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Recent measurements of broad-band turbidity in the United Kingdom

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Summary

The results of recent measurements of turbidity, calculated using pyrheliometer data at 1-minute intervals, are presented. Estimates of turbidity derived from hourly pyranometric observations indicate the annual cycle at different locations within the United Kingdom. The effect of the spread of stratospheric dust from the El Chichon eruption is investigated.

1. Introduction

The attenuation of the direct solar beam under cloudless skies is described by the turbidity of the atmosphere, which is principally determined by the optical depth due to aerosol. The presence of aerosol strongly influences solar radiation received at the earth's surface: both the spectral and the angular character of the radiation field are modified by scattering and by absorption of photons by suspended particles. The turbidity is an important parameter in many short-wave radiative transfer calculations, which are of particular interest for solar energy and agrometeorological studies. Only a limited number of measurements of turbidity in the United Kingdom have been published — Unsworth and Monteith (1972), and an annual series beginning with National Oceanographic and Atmospheric Administration (1973) — so that seasonal and geographical variations are largely unknown.

Owing to the aerosol optical depth being a function of wavelength, turbidity can be described by various coefficients. Here we consider only broad-band coefficients, which depend upon the attenuation over the entire solar spectrum (0.3–3.0 μm), and which can be determined from unfiltered pyrheliometric measurements of normal-incidence direct solar irradiance, as described in Armstrong and Richards (1981). Two coefficients of turbidity are employed: the Unsworth and Monteith (1972) coefficient, τ_a, and the Linke (1922) turbidity factor, T_L. The former is defined by the equation

$$I = I^* \exp(-\tau_a m) \qquad (1)$$

where I^* is the normal incidence irradiance at the bottom of a dust-free atmosphere with a specified water vapour content, I is the normal incidence direct irradiance at the same level, and m is the air mass number. The Linke factor is defined by

$$I = I_0 \exp(-T_L \tau_s m) \quad \ldots \quad (2)$$

where I_0 is the extraterrestrial direct irradiance and τ_s is the broad-band Rayleigh scattering optical depth. A convenient approximation for inverting equation (2) and obtaining T_L is supplied by Kasten (1980),

$$(\tau_s m)^{-1} = 0.9 + 9.4m^{-1} \quad \ldots \quad (3)$$

which is sufficiently accurate for the calculations described. The Linke factor (for a constant aerosol content) is dependent upon the water vapour optical path and hence upon the air mass number, m. When the water vapour content is known, the Unsworth–Monteith coefficient can be used to study changes in aerosol. However, the Linke factor is useful for applications when the water vapour content of the atmosphere is not available.

Three sources of turbidity data are considered: from occasional, manual pyrheliometric measurements, starting in 1968; from more recent pyrheliometric data recorded at a resolution of 1 minute; and from hourly pyranometric observations. Data have been recorded from pyrheliometers at three sites in the United Kingdom with a resolution of 1 minute, which facilitates identifying cloud-free conditions and allows the broad-band turbidity to be found whenever the vicinity of the sun's disc is unobscured by clouds; these results are presented in terms of the Unsworth–Monteith coefficient of turbidity.

Less precise estimates of average turbidity are obtained from hourly direct solar irradiation, calculated from pyranometric measurements of hourly global and diffuse irradiation, using the method of Page (1978), in which the problem of cloud contamination is circumvented — this method is described in a later section. Although several sources of error are introduced in this procedure, it has the considerable merit of providing an estimate of average turbidity, here labelled a 'derived turbidity', from routine solar radiation measurements, allowing values to be calculated from a larger number of stations over a longer period. These results are presented in terms of the Linke factor, partly because the atmospheric water vapour content is not required for this coefficient (which, by the method of Page, is based on a set of measurements on different days) and partly to distinguish between these pyranometric estimates of average turbidity and individual pyrheliometric observations.

Aerosol in the atmosphere arises from many sources, including the emission of pollutants, wind-blown dust and the chemical reaction of trace gases — the turbidity is largely determined by aerosol loading within the boundary layer, where the nature and concentration of particles exhibit great variability. However, a major perturbation in the aerosol optical depth at stratospheric heights occurred after the El Chichon eruptions in Mexico during April 1982 (Pollack *et al.* 1983). Large amounts of volcanic debris were injected into the stratosphere and gradually extended a veil of dust into northern latitudes during the following months. A stratospheric aerosol optical depth exceeding 0.1 (at 0.5 μm) was found from aircraft measurements by Dutton and DeLuisi (1983) at 50° N during December 1982; the background value is about 0.005 (at 0.55 μm) (Toon and Pollack 1976). This raises the possibility of detecting the spread of stratospheric dust to United Kingdom latitudes through turbidity measurements, although these include the effect of aerosol within the entire depth of the atmosphere.

2. Measurements

The United Kingdom network for measuring solar radiation is co-ordinated by the National Radiation Centre at Beaufort Park, near Bracknell, which maintains standard instruments with calibrations traceable to the World Radiation Reference. A list of stations within the network and their

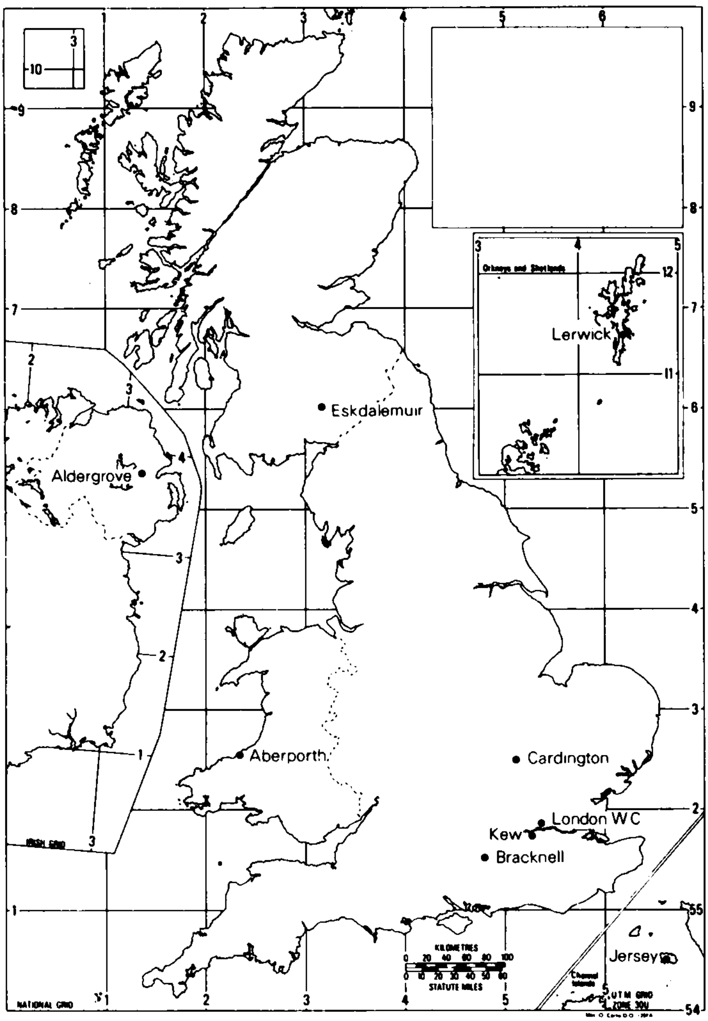

Figure 1. The geographical location of stations in the United Kingdom solar radiation network for which estimates of turbidity have been made.

periods of observation can be obtained from the Meteorological Office; calibration techniques are described in Budgen and Price (1981).

Currently, three stations measure normal incidence direct irradiance using Eppley NIP sun-tracking pyrheliometers — observations began in 1974 at Bracknell, and in 1981 at Lerwick and Eskdalemuir. From 1979 onwards, these measurements have been recorded at a resolution of 1 minute. Hourly global irradiation, G, and diffuse irradiation, D, have been obtained for at least 10 years since 1970 at nine sites using Kipp and Zonen thermopile pyranometers; the geographical locations are shown in Fig. 1. Diffuse irradiation is measured by obscuring the pyranometer with a shade ring — routine corrections are normally applied for the obscured regions of sky, assuming a uniform radiance distribution. This correction is too small under most conditions, and especially for clear skies, owing to the anisotropy of the sky radiance. Hence in this paper, measured values, D_m, are corrected by an empirical expression in the form suggested by Kasten *et al.* (1983),

$$D/D_m = 1.148 - 0.142\,(D_m/G)^3 - 0.0012\delta \quad \ldots \quad (4)$$

where δ is the solar declination (in degrees), and the coefficients were calculated from a comparison of diffuse irradiation measured by pyranometer with that obtained from pyrheliometric observations, for all available hourly data within the United Kingdom.

Occasional measurements of turbidity have been performed at Kew during 1968-73, and Bracknell during 1974-78, using Ångström compensation pyrheliometers (Armstrong and Richards 1981). Data were obtained on about 150 days — a minor drawback of these measurements is that a majority were taken on days chosen for the calibration of pyrheliometers, which biases the data towards settled, cloudless conditions.

In 1982, Eko sun photometers were introduced at Bracknell and at Eskdalemuir. These are manually aligned to measure the solar irradiance in small spectral intervals at four wavelengths and, potentially, can reveal more information concerning the character of atmospheric aerosol than can be obtained from a single broad-band measurement (Volz 1974). Unfortunately, the stability of calibration was poor and these measurements have not been used.

3. Turbidity from pyrheliometric measurements (1-minute resolution)

When the sun is unobscured by cloud, values of the Unsworth-Monteith coefficient, τ_a, can be found for each minute from the record of normal incidence direct irradiance, using equation (1). I^* was calculated from tables, supplied by Unsworth (1975), as a function of the precipitable water vapour content of the atmosphere, which was estimated from synoptic observations of the surface vapour pressure, e (mb). The precipitable water vapour content (in millimetres) was approximated by $1.7e$ (Dogniaux and Lemoine 1982). This empirical estimate is sufficiently accurate for calculations of τ_a. In this procedure the effect of attenuation due to water vapour absorption is removed, and τ_a represents a broad-band aerosol optical depth. Fig. 2(a) shows an example of the turbidity found on a mostly cloudless day.

An obstacle to obtaining reliable values of turbidity is the passage of cloud, particularly cirrus, in front of the sun, which leads to a spuriously high estimate of turbidity. Fig. 2(b) indicates the turbidity calculated from the 1-minute record on a day of intermittent sunshine. This problem was overcome by dividing the measurement period into running 11-minute intervals: any single value of τ_a larger than 0.5 was considered to be due to cloud, not aerosol, and the entire interval was rejected. Also, if the range of values of τ_a within the 11 minutes exceeded 0.1 it was assumed that cloud was present and the record was eliminated. After these checks an average of the remaining 11-minute segments was taken and these averages constitute the basis of the turbidity record described subsequently.

Clearly, some difficulty remains in distinguishing between the incursion of a thin, uniform cloud layer and a heavily polluted air mass: it is likely that some days of high, variable turbidity will be rejected accidentally. Other problems, such as a marginal misalignment of the sun-tracking pyrheliometer, will also tend to lead to an overestimate of τ_a. Hence the minimum turbidity recorded during the day is a more reliable indicator of changes in aerosol than an average value, particularly because of the ambiguity in defining an upper limit for τ_a. Fig. 3 indicates the variation of the daily minimum turbidity for each month of the year, with total samples of 410, 400 and 780 days at Lerwick, Eskdalemuir and Bracknell respectively. The averages of the daily minima are shown, and the vertical bars mark the extent of the 30% and 70% levels of the frequency distribution of daily minimum τ_a (i.e. if the

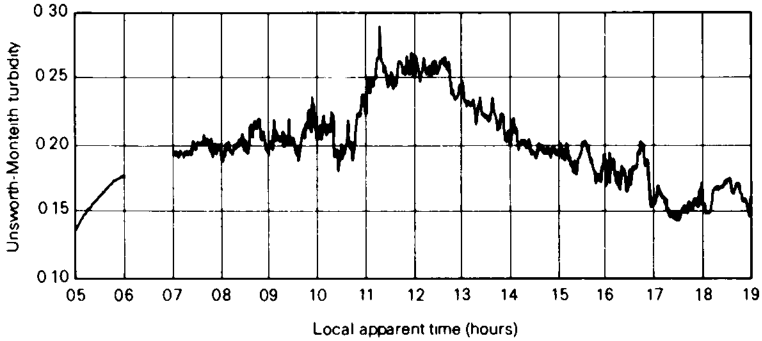

Figure 2(a). An example of the variation of Unsworth-Monteith turbidity at 1-minute resolution, measured by a sun-tracking pyrheliometer, for a day with little cloud (Bracknell, 13 May 1980).

