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THE MAGNITUDE OF THE HORIZONTAL DIVERGENCE AND THE VERTICAL COMPONENT OF VORTICITY IN THE SURFACE WIND FIELD OVER THE OCEAN

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SUMMARY

The magnitude of the horizontal divergence and the vertical component of the relative vorticity were computed from observations of the surface wind field over the North Atlantic during September 1972. The computations indicate that for the generally fair prevailing weather conditions, the magnitudes of the vorticity and divergence were approximately inversely proportional to the scale over which they were computed, with scales ranging from 4 to 1000 kilometres.

INTRODUCTION

It has been suggested by Haltiner and Martin (1957) and in the Experiment Design Proposal for the GARP Atlantic Tropical Experiment (World Meteorological Organization, 1972) that the magnitude of the horizontal divergence and vertical component of the relative vorticity (hereinafter referred to as divergence and vorticity) of the wind field varies as L^{-1}, where L is the length scale over which the computation is made. Verification of the L^{-1} relation, by computing vorticity and divergence from the plentiful wind data which are available from land stations, is complicated by terms that appear in the defining equations due to terrain effects. Schaefer (1973) has shown that maps of divergence derived from data over land appear quite different, depending upon the degree to which corrections are made for the differences of the altitude of the stations from which the data have been derived. One might also expect errors due to local terrain features near the measurement sites. These problems disappear over the ocean surface. However, no discussion has appeared from observations over the ocean because of the lack of surface wind measurements made simultaneously at different length scales. The authors were unable to locate in the literature any presentation of data, either over land or sea, illustrating the L^{-1} relationship.

Observations

The Joint Air–Sea Interaction Experiment, 1972 (JASIN 72), sponsored by the Royal Society of London, provided a unique opportunity to estimate, through surface wind velocity measurements, the magnitude of the divergence and vorticity of the surface wind field over the ocean as a function of horizontal scale. The measurements were made from 6 to 19 September in superimposed triangular areas located from 700 to 1200 km west of Ireland. Figure 1 shows the locations where the data were collected.

The measurements were made with cup anemometers and wind vanes mounted on ships and buoys. Table I describes the observational program and equipment used. The horizontal spacing of surface meteorological buoys and weather ships provided wind velocity data on four different size scales, encompassing almost four orders of magnitude from 4 km to approximately 1000 km.

The JASIN area was dominated by an intense high-pressure system during the observational period. However, several low-pressure systems passed close to the area, causing occasional showers. Cumulus clouds were usually present. Wind speeds ranged from 1 to 12 metres per second.

Analysis

The reduction of data was carried out on a digital computer. The divergence and vorticity were estimated without correction for convergence of meridians (Panofsky, 1946), a correction which was negligible for all cases. The equations used were

$$\Delta = \frac{1}{A} \oint \boldsymbol{u} \cdot \boldsymbol{n} \, \mathrm{d}l, \quad \ldots \quad (1)$$

$$\zeta = \frac{1}{A} \oint \boldsymbol{u} \cdot \mathrm{d}\boldsymbol{l}, \quad \ldots \quad (2)$$

where Δ is the horizontal divergence, A is the area of the triangle over which the estimate is made, $\boldsymbol{u}$ is the wind velocity vector, $\boldsymbol{n}$ is a unit vector normal to the perimeter of the triangle, $\mathrm{d}l$ is a differential increment of length along the perimeter, and ζ is the vertical component of the relative vorticity. The vector $\mathrm{d}\boldsymbol{l}$ is defined such that the integration is counter-clockwise around the perimeter when looking down on the triangle. The winds were assumed to vary linearly between observation sites. As a result the integrations in equations 1 and 2 each reduce to a sum of three terms. For the divergence, each term is the product of the normal velocity component at the centre of a particular side of the triangle and the length of the side divided by the area. Vorticities were computed similarly, by use of the mean velocity components tangent to the centre of each side, defined as positive if in the same direction as $\mathrm{d}\boldsymbol{l}$. Although the formalism is different, the procedure used for estimating vorticity and divergence is equivalent to that suggested by Bellamy (1949).

Individual values of vorticity and divergence were averaged over time periods equal to the average length of a side of the triangle divided by the mean wind speed. This procedure is equivalent to averaging the wind observations before computing divergence and vorticity. The averaging was done to reduce errors

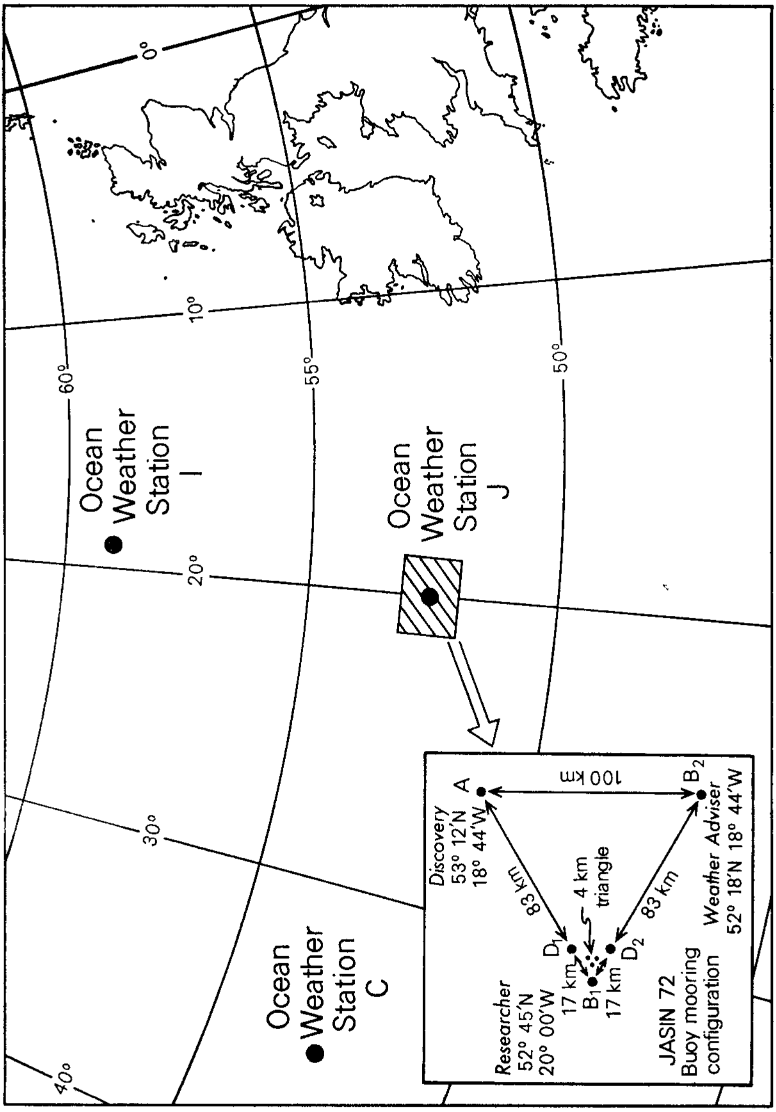

FIGURE 1—POSITIONS OF THE METEOROLOGICAL BUOYS AND PARTICIPATING SHIPS DURING JASIN 72

TABLE I—OBSERVATIONAL PROGRAM AND EQUIPMENT USED DURING JASIN 72

Spacing	Period of record (*inclusive*)	Type of data	Vehicle used
Equilateral triangle 4 km on a side	1635 GMT 6 Sept. to 0835 GMT 7 Sept.	Integrated wind speed and instantaneous wind direction each 6 seconds, geodyne sensors, 3·3 metres above mean sea level recording on magnetic tape.	Free floating 60 ft damped aluminium spar buoys.
Equilateral triangle 17 km on a side	0000 GMT 9 Sept. to 1100 GMT 10 Sept.	Integrated wind speed and instantaneous wind direction each 10 minutes. Aanderaa sensors 2·3 metres above mean sea level recording on magnetic tape.	Large anchored toroid buoys.
Equilateral triangle 100 km on a side	1900 GMT 6 Sept. to 0900 GMT 19 Sept.	Same as 17 km triangle.	Same as 17 km triangle.
Right-angled triangle 1245 × 711 × 1140 km	1800 GMT 6 Sept. to 0600 GMT 8 Sept. 1800 GMT 11 Sept. to 0000 GMT 15 Sept. 1200 GMT 15 Sept. to 1200 GMT 19 Sept.	Two-minute averages of wind speed and direction every 6 hours.	Weather ships on Stations 'C', 'I' and 'J'.

due to velocity fluctuations on scales smaller than the separation of measurement sites. The absolute value of each average was then taken, and the mean and standard deviation of the absolute values corresponding to each length scale was computed. The distributions of the absolute values of the means and the standard deviations were highly skewed towards smaller values.

