order to do this the accuracy of the estimates of wave conditions must be determined by comparison with the measured wave data.

### 2. Data sources

Measured wave heights were compared with estimated wave heights from the  $2^{\circ} \times 2^{\circ}$  areas surrounding each site at which instrumental measurements were made. The positions of these 12 sites are shown in Fig. 1(a) together with Ocean Weather Stations (OWS) 'I' and 'J'. Fig. 1(b) shows the areas around each instrumental site, except for OWS 'L' which is an oceanic site and well exposed from all directions.

The instrumental data were of significant wave heights whereas the visually estimated data comprised wind wave and swell wave heights.

#### (a) Visually estimated wave heights

Visually estimated data were available for the period 1961–1978 and consisted of wind wave and swell wave heights, randomly distributed in space and time throughout the area.

(i) *Observations of wave heights.* The deck officer is required to report estimates of both wind wave and swell wave heights when it is possible to distinguish between the two. The actual instructions for making these estimates can be found in more detail in the *Marine observer's handbook* (Meteorological Office 1977), but briefly the estimate should be made from observation of at least 20 waves, the method depending on whether the length of the wave is longer or shorter than the length of the ship. It is noted that in general there is a tendency to overestimate the height of waves with short wavelengths and underestimate those with long wavelengths. At night or in poor visibility the observer has difficulty in observing wave heights and often will be unable to report on them.



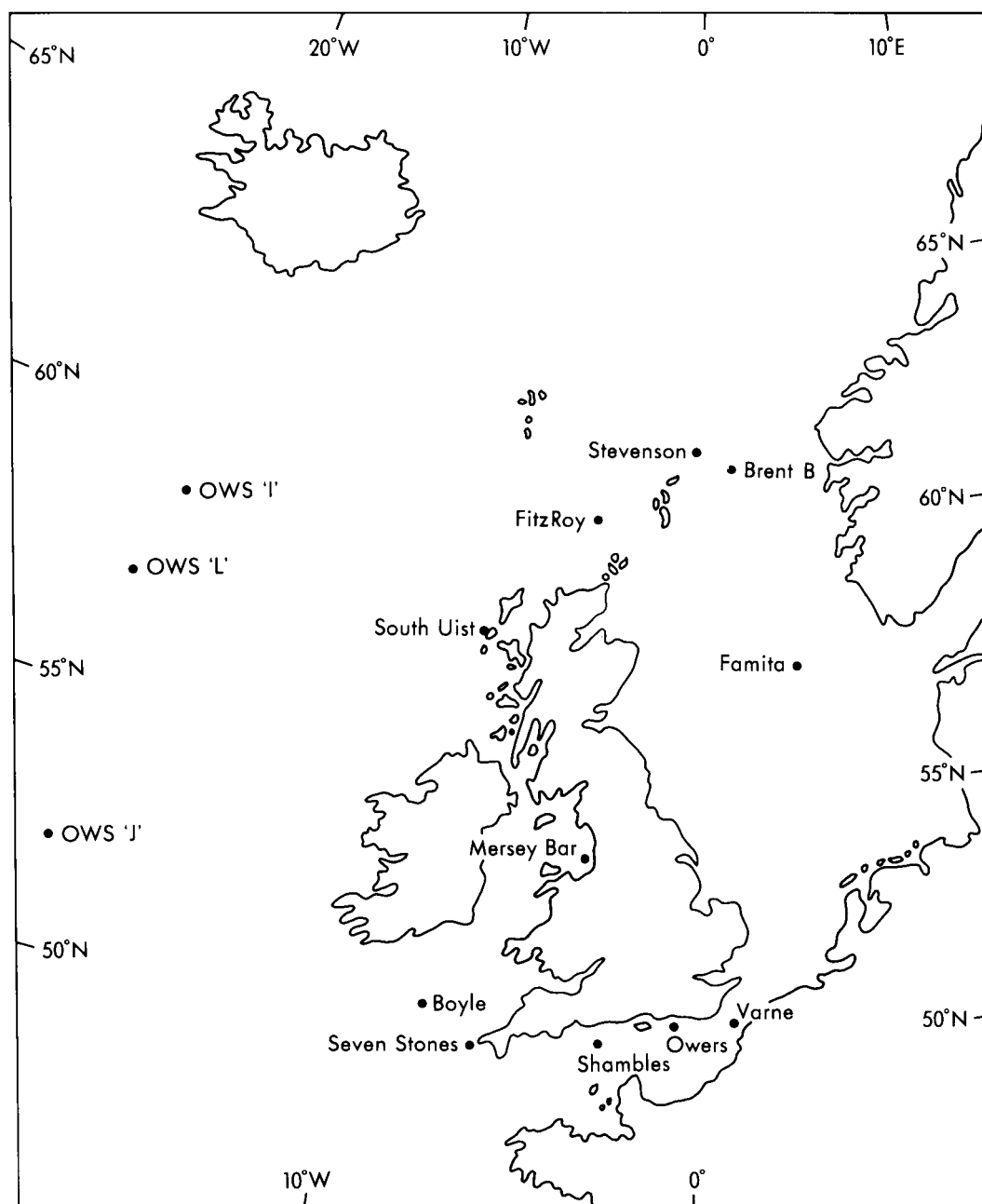


Figure 1(a). Positions of the fixed stations used in the analysis.

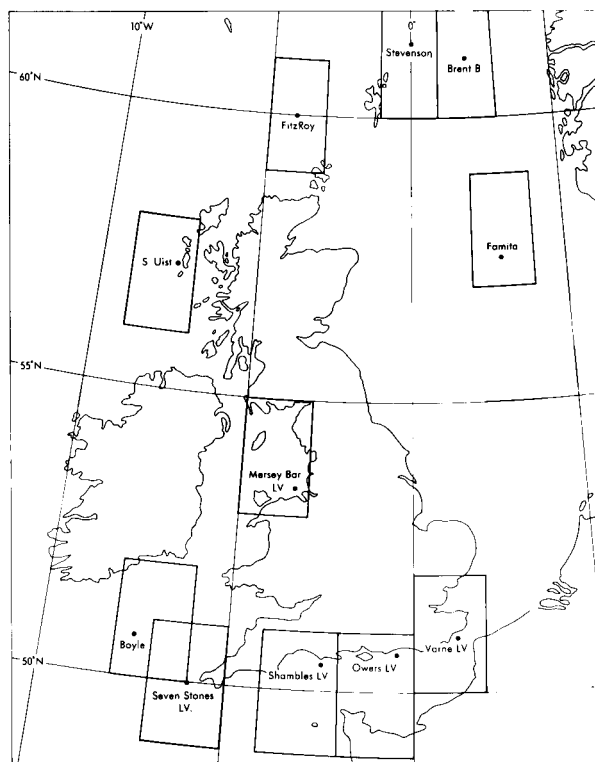


Figure 1(b). Positions of fixed stations and areas from which the VOF data were taken.