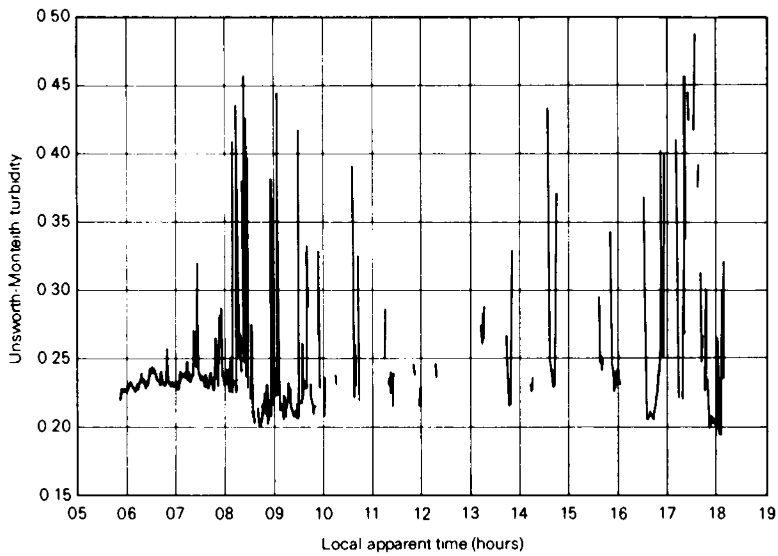

Figure 2(b). As fig. 2(a), for a day with intermittent cloud (Bracknell, 12 April 1983).

distribution was Gaussian, this would approximate to plus or minus one standard deviation). An annual cycle is obviously present, with the least turbid conditions occurring in winter months; the intra-month variation is shown to be large, and a significant difference between Bracknell (southern England suburban location) and the two sites in less-populated areas is evident.

Minimum turbidity 1981–83

The minimum values of τ_a in each month from 1981 until 1983 are shown in Fig. 4 — only those months with four or more days of reliable turbidity measurements were included. In the period of interest, all three sites indicate an increase in the monthly turbidity. Fig. 5 shows the minima averaged over the three stations, as well as an annual cycle based on all pre-July 1982 data. An increase in the minimum turbidity, compared to earlier values, is seen to extend from October 1982 until the end of the record.

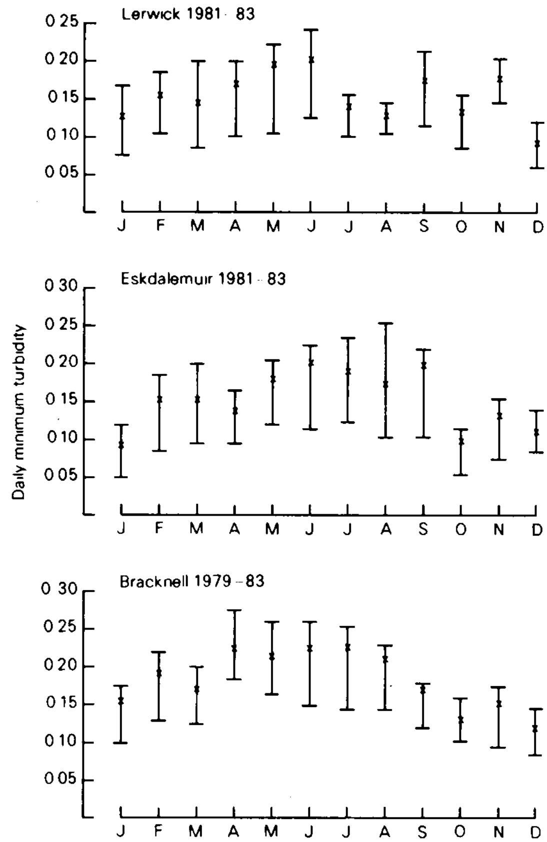

Figure 3. The distribution of daily minima of Unsworth–Monteith coefficients of turbidity in each month of the year at Lerwick, Eskdalemuir and Bracknell. The turbidity value at the upper end of the error bar is exceeded on 30% of occasions and that at the lower end on 70% of occasions. Averages of the daily minima are denoted by ×.

Owing to the brevity of the measurement period and to gaps in the data record, the duration and significance of the perturbation in turbidity is difficult to quantify. However, it is notable that at all sites and in every month, from October 1982 to May 1983, the minimum value of τ_a was higher than in any corresponding month outside that period. The average increase in minimum turbidity from October 1982 to May 1983 was about 0.06. Although it cannot be conclusively demonstrated that this change was due to the evolving El Chichon dust veil, the results are consistent with an enhancement of the aerosol optical depth over a large geographical area, partially masked by local variations in boundary-layer aerosol.

4. Turbidity from pyranometric measurements

(i) *Preliminary work*

When pyrheliometric measurements are not available, the normal incidence direct irradiance, I, can be found from pyranometric measurements of global and diffuse irradiance, from the relationship

$$I = (G - D)/\cos z \qquad \text{(5)}$$

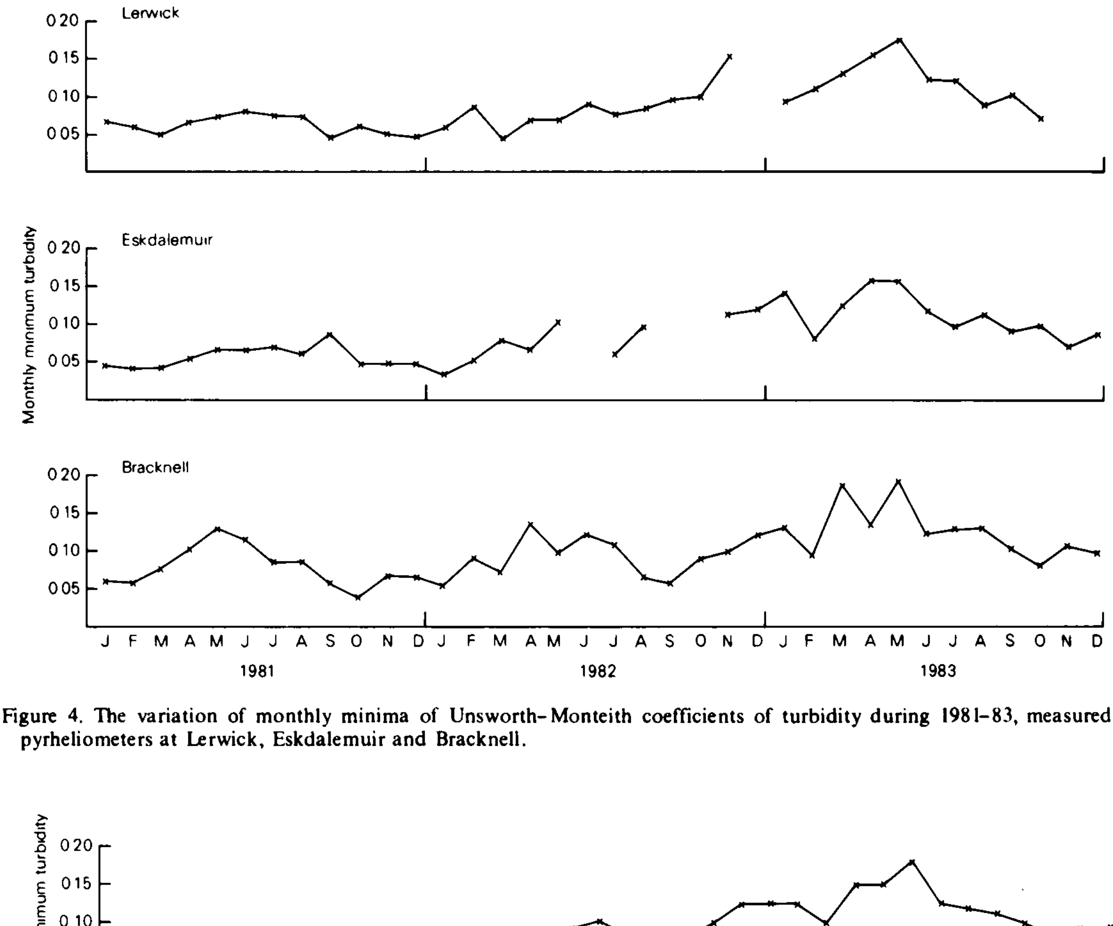

Figure 4. The variation of monthly minima of Unsworth-Monteith coefficients of turbidity during 1981–83, measured by pyrheliometers at Lerwick, Eskdalemuir and Bracknell.

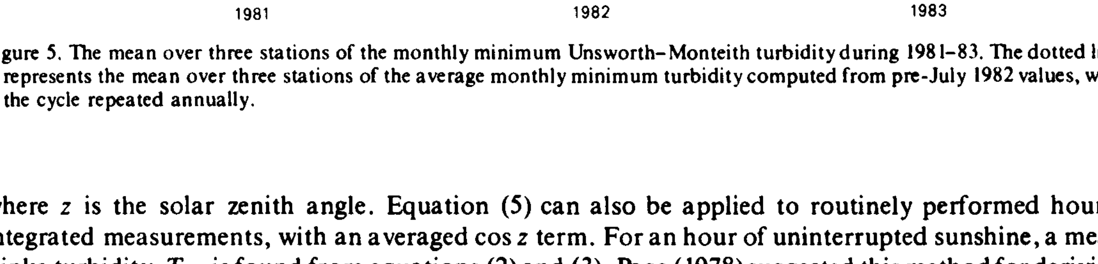

Figure 5. The mean over three stations of the monthly minimum Unsworth-Monteith turbidity during 1981–83. The dotted line represents the mean over three stations of the average monthly minimum turbidity computed from pre-July 1982 values, with the cycle repeated annually.

where z is the solar zenith angle. Equation (5) can also be applied to routinely performed hourly integrated measurements, with an averaged $\cos z$ term. For an hour of uninterrupted sunshine, a mean Linke turbidity, T_L, is found from equations (2) and (3). Page (1978) suggested this method for deriving turbidity, using mean values of G and D.

For most hours the sun is partially or completely obscured by cloud for some of the time, leading to a spuriously high value of turbidity from equation (2) and the problem of determining a realistic T_L reduces to finding cloud-free hourly measurements. This can be circumvented by selecting a representative value of I/I_0 from a large ensemble of hourly measurements. In this work the hourly value of I/I_0 which is exceeded on only 5% of occasions in each month of the year is selected to represent the average clear sky irradiance; only hourly measurements between 0900 and 1500 local apparent time for each day are used in a sample of over 10 years. The sample excludes hours for which the average solar altitude is less than 10°, when equation (5) yields only very poor estimates. A 'derived Linke turbidity' is obtained from equation (2) and this can be regarded as an average turbidity for the month.

Fig. 6 compares the monthly Linke turbidity derived by this method from the sample 1968–73 for Kew, and 1974–78 for Bracknell, with the mean turbidity found from the series of occasional, manual observations by pyrheliometers during the same periods — the vertical bar denotes the standard error of the mean of the latter. Although complete agreement between measured and derived turbidity is not

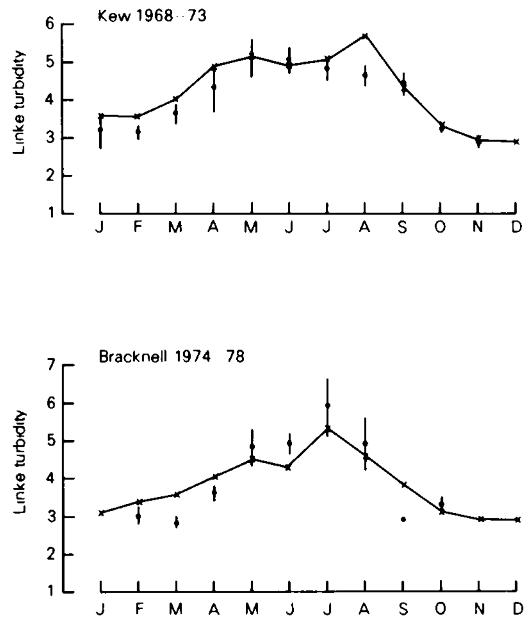

Figure 6. Comparison of monthly averages of Linke coefficients of turbidity at Bracknell and Kew, between measurements from Ångström pyrheliometers (with the standard error of the mean) and values derived from hourly pyranometer data (the continuous trace). The periods of the respective types of measurement are chosen to correspond to each other.

seen, the seasonal variation is successfully reproduced. Taking the deficiencies of the measurements into account, the agreement was deemed to be sufficiently good to treat the derived turbidity as a useful supplement to conventional measurements and justifies the choice of the 95% level a posteriori. The inclusion of latter values of T_L obtained from 1-minute resolution data (not shown) does not significantly affect these results.