The results of the computations are plotted in Figure 2. The length scale for each value of vorticity and divergence is taken to be the mean of the sides of the triangle formed by the observation sites and is identified as 'scale length' in Figure 2 and as 'L' below. The lines drawn have a slope of -1, suggesting that divergence and vorticity were approximately inversely proportional to the scale over which they were measured. The nearly linear relationship that is shown over such a large range of scales may be partly related to the fact that no strong weather disturbances passed through the area under study during the period of

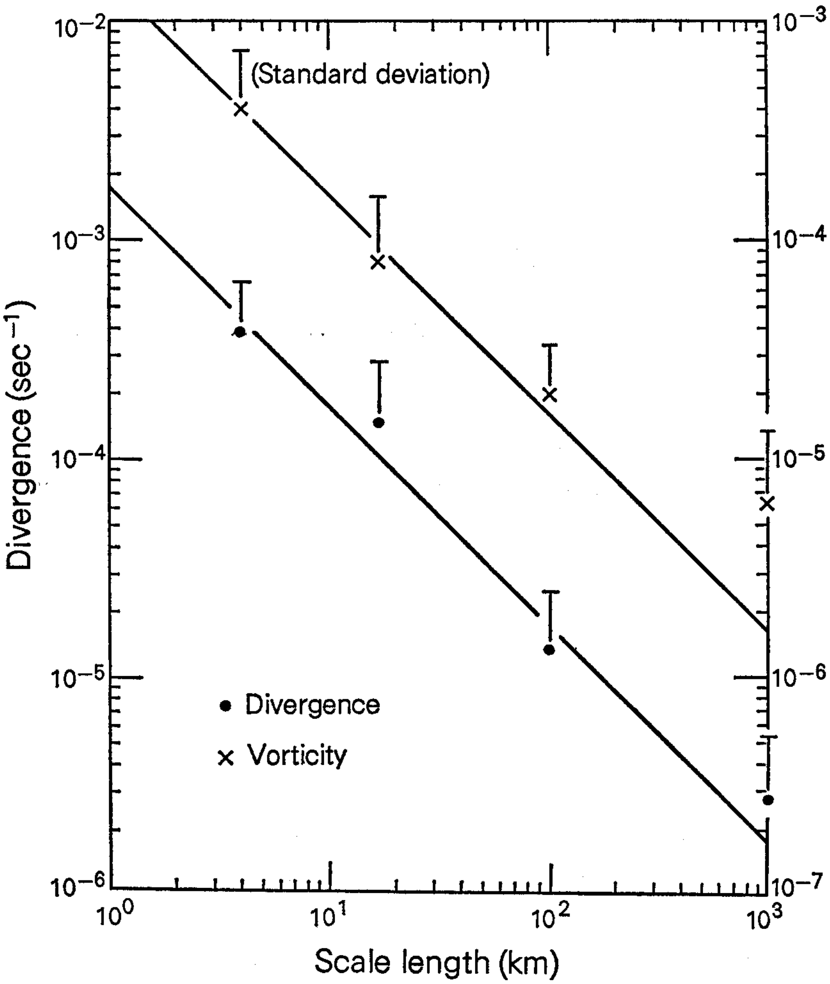

FIGURE 2—ABSOLUTE VALUES OF THE HORIZONTAL DIVERGENCE AND VERTICAL COMPONENT OF THE VORTICITY AS A FUNCTION OF HORIZONTAL SCALE

observations. The statistical significance of the 1000 km value is, of course, low because the plotted point is the average of only five individual estimates.

Uncertainties in the estimates of divergence and vorticity may be estimated from comparisons of long-term averages of wind speed and direction observed at buoys separated by 4 km. These comparisons show that the mean wind speeds agree within 0·05 m/s. The corresponding uncertainty in direction is 13°. An error equation for divergence or vorticity is

$$\text{ERROR} = \pm \frac{4\,\delta v}{L}, \qquad (3)$$

where L is the length scale in question and δv is the uncertainty in wind speed. Substituting 0·05 m/s and 4 km for δv and L respectively, gives an uncertainty of about $\pm$ 10 per cent of the divergence and vorticity estimates. The percentage error is independent of L since both divergence and vorticity vary approximately as L^{-1}. Uncertainties due to errors in direction were estimated by arbitrarily subtracting 13° from one set of observations in the 4 km array. This resulted in a change of 9 per cent in the vorticity and 18 per cent in the divergence computed as in equations 1 and 2. The uncertainty in the vorticity and divergence estimates from the ship observations is estimated to be about as large as the estimates themselves (see Figure 1) because of fewer samples and less accurate measurements.

One may define a characteristic velocity difference, δu, as follows:

$$\text{DIVERGENCE} = \frac{\delta u}{L}. \qquad (4)$$

A similar relation may be defined for vorticity. If divergence and vorticity vary as L^{-1}, then δu is independent of L. The average values of δu for the data in Figure 2 are 1·8 m/s (neglecting the 1000 km values) for divergence and 1·6 m/s for vorticity. The lines drawn in Figure 2 correspond to these values of δu.

Discussion

We have shown that the horizontal divergence and vertical component of the vorticity do indeed appear to vary approximately as L^{-1}, where L ranges from 4 to 1000 km. This result is important in the design of experiments over those parts of the ocean where it is intended to make measurements from which divergence, vorticity, and the curl of the wind stress can be estimated. The result may also be useful to modellers of the lower atmosphere for analysing the effect of sub-grid scale motions on the accuracy of simulations.

The result of our observation that the characteristic velocity difference δu is independent of scale may be crudely compared to power laws for the spectral density of horizontal velocity by assuming $L\delta u^2$ to be proportional to the spectral density. Such a comparison indicates that δu being equal to a constant corresponds to the spectrum density being proportional to κ^{-1}, where κ is wavenumber. For comparison, the $\kappa^{-5/3}$ law for an inertial or locally isotropic range corresponds to $\delta u \propto L^{1/3}$. The turbulence could not, of course, have been locally isotropic for the scales we considered because the scales are much greater than the height of the measurements above the surface.

Care should be taken not to generalize too extensively the results presented here. These results are based on observations which are limited to a particular area during anomalously fair weather conditions. In addition, uncertainties are introduced by approximations in the calculations and errors in the measurements. The significance of the computations for the 1000 km scale is particularly low.

An examination of northern hemisphere surface weather charts for the month of September for ten years indicated that frontal passages affected the JASIN 72 study area (the 100 km triangle shown in Figure 1) about a third of the time during September. During the JASIN 72 study period from 6 to 19 September 1972, only one very weak front with maximum wind speeds of only 6 or 7 m/s passed through the study area. One low passed to the south of the area, giving maximum wind speeds over the area of 9 to 10 m/s for a short period of time. During the remainder of the time, the area was covered by a stationary high-pressure area. Average wind speeds for the whole period were about 4 m/s. Thus one would intuitively expect that the values of divergence and vorticity would be below average for the time of year and latitude for the 4, 17 and 100 km triangles.

Figure 44 in WMO (1972) presents typical values of divergence and relative vorticity. The mean values shown are about two and a half times as great as those shown in Figure 2 of the present paper, for the three smaller triangles.

However, the results from the largest triangle made up of Ocean Weather Stations 'C', 'I' and 'J' are somewhat more in line with the results presented in WMO (1972). Wind speeds were consistently low at Station 'J'. Several weak fronts passed over Station 'I', accompanied by increased wind speeds and changes in wind direction. For most of the time, however, Station 'I' was situated between the high-pressure area over the JASIN 72 study area and low pressure areas to the north and north-east. Wind speeds at Station 'I' ranged up to 15 m/s (Force 7).

The winds at Station 'C' were influenced by several relatively deep low-pressure areas and the passage of several strong fronts. Several sharp changes in wind direction occurred and wind speeds were in the 12 to 15 m/s range (Force 6 and 7) approximately one-fourth of the time.

With each of the three weather ships on Stations 'C', 'I' and 'J' located in consistently different weather situations for most of the JASIN 72 experiment, one might expect higher than average values of divergence and vorticity to occur. This is borne out in Figure 2. The vorticity is approximately the same as that given in WMO (1972) for the same distance scale.

As stated above, care should be taken in generalizing from the results shown in Figure 2. The same is true of the material presented in WMO (1972) on the relationship between scale and magnitude of divergence and vorticity. The diagram in WMO (1972) is based on data from several different latitudes covering only one order of magnitude in length scales. The experimental data were then extrapolated over three more orders of magnitude. Further cause for uncertainty comes from comparing similar graphs in WMO (1972) and an earlier unpublished document on the same subject. The values for divergence and vorticity as a function of scale shown in Bellamy (1949) are only about one-third of those shown in WMO (1972). The mean values shown in Figure 2 of the present paper are almost identical to those shown in Bellamy (1949).

Despite the above qualifications, the results ought to be useful for practical calculations and ought to encourage further efforts to quantify the relationships between divergence and vorticity and the scale over which they are computed.

ACKNOWLEDGEMENTS

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THE METEOROLOGICAL OFFICE DIGITAL ANEMOGRAPH LOGGING EQUIPMENT (DALE)

By A. E. BURTONSHAW* and N. MUNRO

SUMMARY

The decreasing availability of manpower and the need for a computer-assimilable system have highlighted a growing requirement by the Meteorological Office for an automated system for recording surface wind information. The Operational Instrumentation Branch of the Meteorological Office has produced a Digital Anemograph Logging Equipment to meet this need. The operation of the system is described in this paper.

1. INTRODUCTION

The Meteorological Office Mk 4 wind system has been used operationally since 1954 and has been installed at most meteorological offices and at a large number of auxiliary observing stations. Other organizations also use this system and their records have helped to improve the national observational network. Wind information from the Mk 4 system is recorded on charts, and the data are subsequently extracted manually.

Recently the reduced availability of manpower has resulted in some auxiliary

* Deceased

and other stations restricting or stopping the analysis of Mk 4 wind charts, although they still keep the instruments and send the records to Bracknell for analysis, thereby increasing the burden on Meteorological Office resources. The closure of certain RAF stations and other observational organizations has increased the value of the remaining network, and consistent computer-compatible wind information, from an integrated system, is necessary to maintain the essential climatological records.

In order to meet this need the Operational Instrumentation Branch of the Meteorological Office has designed electronic equipment which logs on magnetic tape the data at present recorded on autographic instruments and analysed manually (see Plate I).

Three prototype systems have been built. These were installed at Valley (June 1974), Boscombe Down (February 1975), and Stornoway (March 1975). The data tapes were processed at Bracknell and the recorded hourly mean wind speed and direction, and the highest gust, were compared with data derived manually from chart recorders. This analysis showed that the differences between the two sets of data were no greater than would be expected from the specifications of the two systems, and that the data from the digital anemograph logging equipment (DALE) are acceptable for climatological purposes.

2. Requirement

The following features were considered in designing the system:

(a) The system technology should have exceptional reliability and very good long-term stability so that the system may operate unattended for long periods.

