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The measurement of atmospheric turbidity

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Summary

Measurements of atmospheric turbidity have been made at the National Radiation Centre on an irregular basis since 1968, based upon measurements of the normal incidence solar irradiance. They were originally carried out at Kew Observatory, but since 1974 they have been made at the Meteorological Office's experimental site at Easthampstead Park near Bracknell. This article defines several coefficients of turbidity and describes how they are derived from measurements of direct solar irradiance.

1. Basic definitions

The intensity of direct solar irradiance, I , at sea level, measured at normal incidence in the absence of cloud, clearly depends upon the attenuation of the solar beam as it passes through the atmosphere and this is determined largely by the optical air mass, molecular scattering and aerosol content, or 'turbidity' of the atmosphere. The optical air mass, m , is the effective path length taken by the incoming solar radiation through the atmosphere and is expressed as the equivalent number of atmospheres through which the radiation travels before reaching the observer (usually at sea level). If θ is the apparent elevation of the sun above the horizon then,

$$m = (p/p_0) \operatorname{cosec} \theta \quad \dots \quad (1)$$

where p is the atmospheric pressure at the observing station and p_0 is the standard atmospheric pressure at mean sea level (1013.25 mb). The factor $\operatorname{cosec} \theta$ is often referred to as the 'relative air mass', m_h , and can be determined by Bemporad's function (see Table 4 in *IGY instruction manual* (CSAGI 1958) which includes a correction for the effect of atmospheric refraction, especially for elevation angles of less than 10° .

The turbidity of the atmosphere can be expressed in terms of a mean attenuation coefficient, \bar{a} , (integrated mean over all wavelengths) which is a measure of the fractional attenuation of the solar beam due to absorption and scattering processes in the presence of water vapour, dust, smoke and the constituent gases of the atmosphere. It is defined by the exponential relationship,

$$I = S^{-1} I_0 \exp(-m\bar{a}), \quad \dots \quad (2)$$

where I_0 is the extraterrestrial intensity of solar irradiance (i.e. at the top of the atmosphere) and S is defined below. The greater is the optical air mass (i.e. decreasing θ) and the greater is the turbidity, the

smaller is the intensity of the transmitted radiation at sea level. Hence the attenuation coefficient \bar{a} can be derived from measurements of the normal incidence irradiance.

Since the attenuation of solar radiation is a function of wavelength, λ , equation (2) may be written in the more general form,

$$I = \int_0^{\infty} I(\lambda) \cdot d\lambda = S^{-1} \int_0^{\infty} I_0(\lambda) \exp\{-ma(\lambda)\} \cdot d\lambda, \quad \dots \dots \dots (3)$$

where

- $I(\lambda)$ = intensity of the normal incidence irradiance at the observing station, as a function of wavelength (units W m^{-2} per unit waveband at wavelength λ),
- $I_0(\lambda)$ = extraterrestrial intensity of the normal incidence irradiance at the mean earth-sun distance similarly expressed as a function of wavelength,
- $S (=R^2/R_m^2)$ = correction factor to allow for the variation in the actual earth-sun distance, R , from the orbital mean, R_m , and
- $\exp\{-ma(\lambda)\}$ = the transmission factor for solar radiation of wavelength λ .

The total attenuation coefficient, $a(\lambda)$, may be split into three separate components as follows:

$$a(\lambda) = a_R(\lambda) + a_D(\lambda) + a_w(\lambda), \quad \dots \dots \dots (4)$$

where a_R = the attenuation of solar radiation in clean dry air according to Rayleigh's theory of scattering by air molecules,

a_D = the attenuation by the atmospheric aerosol content, and

a_w = the attenuation due to water vapour.

Elterman (1964) provides values of a_R as a function of wavelength and altitude above sea level and Fröhlich (1977) gives the following equation to calculate the Rayleigh scattering coefficient for wavelength λ and pressure p :

$$a_R(\lambda) = (8.69 \times 10^{-6}) p \lambda^{-4.09},$$

where p is in millibars and λ is in micrometres. Usually an allowance must be included for a given concentration of ozone. Equation (3) can therefore be rewritten thus:

$$I = S^{-1} \int_0^{\infty} I_0(\lambda) \exp [-m\{a_R(\lambda) + a_D(\lambda) + a_w(\lambda)\}] \cdot d\lambda \quad \dots \dots \dots (5)$$

Several methods have been devised for parametrizing the turbidity of the atmosphere and the three most common are described below. Two of them, those of Linke and Ångström, were developed during the 1920s.

2. The Linke turbidity factor, T

One of the first turbidity coefficients was introduced by Linke (1922) and it is a relatively simple measure of the haze and water vapour content of the atmosphere. He defined a turbidity factor, T , as the equivalent number of clean dry ('Rayleigh') atmospheres required to produce the observed attenuation of solar radiation, that is:

$$T = \bar{a}/\bar{a}_R(m) = \{\bar{a}_R(m) + \bar{a}_D + \bar{a}_w\}/\bar{a}_R(m) \quad \dots \dots \dots (6)$$

The bar represents a wavelength-integrated mean over the solar spectrum and $\bar{a}_R(m)$ has been expressed

as a function of the optical air mass, m , because the spectral distribution of $I(\lambda)$ changes with increasing m . Usually $\bar{a}_R(m)$ is expressed in the form of the function $P(m)$, where

$$P(m) = \{m \cdot \bar{a}_R(m) \cdot 1g e\}^{-1}.$$

(See, for instance, CSAGI 1958, Robinson 1966, or Coulson 1975.) Table I gives $P(m)$ for values of m between 1.0 and 10.0. From equations (2) and (6) therefore,

$$I = S^{-1} I_0 \exp [-T / \{P(m) 1g e\}],$$

$$\text{i.e. } T = P(m) 1g \{I_0 / (IS)\}. \quad \dots \quad (7)$$

Equation (7) implies that T may be calculated from measurements of both I and solar elevation. The definition of T in equation (6) implies that T can never be smaller than unity, the limit corresponding to a perfectly clean dry atmosphere.

Table I. The factor $P(m)$ as a function of optical air mass m , for the computation of the Linke turbidity factor T from measurements of total irradiance I .

m	$P(m)$	m	$P(m)$
1.0	23.2	4.0	7.55
1.2	19.8	4.5	6.95
1.4	17.3	5.0	6.45
1.6	15.5	6.0	5.72
1.8	14.0	7.0	5.18
2.0	12.9	8.0	4.77
2.5	10.8	9.0	4.45
3.0	9.35	10.0	4.19
3.5	8.33		

Originally the Linke factor was based upon measurements of the total (all-wave) irradiance intensity, I , and this has been a useful measure of turbidity under various conditions. Unfortunately the factor is prone to erratic diurnal variations which appear in the absence of any significant change in atmospheric conditions and are attributed to the different wavelength dependence of aerosol and water vapour absorption/scattering compared with that of Rayleigh's theory. One solution to this problem has been to eliminate the effects of variable water vapour absorption in the infra-red by confining measurements of I to wavelengths of less than $0.63 \mu\text{m}$, using a red (Schott RG 2) cut-off filter. This method was introduced by Ångström (1929) and is discussed in detail below. However, this approach demands much greater accuracy in the measurement of I and, in particular, knowledge of the filter's transmission characteristics.

3. The turbidity coefficient, τ_a

A second measure of atmospheric turbidity, which is a function of atmospheric aerosol content only, has been suggested by Unsworth (1975) and is defined by the equation,

$$\tau_a = -m_h^{-1} \ln(IS/I^*), \quad \dots \quad (8)$$

where $m_h = \text{cosec } \theta$, as defined earlier, and I^* is the normal incidence irradiance (for mean solar distance) at the bottom of an aerosol-free atmosphere which includes a specified amount of water vapour. Unsworth (1975) has tabulated I^* as a function of both the relative air mass m_h and the precipitable water content of the atmosphere and these values are listed in Table II. (See also Rodgers, Souster and Page 1978, and Unsworth and Monteith 1972.) Mathematically, I^* is given by

Table II. Values of the normal incidence irradiance I^* at mean solar distance below an aerosol-free atmosphere, as a function of relative air mass m_h and precipitable water content, assuming $I_0 = 1353 \text{ W m}^{-2}$ and a fixed ozone content of 3 mm.

Precipitable water content (mm)	Relative air mass (m_h)						
	1	1.5	2.0	3.0	4.0	5.0	6.0
5	1100	1055	1010	940	885	835	800
10	1090	1035	990	915	860	810	775
15	1080	1020	975	900	845	800	760
20	1065	1010	960	890	835	790	750
30	1050	990	945	870	820	770	730
40	1035	980	930	860	805	755	720

$$I^* = I_0 \exp [-m\{\bar{a}_R(m) + \bar{a}_w\}],$$

hence equation (2) can be written in the form

$$I = S^{-1} I^* \exp(-m\bar{a}_D). \quad \dots \quad (9)$$

The definition of τ_a in equation (8) is therefore equivalent to

$$\tau_a = m_h^{-1} m \bar{a}_D = (P/P_0) \bar{a}_D,$$

that is, equivalent to the mean attenuation coefficient for dust and aerosol at sea level. Values of τ_a generally lie in the range 0.0–1.0, but can exceed 1.0.

4. The Ångström turbidity coefficient, β

In order to account for the difference in transmission characteristics between aerosol and 'Rayleigh' particles (i.e. gas molecules), Ångström (1929, 1930) represented the attenuation of solar radiation by aerosols in terms of a turbidity coefficient β and a wavelength exponent α , thus

$$a_D(\lambda) = \beta \lambda^{-\alpha}, \quad \dots \quad (10)$$

where λ is in micrometres. The exponent α is a measure of the particle size and varies between $\alpha = 0$ for very large particles (where scattering and absorption are independent of wavelength) and $\alpha = 4$ for very small Rayleigh particles (i.e. gas molecules). Its value therefore provides a good indication of the particle size of the aerosols.

From spectral investigations the value $\alpha = 1.3$ has been found to be a realistic average value which can be used in the calculation of β only. (See Ångström 1930 and Volz 1956.)

The coefficient β also has a simple physical interpretation. From equation (10), the proportion of solar radiation of wavelength λ reaching the ground after attenuation by aerosols is

$$\exp\{-ma_D(\lambda)\} = \exp(-m\beta\lambda^{-\alpha}).$$

For an overhead sun at sea level ($m = 1$) and at a wavelength $\lambda = 1 \mu\text{m}$ this reduces to $\exp(-\beta)$ which is approximately equal to $(1 - \beta)$ for $\beta \ll 1$. In other words, β is the fraction of solar radiation at a wavelength of $1 \mu\text{m}$ that is scattered or absorbed by aerosols in the atmosphere for unit air mass. Similarly, since $\lambda^{-1.3} = 2$ for $\lambda = 0.6 \mu\text{m}$, 2β gives the fractional attenuation of solar radiation at around $0.6 \mu\text{m}$ (i.e. in the visible spectrum). The coefficient β is defined for a standard atmosphere with a surface pressure of 1000 mb.

(a) Pyrliometric determination of β

Owing to the considerable selective absorption of radiation by water vapour within the infra-red region of the spectrum, the determination of β from pyrliometric measurements of normal incidence irradiance is usually restricted to the ultraviolet and visible wavebands. In practice, the coefficient β is derived by making two simultaneous measurements of the solar irradiance: one of the total irradiance I over all wavelengths and the other of the irradiance I_R in the infra-red waveband ($\lambda > 0.63 \mu\text{m}$), by using a Schott RG 2 red filter over the pyrliometer. The difference between the two measurements, I_k , gives the solar irradiance over the waveband $\lambda < 0.63 \mu\text{m}$:

$$I_k = I - I_R$$

$$= S^{-1} \int_0^{0.63 \mu\text{m}} I_0(\lambda) \cdot \exp[-m\{a_R(\lambda) + \beta\lambda^{-1.3}\}] d\lambda. \quad \dots \dots \dots (11)$$

The measured value of I_R , I_R' , is related to I_R by the expression $I_R = D_1 I_R'$, where D_1 is a correction factor for the characteristics of the filter. Since the variation of $I_0(\lambda)$ and $a_R(\lambda)$ with λ are known, the above integral can be calculated for any value of m and β . Values of irradiance I_k have been tabulated against m (see, for instance, Table 7 of the appendix to the *IGY instruction manual* (CSAGI 1958)). This particular table is based on a mean value of $I_0 = 1.98 \text{ cal cm}^{-2} \text{ min}^{-1}$. The table is entered at the appropriate value of m and from the measured irradiance I_k (corrected for the mean solar distance by multiplying by the factor S) the equivalent value of β is derived.