Sources of error in the derived turbidity include: differences in the cosine response of the pyranometers which measure global and diffuse irradiation; averaging the cos z term in equation (5) over an hour; the shade-ring correction for diffuse irradiation; and the choice of a representative value of I/I_0 for clear conditions. Clearly, quantitative results should be treated with caution, especially for northern sites in winter, when relatively few uninterrupted hours of sunshine occur. This topic is discussed in Rawlins (1983).

(ii) *Average turbidity within the United Kingdom*

The Linke turbidity was derived from hourly global and diffuse irradiation for the period 1970–83 at nine sites: the monthly figures are given in Table I. It should be noted that the results are in accord with a subjective assessment of the relative aerosol concentration at each location, particularly for summer months, with the lowest turbidity found in coastal or rural areas and the highest turbidity recorded inland, at urban sites — this encourages confidence in the method employed. Data from some months are missing, owing to the infrequency of cloud-free hours in winter — at these times turbidity values found from 1-minute resolution pyrheliometric measurements are also scarce, for the same reason. The seasonal variation of T_L is shown in Fig. 7, with all stations combined.

Table I. *Monthly averages of Linke turbidity factor derived from hourly pyranometric data for different sites within the United Kingdom*

Station	Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Lerwick	1970–83	-	2.9	3.4	3.6	3.5	3.5	4.3	3.8	3.7	3.3	3.3	-
Eskdalemuir	1970–83	2.1	2.4	3.6	3.6	3.8	4.0	4.2	4.3	4.1	3.0	2.2	2.2
Aldergrove	1970–83	2.4	2.8	3.2	3.7	4.0	4.4	4.7	4.2	3.6	3.1	2.5	2.6
Aberporth	1970–83	2.8	3.2	3.2	3.5	3.6	3.6	3.9	3.8	3.6	3.3	3.0	2.8
Cardington	1970–79	2.7	3.2	3.7	4.4	3.9	4.8	5.0	4.7	3.8	3.3	2.8	2.6
London W.C.	1970–83	3.3	3.9	4.1	4.9	5.1	5.0	5.4	5.1	4.3	3.6	3.3	3.3
Kew	1970–80	2.9	3.6	3.9	4.7	4.7	4.7	5.2	5.0	3.9	3.3	2.8	2.9
Bracknell	1970–83	2.8	3.4	3.7	4.3	4.6	4.7	5.1	4.7	3.9	3.1	2.8	2.8
Jersey	1970–83	2.7	3.0	3.2	3.5	3.8	3.9	3.9	3.8	3.4	3.0	3.0	2.8

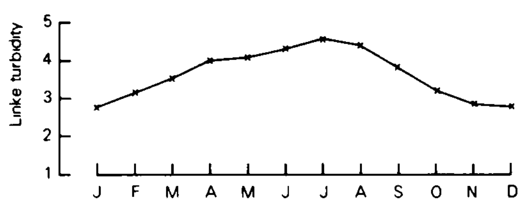

Figure 7. Annual variation of average Linke turbidity derived from hourly pyranometric measurements, averaged over nine stations around the United Kingdom for the period 1970–83.

5. Discussion

Three types of turbidity measurement have been described: manual observations using Ångström pyrheliometers, values found from the 1-minute resolution data record of sun-tracking pyrheliometers and estimates derived from routine hourly pyranometric measurements of global and diffuse irradiation. These constitute a longer period of measurement, for more areas, than previously available in the United Kingdom. The current series of 1-minute resolution normal incidence direct irradiance measurements can lead to a climatology of broad-band turbidity at three sites; this method uses existing routine observations with no need for extra manual intervention and is efficient in exploiting any cloud-free intervals.

There is some uncertainty concerning the relative importance of aerosol sources. Some aerosol arises from local natural or man-made sources, and some by transport from more distant regions. The dependence of turbidity on the prevailing air mass has been described by a number of workers, including Kondratyev (1969), Ball and Robinson (1982) and is assumed by Unsworth and Monteith (1972) to be largely responsible for the variability shown in any month of the year (cf. Fig. 3). Regional differences in turbidity are also present, which are not due simply to a different prevalence of air mass types and some authors, for example in International Energy Agency (1980), have proposed estimating the turbidity of a location from the nature of its surroundings. Fig. 3 indicates relatively small differences in the daily minimum turbidity between the three sites of different character, compared to the variation between days within the same month of the year, as indicated by the frequency distribution.

Regional differences are more obvious in the Linke turbidity derived from long-term pyranometric measurements (Table I). Owing to several sources of error inherent in its determination, the derived turbidity should be considered only as a supplement to conventional measurements. However, in the absence of other measurements, values of derived turbidity provide useful estimates. There have been other attempts to estimate turbidity — e.g. from the maximum duration of bright sunshine (Unsworth and Monteith 1972); their results produced slightly larger values of turbidity than presented here, probably owing to the influence of thin cloud. Also, Dogniaux and Lemoine (1983), estimated mean annual turbidity from the 'Ångström' regression coefficients of global irradiation against bright sunshine duration — the extension of this work to allow rough estimates of monthly values of turbidity in the United Kingdom is described in Rawlins (1983).

Turbidity is dominated by the loading of aerosol in the troposphere, particularly within the boundary layer, and the contribution of dust at stratospheric heights to the attenuation of the direct solar beam is usually negligible. A number of workers at different locations (e.g. Spinhirne 1983, Swissler *et al.* 1983) have established that a major perturbation in the stratospheric aerosol optical depth followed the eruption of El Chichon in 1982. Our results for the United Kingdom do not reveal a large jump in turbidity at every location, when compared with normal variations within the data record. However, a coherent picture emerges from different stations: all sites recorded an increase in turbidity from about October 1982 until March 1983, of the order of $\Delta \tau_a \approx 0.06$, with a less widespread enhancement continuing throughout 1983. The limited scope of the measurements precludes a conclusive demonstration of detecting a progressive incursion of stratospheric aerosol above the United Kingdom but the results are consistent with a gradual northwards spreading of volcanic debris, which affects the minimum turbidity measured at widely separated stations.

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Investigation of the effect of length of record upon extreme values

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Summary

The variability of extreme wind speed estimates using short-period data has been investigated using wind-speed data from Prestwick, Gorleston and Point of Ayre.

Introduction

The long-accepted method of obtaining environmental extreme data for design or planning purposes is to apply the statistical theory of extremes as developed by Fisher and Tippett. This requires long periods of data (Tabony 1983) from which annual extremes can be extracted. In the case of structures offshore, designers require data on waves but there are few locations with instrumental wave data for more than a few years. Such runs of data provide only a small number of data points, so the Fisher–Tippett type of distribution cannot be used. Instead it is normal practice to fit a frequency distribution to the complete data set and then extrapolate to obtain values corresponding to the required return period. Inevitably, the value of this technique can be questioned since it implies that extremes will lie on the same frequency distribution as the main body of the data. Tabony has shown that even extreme values do not necessarily belong to one distribution.

In order to examine the accuracy of extremes derived from short data runs Painting (1980) applied the Weibull (1951) distribution to observations of wind and waves at Ocean Weather Station 'I'. He compared the results of using overlapping 3-year runs of data with those obtained using the whole (18 years) data set. He showed that the once-in-50-year values based on 3 years of data could differ by up to 7% for wind and 16% for waves from those obtained using all the data. Painting's results could be queried because the wave data used were visual estimates and, therefore, not very reliable. Also, wind observations from weather ships are averaged by eye from an anemometer dial, with reference to the state of sea, rather than being a true 10-minute instrumental reading as should be the case for a land-based observer having an anemograph. His figures for winds may have been affected as a result.

This paper describes the results of an investigation repeating Painting's work for a land station using both the 10-minute 'synoptic' winds and the hourly mean winds obtained from anemograph traces.

Choice of site

Prestwick was chosen for the study because it has one of the longest records of wind data in the computer archive and had no major site or instrument changes during the period of record used (1959–82 inclusive). The Prestwick anemometer has an effective height of 10 metres and is situated on an unobstructed site in the centre of the airfield, although wind speeds from the south-west may be affected by the close proximity of Prestwick town. A change from pressure-tube anemograph to electrical recording anemograph occurred in 1958 but since then the site and instrument type have remained substantially unchanged.

Method

Estimates of once-in-50-year and once-in-5-year 10-minute mean wind speeds were calculated from all the data (1959–82 inclusive) and from data for overlapping 3-year periods (i.e. 1959–61, 1960–62, etc.) using the Weibull distribution. All Weibull analyses were carried out entirely by computer to ensure objectivity in the results. A once-in-50-year Gumbel* extreme 10-minute wind speed was also calculated using the Lieblein technique (Lieblein 1974). The overlapping short-period once-in-50-year extremes were then plotted as percentages of the once-in-50-year Weibull estimate based on all the data and as percentages of the once-in-50-year Gumbel estimate based on all the data (see Fig. 1). The estimate plotted for 1960 uses data from 1959–61, that for 1961 uses data from 1960–62, etc.

The above work repeats that undertaken by Painting although, in practice, the Meteorological Office Marine Enquiry Bureau does not use the Weibull distribution extrapolated to long return periods unless there are other corroborating values available, such as a Gumbel extreme value from a nearby station. This is because there is evidence (Graham 1983) that the Weibull distribution underestimates values at long return periods. What constitutes a long return period depends on the site and location but, in general, a return period greater than 5–10 years would be described as long. Jenkinson (1977) and Graham (1982) have used long periods of wind data from coastal stations to obtain average slopes of the Gumbel distribution. Values at 16 stations quoted by Graham gave an average value of 0.82 for the ratio of the once-in-5-year extreme to the once-in-50-year extreme (with a standard deviation of 0.02). Using more stations, Jenkinson quotes a value of 0.83. For enquiry purposes this value is used to estimate once-in-50-year Gumbel extremes from once-in-5-year values obtained using the Weibull distribution. The ratio for Prestwick is 0.82.

For each 3-year period once-in-50-year extremes were recomputed by first calculating the 5-year value using the Weibull distribution, and then applying the 0.83 standard ratio. These values were plotted as percentages of the once-in-50-year Gumbel extreme based on all the data (see Fig. 1). Using the complete data the once-in-5-year, 10-minute mean value derived using the Gumbel distribution and that derived using the Weibull distribution were virtually identical (43.0 and 43.2 knots). This justifies the use of this scaling technique to obtain 50-year Gumbel extremes from 5-year Weibull extremes.

The graphs shown in Fig. 1 were replotted using extremes estimated from hourly mean wind-speed data (see Fig. 2).

It can, of course, be argued that meteorological events are subject to physical limits and that the extreme-value distribution used to represent wind should be the Fisher–Tippett type 3 (bounded) and not the Type 1 (straight line, unbounded). Values derived from the latter distribution may, themselves, be overestimates as a consequence. However, Figs 3(a) and 3(b) show that there is no evidence of any significant curvature in the distribution of extremes and that, at least for a return period of 50 years, it is satisfactory to use the straight-line, unbounded form. For practical applications it is probably safer to use the straight-line distribution to guard against the kind of effect noted by Tabony who showed that there could be discontinuities in extreme-value distributions which might not be well represented even with quite long periods of data.