Visual estimates of wave heights are made in the same way by observers on board ships at the OWS. The data sets of wave heights from the OWS consist of regular observations made at the same location. A comparison of such data with the randomly observed data from the VOF was made for the three OWS, 'I', 'J' and 'L'. For OWS 'L' the regularly observed estimates could also be compared with the instrumentally measured wave heights available at that site.

For comparison with the measurements of significant wave heights it is necessary to combine wind wave and swell wave estimates since it is this combination of all wave conditions that equates with the significant wave. An equivalent significant wave height, here called the resultant,  $R$ , can then be found using a formula derived by Nordenstrøm (1971):

$$R = 1.68c^{0.75}$$

where

$$c = \{(\text{wind wave})^2 + (\text{swell wave})^2\}^{1/2}$$

Consequently, only those occasions when both wind wave and swell waves had been reported were used in the analysis.

(ii) *Coding of wave heights.* The period covered by the VOF data used in this study was 1961–1978; this period includes a change of coding practice on 1 January 1968.

The observer is required to report the estimated wave height to the nearest half metre using a code figure, but before 1968 the wave heights were reported using code figures 0–9 only. This required an addition of 50 to the estimation of the wave direction for wave heights greater than 4.5 m. (See Table I(a).)

Table I(a). *Wave height code table pre-1968*

Code figure	Height		Code figure	Height	
	metres	feet		metres (50 added to wave direction)	feet
0	< 0.25	< 1	0	5	16
1	0.5	1.5	1	5.5	17.5
2	1	3	2	6	19
3	1.5	5	3	6.5	21
4	2	6.5	4	7	22.5
5	2.5	8	5	7.5	24
6	3	9.5	6	8	25.5
7	3.5	11	7	8.5	27
8	4	13	8	9	29
9	4.5	14	9	9.5	30.5

*Note.* The range of heights covered by a number is half a metre; e.g. number 3 applies to waves whose heights are between  $1\frac{1}{4}$  m and  $1\frac{3}{4}$  m (4 feet and  $5\frac{3}{4}$  feet).

From the beginning of 1968 code figures 01–49 were used (see Table I(b)). This did not involve changes to the report of wave direction for any height.

The wind wave and swell wave height distributions were examined for the pre- and post-1968 periods, but no evidence was found that there had been a marked reduction in reports of five metre wave heights before the code change compared with those made afterwards. The major difference between the pre- and post-1968 distributions is the lower number of observations in the former period. In 10 of the 12 areas the pre-1968 observation count for the resultant wave heights was less than half that for post-1968, and just over half for the remaining two. The pre-1968 period covers only 7 years whereas 11 years of data were available post-1968. This could account for some, but not all, of the discrepancy.

Another change in the coding practice was that before 1968 the same code was used for both wind waves and swell. The first wave group reported referred to the wind waves, and subsequent groups to swell. Since 1968 one code has been used for the wind waves and a different one for swell, with two or more groups being used in the event of more than one swell wave train. This may have encouraged the reporting of a separate swell wave and may account for the increased number of resultant waves in the post-1968 period.

#### (b) *Instrumental wave heights*

The wave height derived from instrumental recordings is known as the significant wave height,  $h_s$ . Originally this was defined as the mean height of the highest one third of waves sampled. It is now defined (Tann 1976) in terms of the variance  $m_0$  of the sea surface elevation such that:

$$h_s = 4\sqrt{m_0}.$$

**Table I(b).** *Conversion table (feet/metres) with reference to height of waves as used after 1 January 1968.*

Feet	Metres	Code figure	Feet	Metres	Code figure
1	0.3	1	41	12.5	25
2	0.6	1	42	12.8	25
3	0.9	2	43	13.1	26
4	1.2	2	44	13.4	27
5	1.5	3	45	13.7	27
6	1.8	3	46	14.0	28
7	2.1	4	47	14.3	29
8	2.4	5	48	14.6	29
9	2.7	5	49	15.0	30
10	3.1	6	50	15.2	30
11	3.3	7	51	15.5	31
12	3.7	7	52	15.8	32
13	4.0	8	53	16.1	32
14	4.3	9	54	16.5	33
15	4.6	9	55	16.8	34
16	4.9	10	56	17.1	34
17	5.2	10	57	17.4	35
18	5.5	11	58	17.7	35
19	5.8	12	59	18.0	36
20	6.1	12	60	18.3	36
21	6.4	13	61	18.6	37
22	6.7	13	62	18.9	38
23	7.0	14	63	19.2	38
24	7.3	15	64	19.5	39
25	7.6	15	65	19.8	40
26	7.9	16	66	20.1	40
27	8.2	16	67	20.4	41
28	8.5	17	68	20.7	41
29	8.8	18	69	21.0	42
30	9.1	18	70	21.3	43
31	9.5	19	71	21.6	43
32	9.7	19	72	21.9	44
33	10.1	20	73	22.3	45
34	10.4	21	74	22.6	45
35	10.7	21	75	22.9	46
36	11.0	22	76	23.2	46
37	11.3	23	77	23.5	47
38	11.6	23	78	23.8	48
39	11.9	24	79	24.1	48
40	12.2	24	80	24.4	49

Wave heights can be measured using several kinds of device. Those involved here are the waverider buoy (WRB) and the shipborne wave recorder (SBWR).

The WRB contains an accelerometer which measures vertical displacement as the buoy rides the waves. Thus, it records the variability of the sea surface elevation about the mean sea level.

The SBWR consists of two pairs of accelerometer and pressure units. These are located one on each side of the ship, approximately on the pitch axis. When the waves are of longer wavelength than the length of the ship the accelerometers measure vertical displacement as in the WRB. For waves with wavelength shorter than the length of the ship, the pressure units detect variations in pressure as the waves pass by.

The precise method of obtaining the significant wave heights from the recording device depends on the agency responsible. As an example, for wave recorders belonging to the Institute of Oceanographic

Sciences, the waves are recorded over an approximate 15-minute period every three hours. Significant wave heights are then calculated using the Tucker-Draper method (Tann 1976).

Table II lists the stations with measured wave data together with the period of measurement and number of observations. The corresponding numbers of resultant estimated wave observations for the 18-year period 1961–1978 are also shown.