Although a value of $\alpha = 1.3$ is assumed in the above determination of β , it is possible in principle to calculate the exact value of α . For this purpose an extra pyrliometer is required so that a different simultaneous measurement of filtered irradiance can be made in addition to I and I_k for, say, the waveband $\lambda > 0.525 \mu\text{m}$, using a yellow-green (Schott OG 1) filter. The integral in equation (11) can be tabulated as a function of m and β for each of the two wavebands, $\lambda < 0.525 \mu\text{m}$ and $0.525 < \lambda < 0.63 \mu\text{m}$, in a similar manner to that used in the table referred to above for the waveband $\lambda < 0.63 \mu\text{m}$. The deduced irradiance measurements over these wavebands will generate two independent estimates of β (β_1 and β_2), assuming that $\alpha = 1.3$. If this latter assumption is correct then these two values of β should, of course, be identical. However, this is unlikely to be the case, as α varies with aerosol size and hence will have some general value α_0 , with a corresponding value of $\beta = \beta_0$ (and $\beta_0 = \beta_1 = \beta_2$).

Ångström (1929, 1930) described how one can regard the integral over wavelengths of solar irradiances as 'homogeneous' (i.e. monochromatic), which means that the integral in equation (11) can be replaced by an irradiance of fixed wavelength (the 'effective' wavelength). So, for the waveband $0 < \lambda < 0.525 \mu\text{m}$ the 'effective' wavelength $\lambda_1 = 0.45 \mu\text{m}$ and similarly, $\lambda_2 = 0.575 \mu\text{m}$ for the waveband $0.525 < \lambda < 0.63 \mu\text{m}$.

We can express the total attenuation of radiation due to dust and aerosols (a_D) in each waveband, not by the wavelength-dependent function (equation (10) or (11)), but by some mean weighted function. So we let

$$a_D' = \beta_1 \lambda_1^{-1.3}, \dots \dots \dots (12)$$

where a_D' is the total (integrated) attenuation coefficient over the waveband $0 < \lambda < 0.525 \mu\text{m}$. Similarly, for the waveband $0.525 < \lambda < 0.63 \mu\text{m}$,

$$a_D'' = \beta_2 \lambda_2^{-1.3}. \dots \dots \dots (13)$$

(Note that β_1 and β_2 in equations (12) and (13) are expected to be different as we have used the assumed

mean of 1.3 for α .) Now if we use α_0 , the true atmospheric value ($\neq 1.3$), then β_1 and β_2 will be the same—equal to β_0 as mentioned earlier. Therefore,

$$a_D' = \beta_0 \lambda_1^{-\alpha_0} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (14)$$

$$\text{and } a_D'' = \beta_0 \lambda_2^{-\alpha_0} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (15)$$

Equating (12) with (14) and (13) with (15),

$$\beta_1 \lambda_1^{-1.3} = \beta_0 \lambda_1^{-\alpha_0} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (16)$$

$$\beta_2 \lambda_2^{-1.3} = \beta_0 \lambda_2^{-\alpha_0} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (17)$$

Hence, using (16) and (17), α_0 is given by

$$\alpha_0 = 1.3 - \{\ln(\beta_1 \beta_2^{-1}) / \ln(\lambda_1 \lambda_2^{-1})\} \quad \dots \quad \dots \quad \dots \quad \dots \quad (18)$$

and, finally, β_0 can be derived from either (16) or (17) once the true value of α_0 has been calculated.

The determination of α_0 to even moderate accuracy demands great care and precision in the derivation of β_1 and β_2 , which implies that the filtered irradiances must be measured with an accuracy of at least 1%. In practice it is very difficult to meet this requirement with filtered pyrheliometric measurements and erroneous values of both α and β are easily obtained, with quite unrealistic variations appearing between individual 'observations'. For these reasons the use of the sun photometer (see below) is now favoured by the World Meteorological Organization in the determination of β .

(b) *The sun photometric determination of α and β*

The sun photometer, based upon an original design by Volz, is a dual-channel device for measuring the normal incidence solar irradiance in narrow spectral regions centred at approximately 0.38 μm and 0.5 μm . The conical acceptance aperture has a half-angle of 1–2° and the detector is a photovoltaic selenium cell. The signal from the detector is amplified and is observed on an attached microammeter.

The measured irradiance can be regarded as being monochromatic at the above wavelengths, so equation (5) can be used to express the measured irradiance $I(\lambda)$ in terms of the extraterrestrial irradiance $I_0(\lambda)$, ignoring water vapour absorption which can be neglected at these wavelengths. Thus,

$$I(\lambda) = S^{-1} I_0(\lambda) \cdot \exp[-m\{a_R(\lambda) + a_D(\lambda)\}],$$

where $a_D(\lambda) = \beta \lambda^{-\alpha}$ for $\lambda = 0.38 \mu\text{m}$ and $0.5 \mu\text{m}$ respectively.

$I_0(\lambda)$ is the extraterrestrial irradiance which would be measured with the same instrument at air mass zero. At present this value is determined by the Langley method (World Meteorological Organization 1978). The readings over a range of air mass values are made during periods of stable turbidity and their logarithms are plotted against m and extrapolated to air mass zero to obtain I_0 . Usually, sun photometers used in the field are calibrated by direct comparison with reference instruments. These instruments are stable sun photometers that have been calibrated by carefully selected Langley plots.

$a_R(\lambda)$ is normally tabulated as a function of λ for mean sea level (Elterman 1964) and as an example Table III shows sea level values of the Rayleigh scattering coefficient for 0.35 cm of total ozone for three values of λ . Since ozone absorption is not negligible at 0.5 μm the value of $a_R(\lambda)$ at this wavelength is usually increased by the absorption coefficient due to ozone at 0.5 μm .

Since $I_0(\lambda)$, $a_R(\lambda)$, m and S are known, the two measurements of $I(\lambda)$ will give the attenuation coefficient $a_D(\lambda)$ at each wavelength, producing the simultaneous equations,

$$a_D(\lambda = 0.38) = \beta(0.38)^{-\alpha}$$

$$a_D(\lambda = 0.5) = \beta(0.5)^{-\alpha}.$$

Table III. Sea level values of Rayleigh scattering optical thickness for 0.35 cm of total ozone.

λ	a_B	a_{ozone}
380 nm	0.45	0
500 nm	0.145	0.012
850 nm	0.014	0

Eliminating β ,

$$\alpha = \ln\{a_D(\lambda = 0.38)/a_D(\lambda = 0.5)\}/\ln(0.5/0.38), \quad \dots \quad (19)$$

from which β can be derived by substituting for α in either of the two simultaneous equations above.

5. Practical determination of turbidity—method of measurement

At the National Radiation Centre the derivation of atmospheric turbidity has been based upon the measurement of normal incidence irradiance using an Ångström compensation pyrheliometer (see page 390 of *IGY instruction manual* (CSAGI 1958)). This is one of the most reliable instruments for measuring solar irradiance and is often used as a standard in the calibration of secondary pyrheliometers. The detector consists of two identical thin blackened manganin strips, one of which is exposed to the sun and the other shielded. An electric current is passed through the shielded strip until the temperatures of the two strips are equal. The electrical heating of the shielded strip is then equivalent to the heating produced in the exposed strip by the absorption of solar radiation. The temperature difference between the two strips is monitored by means of a thermocouple, one junction being on the back of each strip. If the temperatures are identical there can be no output from the thermocouple, thus heating equivalence is indicated by a sensitive null-detector and the heating current can be adjusted until balance is achieved.

- Let i_0 = the equilibrium heating current (amperes),
- r = the resistance per unit length of the shielded strip (ohm m^{-1}),
- b = the mean width of the strip (m),
- L = the length of the strip (m) (area of strip = $bL \text{ m}^2$),
- a = the absorption coefficient of the blackened surface of the strip (usually taken as 0.98 for the coating of camphor soot), and
- I = the normal incidence solar irradiance (W m^{-2}).

The rate at which radiant energy is absorbed by the exposed strip, Q_1 , is given by

$$Q_1 = IbLa.$$

The rate of electrical heating, Q_2 of the shielded strip is given by

$$Q_2 = i^2 rL \text{ (current}^2 \times \text{resistance)}.$$

At equilibrium, when the temperatures of the two strips are equal, i.e. $i = i_0$ and $Q_1 = Q_2$ then

$$I = (i_0^2 r)/(ba) = ki_0^2 \text{ (W m}^{-2}\text{)},$$

where $k = r/(ba)$ and is a constant for the instrument being used. In practice, k is derived by comparing the instrument with a world-wide standard instrument.

In order to derive turbidity as reliably as possible a number of irradiance measurements are normally made in quick succession over a period of, say, nine minutes. During this time each of the blackened strips is alternately exposed to the sun whilst the heating current i is passed through the other (shielded) strip.

An average equilibrium current is calculated for each strip and the mean of the two strips i_0 is then used in the above equation to derive the mean irradiance I . Given the time of the observation and the precipitable water content of the atmosphere the relative air mass can be calculated and hence the Linke turbidity factor T and Unsworth's coefficient τ_a derived according to equations (7) and (8). In order to determine the Ångström turbidity coefficient β using, say, equation (11) two simultaneous sets of irradiance measurements are required (using two pyrheliometers): one instrument measuring the total all-wave irradiance I and the second measuring the filtered irradiance I_R by isolating the waveband $\lambda < 0.63 \mu\text{m}$ with a red (RG 2) filter.

At the National Radiation Centre practical attempts have not proved very successful in determining the exponent α from filtered pyrheliometric irradiance measurements over different wavebands, according to the theory of section 4(a). Unrealistic values of both α and β have been obtained and these may be partly due to the interpolation error which arises from the practice of making filtered measurements alternately rather than simultaneously, since only two Ångström instruments are in service at the Centre.

A suite of computer programs has been developed for calculating each of the three turbidity coefficients for those occasions when special irradiance measurements have been made at the National Radiation Centre. A 'master' archive data set has also been created to store these parameters, together with a variety of relevant meteorological and astronomical data.

The World Meteorological Organization (WMO) which collects, stores and publishes turbidity data at the National Climatological Center (NCC), Asheville, North Carolina, USA, provides details on the operating instructions when making turbidity observations (World Meteorological Organization 1978). The Meteorological Office does not make routine measurements nor has it sent any turbidity data to the NCC but one of the new generation of sun photometers has been obtained from Japan, together with four filters at 368, 500, 675 and 778 nm ($\pm 5-6$ nm). Of these, the 500 nm filter is mandatory for any data sent to WMO. After a test period at Easthampstead Park it will probably be installed at Eskdalemuir which is a WMO climatological station and a WMO baseline air pollution monitoring network (BAPMoN) station and is jointly run by the Meteorological Office and the Natural Environmental Research Council. As turbidity is one of the three minimum requirements from a BAPMoN station it is hoped that routine measurements will be made and sent to the NCC in the near future.

In order to test the limits of sun photometric readings an error analysis can be performed based on the following formula:

$$\Delta a_0(\lambda) = m_h^{-1}\{\Delta I(\lambda)/I(\lambda)\} + m_h^{-1}\{\Delta I_0(\lambda)/I_0(\lambda)\} + \Delta a_R(\lambda). \quad \dots (20)$$

Fröhlich (1977) gives a table of typical errors for an Environmental Protection Agency (USA) sun photometer, at a relative air mass of 2 and λ equal to 380 and 500 nm. For the worst case, when the temperature range of the instrument is ± 10 K (kelvins) and the ozone variation is $\pm 30\%$, $\Delta a_D(380) = 0.05$ and $\Delta a_D(500) = 0.03$. For the best case, with no temperature change and exact ozone values, $\Delta a_D(380) = 0.03$ and $\Delta a_D(500) = 0.02$.

One of the most important contributions to this uncertainty is the difficulty in determining the value I_0 . For example, on a day when the turbidity gradually decreased from a midday value of $a_D = 0.34$ to $a_D = 0.24$ by 1800 hours, there was an error of 12% in the calculation of I_0 . The degree of linearity of the Langley plot is normally taken to judge the degree of stability of turbidity although in some special cases linearity can be preserved for varying turbidity. It follows, therefore, that calibration of sun photometers can only be performed accurately during clear days at mountain stations. However, new technology using a combination of dye-lasers and absolute radiometers should make accurate calibrations possible. These new techniques should permit a calibration scheme to be developed whereby standard sun photometers are periodically compared with those instruments at the recording sites.