(b) The sensors should ensure homogeneity with earlier data.

(c) The system should have an accuracy commensurate with past data records.

(d) The system should operate from the normal mains supply, but continue to operate over breaks in that supply for a reasonable period.

(e) The data should be logged on tape in a computer-compatible format.

The data required are: (i) running mean* of wind speed; (ii) running mean* of wind direction; (iii) maximum gust over a specified period; (iv) direction of maximum gust; (v) time of maximum gust; (vi) the day; (vii) the hour; (viii) the minute; and (ix) station number of the system.

To give flexibility to the system, the period of the running means for speed and direction, the 'maximum-gust sensing period', and output scan intervals were designed to be selectable.

Initially DALE was designed to be compatible with the Meteorological Office Mk 5 wind system at Heathrow (Else, 1974). This system differs from the Mk 4 in that the outputs are in the form of d.c. voltages, whereas the Mk 4 outputs are for wind speed—an alternating voltage increasing in amplitude with increasing wind speed, and for wind direction—50 Hz, single-phase, amplitude-dependent 'synchro' information on three inputs from a transmitter 'magslip'.†

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* The term 'running mean' is here applied to a moving time-average, produced electronically, in which the relative weighting of instantaneous values decreases exponentially with lag before the current time.

† 'Synchros' and 'magslips' are commercially produced devices for electrically relaying angular motions in a precise way.

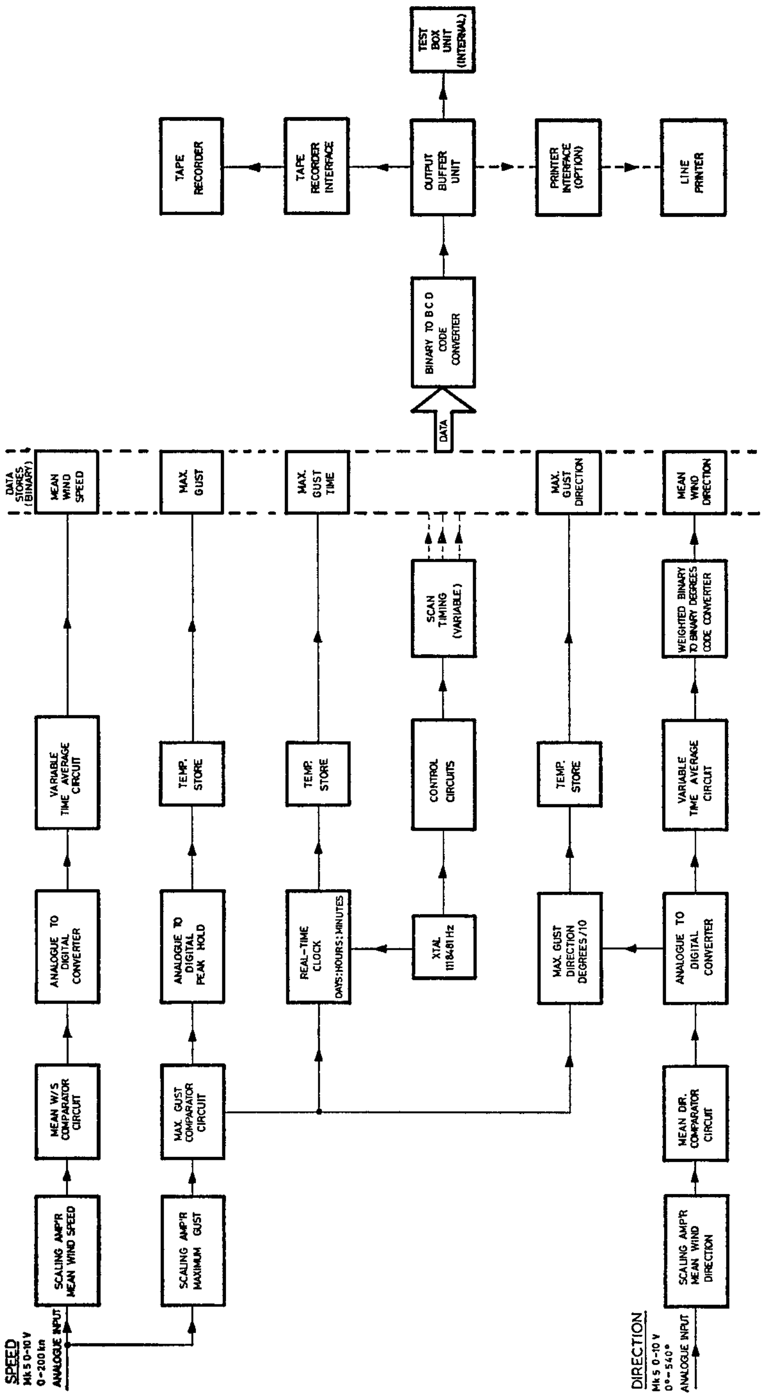

FIGURE 1—DIGITAL ANEMOGRAPH LOGGING EQUIPMENT BLOCK DIAGRAM

BCD denotes binary coded decimal.

The following description of DALE refers to the Mk 5 system outputs, but a suitable interface has been developed which also enables DALE to be used with the more common Mk 4.

3. General description

DALE (see Figure 1) is a five-channel data-logging system, two channels of which (the mean wind speed and direction) are sampled more frequently than the other three channels which relate to the maximum-gust information.

(a) *Mean values of wind speed and direction*

The analogue inputs to DALE are first scaled and then processed by 'analogue-to-digital converters' into binary numbers. Time-averaging of the binary numbers is accomplished by a digital filter circuit whose time-constant can be selected by the user for his individual requirements.

The time-averaged outputs of mean wind speed and direction are fed into individual data stores to await sequential scanning to the output at an interval selected by the user, normally each minute.

(b) *Maximum value of wind speed*

The Mk 5 wind-speed voltage is also fed to a 'maximum gust' circuit where scaling followed by binary conversion takes place, similar to the mean-speed circuitry. The maximum binary value of wind speed is held within the digital conversion circuitry and updated with a new value each time the preceding peak value has been exceeded. When this occurs, the maximum-gust comparator circuit senses and 'holds' the new maximum value, simultaneously transferring 'direction' and 'time' data into their individual stores to await the output scanning sequence, normally every hour, which feeds all the binary data (via a code converter) to the magnetic recorder, and to other output devices if required. The scan sequence for 'maximum-gust information', at the same time, resets the peak-hold circuit to zero, thus allowing successively higher values to be sensed throughout the next period.

(c) *Time*

An internal crystal-controlled oscillator is counted down and used as a 'real-time' clock for display and recording purposes; several subdivisions of the fundamental frequency are used for synchronization, clock and timing pulses for the control and scan sequences within the system. Time is displayed at an internal 'test box' facility, and can be updated manually as required. Day-number throughout the year, hours and minutes are shown and the extra day in leap years is taken into account for reset purposes at the New Year.

(d) *Test box*

Data can be examined 'on demand' from the 'non-volatile' data stores associated with the display, which are cleared only every hour, allowing calibration and testing of the system in the field without translation from the tape being required.

(e) *Printer*

A printer interface can be included for special-purpose applications.

4. Wind speed

(a) *Mk 5 input to DALE*

The Mk 5 wind system converts the frequency from the wind-speed sensor into a 0–10 volt scale, representing 0–200 knots, which is continuously supplied to the averaging and maximum gust circuits.

(b) *Analogue-to-digital scaling*

The d.c. voltage range from the Mk 5 system is too restricted to enable adequate resolution to be obtained from direct conversion of analogue to binary form, so it is necessary for scaling to take place before conversion. The conversion is carried out by an integrated circuit in which 10 V is represented by a 10-bit integer input of 1023, so that, since a count of 1000 is required to provide a decimal representation of the maximum design mean speed of 100 knots with a resolution of 0·1 per cent, it is necessary to amplify the input voltage by a factor of 1·955.

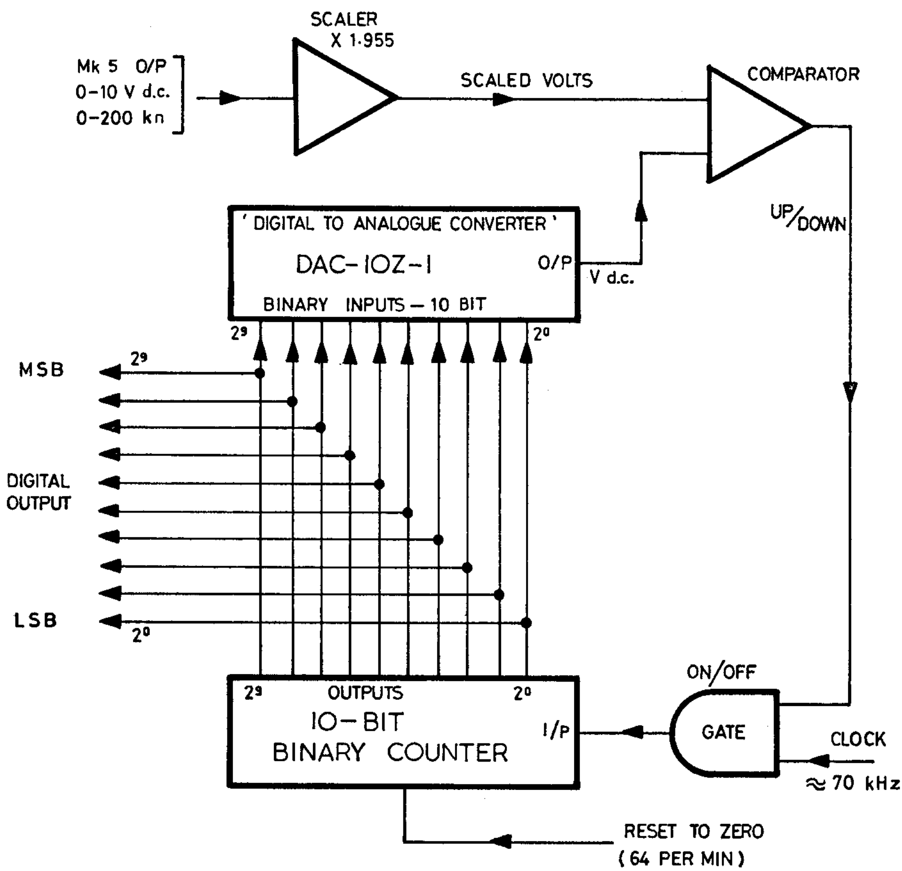

FIGURE 2—DALE ANALOGUE-TO-DIGITAL CONVERSION (MEAN WIND SPEED 0–100 KNOTS)

MSB denotes 'most significant bit' and LSB 'least significant bit'.