**Table II.** *Availability of measured wave data and estimated data used in the analysis*

Station	Type of measurement	Period of measured data	Number of measured observations	Number of estimated observations during 1961–78
Famita	SBWR	1969–77	8566	8183
OWS 'L'	SBWR	1975–77	5188	2835
Seven Stones LV	SBWR	1968–78	24369	11899
Mersey Bar LV	SBWR	1965–66	2919	1475
Shambles LV	SBWR	1966–68	2920	12302
Varne LV	SBWR	1965–66	3146	9465
Owers LV	SBWR	1968–70	4426	10535
Stevenson	WRB	1973–76	6028	5520
Stevenson	SBWR	1973–76	5370	5520
FitzRoy	WRB	1973–76	4589	2972
FitzRoy	SBWR	1973–76	5008	2972
Boyle	WRB	1974–77	7175	6032
Boyle	SBWR	1974–77	7029	6032
South Uist (Offshore)	WRB	1978–80	9342	1665
South Uist (Onshore)	WRB	1978–80	3714	1665

For three of the sites there are two data sets, one from WRB measurements and one from SBWR measurements. These three sites are Stevenson, FitzRoy and Boyle, manned by ships sponsored by the United Kingdom Offshore Operators Association (UKOOA).

At the South Uist site there are two data sets of WRB measurements, one from a position 10 miles off shore in 42 m of water and the other 5 miles off shore in 14.5 m of water.

### 3. Analysis of data

#### (a) *Distributions of resultant estimated wave heights*

As with most meteorological data used for climatological purposes some quality control is necessary. The normal sequential checks and areal comparisons are difficult for ships of the VOF because of their random distribution in space and time. Comparison of the wave heights with the corresponding wind speed estimates provides a rather crude method of quality control, but one which eliminates the more obviously incorrect wave heights.

However, there were still several values in each data set producing a distribution with a long 'tail' of higher wave heights. In each case this tail consisted of resultant wave heights derived from estimates made in the post-1968 period. The most likely reason for this is the larger sample of wave heights present in the longer post-1968 period, allowing a greater likelihood of sampling more high waves.

The percentage frequency distributions of the resultant wave heights for each site are shown in Figs. 2(a)–2(f). With the exception of OWS 'L' with the mode at three metres, all the distributions have the mode at two metres and contain some zero wave heights.

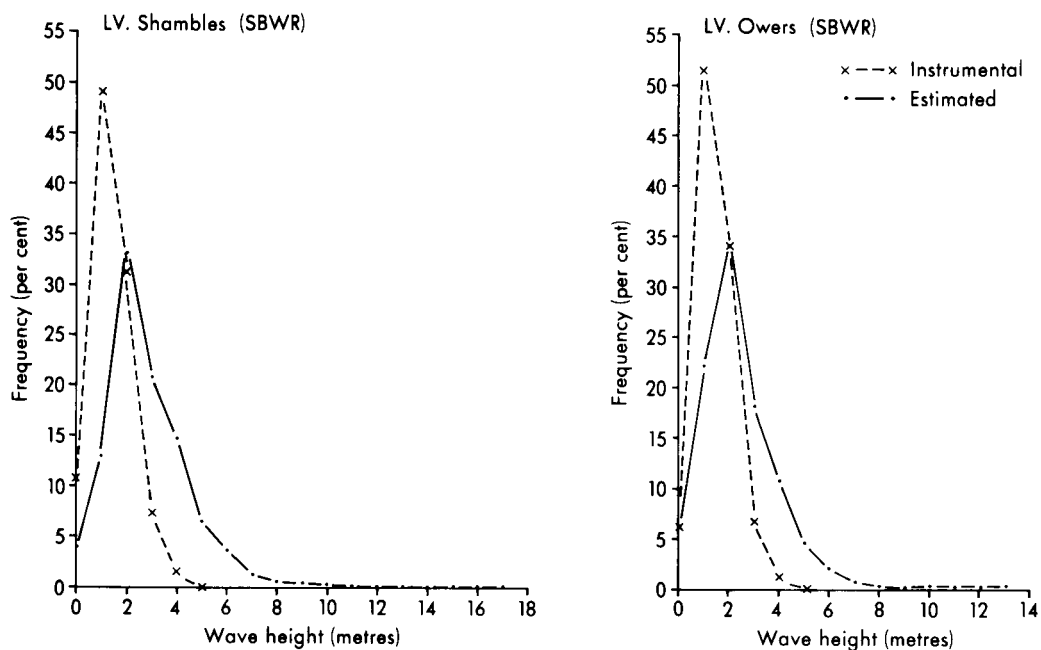


Figure 2(a). Wave-height frequency distributions for LV Shambles and LV Owers compared with those for co-located VOF ships within the  $2^\circ \times 2^\circ$  area around the fixed position.

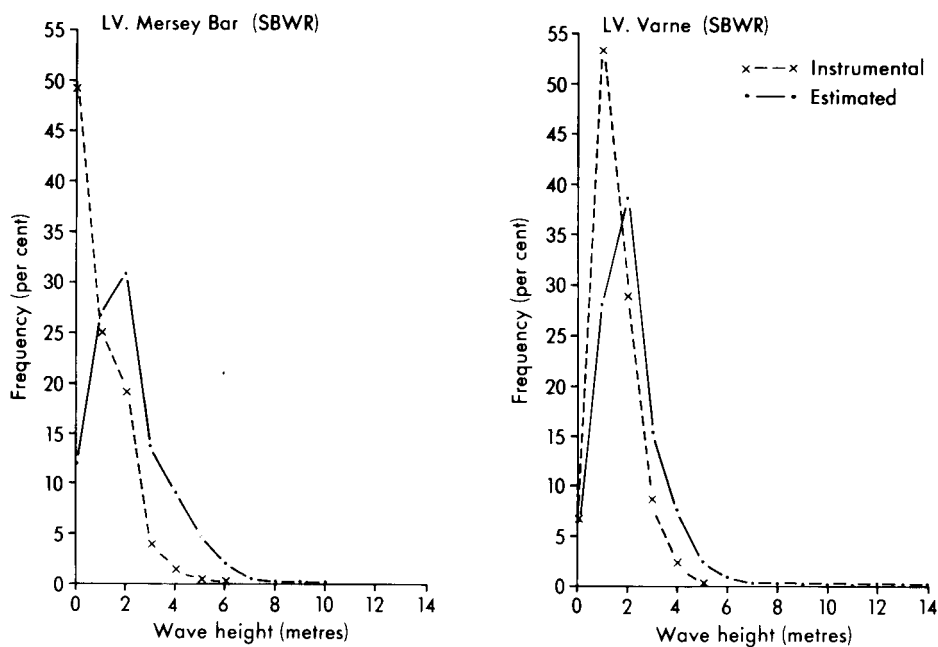


Figure 2(b). Wave-height frequency distributions for LV Mersey Bar and LV Varne compared with those for co-located VOF ships within the  $2^\circ \times 2^\circ$  area around the fixed station.