Errors can also be caused in the actual measurement of $I(\lambda)$ and hence $\Delta I(\lambda)/I(\lambda)$ in equation (20). Normally a 0.5% reading error is assumed together with an error due to the aureole influence which is related to the aperture of the instrument and can cause 0.8% errors at 380 nm and 0.4% errors at 500 nm. The effect of the latter is reduced by a factor of three with the new generation of sun photometers because of the more suitable acceptance geometry of the instruments. Similarly, the temperature coefficient has been reduced by a factor of typically from two to five by the use of silicon cells.

6. Future developments

The WMO has recognized the problem of obtaining reliable and comparable values between observing stations of the Ångström turbidity coefficient from filtered irradiance measurements using pyrhelio-meters. At a WMO meeting of experts on turbidity held at Boulder, Colorado, in the autumn of 1978, the use of the new generation of sun photometers was recommended for the determination of both α and β (according to the method of section 4(b)). Although turbidity measurements made by pyrhelio-meters will still be accepted, only those made by the sun photometers will be published by the WMO. However, until the time that sun photometers are installed at observing stations in the UK radiation network (probably Easthampstead and Eskdalemuir) and hence routine measurements of the turbidity coefficient β are available, work continues on the expansion of the archived turbidity data set. By exploiting the normal incidence irradiation data sets for Easthampstead and Kew it is possible to calculate the Linke and Unsworth turbidity coefficients. However, since much of these data consist of hourly irradiances, turbidity coefficients can only be calculated for those hours when sunshine was continuous and not obscured by cloud. The routine observations of cloud cover at these stations, together with the recorded sunshine durations, are therefore being used to diagnose suitable periods during which the mean hourly turbidity can be calculated. Since mid-1979 values of normal incidence irradiance, sampled at one-minute intervals, have become available for both Kew and Easthampstead. These measurements will make it much easier to detect intervals of unobscured sunshine over time-scales ranging from several hours to just a few minutes and therefore will allow some measure of the diurnal variation of atmospheric turbidity to be made at those stations. Work is currently under way to produce statistical, graphical and tabular analysis of the turbidity data, together with the other parameters stored in the archived data set.

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551.515.33(423)

A Wiltshire tornado, 30 May 1979

By E. J. Smith

(Meteorological Office, Netheravon)

Summary

An account is given of a tornado that formed near Netheravon, Wiltshire, on a day during which heavy rain and thunderstorms developed over much of southern England. Use is made of rainfall radar photographs and several eyewitness accounts describe the tornado in its various stages of development.

Introduction

Moderate or heavy rain, with occasional thunderstorms, was reported over many parts of southern England on 30 May 1979. It is shown that a cold-front wave, which led to the development of a tornado near Netheravon, crossed Wiltshire in the afternoon of that day. Drawings from rainfall radar photographs are used to illustrate the areas of heavy rainfall associated with the wave. Several eyewitnesses were questioned and their accounts describe the tornado in most of its stages of development.

Fig. 1 shows that part of Wiltshire on the eastern edge of Salisbury Plain, including the main centres of population. There are many military establishments in the area and, as a result, a high density of meteorological offices and trained observers. Fig. 2 shows, in more detail, those areas affected by the tornado. The contours indicate the undulating nature of much of the county and show a ridge near Larkhill falling away to the River Avon. The ground then rises gently north-eastwards to the Wig plantation.

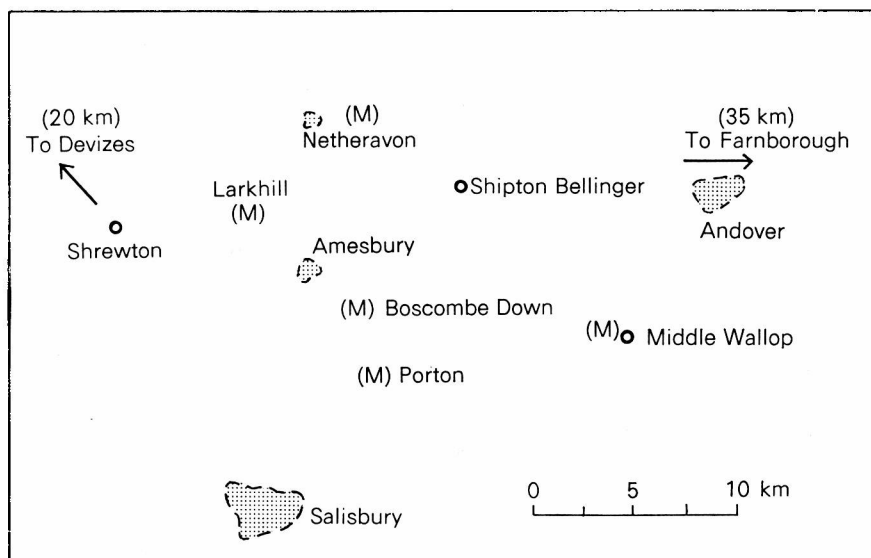


Figure 1. Part of Wiltshire on the eastern edge of Salisbury Plain showing locations of meteorological offices (M).

The formation of severe storms and tornadoes

The parameters necessary for severe storm and tornado development are well documented in the United Kingdom: Browning (1968), Hardman (1968), Hindley (1977), Lacey (1968) and Wright (1973). They are summarized as follows:

- (a) Great buoyancy—necessary for a strong, persistent updraught, which is achieved if the air is potentially unstable, i.e. θ_w^* decreases with height.
- (b) A supply of warm moist air at low levels, i.e. a high value of θ_w in the lower layers.
- (c) Mid-troposphere regions of dry air—necessary to aid downdraught development.
- (d) Vertical wind shear, typically a veer of wind with height throughout the convective layer and an increase of 30–60 kn from the ground to, say, 500 mb in order that updraught/downdraught circulations may persist for long periods.
- (e) Usually consideration is given to some form of trigger action—for instance, high surface temperatures, forced mechanical uplift or generally falling pressure.
- (f) Development of the updraught will be more rapid if the initial energy release is restricted, say by a temperature inversion, so that the eventual energy release is more 'explosive' and leads to a stronger updraught.

It is suggested that all these factors can be identified from the meteorological information available for 30 May 1979 which is presented below.

* θ_w —the wet-bulb potential temperature—combines water vapour and temperature data in a single parameter and is defined as that temperature at which the saturated adiabatic through the wet-bulb temperature at a particular level intercepts the 1000 mb isobar.

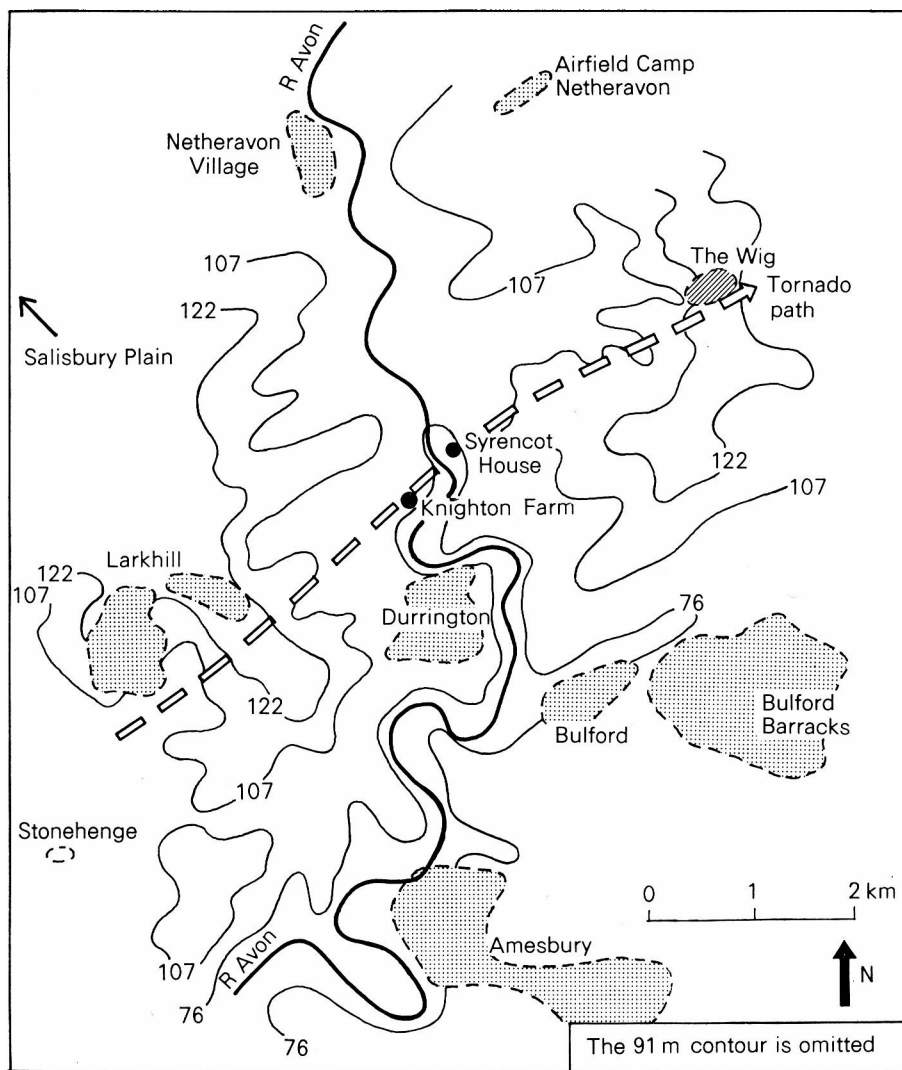


Figure 2. The path of the tornado.

The synoptic situation

Moore (1980), in an article describing the uses of pictorial satellite data, chose as an illustration the particular cold-front wave under discussion. It moved north-eastwards, crossing southern and eastern England on 30 May 1979, eventually reaching the North Sea on the 31st. Fig. 3 shows the position of the cold front at 1300 GMT on 30 May 1979 with the wave centred very near Netheravon. Rainfall radar displays (Figs 4 to 6) indicated a line of intense echoes progressing north-eastwards across Salisbury Plain between 1318 and 1403 GMT. This line represents the cold front which contained one or more severe storm cells that in turn led to the development of the Netheravon tornado. A more detailed account of the heavy rain of 30 May is given by Woodley (1981).

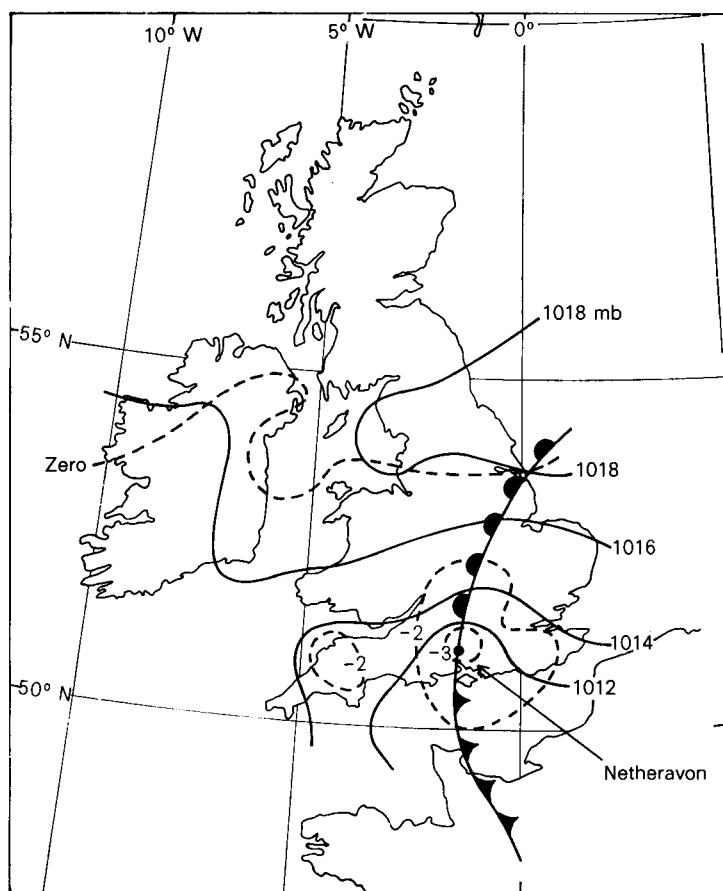


Figure 3. Surface synoptic chart for 1300 GMT, 30 May 1979.
 ————— mean sea level isobars
 - - - - - isallobars

The weather observed on 30 May 1979

The five meteorological offices in the area each reported a squall; the time of onset varied between 1315 and 1335 GMT. See Table I.