Results

Figs 1 and 2 show that even if the once-in-50-year Weibull estimate based on all the data is capable of giving an accurate extreme value, the extremes based on only 3 years of data vary by as much as 14% from this value. In practice, the Weibull distribution applied to winds apparently gives an overestimate

*The Fisher–Tippett Type 1 (straight line) extreme value distribution was popularized by Gumbel (1958) and, for the sake of brevity, will be referred to as the Gumbel distribution.

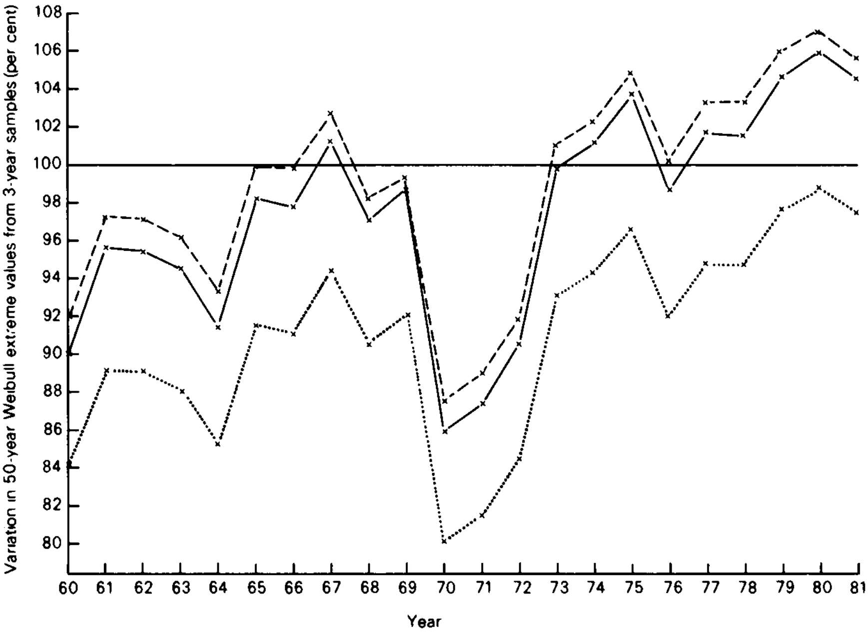

Figure 1. Weibull estimates of extreme 10-minute mean wind speeds based on 3-year running data samples from Prestwick compared with extreme values based on all the data (1959–82).
X————X All-data Weibull estimate X ·········· X All-data Gumbel estimate
X — — — — X All-data Gumbel estimate where Weibull estimates are derived from once-in-5-year winds and the standard ratio.

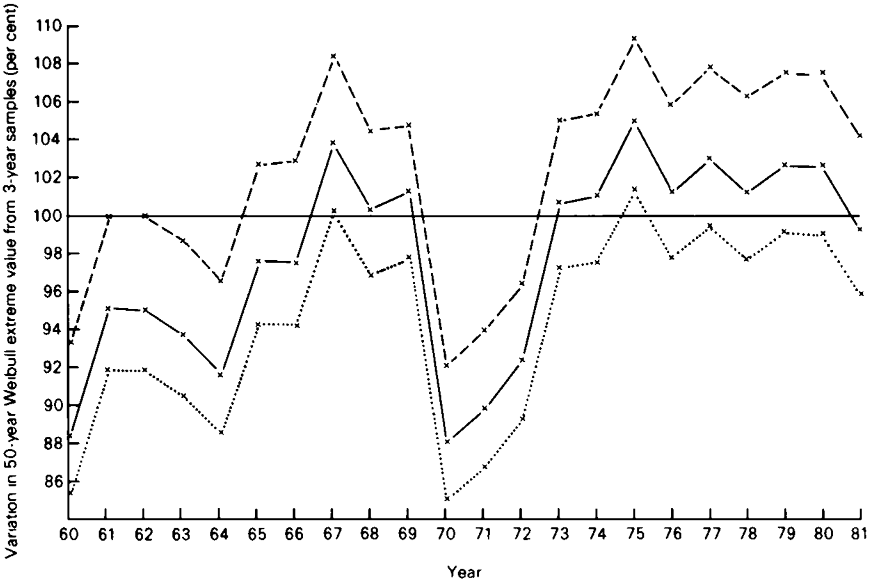

Figure 2. Weibull estimates of extreme hourly mean wind speeds based on 3-year running data samples from Prestwick compared with extreme values based on all the data (1959–82).
X————X All-data Weibull estimate X ·········· X All-data Gumbel estimate
X — — — — X All-data Gumbel estimate where Weibull estimates are derived from once-in-5-year winds and the standard ratio.

of extreme values at short return periods and an underestimate at long return periods, so the variation from the 'true' extreme may be even greater than shown in the graphs.

The once-in-50-year Gumbel estimate based on all the data is generally thought to be close to the 'true' extreme value. Figs 1 and 2 show that the once-in-50-year Weibull extremes based on only 3 years of data varied by as much as 20% from this 'true' value. Similarly, Figs 1 and 2 show that the once-in-50-year extremes calculated from only 3 years of data using the once-in-5-year Weibull estimate and the standard return period conversion factor (0.83) varied by nearly 13% from the 50-year Gumbel estimate.

The standard error (SE) associated with fitting a Gumbel distribution by the Maximum Likelihood method can be calculated as

$$SE(\chi) = \alpha(1.11 + 0.52Y + 0.61Y^2)^{1/2}/M^{1/2}$$

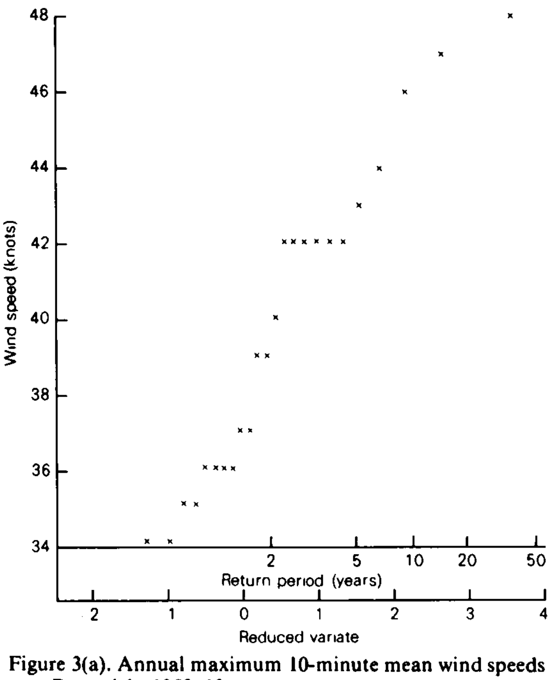

Figure 3(a). Annual maximum 10-minute mean wind speeds at Prestwick, 1959–82.

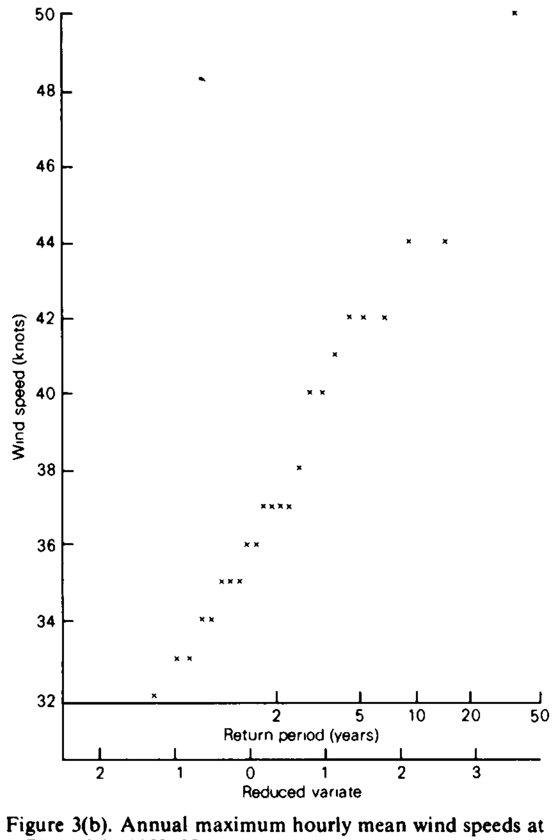

Figure 3(b). Annual maximum hourly mean wind speeds at Prestwick, 1959–82.

The annual maximum mean wind speed values shown in Figs 3(a), 3(b) and 6 were plotted according to the relation $p = (m - 0.31)/(M + 0.38)$, which gives a cumulative probability p to the mth ranking of a series of M observations and has often been used in the Meteorological Office since it was adopted by Jenkinson (1969).

Comparison of Figs 3(a) and 3(b) casts some doubt on the maximum observed 10-minute wind at Prestwick shown, unusually, to be slightly less than the maximum hourly mean wind. Careful examination of the original wind trace suggests that the highest 10-minute wind (0400 GMT on 15 January 1968) might have been slightly higher, but not sufficiently so to affect in any significant quantitative sense the results of this paper. A 2-knot increase in the maximum 10-minute wind leads to an increase from 51.4 to 51.7 knots in the once-in-50-year Gumbel value.

where α is the slope, M is the number of extremes and Y is the value of the reduced variate corresponding to an estimate χ of the variable under analysis (Natural Environment Research Council 1975). This expression gives standard errors of 2.5 knots for both the once-in-50-year, 10-minute mean and hourly mean wind-speed estimates produced using the Gumbel technique (51.4 knots and 49.5 knots respectively) and although, strictly, it applies to Maximum Likelihood estimates, the standard error associated with fitting a Gumbel distribution by the Lieblein technique is not likely to be significantly different from this figure. This means that the percentage variation of extremes using short periods of data from the 'true' extreme value may be even greater than that shown in the graphs.

Comparison with other sites

Although Prestwick was chosen for the study because it has one of the longest records of wind data in the computer archive with no major site or instrument changes, the once-in-50-year Gumbel estimate was an extrapolation based on only 24 annual maximum wind-speed values (i.e. values for the years 1959–82 inclusive). A number of stations with longer periods of record were not considered suitable for the original study owing to site changes, instrument changes or relatively short records of wind data in the computer archive. Two stations, Gorleston and Point of Ayre, were chosen as examples of stations having longer records of annual maximum wind speeds and the work carried out using Prestwick data was repeated for comparison purposes.

Once-in-50-year hourly mean Gumbel estimates for Gorleston and Point of Ayre were multiplied by 1.06 (Hardman *et al.* 1973) to obtain 10-minute mean extreme values. The Gorleston value was based on 57 annual maxima, recorded over the period 1913–81, and that for Point of Ayre on 46 annual maxima, recorded over the period 1936–81. Weibull estimates were calculated from Gorleston and Point of Ayre 10-minute mean wind data for the years 1957–74 and 1957–82 respectively. The extreme-value distributions (Fig. 4(a) and (b)) both show little evidence of any curvature and the 50-year Gumbel values can be regarded as definitive values rather than estimates.

Although the Gorleston and Point of Ayre Gumbel estimates are applicable to heights of 10 metres and 11 metres respectively and there were site changes during the record of 10-minute mean wind speeds, the once-in-50-year Gumbel estimates and Weibull 10-minute mean estimates were plotted with no correction for height as it appears that the effective heights of the anemometers were always between 8 and 13 metres at both stations. Figs 5 and 6 show values of once-in-50-year 10-minute winds for Gorleston and Point of Ayre using the same representation as Figs 1 and 2 for Prestwick.

Comparisons of the results obtained using 10-minute mean wind data from Prestwick with those obtained using Gorleston and Point of Ayre 10-minute mean wind data are shown in Fig. 7 and Table I and it is clear that the extremes based on only 3 years of data from Gorleston and Point of Ayre vary from the all-data extremes by a smaller amount than the corresponding values from Prestwick. The use of only 16 three-year data sample extremes (compared to 22 for Prestwick and 24 for Point of Ayre) may explain some of the reduction in variation for Gorleston. However, the Weibull extremes for Gorleston and Point of Ayre based on only 3 years of data still vary by as much as 10% (Gorleston) or 11% (Point of Ayre) from the Weibull extremes based on all the data and by as much as 13% (Gorleston) or 19% (Point of Ayre) from the Gumbel extremes based on all the data. Similarly, Figs 5 and 6 show that the once-in-50-year extremes calculated from only 3 years of data using the once-in-5-year Weibull estimate and the standard return period conversion factor (0.83) varied by as much as 9% from the 50-year Gumbel estimate at both Gorleston and Point of Ayre.