(c) *Analogue-to-digital conversion*

The two main components in the 'Analogue-to-Digital' (A-to-D) conversion circuitry (see Figure 2) are:

(1) A 'Digital-to-Analogue Converter' integrated circuit (DAC-10Z-1), whose d.c. voltage output is directly dependent upon the binary count at its input (i.e. a maximum 10-bit binary count of 1023 = 10 V).

(2) A 'comparator', which is a two-state switch, either up or down depending upon the differential voltage at the two inputs; the output controls the clock gate, either letting through pulses or inhibiting them.

The action of the circuit is as follows: if the d.c. voltage from the DAC-10Z-1 is lower than the scaled wind-speed voltage, the comparator is forced up, opening the clock gate and allowing pulses into the binary counter, raising the count, and similarly the DAC-10Z-1 output voltage, until such time as the converter and the scaled wind-speed volts are equal, when the comparator is forced down, closing the gate, inhibiting the pulses, and holding the binary count which digitally represents the analogue input parameter. This count is presented as the binary input to the averaging circuit. A continuous clock frequency of approximately 70 kHz ensures that the digital representation of the wind speed is obtained in less than 1/70 second after initiation. It is updated at a rate of 64 times per minute.

(d) *Time-averaging circuit (digital filter)*

The logarithmic time-averaging circuit (Painting, 1974) is essentially a feedback digital filter whose time-constant is determined by its associated output store length and individual clock frequency. Selectable clock frequencies (subdivisions of the internal clock) enable the period of averaging, in the range 7·5 seconds to 1 hour, to be chosen by the user. The chosen averaging time is common to both the wind speed and direction and is independent of the period of output scan selected. The output will reach 95 per cent of any step-function input within the selected averaging period.

(e) *Data store and output scan*

The time-averaged output is transferred into the mean-speed data stores and thence to the output buffer unit via a 'Binary Coded Decimal' (BCD) code-converter circuit. The output scan rate can be selected by the user within the range 7·5 seconds to 1 hour, and internal control of the real-time clock ensures transfer of the wind-speed data from the data store to the output devices synchronously at 64 Hz. The data characters are written into the tape circuitry with a data strobe pulse.

Before receiving the data stream, the system electronics automatically scan a fixed BCD 'line-synch' character to aid in the translation and formatting of the recorded data.

(f) *Maximum-gust circuit*

The maximum-gust circuitry is similar to that used for the mean speed. Scaling of the analogue input takes place before digital conversion, the 0–10 volt d.c. scale, representing 0–200 knots, being resolved to one-quarter of a knot.

The scaled wind-speed voltage is fed to one input of the maximum-gust comparator, the other input being connected to the output from the converter circuitry. The effect is similar to that described for the A-to-D converter shown in Figure 2. The counter associated with the converter is only reset at the end of the sampling period, normally one hour, ensuring that the peak value of the analogue input has been selected.

When the scaled wind-speed voltage rises above the previously sensed value, the comparator circuit is forced to open the clock gate, allowing pulses to be fed to the binary counter, raising the digital input to the DAC-10Z-1 and the output voltage until such time as the comparator inputs are the same, when the clock gate is forced to close. When the comparator is switched to the 'count' condition, the time circuit is sampled and the 'minutes count' held within a separate store. Simultaneously the 'direction' is also sensed and latched into its appropriate store to await output scanning.

At the end of the selected period the maximum-gust data are transferred into the data stores and scanned to the output devices at 64 Hz.

Although the comparator circuit has a resolution of a quarter of a knot, the output maximum wind speed is given in whole knots.

(g) *Maximum-gust delay*

To ensure that spurious noise pulses do not trigger the maximum-gust comparator, a delay of 150 milliseconds is incorporated in the circuitry. The circuit may be initiated by any analogue voltage which is higher than the previously stored value, but the circuit will take action to transfer the new value into store only if the new value is still higher than the previous one at the end of the delay period.

5. Direction

(a) *Analogue-to-digital direction scaling*

A 10-bit counter is used with the directional A-to-D circuit, giving a weighted binary output; the 2^9 MSB (Most Significant Bit) is given the value 360, the 2^8 bit 180, the 2^7 bit 90, and so on; the LSB (Least Significant Bit) is valued at 0·7 degree. The value of this system is utilized in changing the 540 degree input scale from the Mk 5 into one of only 360 degrees.

(b) *Analogue-to-digital conversion*

The counter for the direction A-to-D conversion circuit is reset at the same rate as the wind-speed circuit, i.e. 64 times per minute. The digital number is presented to the direction-averaging circuit (similar to the speed averager) which time-averages at the same rate as the speed circuit. The output from the filter is fed into a 'weighted binary to binary degrees' static code-converter circuit, to translate the 'weighted number' to 'binary degrees'. The output from the code converter is fed into the data store to await sequential scanning to the output via the common BCD encoder as described previously.

(c) *Direction of maximum gust*

When the maximum-gust comparator circuit functions, the direction binary count is latched into a separate code-converter circuit which outputs a 6-bit code value into a temporary store. A separate code converter permits asynchronous operation of maximum-gust data at all times. If no further values are received within the hour, this value is decoded and presented as maximum-gust 'direction' to the appropriate data store.

6. MK 4 WIND SYSTEM DIRECTION INTERFACE

The preceding discussion has assumed that a Mk 5 wind system provided DALE with the necessary d.c. input voltages for processing. An interface to the existing Mk 4 magslip direction system has also been developed. This circuit (Painting, 1975) converts the single-phase 'synchro' information, received from the Mk 4 direction system, into a d.c. voltage, making DALE compatible with the large number of existing wind systems in general use in the United Kingdom, and thereby making the system available as an 'add-on' unit.

Since DALE can accept up to 10 bits of digital information to the averaging circuits, any binary system for mean speed and direction could be accepted if scaled correctly.

7. 3M CARTRIDGE LOGGING SYSTEM

At a late stage in the development period, the supplies of the tape-recorder unit originally used became unobtainable and a new logging system had to be devised. The 3M cartridge system was chosen as the most suitable recording medium, and interfacing of a prototype new system is completed. The recording specification is of an international standard and format. Data are recorded in ASCII characters (American Standard Code for Information Interchange) in the ANSI format (American National Standards Institute—X3 BI/626) compatible with translation equipment already used within the Meterological Office.

8. CONCLUSION

A digital anemograph logging equipment (DALE) has been described. This equipment is capable of providing mean wind speed, direction, and gust data of sufficient accuracy to be of use in climatology, and will therefore be an aid in maintaining records where it is becoming increasingly difficult or impossible to do so using existing manpower. The Meteorological Office intends shortly to ask for tenders for a further 20 systems to be manufactured to this design. Within ten years there may be many such systems in use in the United Kingdom.

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The authors wish to express their gratitude to Mr D. J. Painting who initiated much of the original work in this system.

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THE RELATIONSHIP BETWEEN THE STRENGTH OF THE QUASI-BIENNIAL OSCILLATION IN THE EQUATORIAL STRATOSPHERE AND THE MEAN ANOMALY OF THE MONTHLY MEAN MAXIMUM SCREEN TEMPERATURE AT OXFORD

By J. D. PERRY

SUMMARY

The regression of the mean anomaly of monthly mean maximum temperature at Oxford is calculated for a particular phase of the quasi-biennial oscillation (QBO) on the mean strength of the phase of the QBO in which the anomaly occurred. The calculation was repeated with displacements from minus six months to plus fifteen months and the regression was found to be significant at better than the 5 per cent level between M—4 and M, and between $M + 11$ and $M + 13$ months, where M is the month in which a particular phase of the QBO starts.

Significant correlations at the 2 per cent and 1 per cent levels are found for the regression of the mean anomaly of the monthly mean maximum temperature for the summer months and at the 5 per cent level for the autumn months, on the strength of the prevailing QBO and on the strength of the previous phase of the QBO respectively. The regressions for spring and winter were not significant.

1. INTRODUCTION

The cycle approximating to 2 years in various meteorological quantities, including temperature, rainfall, pressure and stratospheric winds, has been well documented and the reader is referred to an appraisal of the most important papers by Craddock (1968).

The association between the quasi-biennial oscillation (QBO) in the equatorial stratosphere and the surface pressure distribution for the northern hemisphere for the mid-season months, January, April, July and October, was studied by Ebdon (1975) who found significant differences in the pressure distribution during easterly and westerly phases of the QBO in January and July. Further work by Ebdon (personal communication) on the monthly mean temperature for central England during opposite phases of the QBO showed significant differences in July, August and September but not in the other 9 months of the year.

Folland (personal communication), on the other hand, performed a power spectrum analysis on the annual mean temperature for central England for the period 1659 to 1974, and found a peak, among others, at about 26 months which is significant at the 5 per cent level, and this suggests that further examination of the temperature may be profitable.

The comparison of the variation of temperature over the British Isles and the equatorial QBO is made easier if, in the first instance, normal annual variations of temperature are eliminated and the strength of the QBO is compared with the anomalies of maximum surface temperature.