Table I. Maximum gusts recorded by the meteorological offices in the area of the tornado of 30 May 1979

	Direction degrees	Gust speed knots	Time GMT
Boscombe Down	300	49	1318
Larkhill	240	41	1316
Middle Wallop	290	26	1328
Netheravon*	330	47	1335
Porton	260	50	1317

* No anemograph—wind read from anemometer dial.

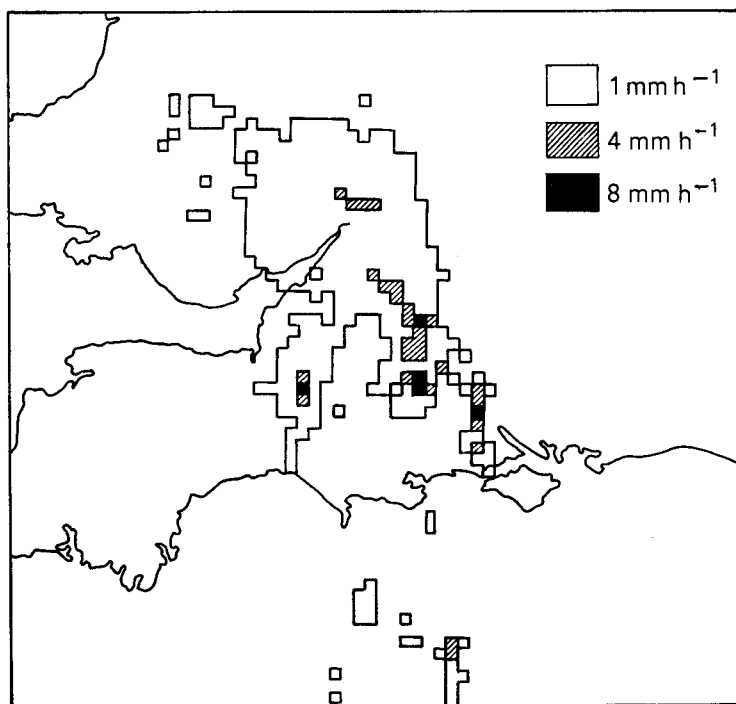


Figure 4. Drawing from photograph of rainfall radar display, 30 May 1979 at 1318 GMT.

Taylor and Browning (1974) described the versatility of radar for observing the weather. They showed that suitable calibrated radars are able to indicate the horizontal and vertical distribution of precipitation and its intensity. Such radars can be used to identify those echoes characteristic of thunderstorm development. They described how digital processing techniques had been employed to produce precipitation maps for display on a television screen. These maps may be depicted on the screen in grid form (Figs 4–6) with each box having a colour or shading to show a particular average rainfall rate. The shading often indicates precipitation intensities ranging from light rain to thunderstorms.

None of the meteorological observers reported thunder but an aircraft was struck by lightning over Devizes and thunder was heard at Shrewton. Thunderstorms had been reported earlier in the day in Somerset and Dorset and confirmed by SFLOCs (lighting flash location reports). Radar reflectivity between 1318 and 1403 GMT, although qualitative, often showed rainfall intensity of 4–8 mm h⁻¹ along the cold front, with a small area of 16 mm h⁻¹ north-east of Netheravon at 1403 GMT.

Upper-air data

It is unlikely that a truly representative upper-air sounding was available on this occasion but tephigrams for Larkhill at 0900 GMT and Crawley at 1200 GMT are reproduced in Fig. 7.

A sharp trough persisted to the west of Ireland throughout the period and southerly winds are shown on both ascents at middle and upper levels. With maximum upper winds across the front reported between 327 mb and 198 mb, the 250 mb level was selected to represent the jet stream (Fig. 8). Central southern England was lying under the right entrance to this jet—an area considered favourable for the intensification of low-level cyclonic circulation.

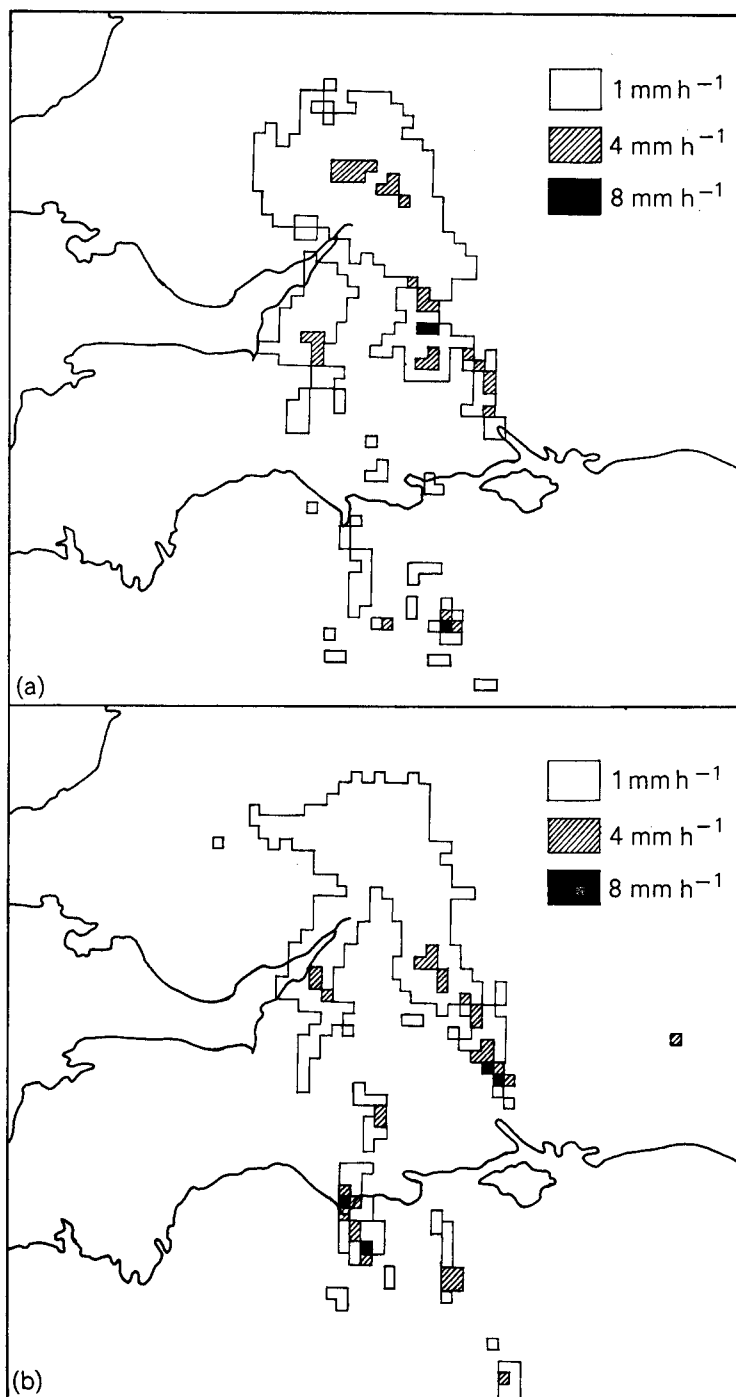


Figure 5. Rainfall radar display, 30 May 1979, (a) at 1333 GMT, and (b) at 1348 GMT.

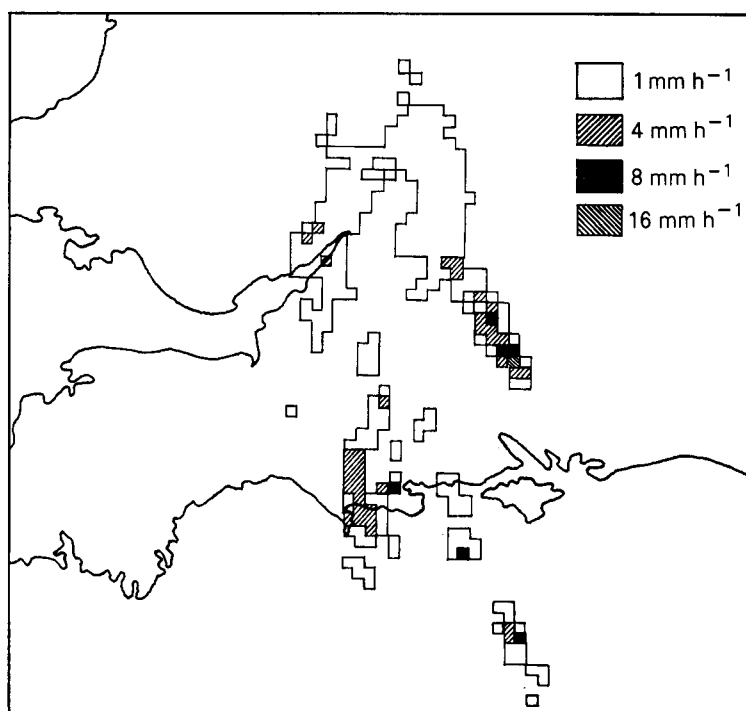


Figure 6. Rainfall radar display, 30 May 1979 at 1403 GMT.

Lower-level winds indicated a south-easterly flow ahead of the waving cold front and surface dry-bulb temperatures as high as 21 °C and dew-point temperatures as high as 18 °C were reported as far west as the Farnborough area. At Netheravon airfield, however, much lower values were observed—14 °C and 11 °C.

It is assumed that the upper-air pattern in the Netheravon area at the time of the tornado was represented by a tephigram somewhere between the two shown in Fig. 7, with a south-east wind bringing warm moist Crawley-type air below the Larkhill air of middle and high levels. Estimated θ_w values of 15 °C or 16 °C at 900 mb would fall to about 14 °C at 700 mb, then around 13 °C aloft. Dry zones were shown on both ascents.

Obviously this subjective estimate of a representative vertical temperature and humidity profile has limited value but, without a detailed multi-level trajectory analysis, was considered to be a reasonable first guess. The reduction of θ_w with height was definite, although small, but the low-level horizontal discontinuity of θ_w across the front was very marked, at least 7 °C over a few tens of kilometres.

The vertical wind shear, considered necessary for severe storm development, was confirmed by the Larkhill upper-wind profile.

The isallobaric low (the area of maximum local fall of pressure with time) was traced from a position over Brittany at 0600 GMT (not shown). Moving at 30 kn it reached the Netheravon area at 1300 GMT (Fig. 3). This area of falling pressure was considered to be the trigger action necessary to overcome the low-level temperature inversion.