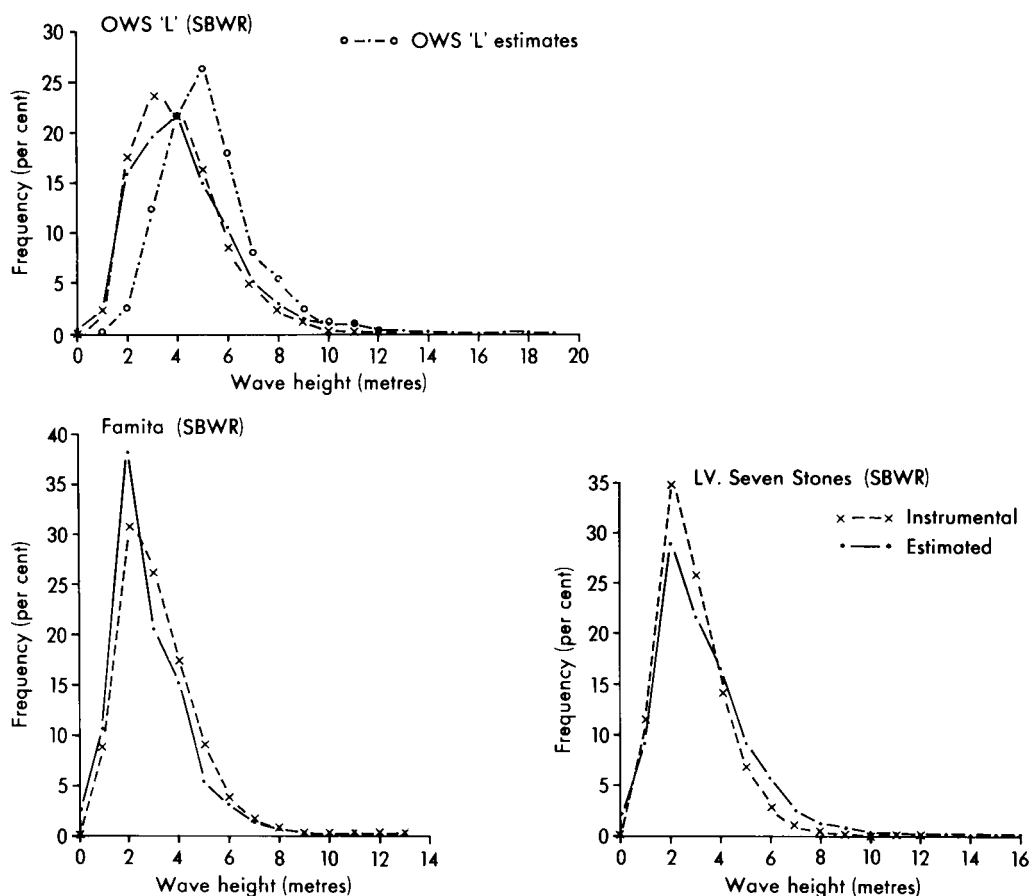


Figure 2(c). Wave-height frequency distributions for OWS 'L', LV Seven Stones and Famita compared with those for co-located VOF ships within the  $2^{\circ} \times 2^{\circ}$  area around the fixed position.

(i) *Visual estimates of wave height by OWS observers.* There are three data sets available for comparison at the OWS 'L' site: the measured (SBWR) significant waves, the estimates made by the VOF in the surrounding area, and those made by the OWS observers. Fig. 2(c) shows the percentage frequency distributions of the wave heights in these three data sets. The distributions of measured wave heights and the resultant waves derived from the VOF estimates agree reasonably well, but that for the OWS estimates is rather different having a mode of five metres. Visual estimates from OWS 'I' and 'J' were examined to check that the difference was not due to the short period of data available from OWS 'L' (1975–1979). The distributions of resultant wave heights from OWS 'I' and 'J' spanned the period 1961–1975 and the corresponding VOF estimated wave heights the years 1961–1978. Fig. 3 shows that for these locations also the OWS mode is higher than that of observations from the VOF. Examination of distributions of simultaneously observed data showed the same difference, thus eliminating the possibility that it is due to the comparison of regularly observed with randomly observed data.