2. DATA

The monthly mean zonal wind components at 30 mb for Canton Island and Gan, as shown in Figure 1 (from Ebdon, 1975), were used as representative of the equatorial stratosphere and were meaned for individual phases of the QBO, that is to say the mean of the monthly mean zonal wind for consecutive months with westerly or easterly components were evaluated irrespective of the length of the particular phase of the QBO. Nine complete cycles of the QBO were available

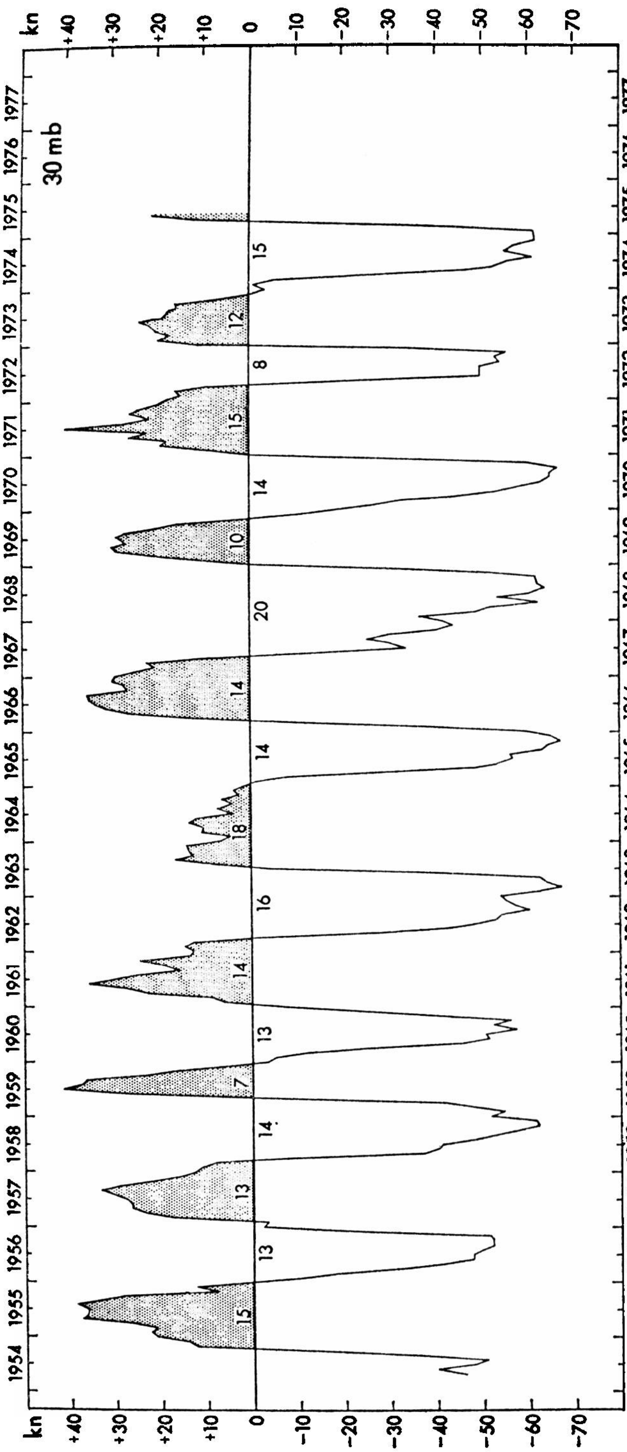


FIGURE 1—30 mb MONTHLY MEAN ZONAL WIND COMPONENTS AT CANTON ISLAND/GAN

Components towards the east are positive and stippled. Figures along the zero line indicate the duration, in months, of westerlies or of easterlies.

from November 1954 to March 1975 inclusive and are shown in Table I with appropriate 'meaned zonal wind'. It was found convenient to use screen maximum air temperatures for Oxford, and averages were calculated for the period in question from which monthly anomalies of maximum temperature were evaluated.

3. Results

The mean anomalies of the monthly mean maximum screen temperature at Oxford for each phase of the QBO, there being nine westerly and nine easterly phases in all, were calculated and are also shown in Table I against the appropriate phase of the QBO, i.e. the anomalies were meaned for the period of each phase irrespective of its length.

TABLE I—THE MEAN ANOMALY OF MAXIMUM TEMPERATURE IN EACH PHASE OF THE QBO

Phase of QBO	Mean zonal wind in knots	Mean anomaly of maximum temperature in degrees Celsius
Westerly		
Nov. 1954–Jan. 1956	+23·2	0·39
Mar. 1957–Mar. 1958	+21·7	0·35
Jun. 1959–Dec. 1959	+26·8	2·17
Feb. 1961–Mar. 1962	+19·1	0·64
Aug. 1963–Jan. 1965	+8·3	—0·18
Apr. 1966–May 1967	+26·2	—0·05
Feb. 1969–Nov. 1969	+20·9	—0·14
Feb. 1971–Apr. 1972	+20·5	0·24
Jan. 1973–Dec. 1973	+15·9	0·35
Mean	+20·3	+0·42
Easterly		
Feb. 1956–Feb. 1957	—33·4	—0·26
Apr. 1958–May 1959	—43·7	0·11
Jan. 1960–Jan. 1961	—33·1	0·14
Apr. 1962–July 1963	—47·3	—1·46
Feb. 1965–Mar. 1966	—45·2	—0·38
June 1967–Jan. 1969	—41·8	—0·34
Dec. 1969–Jan. 1971	—43·3	0·14
May 1972–Dec. 1972	—45·6	—0·69
Jan. 1974–Mar. 1975	—40·7	0·15
Mean	—41·6	—0·29

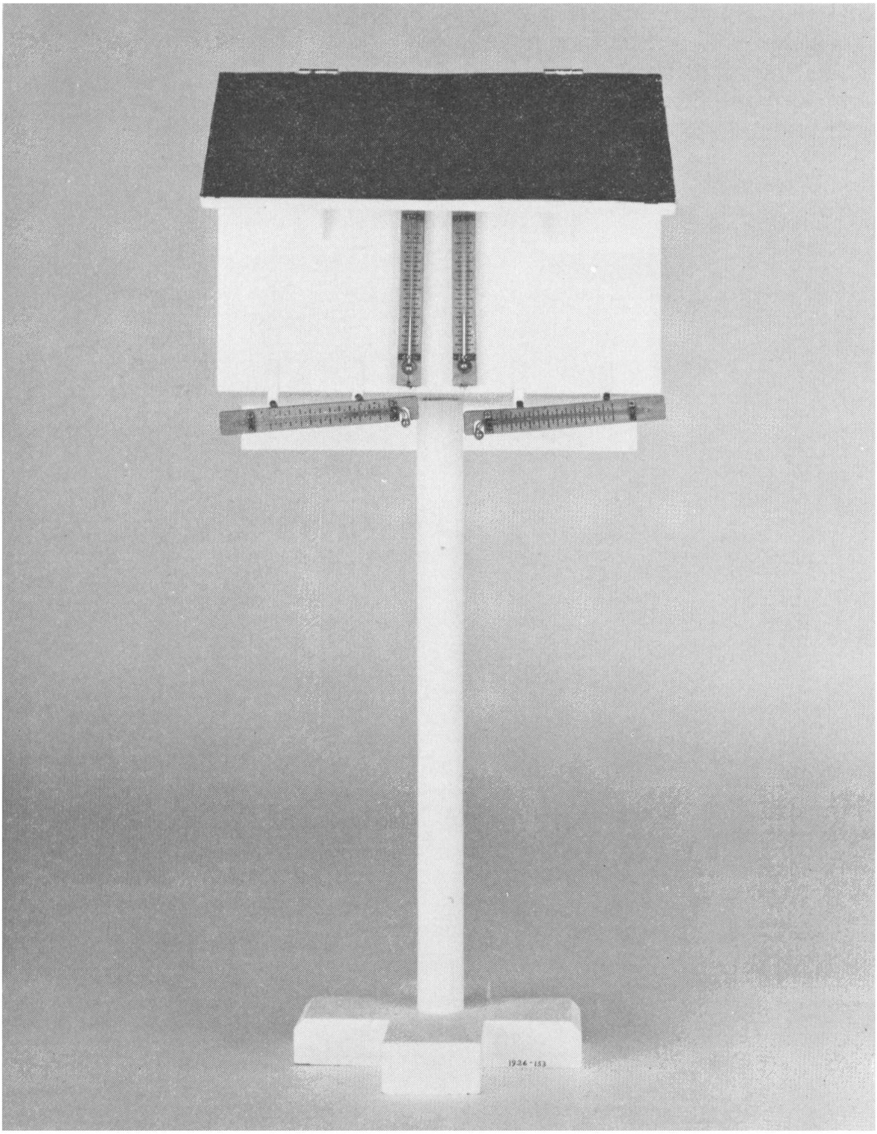
On eight out of eight occasions the mean anomaly of maximum temperature for a westerly phase was algebraically greater than for the preceding easterly phase, and on eight out of nine occasions the mean anomaly was less for an easterly phase than for the preceding westerly phase. The distribution of the mean anomalies for opposite phases of the QBO is shown in Table II.