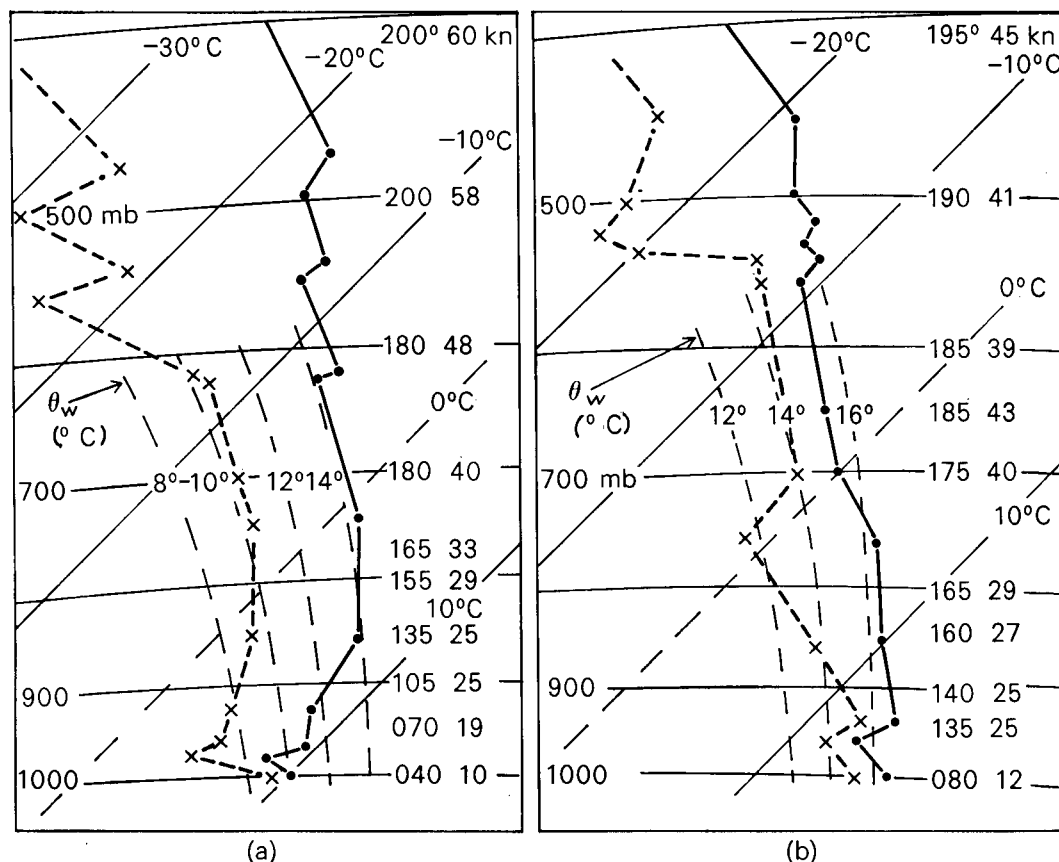


Figure 7. Tephigrams for (a) Larkhill 0900 GMT and (b) Crawley 1200 GMT, 30 May 1979.

Descriptions of the tornado

A worker from Knighton farm was interviewed and he told of working just south of Larkhill camp (Fig. 2). He had naval experience and described, without prompting, a definite funnel cloud reaching the ground, approximately 15 m wide at ground level and moving towards Syrencot House. He told of very strong winds with the funnel appearing white or light-coloured and he assumed it was filled with rain. He did not notice the rotational direction.

Office workers at Syrencot House were aware initially of a very strong wind. Their window view was towards east-north-east and it was noted that the wind was blowing from right to left, that is approximately from the south-east. Next the sky became black and a rotation was seen in the cloud but this did not reach the ground. Heavy rain followed and was being driven from left to right by the wind as viewed from the window, i.e. on a north-westerly wind. This indicated cyclonic motion in the tornado. Eventually the bad weather moved into the distance away from the window.

Mr McAllister, a Lands Agency official, observed the tornado near the Wig but did not see it hit the plantation. Initially the area became very dark; then, near to the ground, it became lighter and a funnel-type rotation was seen underneath the main cloud mass which remained black. Very heavy rain soon followed and it became very windy. Mr McAllister did not notice the rotational direction.

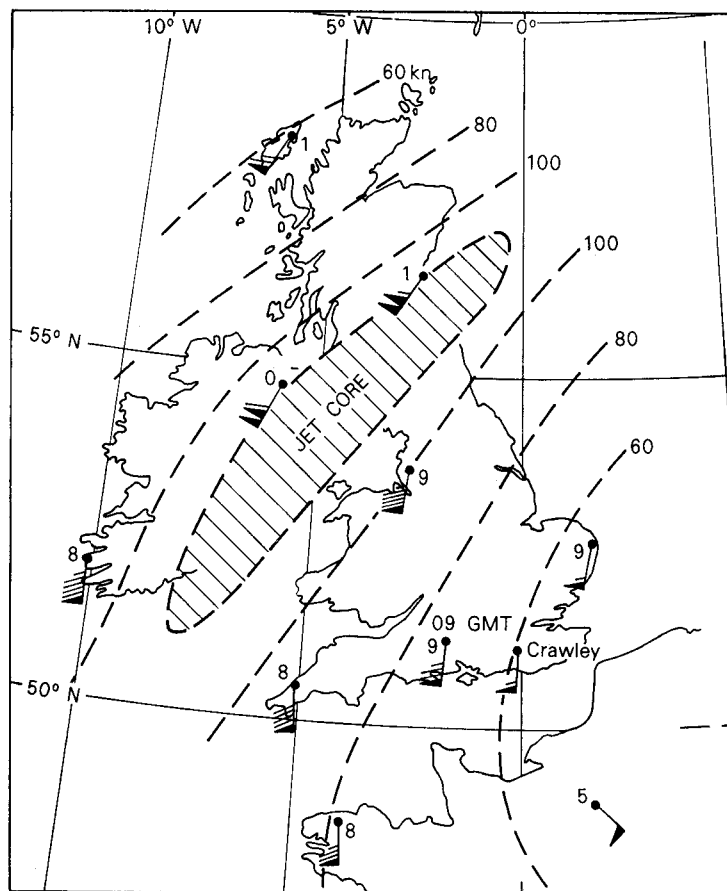


Figure 8. 250 mb plotted winds with isotachs, 1200 GMT, 30 May 1979.

Mr Loder, another farm worker, actually saw the tornado cross the Wig plantation. Once again a definite rotation was seen and Mr Loder estimated that he was about 400 m from this and that the width of the funnel was of the order of 100 to 150 m. He described the weather as being generally very dark and windy with rain. The whole sequence lasted a few minutes and Mr Loder estimated the speed of the tornado to be about 20 miles per hour (9 m s^{-1}). He saw much debris—tree pieces etc.—becoming airborne as the tornado crossed the Wig. It became obscured by the plantation itself soon after.

The author visited the Wig on 4 June before clearing-up operations had begun. This small plantation covers an area roughly 300 m square and consists of Scots pine approximately 40–50 years old. The path of the tornado and the damage it caused are described with reference to Fig. 9 and Plate I.

The tornado came over the brow of a rise to the west of the plantation. Two trees at A were broken but the lone tree at A1 was undamaged. Approximately one-third of the plantation area, on the south side, was devastated. Several trees, including two of about 1 m base diameter, were completely uprooted and many others snapped off at some point, usually in the upper half. Some branches, up to about 25 cm in thickness, appeared to have been twisted off the trunks. The remaining two-thirds of the plantation was undamaged.



Plate I. Tornado damage to the Wig plantation. (The same tree appears at the bottom right of the upper picture and the bottom left of the lower picture.)

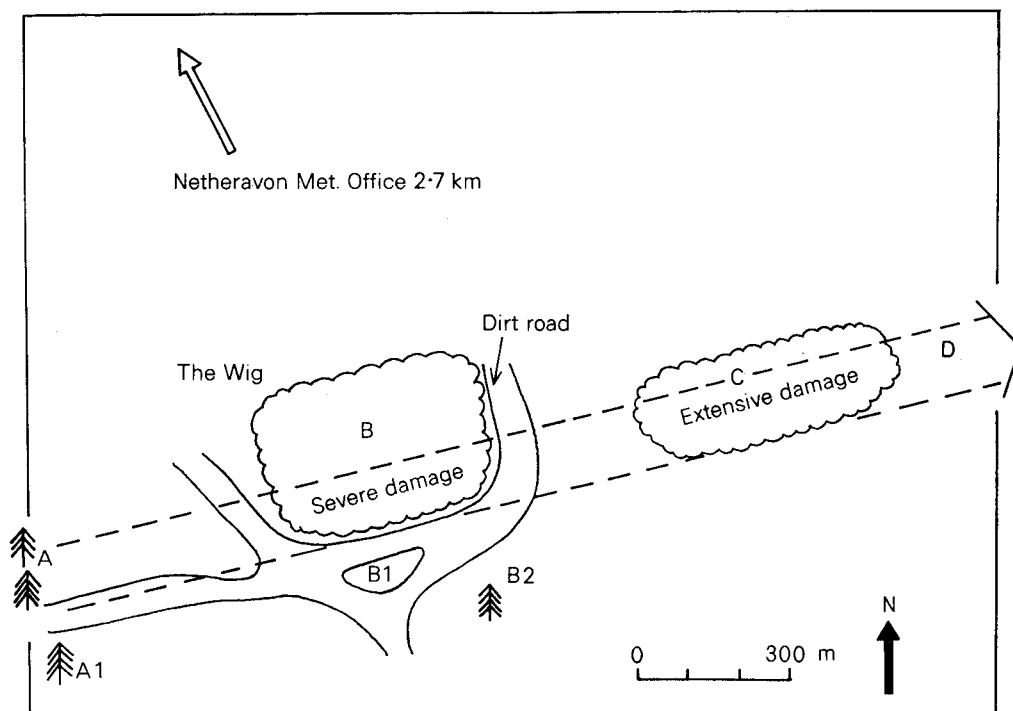


Figure 9. The track of the tornado in the area of the Wig plantation.

A notable feature was that, within an area roughly 50 m square, trees were lying in different directions, the pattern suggesting their being uprooted or snapped by winds of a small circulation. Trees at B1 were partially damaged but that at B2 was unscathed. At C, in a much less densely wooded spinney of smaller trees, extensive damage was seen—usually branches or trunks broken. Some debris from C was carried outside the spinney edge to D. From D a hedge with deciduous trees at approximately 700 m distance appeared undamaged.

A further detailed report was given by an experienced helicopter pilot who was at home at Shipton Bellinger. His view to the west was partly obscured by nearby houses but he was able to observe the squall line as it approached. A very dark vertical core appeared and fractostratus cloud at the edges was sucked up into it. He estimated that the vertical motion represented twice the rate of maximum helicopter ascent, i.e. 60 miles per hour (about 25 m s^{-1}). The storm then, suddenly, produced very heavy rain soon followed by hail, then lighter rain. The storm passed to the east within two or three minutes of the first observation.

No rotational motion within the vertical core was observed but this account appeared to present clear visual evidence of very strong local vertical motions within the cold front.

The track of the tornado

It appeared to form to the south-west of Larkhill (Fig. 2) as it is assumed to have been in an early stage of development from the description of it when just south of the camp. It moved just to the north of Knighton farm, where the tops of two or three trees were broken off, then crossed Syrencot House. It is

probable that the funnel cloud, undoubtedly at ground level at Larkhill, crossed the Avon valley with the funnel above the ground, possibly by several tens of metres. The land containing Syrencot House slopes gradually upward from the river and contains many trees of different varieties, dimensions and ages. Only one of these was damaged, the top being broken. Inspection of this tree revealed that it was diseased and therefore weaker than those around it. The author considered that much more damage would have been done to the trees and buildings if the funnel had been at or near ground level. The observation by the office workers in Syrencot House seemed to confirm the assumption of an 'elevated' funnel at that stage.

The tornado then moved further eastwards out of the valley where the funnel reached the ground once more. By this time it had developed to the size indicated by Mr Loder and was of sufficient intensity to damage or destroy many healthy mature trees in the Wig. Beyond the second, smaller, copse the tornado appeared to dissipate rapidly as no evidence of further sightings or damage was obtained.

Discussion and conclusions

The Salisbury Plain area of Wiltshire is sparsely populated and it is possible that the tornado would not have come to the notice of the author if it had not severely damaged the Wig although it is only 2.7 km to the south-east of Netheravon meteorological office.

From inspection of the Wig it seemed as if the tornado came to a halt, temporarily, within the plantation, felling trees in a more or less circular pattern. It then moved on to destroy most of the trees in the second copse. Over open ground beyond this, however, the tornado apparently became a spent force and decayed quickly although the squall line, within which it was probably embedded, continued north-eastwards.

It is considered that the meteorological evidence confirmed, in a general sense, those requirements necessary for severe storm and tornado development. The weight given to particular factors can be assessed only in a qualitative way but it is suggested that the main features causing the tornado were, in combination:

- (a) the strength of the front, shown by the large θ_w gradient across it at low levels, and
- (b) the wave on the front, well defined by the isallobaric low, which moved, at a critical time, into the development area under the right entrance to the south-south-westerly upper jet stream.

Local topography may have played a part in the formation of the tornado as valleys are often favoured locations for tornado development (Wright 1973). It is certain that between its appearance at Larkhill and its emergence out of the Avon valley this tornado intensified in a dramatic manner.

The evidence from Shipton Bellinger indicated the possibility of other tornado-like features within what was a very active squall line.

Acknowledgements

The author wishes to thank the Principal Meteorological Officer, Upavon, and staff of the Special Investigations Branch (Met O 9) for their advice, suggestions and encouragement in the preparation of this paper, Mr P. Brown of Boscombe Down meteorological office for additional local information, and 7 Regiment, Army Air Corps for supplying the photographs that make up Plate I.