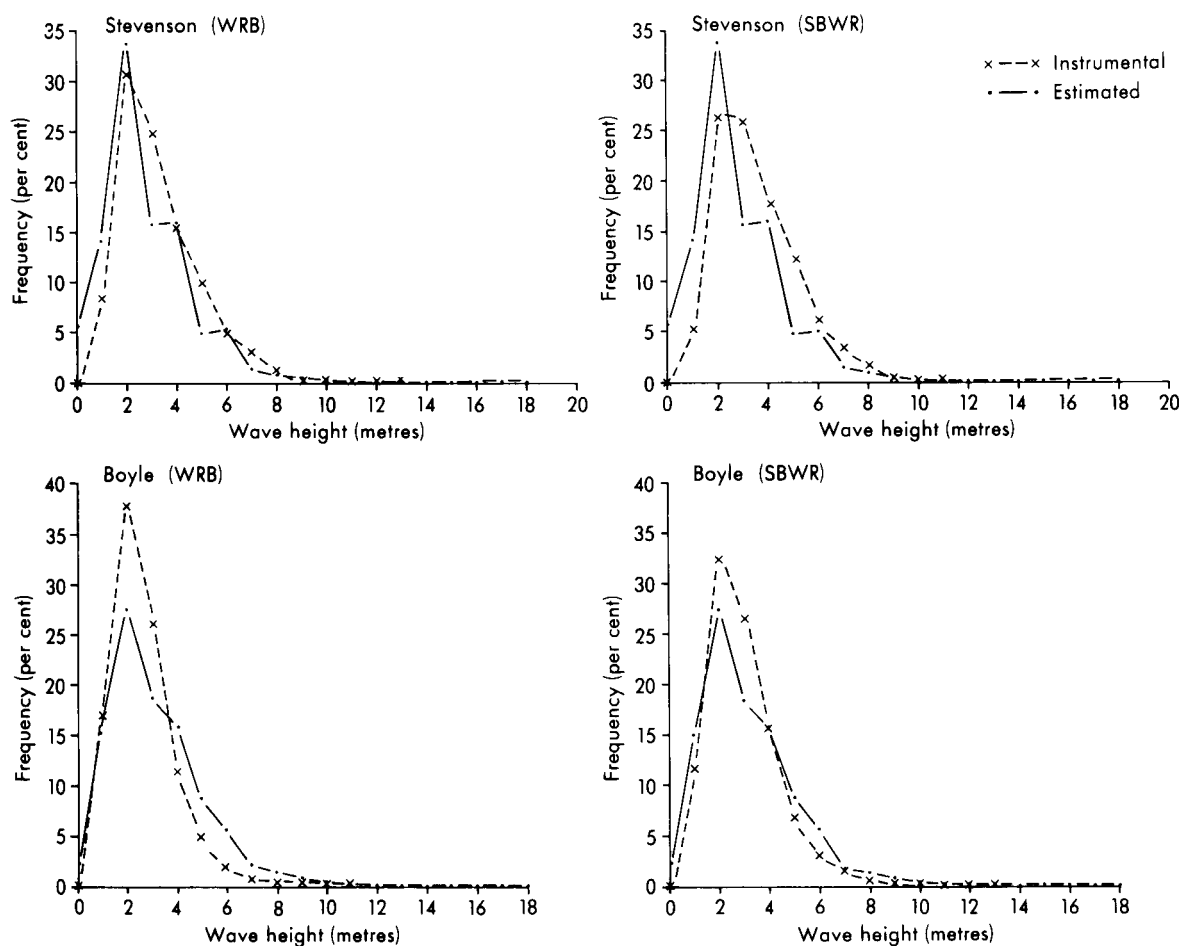


Figure 2(d). Wave-height frequency distributions for Stevenson and Boyle compared with those for co-located VOF ships within the  $2^{\circ} \times 2^{\circ}$  area around the fixed station.

Informal discussion with observers from the Meteorological Office who have worked on ships manning OWS indicates that the opinion of the deck officer is usually sought when estimating wave height. Consequently, this difference is unlikely to be due to the inexperience of the observers of conditions at sea.

Another possible explanation is that the ships at the OWS do not usually steam in wind speeds below Beaufort force 5. When this wind speed is exceeded the ships need to steam to remain on station. When 'stationary' the ship will be subjected to much more pitching and rolling than when steaming. It is possible that wave heights are overestimated when the ship is stationary and this could explain the low percentages of zero and one metre heights and also the shift in the peaks of the distributions. The point at which it becomes necessary to steam to stay on station will vary with the state of the sea, and so Beaufort force 5 is only an estimate. Unfortunately, there is no indication of whether or not the ship was steaming when an observation was made and so this explanation cannot be tested.



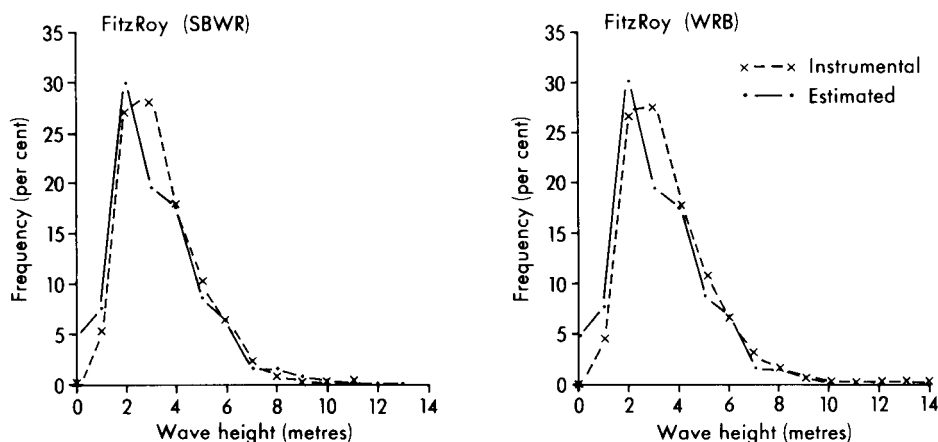


Figure 2(e). Wave-height frequency distributions for FitzRoy compared with those for co-located VOF ships within the  $2^{\circ} \times 2^{\circ}$  area around the fixed station.

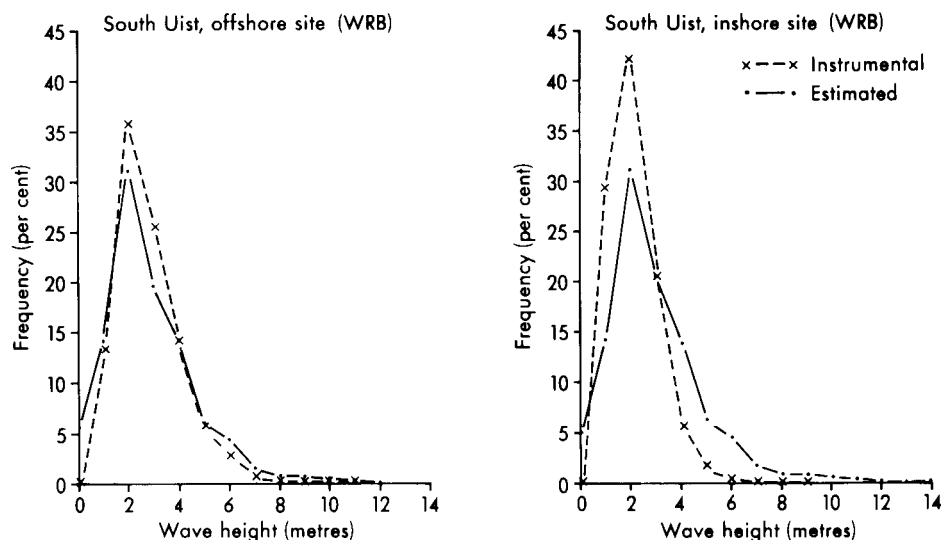


Figure 2(f). Wave-height frequency distributions for South Uist compared with those for co-located VOF ships within the  $2^{\circ} \times 2^{\circ}$  area around the fixed station.

(ii) *Period of VOF data used.* The resultant wave height distributions derived from estimates made by the VOF all cover the period 1961–1978. The distributions of measured data with which the resultant waves were to be compared covered varying periods as shown in Table II. Values for Brent B are not shown since the WRB data is still subject to confidentiality rules. Because of the short periods of measured data involved, the number of resultant waves available in the equivalent periods was too small for reasonable comparison, and so for each data set the distribution of waves from the whole period of VOF data was used. The similarity of the wind climatologies at the sites for both the short and long periods indicated that such comparisons were reasonable.