TABLE II—FREQUENCY DISTRIBUTION OF MEAN ANOMALIES OF MAXIMUM TEMPERATURE (T_{max})

	T_{max}						
	⩽—0·50	—0·49 to —0·25	—0·24 to 0·00	+0·01 to +0·24	+0·25 to +0·49	⩾0·50	Total
Easterly	2	3	0	4	0	0	9
Westerly	0	0	3	1	3	2	9
Total	2	3	3	5	3	2	18

PLATE I—DIGITAL ANEMOGRAPH LOGGING EQUIPMENT (DALE)

(See page 204)



Photograph by the Science Museum, London

PLATE II—THE GLAISHER THERMOMETER STAND

(See page 220)

Photograph by the Science Museum, London

PLATE III—THE GLAISHER THERMOMETER STAND

(See page 220)

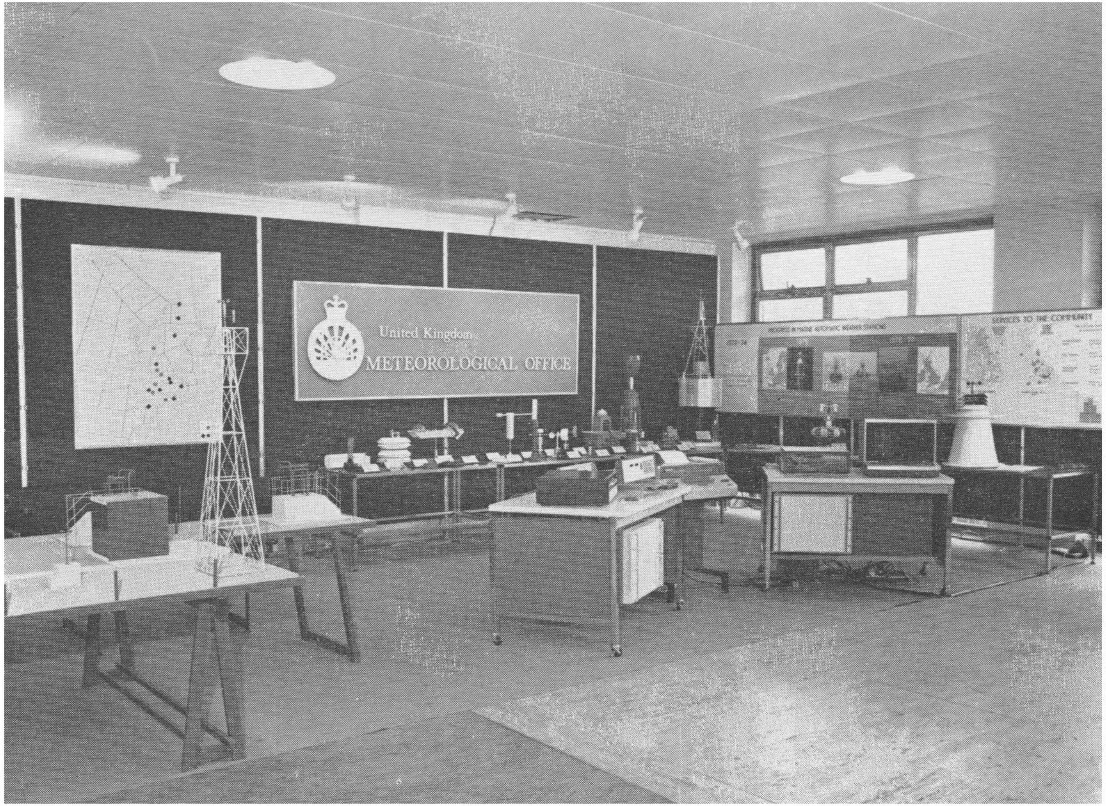


PLATE IV—THE METEOROLOGICAL OFFICE STAND AT THE COST 72 EXHIBITION OF AUTOMATIC WEATHER STATIONS

(See page 228)

Table III shows the differences in the mean anomalies for opposite phases of the QBO and emphasizes the change in the actual value of the anomaly between phases, and indicates some degree of persistance in the mean anomaly of maximum temperature.

TABLE III—FREQUENCY DISTRIBUTION OF DIFFERENCE IN MEAN ANOMALIES OF MAXIMUM TEMPERATURE BETWEEN QBO PHASES ($\Delta\ T_{max}$)

	$\Delta\ T_{max}$						
	⩽—1·00	—0·99 to —0·50	—0·49 to 0·00	+0·01 to +0·49	+0·50 to +0·99	⩾1·00	Total
Easterly following westerly phase	2	2	4	1	0	0	9
Westerly following easterly phase	0	0	0	3	2	3	8
Total	2	2	4	4	2	3	17

The linear regression of the mean anomaly of maximum temperature on the strength of the phase of the QBO in which the anomaly occurred as measured by the mean zonal wind speed during the phase (see Figure 2) was found to be significant at the 2 per cent level for 18 pairs of data giving the following relation,

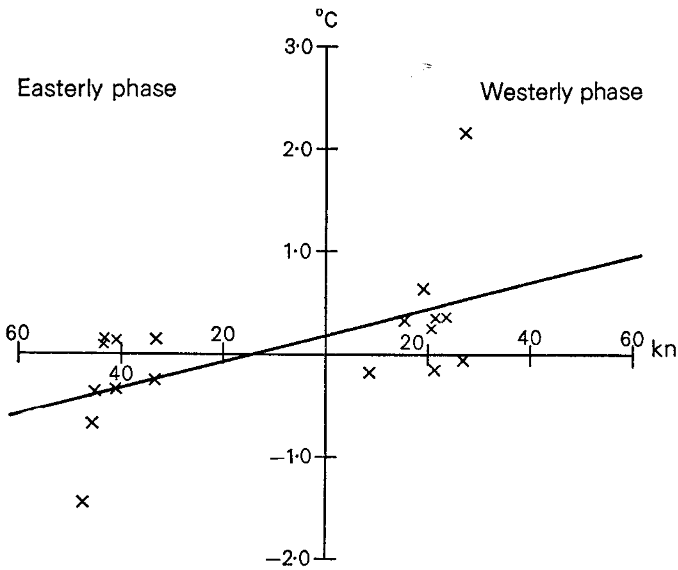


FIGURE 2—REGRESSION OF MEAN ANOMALIES OF MONTHLY MEAN MAXIMUM TEMPERATURE ON THE MEAN STRENGTH OF THE PHASE OF THE QBO IN WHICH THE ANOMALY OCCURRED

which accounts for 33 per cent of the total variance. The standard deviation of the sample is 0·71 and the standard error 0·60.

$$T_{max} = 0{\cdot}01x + 0{\cdot}20,$$

where T_{max} is the estimated mean anomaly of maximum temperature in degrees Celsius and x is the mean strength of the phase of the QBO in knots.

To determine if there is a lag in the relationship, the regression was repeated for periods of the same length as the appropriate phase of the QBO but with displacements from $M-6$ months to $M+15$ months, where M is the month in which each new phase of the QBO starts. The results at Figure 3 show the systematic change of correlation from a maximum at $M-1$ to zero at $M+6$ and to a minimum at $M+12$ months, and suggest an almost-in-phase relation between the QBO and the mean anomaly of maximum temperature with a half cycle of 13 months. The correlation at $M+12$ accounts for 28 per cent of the variance and, using the same notation as before, is given by $T_{max} = -0{\cdot}01x - 0{\cdot}07$. The mean duration of easterly and westerly phases are similar, i.e. 13·1 and 14·1 months respectively, and therefore a regression may be made of the mean anomaly of maximum temperature on the mean strength of the previous phase.

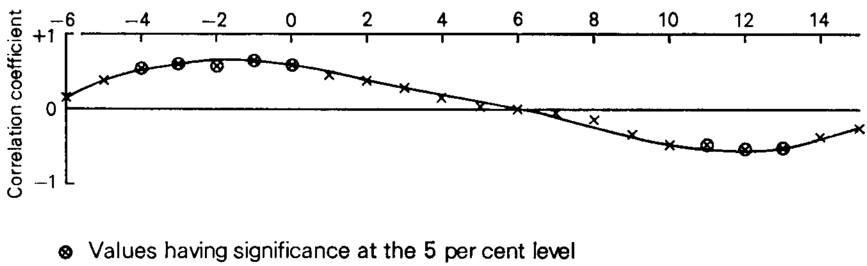


FIGURE 3—CORRELATION COEFFICIENTS OF MEAN ANOMALIES OF MONTHLY MEAN MAXIMUM TEMPERATURE ON THE MEAN ZONAL COMPONENTS OF THE QBO AT 30 mb FOR DISPLACEMENTS BETWEEN MINUS 6 AND PLUS 15 MONTHS

The regression, which is significant at the 5 per cent level, accounts for 23 per cent of the variance and is given by $T_{max} = -0{\cdot}01x_p - 0{\cdot}05$, where x_p is the mean strength of the previous phase of the QBO in knots. Since Parker (1976) has shown that it is possible to predict the onset and duration of a phase of the QBO in advance, some measure of the expected mean anomaly of surface maximum temperature for the following phase of the QBO may be made using a mean value for its strength. Alternatively, the strength of a particular phase may be used to predict the mean anomaly of maximum temperature for the next phase.

The percentage variance accounted for by these regressions is between 23 and 33 per cent; however, as discussed previously, by considering the differences in the mean anomalies of maximum temperature between two consecutive phases, an improved relation is found.