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551.5:06(b):551.5(09)

Reminiscences of the Meteorological Office, 1898-1910

By A. T. Bench

The following account was prepared by Mr A. T. Bench on the basis of his own reminiscences and those of Messrs H. E. Carter, W. Hayes and H. L. B. Tarrant; a shortened version was published in the *Marine Observer* in 1963, but we thought that the full version merited circulation among a wider audience. Mr Bench retired in March 1947 after more than 49 years' service. He entered the Office, which was then housed at 63 Victoria Street, Westminster, on 24 January 1898, as a Boy Clerk in the 'Autographic Records' Branch, and became a Probationer in the Forecast Division in September 1902. He remained in forecasting for 18 years and his memories of this period include the final telegraphic message from Victoria Street on the removal to South Kensington in 1910 and the receipt of the first wireless message from the Eiffel Tower in 1913. In October 1920 he was transferred as Principal Assistant to the British Rainfall Organization on its incorporation in the Meteorological Office, passing to the new General Climatology Branch on its formation in 1925. He remained in that Branch until his retirement.

Several accounts of the history and work of the Meteorological Office have been published, notably by the late R. G. K. Lempfert but they have naturally been limited to official matters. The following notes and personal reminiscences may serve to fill in the background of the picture as seen by members of the staff in the years which immediately preceded and followed the end of the last century.

At that time the Meteorological Office was situated in Victoria Street, Westminster, and was under the direction of Dr R. H. Scott until early in 1901 when Dr W. N. Shaw succeeded him. The annual budget was £12 500. The office premises occupied the four upper floors of a building on the corner of Strutton Ground which had been originally a private residence, the ground floor having been converted into two shops—a piano dealer on the corner, with an oriental rug and carpet store next door. Mr and Mrs Drane acted as caretakers and occupied very gloomy quarters in the basement. Mrs Drane was formerly cook in the household of Dr Scott.

The boy clerks who joined the staff about the turn of the century might almost have thought they were joining a family party, several members of which were in the original 'hive off' from the Board of Trade in 1855. In a staff of just under 40 persons there were four or five sets of brothers and a pair of sisters. The sisters, Miss Rose Smith and Miss Beatrice Smith, with Miss E. A. Anderson in charge, were ensconced in a veritable 'purdah' on the top floor of the building behind double doors and were allowed to arrive 10 minutes later and leave 10 minutes earlier than the male staff in order (ostensibly) to avoid contact with the men. They comprised a section of the Marine Branch and such was their strict seclusion that permission to interview them had to be obtained from their chief.

The principal part of the library was located in the room of the head of the office, Dr R. H. Scott

(succeeded by Dr W. N. Shaw), whose official designation was that of Secretary. Owing to lack of other space the regular meetings of the Meteorological Committee were held in that room, when afternoon tea was provided, the tea being a special brand at 6s. per pound obtained from a firm in Inverness. In the course of years the accession of books and bound volumes of observations had overflowed into other rooms and the increasing weight of these and of several thousands of marine meteorological logs, caused some of the floor joists to sag and it became necessary for iron girders to be put in to hold up the floors.

Even in a small company of individuals there can always be found some with amusing characteristics, and the Meteorological Office staff were by no means lacking in this respect. A recreation of one Marine Superintendent, Captain Toynbee, was writing evangelical pamphlets which he distributed to the staff from time to time. One of these had the intriguing title of 'Go down, proud stomach'; another was headed 'Of the dead, say nothing but good'. Captain Toynbee, when on the active list in the merchant navy, kept meteorological logs, and at one office function some of these were exhibited, as they were beautifully illustrated by coloured sketches of marine animals drawn by Mrs Toynbee, who often accompanied her husband on his voyages. On the same occasion a logbook was shown which had been kept by King George V when, as Prince George, he served as an officer in the Navy.

The Chief Clerk, James S. Harding, a short but very dignified man with a long square-cut beard, had a flair for languages and, although not much of a linguist, could read quite a few. He usually spent his annual summer leave learning a fresh one, and was discovered one year by a boy clerk at Littlehampton, where he always went, sitting on the sands by a groyne learning Russian.

A. J. Rigby was an exceptionally hairy man, which fact, he insisted, was indicative of great strength.

Around the corner from the office, in Strutton Ground, was, and still is, a public house named the Grafton and it was the invariable practice of the two senior forecasters, F. Gaster and F. J. Brodie, to pay a visit there immediately before settling down with the synoptic chart to dictate the forecasts. In those days public houses were open all day. Mr Chas Harding, brother of James Harding, and senior clerk in the Marine Branch, also had the habit of slipping out in the morning and invariably remarked on leaving the Marine Room, 'Just want to call at the Stores' (i.e. the Army and Navy which had not then become one of London's popular public stores; business was restricted to ticket holders who were members or ex-members of the armed or civil services). Mr E. J. Hood of the General Office, also used to 'pop out' for brief periods—not limited to mid-morning.

Street musicians, notably 'German' bands, often played outside the Grafton and, when they became too noisy, Dr Shaw would send Mr Snell down to request them to soften their music, as his room overlooked the side street.

Mr Gaster was also addicted to taking patent medicines for unknown complaints and the large mantelpiece in his room was completely loaded with bottles, empty and otherwise. He always had his lunch in his room, served by Mrs Drane, and had the curious habit of removing his dentures before his meal, placing them on a table-napkin beside his plate. At one period Mr Gaster had a cask of ale in the basement for his own consumption and for anyone else who would pay for a drink. This arrangement, however, did not last very long, as he found that the ale disappeared and he lost money. Mr Gaster also had a goodly row of scientific textbooks, some of them Queen's Prizes, gained for work at an evening institute. He was also Meteorological Correspondent for *The Times* and usually prepared a special account of the day's weather experienced over the country. This was sent to *The Times* office by the messenger who called each evening for a copy of the official forecast and notes which were issued to the Press. He was also a churchwarden and conducted a Bible class for young women.

Charles Thompson, a short rotund figure, was never known to wear an overcoat even during the most severe weather and always used a walking stick with a silver knob, suitable for a much taller man. He

and A. H. Bell, both bachelors, were as 'David and Jonathan' in their habits and as a consequence always spent holidays together. On one occasion they took advantage of an unprecedented excursion of the Great Western Railway to Killarney for thirty shillings return. Thompson and Bell were enthusiastic members of the Old Playgoers Club and from time to time in the first decade of the present century invited members of the Meteorological Office Cycle Club to join them at dinners arranged by the O.P.C. at the Criterion Restaurant. On these occasions the after-dinner entertainments were noteworthy, the artists including many well-known singers and popular music-hall stars of the day. These visits to the 'Cri' were a generous return for hospitality of the office Cycle Club, the members of which invited Thompson and Bell to their annual dinner at a country hotel some 20 or so miles from London. These informal dinners were followed by an entertainment comprising vocal, instrumental and humorous items all presented by the cyclists, and very successful gatherings were held at the Bull at Leatherhead, the Feathers at Merstham and the Swan at Staines.

T. E. Allen, in charge of the autographic records from the first-class observatories (photographic in those days), was formerly an assistant of Glaisher, the famous balloonist, at Greenwich Observatory. He had held Grand Master's office in the Oddfellows and was Secretary of a Lodge. Quill pens were included among the stationary stores and these were invariably used by Mr Allen for his reports.

One of the junior clerks, who earlier framed pictures in his spare time, was Frank T. Bullen, who spent many years in the merchant navy, ending up as Chief Mate before entering the office. He achieved fame and fortune by his books, notably *The cruise of the Cachalot*. This publication, however, was treated with scorn by William Allingham of the Marine Branch who started his career before the mast in a sailing ship, and was the author of a standard textbook on marine meteorology. As two of the juniors who joined at this period had also graduated from naval schools (viz. Greenwich and the *Worcester*), there was a distinctly nautical atmosphere in some of the rooms.

George Francis always appeared to be in debt, both to his colleagues and elsewhere. As a result of the latter, there were occasional mysterious absences from duty owing to visits of a Sheriff's Officer. During one such two-day absence a nasty smell was noticed in his room. Toward the end of the second day this became so objectionable that an organized search was conducted, leading to a locked drawer in his table which, when broken open, disclosed some kippers wrapped in newspaper.

The 'wag' of the office staff was undoubtedly A. E. Pycock who was an excellent comic singer. Under the name of 'Fred Edwards' he was in demand for concerts and dinners and appeared on concert platforms as far away as the Grand Hotel at Eastbourne. Indeed, he earned more by his evening concert work than he did in the office. He was at all times excellent company with a fund of humorous stories. One of his office jokes was in connection with the marriage of Miss Beatrice Smith to a Mr Plank; when Pycock first heard about it he spread it around that it was young Bench whom she had actually married.

Miss Rose Smith had a great interest in music and was a member of the London Choral Society for many years. She retained an interest in choral singing until her death at the age of 91. Mr R. G. K. Lempfert was an accomplished viola player. In 1916 he married Miss Marjorie Hayward, a violinist of international repute. Another competent musician was W. G. James, flautist and organist. L. H. Powers must also be numbered among the musicians. As a violinist he entertained his fellows at staff dinners in the 1890s and even played his 'fiddle' to friends up to within a month of his death at the age of 90 in 1959. It was in the year 1900 that Powers was credited with the discovery that observers at certain seaside resorts were joining up intermittent burns on the sunshine cards by a hot wire in order to augment their daily totals.

Frank Snell was an expert telegraphist who had been transferred to the office from the General Post Office, but in common with other members of the staff in those days, was not averse to doing any other work required of him, and became the first person in the Meteorological Office to use a typewriter.

S. Call (known as 'Paddy'), who came from Armagh Observatory, was notable for his beautiful 'copper-plate' handwriting, a distinction which he retained up to his bed-ridden nineties.

Charles Heinemann was an unusual character with a reputation, which he retained to the end of his service, of never having made a mistake in his computing. He arrived at the office one morning with a very black eye, but all that he would disclose about its origin was that he had met a 'friend' at the Bull and Bush. Heinemann, who was a competent mechanic, also studied astronomy and was a very early rider of a motor cycle. At an advanced age—long after retirement from the Meteorological Office—he sailed model yachts of his own construction on the Round Pond in Kensington Gardens.

With the outbreak of the Boer War in 1899 the staff suffered the temporary loss of two of its lads who joined the City Imperial Volunteers.

The general messenger of the office was a uniformed member of the Corps of Commissionaires, whose main duty was to take the lithographic transfers of the *Daily Weather Report*, etc. to Messrs Weller and Graham in the City at 11 a.m. daily, and bring back the printed copies in the early afternoon. Reports posted by 5 p.m. were delivered in Liverpool, Manchester, etc. by the first delivery on the following morning.

As to sartorial matters, most of the seniors wore top hats and frock or tail coats. In those days a good silk hat could be bought for 12s. 6d. Almost everyone changed into an old 'office coat' on arrival, and some of these were very dilapidated. Behind a screen in his room Dr Scott always changed his suit for a shabby one. The consistently best dressed man of this period was Henry Harries, who changed his shoes also on arrival and stuffed them with paper to help in keeping their shape. By writing daily articles for the *Morning Post*, Harries augmented his income considerably and normally took his annual holiday on a voyage down the Mediterranean or to the Atlantic islands.

Sartorial comment would be incomplete without a reference to Mr Sargeant, a forecaster. He was completely uninhibited and dressed for comfort regardless of appearance. He wore very wide trousers to avoid bagging at the knees and in summer would come to the office wearing his black frock coat, a straw hat (known as a 'boater') with brown canvas shoes and carrying an umbrella in case the forecast 'went wrong'. He was a very likeable man, fond of chess, but had an annoying habit of whistling softly through his teeth—no tune but just audible.

Except for those of the forecasting shifts, time keeping and discipline were very strict. A red line was drawn in the Attendance Book at 9.15 a.m. and anyone who had to sign below this line twice in a week was literally had up on the carpet in the Secretary's room. Richard Curtis once reproved his brother-in-law, Charles Thompson, for exceeding the lunch period of three-quarters of an hour by a couple of minutes! Talking in the rooms except on official matters was not allowed and smoking, of course, was not even dreamt of.