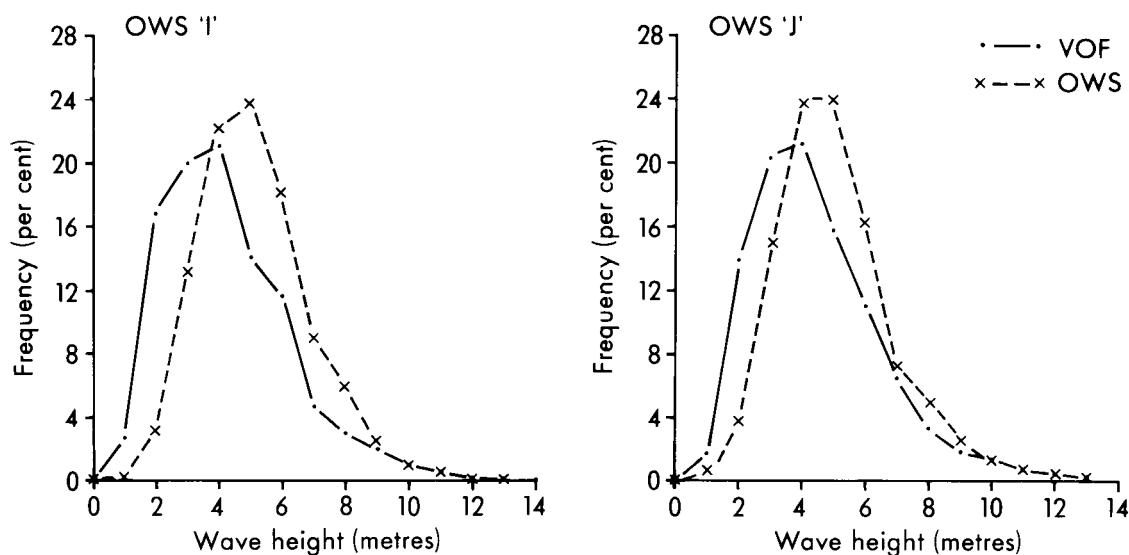


Figure 3. Wave-height frequency distributions for OWS 'I' and OWS 'J' compared with those for co-located VOF ships within the  $2^{\circ} \times 2^{\circ}$  area around the OWS.

*(b) Distributions of instrumental significant wave heights*

The percentage frequency distributions of instrumentally measured significant wave heights are also shown in Figs. 2(a)-2(f). The four light-vessels (LVs) Shambles, Varne, Owers and Mersey Bar have distributions with rather different characteristics from the others. Here the measured data are compared with estimates made over a large area. Many of the estimates will have come from comparatively more exposed positions (see Fig. 1(b)). The data sets for these LVs cover very short periods, one year for each except Owers which covers almost two years. The other LV, Seven Stones, is in a more exposed position, as are the two South Uist sites, although both are fairly close inshore. The South Uist site five miles from the coast does show a slightly higher percentage of low wave heights as would be expected.

For Seven Stones LV and the two South Uist sites there were no zero wave heights recorded and the mode of each distribution occurs at two metres. At all sites, except for the four LVs already discussed, no zero wave heights were recorded. The distributions for Famita, Stevenson (WRB) and Boyle (both SBWR and WRB) also have the mode at two metres. Except for OWS 'L', the remaining sites have produced distributions of significant wave height with no clear peaks, but similar percentage frequency of occurrence for wave heights of two and three metres. For OWS 'L' there was a low percentage frequency for wave heights of one metre with the mode at four metres. OWS 'L' is the only oceanic position considered in this study and the higher modal wave height reflects the different regime.

All of these data sets cover only short periods of time. There are only two with more than four years of data; Seven Stones LV, 1968-1978, but with data for the whole of 1970 and twenty other complete months missing; Famita has data covering a period of nine years, but the bulk of the measurements were made during the winter months and only 32% of the possible total number of observations were available.

Figs. 2(a)-2(f) show that the distributions of instrumentally measured and visually estimated wave heights differ at all sites. The bulk of the observations agree reasonably well, but large differences occur in the lower and higher ranges. The greatest discrepancies occur at the LVs Shambles, Varne, Owers and Mersey Bar. The VOF data for these locations were taken from the surrounding area, often from more exposed positions some distance from the instrumental site.

#### (c) *Extreme-value analysis*

For the design and planning of offshore structures it is necessary to have an estimate of the extreme sea conditions likely to be experienced during the expected lifetime of that structure. Extreme values are estimated by fitting a distribution to the available data, and extrapolating the tail of the distribution to the value having a cumulative probability of exceedance corresponding to the return period required. This gives the value expected to be exceeded, on average, once in  $N$  years, where  $N$  is the return period.

Many distributions used to estimate the extreme values require the identification of annual maxima. This means that long periods (more than ten years) of regularly observed data are required. Consequently, these methods cannot be used for estimating extreme wave heights from the distributions shown in Figs. 2(a)-2(f) since the measured data available cover only a few years and the estimated data are not regularly observed. The method used here to estimate extreme wave heights was to fit a 3-parameter Weibull distribution to the whole spectrum of data.

In practice, when fitting a Weibull distribution to wave heights, it is often necessary to alter subjectively the boundaries of the frequency distribution of the data. This is particularly so when dealing with data collected from the VOF which are random and therefore may give an irregular and unrepresentative distribution in the higher frequency ranges. It has already been noted that, even after some quality control to remove the obviously incorrect wave heights, there is still a long tail of greater wave heights. Where some subjective alteration appeared to be required the estimated extreme values were very similar to those estimated from the unaltered distribution.

This problem did not occur with the distributions of measured wave heights; these were quite smooth throughout the ranges used.

## 4. Results

The 1 in 50-year extremes derived from the significant and resultant wave height distributions are shown in Table III. The whole 18-year period of data was used for the resultant wave height analysis. The extremes estimated from the significant wave heights measured by SBWR were converted to the equivalent WRB height (Graham *et al.* 1979).

The results for the four LVs, Shambles, Varne, Owers and Mersey Bar are not comparable because of the difference in the distributions due to the large area from which the VOF data were taken which covered more exposed seas than those at the LV sites. It is probable that the same reason also accounts for the large difference in estimated extremes at the 'inshore' South Uist site.

In every other case the extremes estimated from the distributions of resultant wave heights are higher than those derived from the significant wave heights. The mean difference is five metres. This represents considerable difference in the 1 in 50-year extreme wave height between the resultant wave height distributions and the measured waves. However, it is important to remember that the measured data sets cover only very short periods and it may be that more extreme situations would be sampled over longer periods reducing the apparent over-estimation of the extreme conditions derived from the visual data. The variability of the percentage frequency of occurrence of wave heights is illustrated in Fig. 4. This figure shows the percentage frequency of occurrence of wave heights in two ranges for ten years of data from the LV Seven Stones. It is apparent that the choice of data from the years 1972-1974 would indicate different long term characteristics from those derived from data from the years 1975-1978.