Conclusion

The variability of extreme wind speeds derived from short periods of data has been studied using homogeneous wind records from Prestwick. The study has shown that extremes estimated from a period

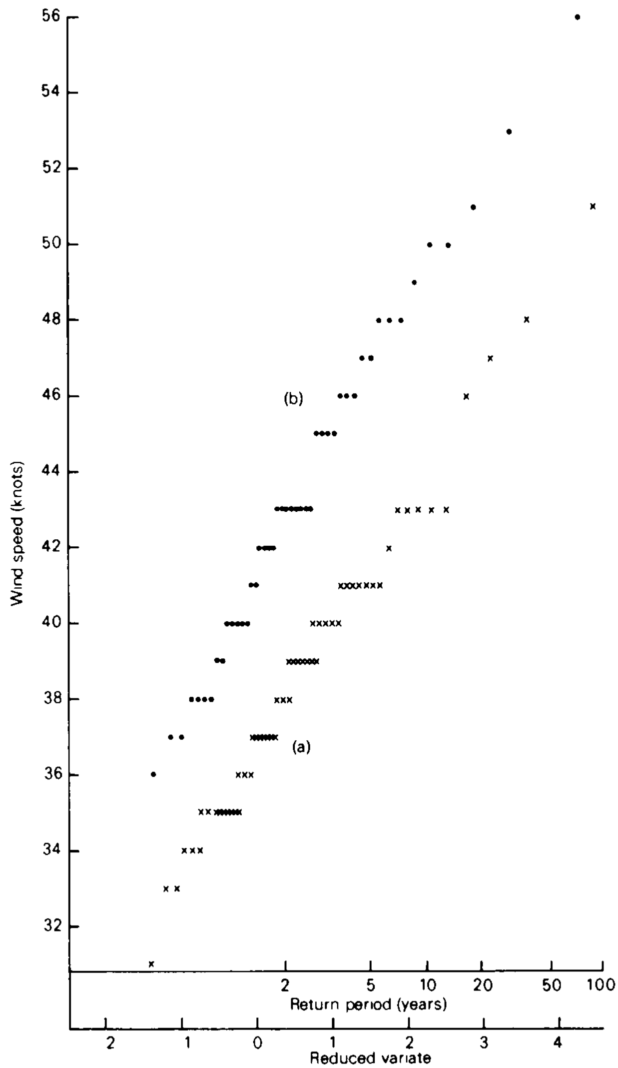

Figure 4. Annual maximum hourly mean wind speeds at (a) Gorleston, 1913–81, and (b) Point of Ayre, 1936–81.

as short as 3 years may be in error by an unknown amount, which could be as large as 20% and therefore cannot be used with confidence for design purposes. A comparison study using less reliable wind data indicated that errors may not always be as large as this although the 3-year data sample extremes from Gorleston and Point of Ayre did differ from the well-defined Gumbel estimates by up to 19% and could not be used with confidence.

Whether these results can or should be applied to wave data is uncertain. Painting showed that for Ocean Weather Station 'I' the variability of the 50-year estimates for wave data was about twice that for wind. However, wave heights are subject to more easily definable physical limits than are wind, so a long

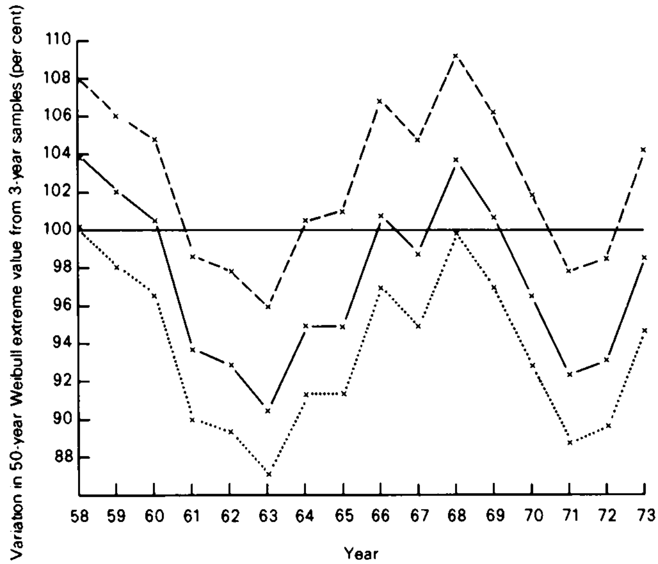

Figure 5. Weibull estimates of extreme 10-minute wind speeds based on 3-year running data samples from Gorleston compared with extreme values based on all the data.
×———————× All-data Weibull estimate, 1957–74 ×··················× All-data Gumbel estimate, 1913–81
× — — — — — — × All-data Gumbel estimate where Weibull estimates are derived from once-in-5-year winds and the standard ratio.

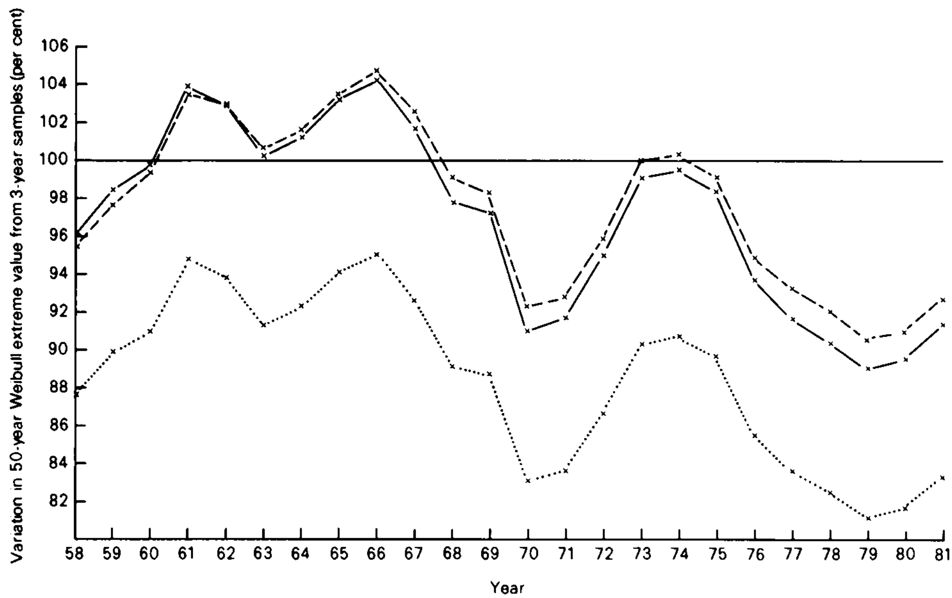

Figure 6. Weibull estimates of extreme 10-minute wind speeds based on 3-year running data samples from Point of Ayre compared with extreme values based on all the data.
×———————× All-data Weibull estimate, 1957–82 ×··················× All-data Gumbel estimate, 1936–81
× — — — — — — × All-data Gumbel estimate where Weibull estimates are derived from once-in-5-year winds and the standard ratio.

Table I. *Comparison of results obtained using 10-minute mean wind data from Prestwick, Gorleston and Point of Ayre*

	Prestwick	Gorleston	Point of Ayre
	Range of variation of Weibull estimates (based on 3-year data samples)		
	per cent		
From all-data Weibull estimate	20	14	15
From all-data Gumbel estimate	19	13	14
(where Weibull estimates were derived from once-in-5-year winds and standard ratio)	20	13	14

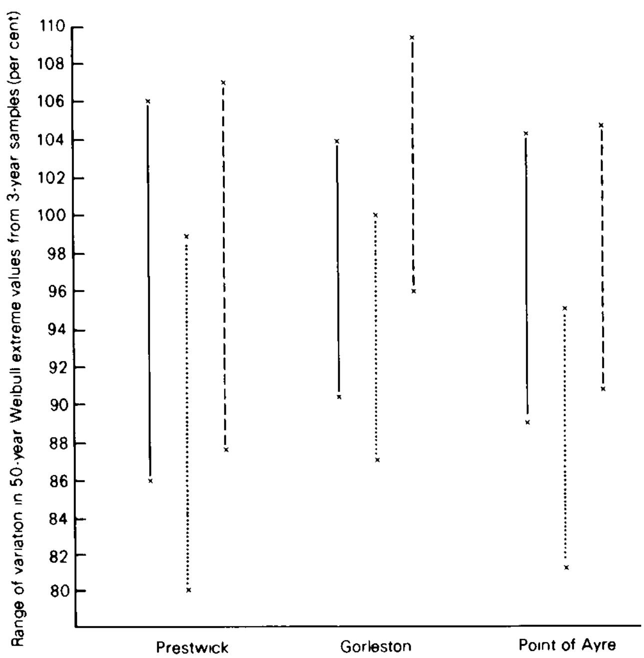

Figure 7. Comparison of the range of variation in Weibull estimates of extreme 10-minute mean wind speed based on 3-year running data samples from extremes based on all data, for Prestwick, Gorleston and Point of Ayre.
×————× All-data Weibull estimate ×··········× All-data Gumbel estimate
×— — — — —× All-data Gumbel estimate where Weibull estimates are derived from once-in-5-year winds and the standard ratio.

period of maximum values might well show a clear trend to a bounded (Fisher–Tippett Type 3) distribution. There are, however, no records of instrumental wave data of sufficient length in the region of the United Kingdom to obtain a reasonably definitive 50-year extreme. The question cannot, therefore, be put to the test.

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Meteorological reconnaissance flights

By R. J. Ogden

Summary

An informal account, based largely on pilot reminiscences, is given of meteorological reconnaissance flights from the United Kingdom during and shortly after the Second World War.

Introduction

This note is an attempt to set down some recollections of meteorological reconnaissance flights (which used to be referred to colloquially as 'Met Recce' flights) from the point of view of a pilot. It is based primarily on conversations during May 1984 with Captain D. H. ('Bill') Mackie, formerly of British Airways, but also includes some material culled from other sources. The routes followed by the various reconnaissance flights were given code-names, and these are illustrated in Fig. 1.

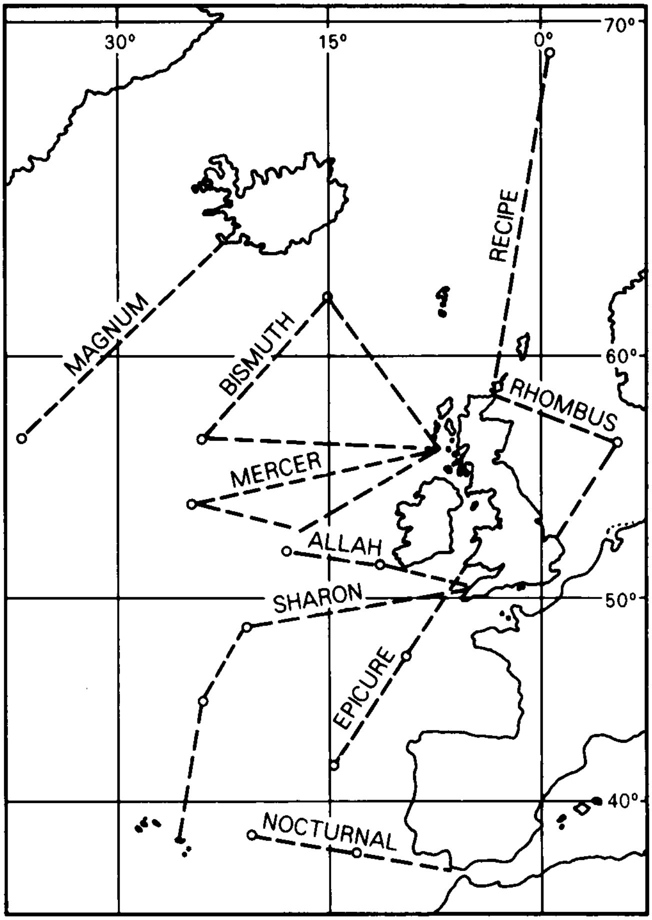

Figure 1. Tracks of meteorological reconnaissance flights in September 1944.