Although official discipline in the office was so strict, it did not debar some of the senior clerks from sending boy clerks on personal errands almost daily; in particular to the Army and Navy Stores for such necessities as tobacco and whisky.

The situation of the office in Victoria Street was advantageous for viewing the processions of those days which passed on their way to Westminster Abbey, including those connected with the death of Queen Victoria and the Coronation of King Edward VII. For the latter occasion the office building was suitably decorated. There was also a time of great excitement when a scare caused a run on the London Penny Bank on the opposite corner of Strutton Ground. For a couple of days the Bank was besieged by hundreds of depositors making withdrawals, but the Bank of England stepped in with funds and the excitement abated.

Books and papers were circulated from floor to floor by means of a leather bag which hung on a long cord fastened to the top banister of the wide staircase by which it could be hauled up. Before the installa-

tion of house telephones communication between some of the rooms was by speaking tubes with a whistle at each end. When blown into at one end an ivory plug protruded at the other.

As there was no telephone in the office at this time, communication with the outside world was by letter, telegram or 'by hand' and boy clerks made fairly frequent trips to the Admiralty with matter for the Atlantic Charts for approval by the Hydrographer. In cases of urgency the use of a hansom cab was authorized. Some journeys could be made in part by horse-drawn buses which passed the office about three times an hour. The first telephone was not installed until after Dr Shaw had succeeded Dr Scott as Secretary. The installation of this telephone caused such excitement in the office that discipline was temporarily relaxed and a crowd of seniors and juniors stood around as the Post Office engineers fitted it to the wall in the office keeper's little room. When it was installed the Chief Clerk was called down to inspect it and with appropriate dignity he made the first call to the Royal Meteorological Society amid hushed silence, to proclaim the news that the Meteorological Office was now 'on the telephone' and would they please note that the number was 'Victoria 153'. Members of the staff rushed to use it as a novelty to ring up friends and a few expressed surprise and indignation when asked to pay for private calls.

A feature of office routine was the daily circulation of *The Times* to all the seniors; starting with the Secretary it eventually found its way to the top floor ending up in the Ladies' Room. A kitchen was situated on the top floor from which Mrs Drane supplied good satisfying dinners to the staff at the modest price of 8d. per head for the juniors and 1s. 2d. for seniors. Facilities for washing by some of the staff were met by the provision of a small cabinet in their room containing a basin, water jug, etc. There was, of course, no hot water circulation in the building.

For lighting purposes, tables in most rooms were supplied with Argand gas lamps which gave very good illumination, but oil lamps were used in the Forecast rooms until 1901. Mr Francis, who was rather bald, used to say that he lost his hair because for years he had to sit under a powerful hanging oil lamp when the Forecast Room was on the first floor. The rooms were warmed in cold weather by coal fires which were kept well stoked by the boy clerks.

For the reception and transmission of telegrams the office was connected by a direct telegraph line to the Central Telegraph Office and this could be switched to instruments (Siemens tape printers) in different rooms. When there was an occasional breakdown it must have been surprising to passers-by to see an almost continuous procession of telegraph messengers from the South-west District Office in Howick Place bringing telegrams addressed 'Weather London' to the building.

The Annual Leave of four weeks was generous compared with other offices. Salaries were paid by monthly cheque on the Western Branch of the Bank of England to those 'on the staff' and weekly in cash to boy clerks and temporary clerks. The wages of Boy Clerks were 12s. 6d. weekly at 15 years of age increasing by 1s. 6d. annually to a maximum of 20s. weekly. Junior clerks rose to a maximum of £150 per annum, Seniors to £275 and the Chief Clerk to £333. The senior clerk in the Forecast Division (F. Gaster) received £309 per annum for a nine-hour day. Other members of the Forecasting Branch received additions to their pay as compensation for time worked before 9 a.m. and after 5 p.m. and Sunday duty. The salary of the Marine Superintendent was £350 per annum and that of the Secretary £800.

The office hours were originally 10 a.m. to 4 p.m. but an agitation for some increase of the previous low salaries had been met by additions to the salary scales (as quoted above) and an addition of two hours to the working day, i.e. from 9 a.m. to 5 p.m. At one time alternate Saturdays were worked as full days, but in 1901 this was altered to a regular half-day every Saturday. On Sunday mornings the telegraph line to the Central Telegraph Office was closed and the staff on duty went there to work. The junior of the shift went from his home to take the morning observations at Westminster and then walked to

Charing Cross Post Office to send them by telegram to C.T.O. For this service he received the sum of 1s. 6d.

In the Forecast Branch the hours of duty were 8 a.m. to 4 p.m. or 1.30 p.m. to 8.30 p.m., 1 p.m. to 8.30 p.m. on Saturdays and on Sunday 8 a.m. to noon at the Central Telegraph Office and 6 p.m. to 8.30 p.m. at Victoria Street. Subsequently, with the change in time of the morning observations, the day duty was from 7 a.m. to 3 p.m. A day off in lieu of Sunday duty did not come into operation until during the 1914–18 war.

Although observations were made on the roof of the Office, the published records for London for many years were those taken by Mr Gaster at his house in Acre Lane, Brixton. A station was subsequently set up in the grounds of Christ Church, opposite the Office. (Christ Church was demolished by bombing in World War II.) At the beginning of the century no electric torches were available and when it was dark at the time of the 6 p.m. observations a colza oil lantern was used to read the instruments. When windy it was difficult to keep this alight and the observers hit on the idea of using a small mirror to reflect the light from a nearby street lamp on to the thermometers. Records from St James's Park commenced in November 1904, and a master key was provided by the Office of Works in order that entry to the park could be made at any time.

The Instruments Branch was housed on the first floor of the building in one room, divided by a partition to separate the stores from the office. Richard Strachan, a small wiry old man, almost entirely bald, with a very rasping voice, presided over this Branch until 1900, when he retired. He was assisted by J. Williams, a pleasant but diminutive hunchback. It was surprising to note the ease with which Williams dealt with large packing cases. Mr Strachan had transferred to the Meteorological Department under Admiral Fitzroy, and died at the age of 90 on Easter Day 1924. He was succeeded by R. F. Wallace, who had the assistance of one of the boy clerks on one day a week. A 'highlight' of this part-time service by the boy clerk was an occasional trip to the docks to deliver a barometer to a ship, the journey being made partly by Underground Railway. In those days the Underground was very dirty and smoky due to emissions from the funnels of the steam locomotives.

The safety bicycle with its inflatable tyres in place of the former solid tyres had become popular; many of the juniors used cycles for their journeys to and from the office and the basement resembled a cycle shop. Some of the cycles had also the new free-wheel hub!

Across the front of the office building was a narrow balcony on the second floor and on this balcony boards were displayed which gave weather information from Valentia, Stornoway, Holyhead, Yarmouth and Dungeness with the state of the sea at Dover. These boards were changed each morning and afternoon. A chart showing the distribution of pressure and station reports at 8 a.m. (later 7), 1 p.m. and 6 p.m. was displayed at the door, together with the latest district forecasts.

The forecasts and remarks thereon were written and duplicated by hectograph process (gelatine plate) every evening for distribution to the newspapers and Press agencies until September 1905 when a more modern method of typing them on stencil sheets for reproduction on a duplicator was introduced.

Throughout its existence the Meteorological Office has always been subject to the attention of cranks, and there was an occasion one evening when the forecast staff had a visit from a man who came from Plumstead and declared he was a 'weather chart'. Mr Brodie asked if he had come so that he could be filed away with the official charts. After some argument he was persuaded to go away and come another day. It was thought necessary to watch him off the premises.

At least two of the senior staff took a prominent part in local municipal affairs. Mr John A. Curtis, brother of Richard Curtis, was Mayor of Fulham for one year and Mr T. Duncan Bell, brother of Arthur Bell, was an Alderman of the Borough of Camberwell. Bell became an official of the London Congregational Union and was chairman for one year. He was also a popular elocutionist and lecturer

on a variety of subjects. John Curtis was also superintendent of a Sunday school in Fulham for many years.

Among notable visitors to the office was Dr Alexander Buchan (of Buchan periods fame), Secretary of the Scottish Meteorological Society. He was a tall, venerable figure, with a long patriarchal beard, and came from time to time, until his death in 1907, in connection with the Scottish stations. The staff were delighted if they could bring to his notice any entry on returns where the wet-bulb temperature value was higher than the dry. He always insisted that the figures were correct.

Correspondence

Comments on 'The problems of anemometer exposure in urban areas—a wind tunnel study' (by R. A. Evans and B. E. Lee, *Meteorol Mag*, 110, 1981, 188–199).

As the recently appointed Head of the Climatological Services Branch of the Meteorological Office I am writing to express my concern at some of the implications in the paper entitled 'The problems of anemometer exposure in urban areas—a wind tunnel study' by R. A. Evans and B. E. Lee. My strong impression upon reading this paper is that some good experimental work is spoilt by ill-informed criticism backed up by that favourite tool of the journalist, the selective quotation.

For the benefit of your readers, and for the sake of accuracy, I feel that the following points should be made:

(a) The Meteorological Office does not have a free hand in the selection of sites for climatological purposes. We are presented with offers from authorities or individuals who have a particular interest in the data but whose sites may be far from perfect.

(b) The choice between which data to publish of two or more stations in a particular area will depend partly on sites and partly upon a number of other factors. The latter may include factors such as the type of instrument being used, the standard of maintenance, the willingness of the co-operating observer to maintain the site to our standards, the interest of the observer in the data, the likelihood of the station itself being of value as a long-term climatological record, etc. These judgements are necessarily subjective.

(c) The decision to cease the publication of wind data from Weston Park Museum and to replace them with readings from the anemometer on the top of the Geography building at Sheffield University was taken, as Mr Hopkins said in his letter to *Weather*, for several reasons of which the siting was but one.

(d) Paragraph 4(d) of the paper by Evans and Lee, in quoting from the letter by Mr Hopkins to *Weather*, stops short of his critical sentence. This reads: 'The disparity between winds measured at the two sites emphasises that, until confirmatory records from a third site in the city become available, both sets of data should be used with the utmost caution'. It is quite clear from this sentence that the Meteorological Office regarded neither site as particularly ideal.

(e) The implication by the authors that the Meteorological Office was wrong to transfer its data source to the Geography building is not borne out by Fig. 7 in their paper. This figure shows, as Mr Hopkins predicted, that both sites leave much to be desired. It is by no means clear that one is better than the other. The authors do not quote the variances from the two curves in Fig. 7; my estimate is that the difference between the two variances is well within the experimental error for the wind tunnel measurements. Furthermore, the building of the Royal Hallamshire Hospital to the south of Weston Park and

within the 550 metre radius from the Museum has created a discontinuity in the record for the Weston Park anemometer. There was thus no long-term climatological reason for wishing to retain Weston Park had all other factors been equal.

(f) The discounting by the authors of the effects of the 'zig-zag' profile of the Weston Park roof on the winds at anemometer height would have carried more weight had they, in fact, modelled that building on the 1:350 scale as they did the others. They may well be right in their assertions that the turbulence created by this roof profile would be minimal but surely they should have proved the point.

(g) The ill-informed criticism and selective quotation in this paper detracts from the interesting and valuable work undertaken in the wind tunnel. Would that this exercise could be repeated for all sites from which we obtain anemometer readings—including our official sites. One cannot help wishing that the Meteorological Office could choose sites for anemometers on the basis of such testing. The experimental work described in the paper does indicate the care needed when using any climatological data and wind data in particular. If any serious user of data considers that detailed knowledge of the characteristics of individual sites would be of value, then the Climatological Services Branch can supply the relevant information. The complete quotation from Mr Hopkins's letter shows the considerable care exercised by Meteorological Office staff when making decisions regarding the acceptance of sites for climatological purposes.

F. Singleton

*Meteorological Office,
Bracknell*

The authors reply:

In reply to the remarks made by the Head of the Climatological Services Branch of the Meteorological Office to our recent paper we would like to respond by thanking him.

R. A. Evans
B. E. Lee

*Department of Building Science,
University of Sheffield*

Comments on 'Rain-gauge network rationalization and its advantages' (by C. A. Nicholass, P. E. O'Connell and M. R. Senior, *Meteorol Mag*, 110, 1981, 92–102).

I should like to comment on the article 'Rain-gauge network rationalization and its advantages'.