**Table III.** *1 in 50-year extreme values for all data sets of measured wave heights and the corresponding VOF resultant wave heights*

Station	Extremes derived from significant waves	Height metres	Extremes derived from resultant waves
Famita	13		16
OWS 'L'	17		19
Seven Stones LV	12		17
Mersey Bar LV	8		12
Shambles LV	5		17
Varne LV	5		16
Owers LV	5		15
Stevenson (WRB)	14		21
Stevenson (SBWR)	13		21
FitzRoy (WRB)	14		16
FitzRoy (SBWR)	14		16
Boyle (WRB)	12		20
Boyle (SBWR)	12		20
South Uist (Offshore)	11		15
South Uist (Onshore)	9		15

Extreme values were also derived from the distributions of resultant wave heights obtained from visual estimates made by OWS observers. The 1 in 50-year extremes are shown in Table IV together with the extremes estimated from the corresponding VOF data. Despite the shift to a higher modal wave height the extremes estimated from the OWS resultant wave heights are lower than those from the VOF resultants. The 1 in 50-year extreme value of 17 metres derived from the instrumental data at OWS 'L' indicates that the OWS resultant distribution underestimates the extremes.

**Table IV.** *1 in 50-year extreme values for OWSs and VOF resultant waves*

Station	Extremes derived from OWS resultant waves	Height metres	Extremes derived from VOF resultant waves
OWS 'L'	15		19
OWS 'I'	15		19
OWS 'J'	14		19

## 5. Conclusion

With a few exceptions, the measured significant wave heights that are available cover very short periods of time and so, despite the high quality of the measurements, their use is limited both climatologically and especially for the estimation of extremes.

The main advantage of the estimated data is that they cover long periods of time and are available for all sea areas. Individually, these data are of much poorer quality being far less accurate than measurements of wave height. However, the bulk of each distribution is probably sufficiently accurate to give an estimate of the general wave climatology. Unfortunately, because of the difficulties in estimating sea and swell separately, many of the resultant wave heights will be incorrect representations

of conditions at the time of observation. The distributions are markedly affected in the higher wave height ranges and consequently difficulties are again created in the estimation of extremes.

Obviously, neither the instrumentally measured data available at present, nor the visual estimates are sufficient for current needs if used separately. Where possible both kinds of data should be used to give the most complete picture. When the visual estimates of wave height are the only source of information available they should be used with caution, bearing in mind the differences known to exist between estimated and measured data especially the tail of high wave heights of doubtful accuracy. Instrumental records should equally be used with caution because of the short length of record and their incompleteness.

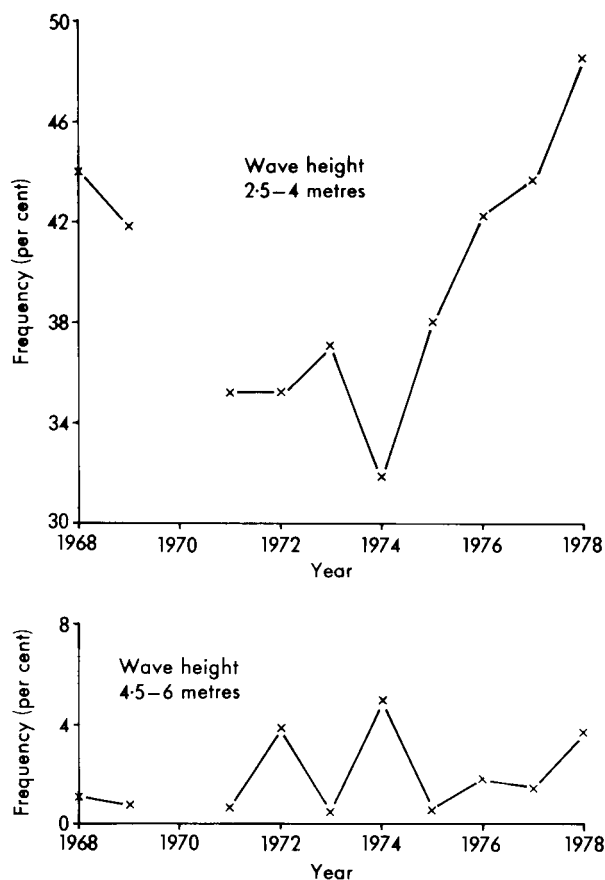


Figure 4. Percentage frequency of waves in each year at LV Seven Stones for wave heights 2.5-4 m and 4.5-6 m inclusive.

Earlier work comparing visually estimated wind speeds with instrumental measurements concluded that the winds reported by the VOF can be used with confidence to derive a wind climatology where no reliable measured data are available (Graham 1982). The National Maritime Institute is developing a wave climate model by combining visually estimated wind speeds and wave heights, together with measured wind and wave data and wind-wave relationships.

However, such a modelled wave climate does not provide a solution to the problem of estimating extreme wave heights. Extremes do not occur in average conditions and therefore cannot be described by models based on average relationships.

## 6. Acknowledgements

This work is part of a wave climate synthesis project carried out in collaboration with the National Maritime Institute with the support of the Maritime Technology Committee.

## References

- |  |      |   |
|--|------|---|
| Graham, A. E.                              | 1982 | Winds estimated by the Voluntary Observing Fleet compared with instrumental measurements at fixed positions, <i>Meteorol Mag.</i> , <b>111</b> , 312–326.   |
| Graham, C. C., Verboom G., and Shaw, C. J. | 1979 | Comparison of shipborne wave recorder and waverider buoy data used to generate design and operational planning criteria. New York. American Society of Civil Engineers, Proceedings 16H, Coastal Engineers Conference, <b>1</b> , 97–113. |
| Meteorological Office                      | 1977 | Marine observer's handbook. London, HMSO.   |
| Nordenstrøm, N.                            | 1971 | Methods for predicting long-term distributions of wave loads and probability of failure for ships. Part 1. DnV-Report No. 71–2–5, Oslo.   |
| Tann, H. M.                                | 1976 | The estimation of wave parameters for the design of offshore structures. IOS Report 23.   |

## **World Meteorological Organization Commission for Agricultural Meteorology (CAGM) Eighth Session, Geneva, 21 February — 4 March 1983**

By N. Thompson

(Meteorological Office, Bracknell)

The need to increase food production, both to keep pace with the rising world population and to raise food intake to proper levels of nutrition, is providing mankind with one of its greatest challenges. Since the last meeting of the Commission in Sofia in 1979 the general trend of agricultural output has continued upwards, but in some countries the production per head of population has actually fallen in recent years. With this background, one of the most important objectives in world agricultural meteorology now is to transfer effectively the experience that continues to be accumulated in developed nations to those countries suffering food shortages and lacking at present the knowledge and organization to reap the full benefits that application of agricultural meteorology can confer.

This theme dominated the Eighth Session of the Commission and is reflected in the resolutions passed for work in the next intersessional period. For example, of the seven Working Groups established to report on various topics within this period, all but one (the President's Advisory Group) have terms of reference that include specifically the agricultural and technical problems of Third World nations; a different response from the Commission in the present circumstances would have been unthinkable.