Bill Mackie joined 518 Squadron at Tiree in August 1944, serving as a co-pilot for three months, but thereafter as captain on the BISMUTH and MERCER meteorological reconnaissance flights. Apart from a short detachment to Wick, flying RECIPE flights whilst the squadron there converted from Fortress to Halifax aircraft, he remained at Tiree until August 1945 when the squadron there was moved to Aldergrove to continue the BISMUTH flights from there. In March 1946 he left 518 Squadron, at first remaining at Aldergrove as Commander of the Communications Flight, then moving to St. Eval for a spell as Adjutant of 210 Squadron which was based there for general reconnaissance and air-sea rescue duties. In November 1948 he agreed to return to Aldergrove as Flight Commander of B Flight, 202 Squadron. By this time, 202 Squadron had taken over the BISMUTH flights as its major responsibility, although it also had a subsidiary role in air-sea rescue, when necessary dropping Lindholme gear — self-inflating rubber dinghies equipped with rations, wireless, and so on. Bill Mackie continued with the BISMUTH flights until March 1951, by then having completed some four years and over 1700 hours flying on these duties — probably more than any other RAF pilot. He was awarded the AFC for this work.

On leaving the RAF, Bill Mackie joined BEA (later British Airways), flying several different types of aircraft until his retirement as Captain in 1977. Throughout this time he maintained his interest in aviation meteorology, and in 1976 received an award from the Director-General for long and meritorious service in providing meteorological reports from civil aircraft (see *Meteorol Mag*, **107**, 1978, 97–98).

Aircraft and crews

During 1944, 518 Squadron was equipped with Halifax V aircraft, fitted with Merlin engines; these were gradually replaced by the Halifax III, fitted with Hercules engines. In late 1950, these in turn were replaced by Hastings.

The Halifax bomber was designed to be operated by a crew of seven, namely: captain, navigator, flight engineer, wireless operator, bomb aimer and two air gunners. For meteorological reconnaissance flights the aircraft were unarmed, so the gunners and bomb aimer were not needed. It was decided that, instead, a second pilot and second wireless operator should be added to the crew, plus the meteorological observer. The second pilot occupied a collapsible seat from which he could assist the captain, for example with control of the throttles during take-off, but the aircraft could not be flown independently from his position. The second wireless operator was used only as a relief and no second working position was provided. The meteorological observer occupied the front turret, which offered a wide view for observing purposes.

The Halifax was not pressurized, so the use of oxygen was essential during high-level flight. Normal climb speed was 140 kn and the cruising speed was 165 kn. Cabin heating arrangements were very primitive. There was no de-icing equipment; a paste was applied to the leading edges of the wings before take-off, but in practice this was far from effective. Modifications to the aircraft to fit them for meteorological reconnaissance work included changes to the turret canopies (in the absence of guns), the installation of the co-pilot's seat and the provision of a radio altimeter for use by the captain in addition to his normal pressure altimeter. Appropriate meteorological instruments (e.g. external thermometers, aneroid barometer connected to a static vent) were fitted for use by the meteorological observer, who was also provided with a radar altimeter for accurate height determination at standard and other pressure levels.

From the pilot's point of view, the Hastings was in several ways an improvement on the Halifax. Although a civil version of the Hastings (known as the Hermes and flown by BOAC during the 1950s) had a tricycle undercarriage and was fully pressurized, the meteorological reconnaissance squadron Hastings still had the traditional tail wheel and were not pressurized. However, they did have de-icing equipment, a higher cruising speed of 185 kn, somewhat better cabin heating and much-improved seating arrangements. The co-pilot had a proper seat alongside the captain and, although the instrument panel was not duplicated, the aircraft could be flown from that position. The modifications to the Hastings aircraft for meteorological reconnaissance work were carried out at Radlett.

Flight procedures

The flights from Tiree and, later, Aldergrove took anything from a minimum of seven hours to nine hours or more, and required prolonged concentration on the part of the captain. By late 1944, both BISMUTH and MERCER flights were on triangular tracks, each leg being some 400 to 500 nautical miles. Routine meteorological observations (cloud, temperature, weather, icing, height of pressure surface, etc.) were made every 50 nautical miles (i.e. at about 20-minute intervals); winds were computed by the navigator.

After take-off the aircraft climbed to 950 mb. The meteorological observer advised the captain when this pressure level was reached; thereafter the captain maintained flight at this pressure level by flying at a constant indicated altitude on his pressure altimeter, the sub-scale being left unchanged. Every 150 nautical miles (i.e. roughly every hour), with the aid of the radio altimeter, the aircraft was brought down to 50 ft above the sea to enable a reliable estimate of mean-sea-level pressure to be made.

At the end of the first leg (i.e. some 500 nautical miles from base), after descending to 50 ft for a mean-sea-level pressure check, the aircraft climbed, using a series of short legs on alternating reciprocal headings; at appropriate standard pressure levels the aircraft was levelled out for a minute or so to allow time for the thermometer to stabilize and so permit determination of an accurate vertical temperature profile. The climb continued in this way to the 500 mb level, oxygen masks being put on at 10 000 ft.

The second leg was flown at 500 mb and at the end of this the aircraft descended to 50 ft above the sea, using short reciprocal-heading legs as on the climb. The final leg home was similar to the first leg, i.e. at 950 mb, but with descents to 50 ft above the sea every 150 nautical miles.

The navigator maintained an air plot throughout the trip. GEE fixes could be obtained only near base and the main navigational aid was loran. However, the wireless operator was able from time to time to obtain bearings by W/T from certain land stations in the United Kingdom and thus provide some additional fixes to help the navigator, who computed winds and passed them to the meteorological observer. On the low-level runs, smoke floats were sometimes dropped to enable winds to be derived by observing drift.

In addition to obtaining W/T fixes, the wireless operator transmitted the meteorological information in the form of coded messages after every third routine meteorological observation, i.e. at roughly hourly intervals; during the War years the messages had to be encyphered before transmission. A continuous listening watch was maintained throughout the rest of the time.

From August 1944 until after VE Day, two BISMUTH and two MERCER flights were operated each day from Tiree, one flight on each track being made at night. Subsequently the night flights were dropped, and with the move to Aldergrove the MERCER flights ceased altogether; from then on, at least until 1951, the commitment at Aldergrove was for one daylight BISMUTH flight each day.

General recollections

It was a point of honour that flights would take off if humanly possible, no matter how bad the weather was, and the regularity of the operational sorties was outstanding. For example, during the period from August 1944 to June 1945 at Tiree, only one or two of the scheduled four flights per day were cancelled for weather reasons (personal communication from Fred Gee who was a meteorological air observer with 518 Squadron during this time).

By definition the flights were sent out to enable weather to be observed, and it was not infrequently far from clear in advance exactly what weather would be experienced; some of this proved to be very bad, indeed hazardous, especially during night flights. Because of the lack of de-icing equipment, airframe icing was a particular problem with the Halifax aircraft. On occasions (e.g. 10 February 1945) aircraft were struck by lightning. Turbulence was also a notable and unwelcome feature of the 950 mb legs during the winter because, all too frequently, cumulus and cumulonimbus clouds seemed to have their bases at or near this level, so the aircraft was constantly being bounced up and down.

The sorties had to be flown on standard tracks, using standard flight procedures which had been designed to enable as much useful meteorological information as possible to be obtained from each flight. This program called for a high degree of flying discipline and, inevitably, the constant repetition of routine manoeuvres during long flights, day after day, led to more than a little boredom on the part of the pilot.

Clearly the captain had overriding responsibility for the safety of the aircraft and its crew, and in the event of trouble he had to decide if and when it became essential to modify the standard flight procedures or even to abort the flight. Enemy action was not a problem to meteorological reconnaissance aircraft operating from Tiree. But the flight tracks went far out over the Atlantic where there was no possibility of making an emergency landing, and the chances of successful air-sea rescue if forced to ditch far from home were slender.

The most worrying part of the flight from the captain's point of view was the climb from 50 ft to 500 mb at the end of the first leg. The aircraft was then at its maximum distance from base (about 500 nautical miles) and, after three hours or so flying at low level, the engines were called upon to produce more or less sustained full power for the climb. The likelihood of engine failure was at a maximum at this stage of the flight and there were often the added problems of airframe and engine icing. For example, on one occasion, after the aircraft had managed to reach 10 000 ft, airframe icing became so severe that even the relatively unladen aircraft was brought down to 4000 ft before level flight could be maintained. A different type of icing was responsible for serious trouble on the first operational sortie using the Hastings aircraft (see below).

Two especially hazardous flights

In retrospect after more than 35 years, two flights in particular stand out as examples of the sort of extreme difficulties that could occur.

During the climb at the end of the first leg in a Halifax aircraft, at about 10 000 ft there was a muffled bang followed by an immediate yaw to starboard. The same thing happened again two minutes later. By then oil pressure on the starboard outer engine had fallen to zero and use of the feathering button had no effect at all. Increased drag was apparent and, although the aircraft continued to fly, it was immediately decided that the sortie would have to be aborted. After what must have seemed a very long leg, the aircraft was landed successfully at Aldergrove, and it was then found that a large part of the engine nacelle and fairings was completely missing. Subsequent investigation by AIB established the cause of the accident as the explosion of two fire bottles set off by displacement of part of the primitive cabin heating system so that certain pipes became red hot in the engine exhaust. Although it could not be proved, this incident suggested a possible cause for the unexplained disappearance of a Halifax on a previous operational mission.

The other especially memorable flight, on 14 December 1950, was the first operational sortie using a Hastings aircraft; as flight commander, Bill Mackie acted as captain on this flight. From earlier RAF flying with this aircraft, there had been a suggestion that difficulties might sometimes arise due to what was known as 'oil coring', i.e. the freezing of oil in the engine oil cooler, but before this incident there was nothing concrete to go on. Although in 1950 flights were scheduled as daylight trips, for various reasons take-off on this occasion was delayed so that the climb at the end of the first leg was made in darkness. During the ascent, first one, then two, three and finally all four engines developed dangerous drops in oil pressure due to coring. One of the few advantages of the North Atlantic in winter from the flying point of view is that the sea temperature never falls to freezing point, so there is at least a possibility of coping with serious icing if the aircraft can successfully be brought down to near the sea surface. On this occasion, using the radio altimeter, the aircraft was levelled off at a height of 100 ft above the sea and the sortie was aborted. Fortunately, despite the very low oil pressures on all four engines they continued to function, and after a long period at this low level the frozen ice cores gradually melted and the oil pressures recovered so that on approaching landfall at Tory Island it was safe to climb again for the final leg over land to Aldergrove. Needless to say, this incident led to the introduction of a modification to the engine lubrication system to prevent recurrence.

Postscript

As a practising forecaster during the period of operation of the meteorological reconnaissance flights, I should like to record the gratitude of all forecasters for the fact that these invaluable observations appeared so regularly on our charts; without them, the charts would have been bare indeed to the west of the British Isles. Although at the time the aircrew must sometimes have wondered why they were given these rigid schedules, tracks and flight procedures, there is no doubt whatever about the value of their contribution. I should also like to thank Captain Mackie for the care and patience with which he recalled for me his experiences with the meteorological reconnaissance flights.

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The use by the Meteorological Office of decyphered German meteorological data during the Second World War

By R. P. W. Lewis

(Meteorological Office, Bracknell)

Summary

An account is given of some aspects of the interception and decypherment of broadcast meteorological data from Axis-occupied Europe during the Second World War and how these data were used by the Central Forecasting Office of the Meteorological Office.

The fall of France in June 1940, following the occupation of Denmark and Norway, meant that the supply of meteorological information from most of the continent of Europe to the United Kingdom was cut off, and thus the means were no longer available of constructing the actual and forecast weather charts that were of vital importance for prosecuting aerial warfare. It is a remarkable fact, therefore, that within a year or two British Intelligence was able to supply the Central Forecasting Office at Dunstable with information of such good quality, so fast, that surface and upper-air charts could be plotted, covering the whole of Axis-occupied Europe, that for something like two-thirds of the time were nearly as good as if there had not been a war on at all.

This was principally due to two facts. The first was that German military installations were spread so widely that communications had largely to be conducted by radio transmission and could thus be intercepted, and the second was the skill and devoted hard work of the meteorological section of the Government Code and Cypher School (GC and CS) at Bletchley Park. The work at Bletchley Park has received considerable publicity in recent years, particularly in connection with the decyphering of the German 'Enigma' messages. Many other codes and cyphers were, however, tackled at Bletchley Park, among them the meteorological ones, and success in this latter field had, indeed, important repercussions on the Enigma work.