The regressions of the differences in the mean anomaly of maximum temperature for a particular phase, and the mean anomaly of maximum temperature for the previous phase on the strength of the QBO for the particular phase, and on the strength of the previous phase, are given by:

$$\Delta\ T_{max} = 0{\cdot}02x + 0{\cdot}27, \text{ and}$$

$$\Delta\ T_{max} = -0{\cdot}02x_p - 0{\cdot}23.$$

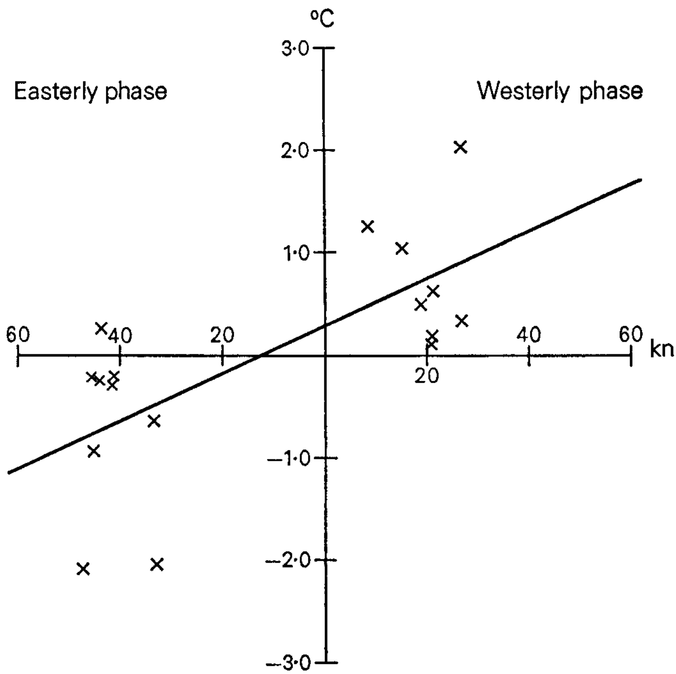


FIGURE 4—REGRESSION OF DIFFERENCES IN MEAN ANOMALIES OF MONTHLY MEAN MAXIMUM TEMPERATURE FOR CONSECUTIVE PHASES OF THE QBO ON THE MEAN STRENGTH OF THE SECOND PHASE OF THE QBO

The regressions, the first of which is shown in Figure 4, are significant at the 1 per cent and 0·1 per cent levels, and account for 48 and 55 per cent of the variance respectively. Since the mean anomaly of temperature for a particular phase of the QBO is known, this value may be added to the result to give an estimated mean anomaly of maximum temperature for the next phase of the QBO, which takes account of the persistence of temperature from one phase to the next.

Similar regressions of mean anomalies of maximum temperature in each season on the mean strengths of the QBO in both the current and previous phases were made, but observations were not included if the QBO changed phase during a particular season. The two summer regressions which give an estimate of the mean anomaly of maximum temperature for June, July and August were significant at the 2 per cent and 1 per cent levels, and account for 31 and 38 per cent of the variance respectively: the regressions are given by $T_{max} = 0{\cdot}01x + 0{\cdot}17$ and $T_{max} = -0{\cdot}02x_p - 0{\cdot}02$, and the first one on the mean strength of the current phase of the QBO is shown in Figure 5.

In the autumn months, September, October and November, the correlation of the mean anomaly of monthly mean temperature on the mean strength of the prevailing phase of the QBO is significant at the 5 per cent level and accounts for 24 per cent of the variance. Regression against the previous phase of the QBO accounts for 19 per cent of the variance and is significant at the 5 per cent level.

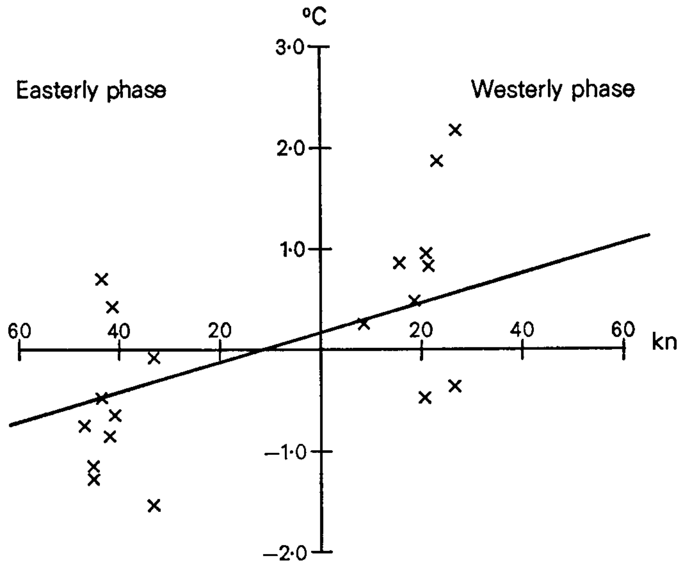


FIGURE 5—REGRESSION OF MEAN ANOMALIES OF MONTHLY MEAN MAXIMUM TEMPERATURE FOR SUMMER ON THE MEAN STRENGTH OF THE PHASE OF THE QBO IN WHICH THE ANOMALY OCCURRED

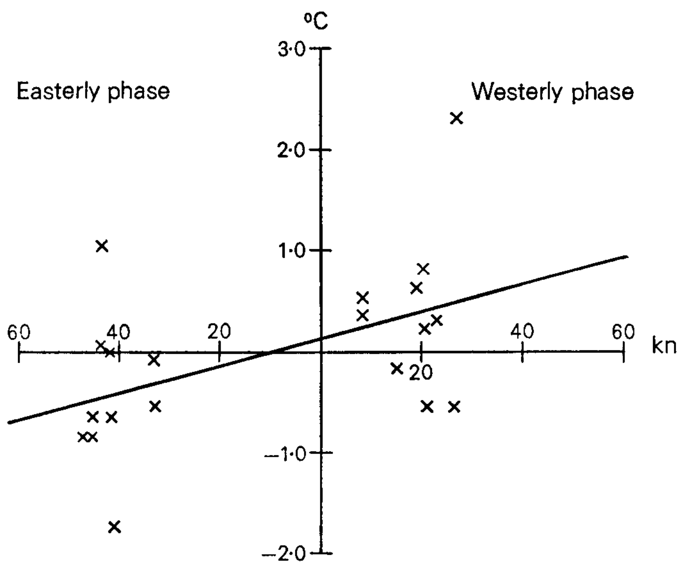


FIGURE 6—REGRESSION OF MEAN ANOMALIES OF MONTHLY MEAN MAXIMUM TEMPERATURE FOR AUTUMN ON THE MEAN STRENGTH OF THE PHASE OF THE QBO IN WHICH THE ANOMALY OCCURRED

The regressions are given by $T_{max} = 0{\cdot}01x + 0{\cdot}13$ and $T_{max} = -0{\cdot}01x_p - 0{\cdot}16$ respectively, and the first one is shown in Figure 6.

The regressions of the mean anomalies of monthly mean maximum temperature for the spring and winter seasons were not significant on either the mean strength of the prevailing phase of the QBO or on the mean strength of the preceding phase of the QBO.

4. Conclusions

Analysis of the mean anomaly of monthly mean temperature for Oxford shows that the mean anomaly for a westerly phase of the QBO exceeded that of the previous easterly phase of the QBO on all eight occasions, and that on eight out of nine occasions the mean anomaly was less for an easterly phase than the preceding westerly phase.

Significance at better than the 5 per cent level was found for the regression of the mean anomaly of monthly temperature on the mean strength of the QBO between $M-4$ months and M months and between $M+11$ and $M+13$ months, where M is the month in which a phase of the QBO starts. When regressions are made of the difference in the mean anomaly of maximum temperature for two consecutive phases of the QBO on the strength of the QBO and on the strength of the preceding phase of the QBO, significance levels of 1 per cent and 0·1 per cent are found which account for 48 and 55 per cent of the variance respectively. These relatively high values suggest that persistence of temperature from one phase of the QBO to the next may be of importance in determining the mean temperature anomaly.

A regression of the mean anomaly of summer mean maximum temperatures (for June, July and August) was found to be significant at the 2 per cent level for the existing phase of the QBO, and significant at the 1 per cent level on the mean strength of the previous phase of the QBO. In autumn, similar regression resulted in significance at the 5 per cent level. The regressions for the spring and winter months on the strength of the prevailing QBO and on the strength of the preceding QBO were not significant.

References

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EBDON, R. A. 1975 The quasi-biennial oscillation and its association with tropospheric circulation patterns. *Met Mag*, **104**, pp. 282–297.

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MAXIMUM SUMMER TEMPERATURES RECORDED IN GLAISHER STANDS AND STEVENSON SCREENS

By JOYCE LAING

SUMMARY

Two types of structure for mounting thermometers, the Glaisher stand and the Stevenson screen, are described. Summaries of the comparisons of summer maximum temperatures made at various times are given, and an attempt is made to relate the 1868 and 1911 national maxima to present-day observing conditions.

INTRODUCTION

The long, hot, dry summer of 1976, with an extreme temperature of 35·9°C (96·6°F) recorded at Cheltenham on 3 July, has stimulated some interest in high temperatures in past years and, in particular, during the summers of 1868 and 1911 in which the extreme maximum temperatures for the United Kingdom occurred: 100·5°F was recorded at Tonbridge, Kent on 22 July 1868, and 100·0°F was recorded at the Royal Observatory, Greenwich on 9 August 1911, but these temperatures were not measured with thermometers in the standard Stevenson screen exposure.

During the latter part of the nineteenth century many of the temperature records were from thermometers mounted in various types of structure similar to the open Glaisher stand. After the Stevenson screen came into use, a number of investigations were carried out into the variation of the results from these two types of thermometer exposure.

THE GLAISHER STAND

In 1841 a structure for supporting thermometers was brought into use at the Royal Observatory, Greenwich, when James Glaisher was Superintendent of its Magnetic and Meteorological Department. Although known by his name, the stand was in fact designed by Sir George Airy, the Astronomer Royal; a description of the stand was written by Glaisher (1868). In essence, the Glaisher stand consisted of a vertical board about 4 ft above the ground on which thermometers could be mounted, sheltered from above; the stand could be rotated about a central pivot so that the thermometers were always shielded from the direct rays of the sun, but were still exposed to radiation from the ground, part of the sky, and some surrounding objects (see Plates II and III). A lot depended on the conscientiousness of the observer in turning the stand regularly, as the maximum temperature could easily be affected by the early morning or late evening sun striking the thermometers. With local modifications this stand was in use for many years.

THE STEVENSON SCREEN

Thomas Stevenson (1818–87) was a civil engineer who, through his work maintaining lighthouses round the Scottish coasts, developed an interest in meteorology. In 1863 he designed a louvered screen which would give better protection to the thermometers from precipitation and radiation. A major improvement is in the long-wave (thermal) radiation environment of the thermometer. Instead of receiving some radiation from the sky and the ground, all the thermal radiation falling on the thermometer comes from the interior of the screen, the temperature of which is very close to the ambient air temperature. A notice describing this screen was published in the *Journal of the Scottish Meteorological Society* in 1864, together with a note stating that the Society had already recommended the box to its observers for its compactness and low price (Bilham, 1937).