The topics which will be studied by the Working Groups, and by a number of specialist rapporteurs who were also appointed at the meeting, range from applications of remote (satellite) sensing to agriculture through to the benefits to be derived from quantifying the experience behind, and further developing the methods of, microclimatic manipulation and management which are features of traditional farming; successful completion of all of these tasks will bring very large benefits to the poorer countries in particular.

In view of the great emphasis on Third World problems at the meeting, it is appropriate to record that the Commission unanimously supported a resolution which indicated in some detail the important role that agrometeorology has in developed nations also; all present recognized that without the progress which continues to be made in the better-endowed countries, and without the efforts that these countries make to adapt and transfer this technology to less fortunate nations, the prospects for world food security would be bleak indeed.

The United Kingdom delegates were Mr C. V. Smith, who was elected to the President's Advisory Working Group, and Dr N. Thompson, who was appointed Chairman of the Working Group on Agrometeorological Aspects of Operational Crop Protection Measures.

### **Review**

*Carbon dioxide review: 1982*, edited by William C. Clark. 210 mm × 280 mm, pp. xix + 469, *illus.* Oxford University Press, 1982. Price £22.50.

The 'Carbon dioxide review: 1982' is intended 'to appeal to a wide cross-section of scientists, policy advisers, news analysts and informed citizens', and 'seeks to provide for experts on various aspects of the CO<sub>2</sub> question a useful introduction to their disciplinary neighbours'. The articles, generally by

experts in the relevant fields, were written during the second half of 1981. The book is well laid out and the diagrams are clear. Each chapter is preceded by a short summary, and the longer articles are followed by two or more short commentaries by other specialists in the appropriate field.

The first section, 'Perspectives', commences with a rather too detailed summary of how man is increasing the concentration of atmospheric CO<sub>2</sub> and the possible effects, including changes in climate. The second chapter considers five past climate studies and attempts to assess why they were (or were not) successful.

The main section, 'Issues', includes chapters on climate modelling, and the biological and chemical response of the oceans. Both are well written, but include a fair amount of technical detail. An article on the first detection of climate change due to increasing CO<sub>2</sub> is less technical and very readable. The essay on the possible effects due to increasing minor atmospheric constituents is confusing as the commentators correctly dispute the method used by the authors. However, the results still give a qualitative impression of the changes in surface temperature that could occur following increases in other trace gases. The remaining chapters, on an ice-free Arctic, the effects on agriculture, and future increases in CO<sub>2</sub> due to man's activities, are of a more speculative nature.

Part 3, 'Notes', comprises short informative articles on the measurement of atmospheric CO<sub>2</sub> concentrations, the role of the earth's vegetation in the carbon cycle, the possible release of methane hydrate in high latitudes, and the relative unimportance of the enhanced production of CO<sub>2</sub> from synthetic as opposed to natural fuels.

Finally, under 'Data', a useful guide is provided to recent publications and data on the carbon cycle, climate, and on carbon dioxide released by the activities of man.

I found the Review easy to read and up to date. There are many references, including a list of the more important papers published in the last few years. I recommend this book to those who wish to know more about various aspects of the increase in atmospheric CO<sub>2</sub> and its consequences.

J. F. B. Mitchell.

## Obituary

We regret to record the death on 12 March 1983 of Mr A. Gray, Higher Scientific Officer, who was a member of the Climatological Services Branch.

Alec Gray joined the Office as an Assistant (Scientific) in October 1941. A member of the RAF Meteorological Branch from 1943 to 1947, he served during the War and for the following couple of years at a variety of forecasting outstations. In August 1947 he was sent on loan to the Bermuda Meteorological Service returning two years later to become an Instructor at the Meteorological Office Training School where he studied for, and in 1951 obtained, the Intermediate B.Sc. of London University. In August 1951 he was promoted to the forecasting grade of Assistant Experimental Officer and was further promoted to Experimental Officer in 1956.

Apart from three years in the Middle East, when he worked at Habbaniyah and Nicosia, Alec Gray's forecasting career was largely spent at Acklington with occasional spells of duty at other UK outstations. In October 1969 he was posted to the Climatological Services Branch (Met 0 3) at Bracknell. While in Met 0 3, he was responsible for dealing with enquiries on overseas climatology and made the job very much his own. His help and advice were much in demand by a wide range of business and commercial interests and covered anything from requests for data for designing air-conditioning plants in Riyadh to information relevant to the forward buying of commodities.

Alec Gray had a somewhat earthy, but colourful, sense of humour; his craggy face, usually with a pipe clenched between his teeth, was a familiar sight in the Library and the Technical Archives Office. He — though not always his pipe — was well liked and respected by his colleagues. His two great interests outside work were his garden and his dog.









# THE METEOROLOGICAL MAGAZINE

No. 1332

July 1983

Vol. 112

## CONTENTS

	<i>Page</i>
<b>Analyses of moisture and convective activity from cloud, visibility and present weather reports.</b>	
A. G. Higgins and P. R. W. Wardle .. .. .	189
<b>Global solar radiation measurements on 6 August 1981. A day of midday darkness. R. J. Armstrong .. .. .</b>	<b>200</b>
<b>Wave heights estimated by the Voluntary Observing Fleet compared with instrumental measurements at fixed positions. Anne E. Graham .. .. .</b>	<b>210</b>
<b>World Meteorological Organization Commission for Agricultural Meteorology (CAgM) Eighth Session, Geneva, 21 February — 4 March 1983. N. Thompson .. .. .</b>	<b>225</b>
<b>Review</b>	
Carbon dioxide review: 1982. William C. Clark (editor). <i>J. F. B. Mitchell</i> .. .. .	225
<b>Obituary .. .. .</b>	<b>226</b>

---

## NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ and marked 'For Meteorological Magazine'.

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

Applications for postal subscriptions should be made to HMSO, PO Box 569, London SE1 9NH.

Complete volumes of 'Meteorological Magazine' beginning with Volume 54 are now available in microfilm form from University Microfilms International, 18 Bedford Row, London WC1R 4EJ, England.

Full-size reprints of out-of-print issues are obtainable from Johnson Reprint Co. Ltd, 24-28 Oval Road, London NW1 7DX, England.

Please write to Kraus microfiche, Rte 100, Millwood, NY 10546, USA, for information concerning microfiche issues.

---

©Crown copyright 1983

Printed in England by Robendene Ltd, Amersham, Bucks.

and published by

HER MAJESTY'S STATIONERY OFFICE

£2 monthly

Dd. 717701 K15 7/83

Annual subscription £26.50 including postage

ISBN 0 11 726936 0

ISSN 0026-1149