The precise methods by which the German cyphers were broken have not been explained. One may be certain, however, that laborious persistence in collating days and weeks of broadcast messages known or suspected to be meteorological, and the exploitation of minor weaknesses and blunders on the part of the Germans must all have played a part. It is clear from works such as that by Kahn (1966) that success in code and cypher breaking in real life is very much in line with Edison's description of genius as one per cent inspiration and ninety-nine per cent perspiration.

The principal German meteorological cyphers were based on trigraph substitution tables (Benkendorff 1946) such that all possible three-digit groups from 000 to 999 were replaced by alternative arbitrary groups. For most of the war, a five-digit group in the ordinary international (Copenhagen) meteorological code would first be replaced by a six-digit group such that the sum of the third and fourth digits, modulo 10, was equal to the third digit of the original group. For example, 12345 could be written as 127645, or 128545, or 121245. The six-digit group would then be encyphered by splitting it into two three-digit groups and applying the substitution tables. Different tables were used at different hours of the day, and from time to time new sets were introduced.

In addition to encyphering conventional surface observations set out in the well-known international code, the Germans also found it necessary, owing to rapid technological advances, to devise new types of code for upper-air information obtained from balloons, sondes, and aircraft reconnaissance flights (the 'Zenith' code); messages in the form of these new codes would then be themselves encyphered. The decyphering of intercepted messages whose basic structure is not understood is clearly a much more difficult problem, and success here may well have depended to some extent on the adventitious capture of coding-sheets and log-books from shot-down aircraft or pilots.

In addition to the purely meteorological value of the work of the Meteorological Unit at Bletchley Park, it was also of great importance in helping to crack the German naval Enigma as is explained by Hinsley (1979):

> From the same date, the spring of 1941, a similar bonus was derived from GC and CS's work on the systems which most countries had introduced at the outbreak of war for encoding the reports transmitted by their meteorological stations. As the reading of these cyphers was in any case of operational importance, and indispensable for the weather forecasting of the Meteorological Office, it required careful organisation and absorbed an increasing amount of labour; although the cyphers were relatively simple, large numbers of them existed and they had to be read with next to no delay. But one of them, the German naval meteorological cypher, turned out to be of especial importance. It was first broken in February 1941 and in May of that year the Meteorological Section at GC and CS discovered that it carried weather reports from U-boats in the Atlantic which had originally been transmitted in the naval Enigma. Thereafter its decrypts were no less useful than those of the dockyard cypher in helping to break the Enigma keys. As we shall see, they were also to be valuable by providing direct statements of the positions of U-boats when the U-boat Command decided that the U-boats must disguise the positions they announced in their Enigma signals.

Examples of the success of GC and CS during periods when the cypher tables had been largely solved, and of their comparative failure immediately after the introduction by the Germans of a new set of tables, are shown in Figs 1–4. Only surface charts are shown, because the presence or absence of decyphered data show up more dramatically than on the upper-air charts, but this should not be taken to mean that upper-air data were unimportant; they were, indeed, extremely important for the conduct of Bomber Command's operations. Ratcliffe (1984) has explained how surface and upper-air observations were used during the War to forecast winds and temperatures to as high as 200 mb; the application of the techniques developed by Swinbank, Petterssen and others would have been impossible had not GC and CS supplied Dunstable with most of the data from occupied Europe. The forecasts for D-day, too, would have been far inferior in the absence of this information (Stagg 1971).

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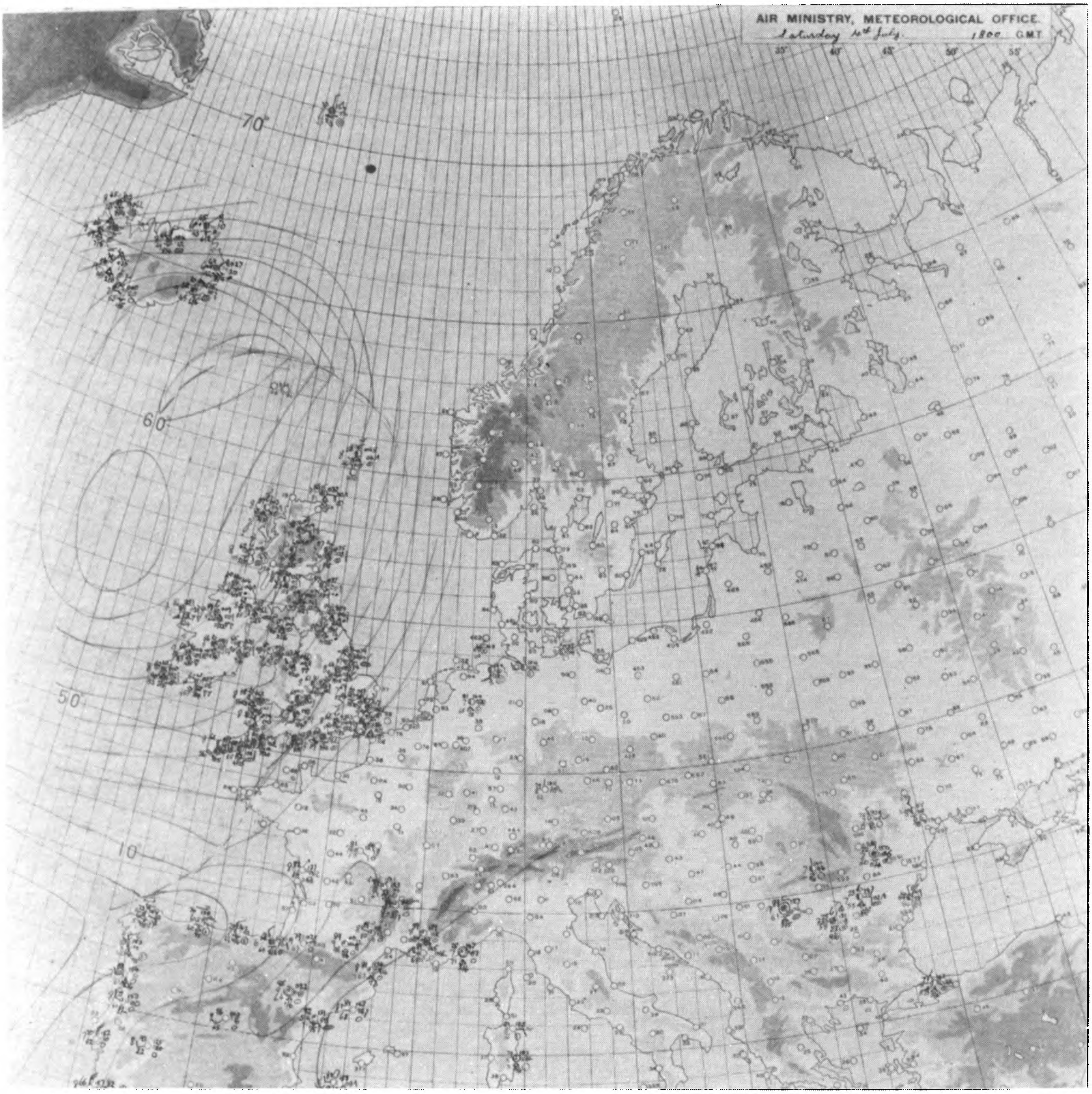

Figure 1. Surface chart as plotted and analysed in the Central Forecasting Office, Dunstable showing decyphered observations from German and other sources over enemy-occupied Europe 4 July 1942 at 1800 GMT.

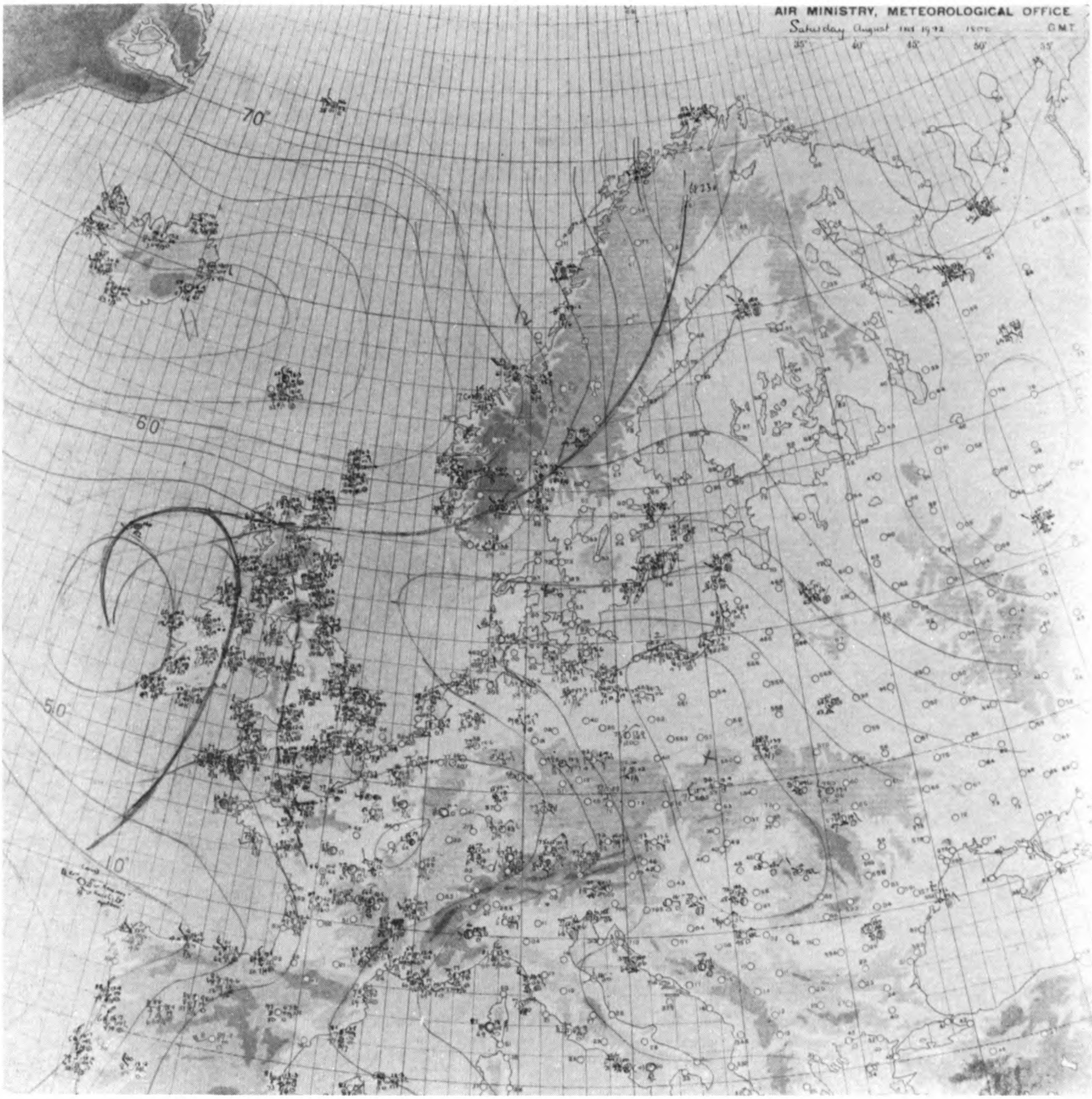

Figure 2. As Fig. 1 for 1 August 1942 at 1800 GMT.