The article makes no reference to the 'Report of the Joint Committee appointed to consider methods of determining the general rainfall over any areas', published by the Institution of Water Engineers, 1937 Trans, Vol. 42, pp. 231–276. This report was prepared by representatives of the Meteorological Office, the British Rainfall Organization and the Institution of Water Engineers. This 1937 report covers most of the main points of the article in a much more objective and realistic manner. The present article could have been much more useful if the earlier report had been studied.

The article does mention the importance of securing a suitable site for the rain-gauge, but seems to accept the position in which some sites are used which are not as good as others. By the time I retired in 1957 we were in a position to define the extent of the exposure error, either by inspection or by examining the fit of the average on the map of average annual rainfall. The authors do not seem to have developed these examinations from the two quite separate aspects to eliminate the doubtful exposures.

The article considers the network of stations required from the user's aspect. We looked at the problem from the different types of rainfall involved. With the orographical and cyclonic types of distribution, as we studied the distributions for a number of wet days each year we felt we could manage

with fewer records to define the distribution adequately. The thunderstorm rains were, however, local and infrequent and usually had little effect on the distribution on the annual, and still less on the average, maps. We thought in terms of a network of reliable records, plus a reserve which could be called upon in the case of instability rains. Indeed it seemed unlikely that we could secure enough records to define the distribution during all these local intense rains. We hoped, however, to be able to use run-off records or the maximum height of streams to add to our knowledge of the rainfall distribution.

On page 95 the article suggests the use of correlation and variances of pairs of rainfall data, without apparently realizing that changes arise from time to time in the accuracy of rainfall records, owing to leaks in the gauge, changes in the sites, etc. An example of the change in the reliability of a record is given in *British rainfall 1923*, page 243. We used the calculation of the mean deviations or correlation coefficients to test the homogeneity of records. The decrease in the correlation with distance over the British Isles was also defined in *British rainfall 1925*, pages 258–259.

The proposals in the article for redesigning rain-gauge networks seem unrealistic. Our emphasis was on using keen observers and suitable sites. Where this gave a close network we examined the relation of rainfall to the configuration so that we could apply the knowledge gained to areas of less information. We gradually increased the distribution as observers and sites became available. We found it a waste of time to use poor observers or unsuitable sites.

We also developed a scheme for examining the station values on the annual percentage maps. As explained in *Weather*, 34, pages 441–442, ‘If a station gave a value differing by 2 per cent or more from that expected from the values at surrounding stations then the record came under suspicion. If the map for the previous year gave a similar difference then some error was likely, and if this difference had persisted for three years then clearly some change had occurred’. This examination brought to light some errors which could be eliminated. It appears that this scheme has been stopped so that the records now being accumulated may have become more uncertain.

John Glasspoole

87 Mostyn Road
Merton Park
London SW19 3LW

The authors reply:

We are grateful to Dr Glasspoole for reminding us of the Report of the Joint Committee (of which he was a member) on ‘The determination of the general rainfall over any area’ (1937). He will recall that in the discussion which followed its presentation there was agreement that the Report would be a useful reference work. However, the discussion also revealed a number of doubts (including some expressed by the then President of the Royal Meteorological Society) about the subjective nature of the methods used.

Our recent study attempted to apply modern statistical techniques using available computer resources to the same problems that confronted the Joint Committee, and to quantify certain aspects which were only qualitatively defined in the 1937 Report.

The conclusions of the Joint Committee were that a precise determination of the general rainfall over any area requires:

- (a) an adequate distribution of suitably exposed rain-gauges,
- (b) a periodic critical examination of records, and
- (c) a regular preparation of isohyetal maps from which the general rainfall may be determined.

Our recent study took into account similar requirements with the following sequence of actions:

- (1) All rain-gauge sites were inspected and classified.

(2) A statistical method was developed for evaluating records and interpolating rainfall values in ungauged areas.

(3) A network was designed to meet users' requirements.

(4) All sites in the design network were to be of a standard approved by the Meteorological Office and the records regularly monitored using the computer-assisted quality control procedures.

Whilst the article did not detail every stage of the project, it is inherent in (4) above that poor sites would either have to be improved or abandoned, with only approved sites being adopted in the new network. Although users' requirements form the basis upon which the network was designed, the effects of topography and variability of rainfall are taken into account in the statistical methods. On a practical level, wherever possible keen observers and suitable sites were included in preference to poor sites and/or observers. Additionally, an element of redundancy was built into the network by retaining all the good sites, even though some of them were not needed to satisfy the users' requirements.

Dr Glasspoole refers (in his fifth paragraph) to the possibility that inhomogeneities in the rainfall records could affect the calculation of correlations and variances of pairs of rainfall data. Assuming that such inhomogeneities had not been detected during the normal data checking and archiving process, the problems resulting would be most noticeable when correlating long series of data, such as for annual totals. In our study the correlations were for monthly and daily data and the periods required to give a reasonable sample size were not too long, 15 years for monthly and 6 years for daily data. This it would be hoped that the problem of data inconsistencies would not be serious.

During this period of reducing resources it is vital that users' requirements are reviewed and that, where justified, cost-effective methods of acquiring and processing rainfall data are employed. The rationalization method described in the paper represents one approach to the problem of designing rain-gauge networks so that they may provide the quality of data which is required by the users in a more cost-effective way compared with the former subjective and often wasteful methods.

C. A. Nicholass

Meteorological Office

P. E. O'Connell

Institute of Hydrology

M. R. Senior

Wessex Water Authority

Reviews

Air in danger, by G. Breuer. 225 mm × 140 mm, pp. xii + 189, *illus.* Cambridge University Press, 1980. Price £10 (hard cover), £3.50 (paperback).

The book sets out to provide the interested non-specialist with an account of man's technological activities on the earth's atmosphere. The account is set in the context of the development of the atmosphere on the geological time-scale, compared with which any man-made changes are both small in extent and extremely recent. The greater part of the book is devoted to the increase in carbon dioxide resulting from the burning of fossil fuels and the reduction in the global biomass. The other topics considered are the effects of oxides of nitrogen and stable chlorine compounds on the ozone layer. This balance can be justified on the grounds both of the magnitude of the effects which might be produced and the extent of the changes in man's economic activities which might have to be adopted to reverse them. The author makes it clear that there is a divergence of opinion as to the consequences of a

continued growth in atmospheric carbon dioxide. There are also difficulties in estimating the global sources and sinks, particularly the source afforded by the reduction in the global biomass and the sink afforded by the transfer of carbonates to deep ocean waters.

The presentation is partly in the form of direct exposition and partly in the form of interviews with workers in the field. At least in translation, these give the impression of being very contrived. The German original was published in 1978 and this translation by Peter Fabien and W. A. Matthews, both of the Max Planck Institute, Lindau, contains references up to 1978. It is unfortunate that the layout of the combined author's notes and bibliographical references makes it very difficult to trace a publication except on the first occasion when it is cited.

The final chapter attempts to make recommendations for future policy. The only point which comes over clearly is the author's advocacy of large-scale reafforestation, particularly in the Third World, with financial aid from the developed countries. The reviewer was left wondering if such large-scale planting of trees could ever be accomplished, bearing in mind that it is only marginal land and land reclaimed from being denuded by erosion and from desertification which could conceivably be used for this purpose.

E. L. Simmons

Klimaschwankungen (Verständliche Wissenschaft Band 115), by C. D. Schönwiese. 185 mm × 115 mm, pp. xii + 181, illus. Springer-Verlag, Berlin, Heidelberg, New York, 1979. Price DM 12.

It is a formidable undertaking to write a book on climatic variations for the layman, which I think is what this is. There is, to judge from some earlier efforts which have been marketed, a temptation to dramatize the subject; this tends to result in false ideas and conclusions. Schönwiese has sternly resisted this temptation but the price is a rather pedestrian book which will, I am afraid, test the endurance of all but the most determined seekers after knowledge. Those who complete the course will be rewarded by a systematic and accurate survey of this difficult and controversial subject.

In the first two chapters he tries to say what climatic variations are—certainly not one hard winter or a hot droughty summer—and surveys the historical data which tell of variations in climate.

Then there is a chapter on the statistical treatment of climatological data, which he advises his non-mathematical readers to skip and perhaps come back to later if they feel the need.

After some more discussion of variations during the last century and the last thousand milleniums he comes to the crucial question of the causes of these variations. He stresses that cause and effect are closely interwoven in the climatic system and discusses the variety of response times, feedback effects and the autovariation of the system. He gives it as his opinion that, even with the most powerful computers, model simulation of past climatic variations is unlikely for several decades to come.

There is a thorough chapter on likely man-made effects on climate, where he makes the strange statement that the cooling in the last three decades has robbed the CO₂ thesis of its importance. He soon regains his customary balance in pointing out that changes of culture are as much if not more responsible than climatic variations for the desertification in the Sahel region of Africa.

He ends with a reminder that increased world population has increased the vulnerability of man to climatic variations which he would have readily adapted to in earlier times.

M. K. Miles

Atmospheric phenomena, with introductions by David K. Lynch. 290 mm × 215 mm, pp. 175, illus. W. H. Freeman and Company, San Francisco and Oxford, 1980. Price £9.50 (board), £4.90 (paper).

This most attractive addition to the series of 'Readings from *Scientific American*' contains 18 articles from that admirable magazine. Six are on 'basic considerations'—water, ice, snow crystals, the growth

of snow crystals, hailstones, and fog—and twelve are on ‘atmospheric phenomena’ including the rainbow, glory, green flash, noctilucent clouds and the zodiacal light. Each is by an expert in his field and may be assumed to have been up to date at the time it was originally published. Publication dates vary in fact from February 1949 (‘The mechanism of lightning’ by Loeb) to April 1978 (‘Atmospheric haloes’ by Lynch); but these dates are clearly displayed and no one could be unwittingly misled. In fact, for the readership aimed at, viz. the scientifically informed general public or the scientist who is not a specialist in the topic discussed, there is little to complain of and much to admire. The whole collection has been put together by David K. Lynch who has supplied a preface and introductions to both sections. The general feeling conveyed is summed up in the closing words of his preface:

‘One might justify the study of atmospheric phenomena on the grounds that it is relevant to agriculture, communications or national defense, but I’ll use a simpler approach, one to which we can all respond and one which is self-justifying. The sky is absolutely fascinating, and a desire to experience its beauty fully is sufficient reason to explore it. This reader is for everyone who shares my love of the sky.’

Diagrams and photographs—many in colour—are of the high standard to be expected from *Scientific American*.

R. P. W. Lewis

The weather almanac (third edition), edited by James A. Ruffner and Frank E. Bair. 235 mm × 160 mm, pp. viii + 801, *illus.* Gale Research Company, Detroit, Michigan, 1981. Price US \$48.00.

The third edition received of this interesting and comprehensive reference guide to US weather and climate, which was first published in 1974, has even more pages, about half of them devoted to a narrative and statistical description of the local climates of over 100 US cities, each with the records of 40 recent years. Other information given includes climate maps with the normals for the United States as a whole, followed by sections on various severe weather phenomena such as hurricanes, tornadoes, thunderstorms, floods, heat waves, etc., each with handy safety rules listed. To the sections on other geophysical hazards such as earthquakes and tsunamis has been added one on volcanoes, based on the Mount St Helens eruption. Some topics of current interest have been added and reviewed, such as solar power, acid rain, the carbon dioxide cycle and climate change. Altogether a volume packed with information for the interested tourist, which even contains a world-wide climate survey with details on 550 cities throughout the world.

N. S. Harrison

Corrections

Meteorological Magazine, 110, 1981

In the article ‘A mesoscale forecast for 14 August 1975—the Hampstead storm’, insert ‘ π ’ in equations (2) and (3), page 150, thus:

$$S = 558 \cos(\pi t/12) + 72 \quad (\text{W m}^{-2}) \quad \dots \dots \dots (2)$$

$$S = 279 \cos(\pi t/12) + 36 \quad (\text{W m}^{-2}) \quad \dots \dots \dots (3)$$

In ‘Synoptic aspects relating to the development of widespread heavy rainfall over southern England on 30 May 1979’, the wet-bulb potential temperature at the bottom of Fig. 1, page 208, should be ‘19’, not ‘10’ as shown.

In ‘The founding of the Meteorological Office 1854–55’, page 223, fourth paragraph, second line should read ‘... voted, namely, 2000*l*, for the Mercantile Marine and 1000*l* for Her Majesty’s ships.’

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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'.

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