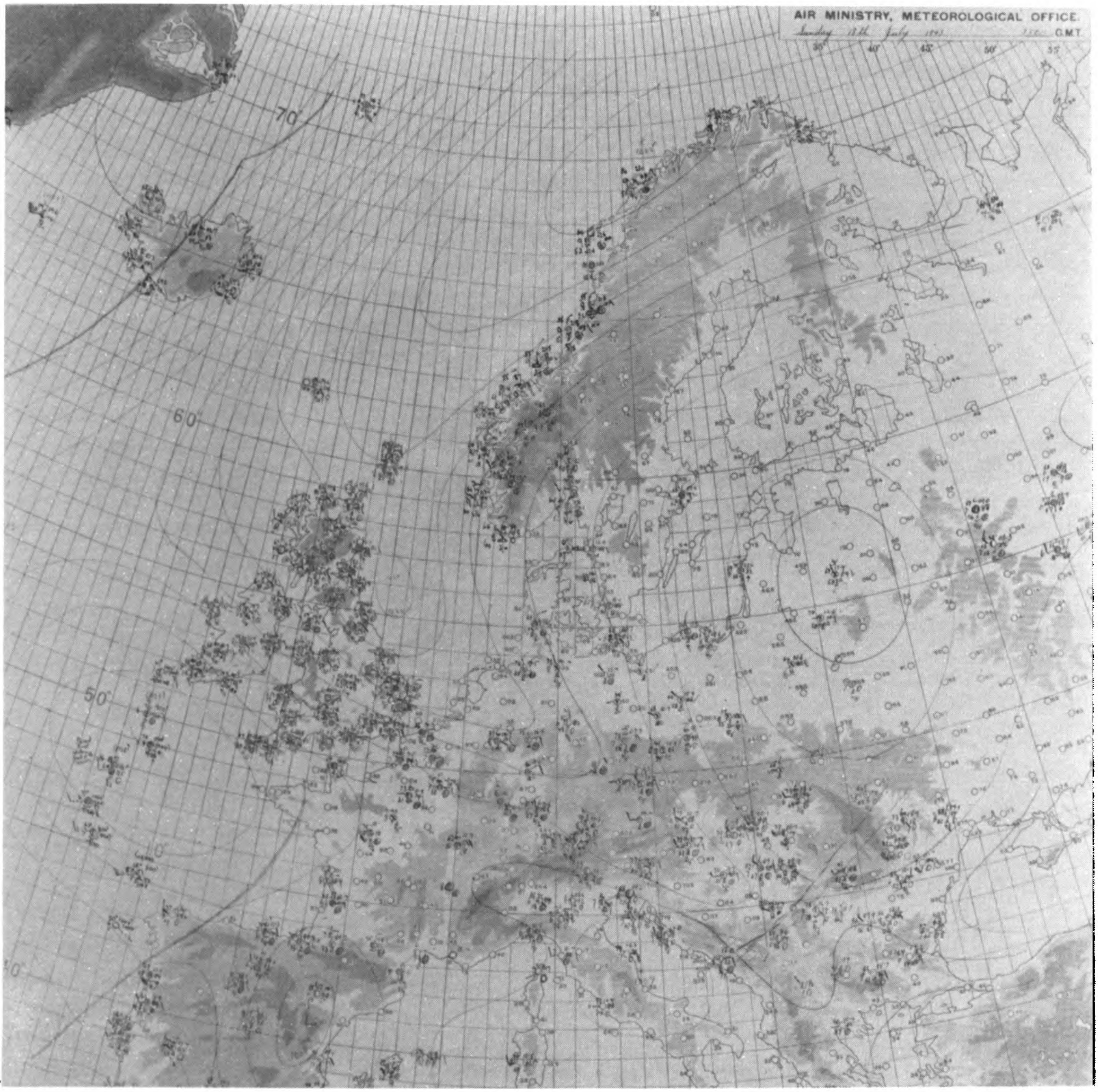

Figure 3. As Fig. 1 for 18 July 1943 at 1300 GMT.

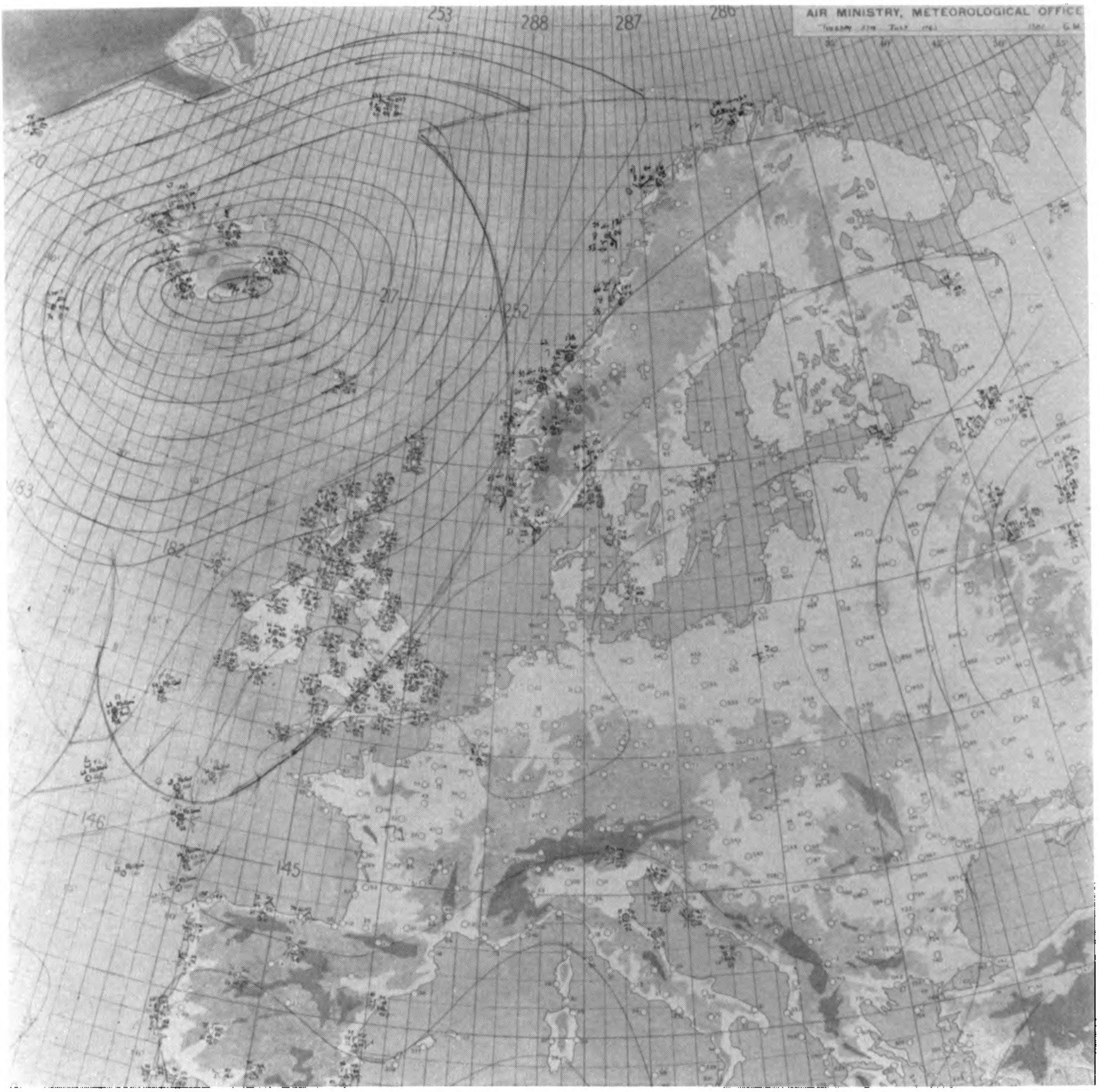

Figure 4. As Fig. 1 for 27 July 1943 at 1300 GMT.

551.5:06(a):556.02

World Meteorological Organization Commission for Hydrology (CHy) Seventh Session, Geneva, 27 August–7 September 1984

By B. R. May

(Meteorological Office, Bracknell)

Every day we are reminded of the importance of water in our lives. The present drought in Ethiopia with its attendant human misery demonstrates how dependent are many developing countries on the efficient use of much-needed water supplies. In contrast, many countries are still ravaged periodically by floods, bringing danger to lives, health and property. It is fitting, then, that one of the WMO's five major programs should be the Hydrology and Water Resources Programme (HWRP), regarded as a means of encouraging activities both within and between countries in tackling these and other problems. The co-operation with water-related programmes of other international organizations.

Operational Hydrology Programme (OHP), particularly the Hydrological Operational Multipurpose Sub-programme (HOMS),

Applications and Services to Water Resources, and

co-operation with water-related programmes of other international organizations.

Much of this session of the Commission was devoted to reviewing progress in these areas and planning future activities.

OHP/HOMS was recognized as a successful means of transferring hydrological 'know-how', particularly from developed to developing countries. With its distribution of National Reference Centres, a manual of over three hundred information components contributed by twenty-six countries and subject to more than six hundred requests, HOMS has already demonstrated its worth. It was agreed, though, that more feedback on the value and applicability to the user of the transferred information was required to increase its effectiveness.

The Applications and Services to Water Resources Programme is intended to bring together hydrological and meteorological activities in support of water resource development. The collection and processing of the data needed for these developments and for the protection of the environment are seen as important factors here.

Many other international organizations have activities in the field of hydrology, particularly UNESCO with its International Hydrological Programme. The need for inter-organization collaboration to increase the effectiveness of WMO activities in operational hydrology was stressed.

Within the two weeks of formal meetings of the session, a two-day technical conference on the use of microprocessors and microcomputers, along with an exhibition of equipment, was organized.

The UK delegation consisted of Mr C. V. Smith and Mr B. R. May of the Meteorological Office and Dr J. C. Rodda and Mr M. A. Beran of the Institute of Hydrology; Dr Rodda also attended in his capacity as Secretary of the International Association of Hydrological Sciences. Over one hundred delegates from fifty-one countries attending the session unanimously approved Dr O. Starosolszky of Hungary and Mr A. J. Hall of Australia as President and Vice-President respectively for the next four-year intersessional period. Three working groups, on instruments, data collection and hydrological models were formed and twenty-eight rapporteurs appointed; Mr M. A. Beran was appointed as rapporteur on the World Climate Programme, Water Component. The appointment of the Advisory Working Group completed the list of members who are to carry out the vigorous programme of work of the Commission during the next four years.

Review

Climatic changes on a yearly to millennial basis, edited by N. A. Mörner and W. Karlen. 155 mm × 240 mm, pp. xviii + 667, *illus.* D. Reidel Publishing Company, Dordrecht, Boston, Lancaster, 1984. Price Dfl 210.00, US$79.00.

This book contains the Proceedings of the Second Nordic Symposium on Climatic Changes and Related Problems held in Stockholm in May 1983. This international symposium was particularly concerned with Nordic records and their relation to global climatic changes. Of the more than 60 papers presented, 52 are included in this volume together with 3 invited contributions. The contents have been divided into four sections — the Deglaciation period, the Holocene, the last 1500 years and finally a discussion of models and mechanisms. Case studies of the Deglaciation period concentrate on southern Scandinavia, the French Alps and Mexico, while vegetation and sedimentary studies from the Holocene include areas as far apart as west Greenland and Lake Chad. The largest number of papers is in the section on the last 1500 years and among the subjects considered in detail are the dendrochronology records in Sweden and in Washington State, USA, and the evidence for links between settlement, agricultural changes and climate. Models and mechanisms are considered in a rather more perfunctory way although there are interesting papers on the effect of solar activity on the earth's atmosphere and on atmosphere–cryosphere interactions.

Scandinavia is a classical area for the study of climatic fluctuations during the last 20 000 years, and the symposium has concentrated on regional processes and data, taking care to distinguish between local, hemispherical and global climatic changes. Indeed one of the major conclusions of the conference was that none of the sometimes rapid climatic changes and shifts during the last 20 000 years has been of global extent and therefore it is redistribution of heat over the globe, regionally and hemispherically, that is of prime importance. One of the editors (N. A. Mörner) in an epilogue suggests that storage and transformation of heat due to oceanographic processes and particularly as a result of differential rotational changes, closely linked to gravitational changes, may represent the primary driving mechanism of climatic change.

This is a stimulating collection of papers, and of particular interest are the many contributions from Scandinavian scientists who are not so well known outside their own countries. This is not to decry the famous names who are well represented and lend the volume authority. Too many of the diagrams are unfortunately difficult to interpret because of their small size and it is a pity that the paper quality of the book is so poor.

Climatic changes at high latitudes of the northern hemisphere have for long been regarded as of great importance, since general trends appear to be magnified in such areas. Scandinavia is an ideal 'laboratory' not only for studying climatic changes but also for measuring the effects of climate on society. The Stockholm symposium brought forward a wealth of new observational data and theories about its interpretation, and the appearance of this collection of papers will be widely welcomed.

A. H. Perry

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