This screen was 15 inches high, 14½ inches long and 7½ inches wide (internal measurements) with double louvered sides, a solid roof (with a ventilator to prevent the build-up of heated air in the screen) and no bottom. The thermometers were mounted on slats and the whole box was supported on four stout posts so that the thermometers were 4 ft above the ground (Gaster, 1879). Modifications to this design were made in 1884 and this modified screen has remained virtually unchanged to the present day (Bilham, 1937 and Meteorological Office, 1956).

COMPARISON OF TEMPERATURE EXPOSURES

Considerable argument (Meteorological Society, 1873, and Stow, 1873) ensued in the late 1800s over which type of screen gave the more accurate value of the temperature of the air, and J. G. Symons organized (with a grant from the Royal Society) an elaborate comparison of screens of various designs at Strathfield Turgiss [old spelling] in Hampshire, the readings being taken by the Rev. C. H. Griffiths during the period November 1868 to April 1870 (Gaster, 1879).

Following these experiments, the Meteorological Office and the Meteorological Society recommended Stevenson's screen for use at observing stations (Meteorological Society, 1876, and Bilham, 1937). However, the Glaisher stand continued to be used at Greenwich to preserve the homogeneous record, and it was not until 1938 that the Stevenson screen was used as the standard.

Various comparisons between the temperatures recorded in a Glaisher stand (G) and those recorded in a Stevenson screen (S) have been made from time to time. One of the difficulties in any comparison is the uncertainty of the exposures in the Glaisher stand. To obtain the best shelter the stand ought, ideally, to be turned continuously. At such places as Greenwich, where observations were made at regular short intervals, the stand would be turned after each reading but, where only one or two observations a day were made, the stand could possibly on some occasions be left long enough without being turned for the sun to reach the thermometers.

The report on the experiments at Strathfield Turgiss in 1868–70 produced the following differences (S—G) in maximum temperature (°F)—see also column 1 of Table I.

	June	July	August	September
Cloudless sky		—1·1	—0·7	
Overcast		—1·4	—1·5	
All aspects	—1·5	—1·2	—0·9	—0·8

Edward Mawley, later President of the Royal Meteorological Society, conducted some comparisons between thermometers in a Glaisher stand and a Stevenson screen in his garden in Croydon, Surrey during the years 1877 to 1881 (Mawley, 1897). He obtained mean differences of between —1·0 and —1·5°F in the maximum temperatures during the summer months (see column 2 of Table I).

Ellis (1891) reported a comparison made at Greenwich during 1887 to 1889 in which he obtained mean differences in the maximum temperatures during the summer months of about —2·0°F (see column 4 of Table I).

Also using Greenwich data, Harding (1912) gave the following comparisons of maximum temperature on days in 1911 when the temperature was over 90°F:

	G	S	S—G		G	S	S—G
21 July	93·7	90·4	—3·3	13 Aug.	90·9	89·3	—1·6
22 July	95·6	91·7	—3·9	7 Sept.	91·6	90·0	—1·6
28 July	91·9	89·3	—2·6	8 Sept.	94·1	92·8	—1·3
9 Aug.	100·0	96·6	—3·4				

Margary (1924) reported a comparison between Stevenson screen and Glaisher stand exposures at Camden Square, London over the years 1881–1920. The differences in the maximum temperature (all occasions), averaged over the years 1881–1915, are given in column 3 of Table I. Several occasions of differences in daily maximum temperatures of —3·5°F or more occurred during this period, the highest being —4·2°F. The following mean differences for occasions when the maximum temperature was 70°F and above gave very similar values to those given in Table I (column 3):

Stevenson screen Max. (°F)	S—G (°F) June	July	Aug.
70–75	—1·1	—1·2	—1·0
>75		—1·3	—1·0

During the three years April 1923 to March 1926 a comparison was made between four types of thermometer exposure at Kew Observatory. J. M. Stagg (1927) analysed the results and gave the temperature differences between the Glaisher stand and the Stevenson screen, as shown in column 6 of Table I. (The differences were calculated in degrees Celsius.) This Glaisher stand was the same as that used at Camden Square since 1858 and which Margary (1924) had used in his work. It was moved to Kew in 1923 and set up in the enclosure, 16 ft due east of the Stevenson screen (with thermometers 4 ft above the ground); a photograph is in the *Observatories' Year Book, 1923* (Meteorological Office, 1926).

From the distribution of maximum-temperature differences (S—G) for the summer (May to August), Stagg gave the following values:

	°C	°F
Mean difference	—1·2	—2·2
1st quartile	—1·4	—2·5
3rd quartile	—0·9	—1·6

Stagg noted that the distribution of differences in temperatures at 1300 h was very similar to that of the differences in maximum temperature, and that during the three years of the experiment the extreme difference at 1300 h was —3·3°C (—5·9°F) on one occasion and —3·1°C (—5·6°F) on two occasions.

An analysis was made of the weather conditions on occasions of large differences in temperature and this showed quite clearly that the differences recorded were due to the effect of radiation on the thermometers in the open Glaisher stand. On fine, dry days in summer, the temperature of the ground around the base of the vertical support would rise considerably, following heating by solar radiation, and thus there would be considerably increased long-wave radiation from the surface. At the same time there would be increased sky and reflected solar radiation. Both these streams of radiation would heat the thermometers themselves and also the back-board on which the thermometers were mounted: together they would more than compensate for the loss of long-wave radiation from the board and thermometers to the clear sky. In general, it may be said that the more intense the solar radiation the greater the resulting temperature differences that were observed.

MORE RECENT WORK ON GREENWICH TEMPERATURES

A Staff Instruction in the Climatological Branch of the Meteorological Office in 1938 required a correction to be applied to Greenwich temperatures used in the compilation of long-period averages so that they would be comparable with those for other stations. Those corrections were based on a comparison made during 1900–13 using monthly mean differences, which produced the differences for maximum temperatures in the summer months as shown in column 5 of Table I.

TABLE I—MEAN DIFFERENCES IN MAXIMUM TEMPERATURES (°F), STEVENSON SCREEN MINUS GLAISHER STAND (S—G)

	1	2	3	4	5	6
	Strathfield Turgiss 1868–70	Croydon 1877–81	Camden Square 1881–1915	Greenwich 1887–89	Greenwich 1900–13	Kew 1923–26
May	—1·2	—1·2	—0·7	—1·8	—1·7	—2·3 (—1·3°C)
June	—1·5	—1·4	—1·2	—2·0	—1·8	—2·2 (—1·2°C)
July	—1·2	—1·4	—1·3	—2·2	—2·1	—2·3 (—1·3°C)
Aug.	—0·9	—1·1	—1·1	—2·0	—1·9	—2·0 (—1·1°C)
Sept.	—0·8	—0·8	—0·7	—1·2	—1·1	—1·3 (—0·7°C)

An early draft for the *Climatological Atlas of the British Isles* quotes C. E. P. Brooks as suggesting that a correction of -2 to -3°F be applied to the extreme temperatures recorded in the Greenwich Glaisher stand, but this comment was not included in the published version (Meteorological Office, 1952).

At the Royal Observatory, Greenwich, the Glaisher stand was originally set up in the Observatory grounds, but there was some doubt as to the exposure and also as to the effect of radiation from the white buildings near by. In 1899 the stand was moved to the Magnetic Pavilion enclosure, and in 1900 a Stevenson screen was installed about 15 ft north-east of the Glaisher stand (Royal Observatory, Greenwich, *passim*). It was from the published values of mean monthly differences between these two exposures that the Climatological Branch produced the figures quoted above (Table I, column 5). The Stevenson screen values were not published between 1914 and 1938, but thereafter they replaced the Glaisher values as the standard Greenwich temperatures. During the ten years 1900–09 daily values of the differences in maximum temperature between the two exposures were published (Royal Observatory, Greenwich). From these values Tables II and III have now been compiled. Table II gives the mean differences of the higher maximum temperature, and Table III sets out the frequencies of occurrence of the differences between maximum temperatures for Stevenson screen values of 70°F or more.

TABLE II—MEAN DIFFERENCES (S—G) AT GREENWICH, 1900–09

	Stevenson Max. (°F)			
	70·0 to 74·9	≥75·0	≥80·0	≥85·0
		Differences (°F)		
May	—1·3	—1·4	—1·5	
June	—1·6	—1·2	—1·1	—3·3
July	—1·7	—1·8	—1·5	—1·6
Aug.	—1·6	—1·4	—1·3	—0·8
Sept.	—0·8	—1·0	—0·9	—1·3

TABLE III—FREQUENCY OF OCCURRENCE OF DIFFERENCES IN MAXIMUM TEMPERATURES RECORDED IN GLAISHER STAND (G) AND STEVENSON SCREEN (S) AT GREENWICH, 1900–09

Stevenson Max. (°F)	Differences (S—G) °F									
	≥0·0	—0·1 to —0·5	—0·6 to —1·0	—1·1 to —1·5	—1·6 to —2·0	—2·1 to —2·5	—2·6 to —3·0	—3·1 to —3·5	—3·6 to —4·0	≥—4·1
	Number of occasions									
May										
70·0–74·9	3		7	9	6	4				
75·0–79·9	1		4	2	1	2		1		
80·0–84·9			1	1		1				
June										
70·0–74·9	6	1	7	16	10	12	3	2	2	
75·0–79·9	1	3	6	1	4	1	1		1	
80·0–84·9	2		3		1					
85·0–89·9								1		
July										
70·0–74·9	5	3	10	13	20	12	4	6	1	1
75·0–79·9	1	2	10	11	10	9	9	8	1	1
80·0–84·9	3	4	10	4	7	5	3	1	3	
85·0–89·9			4		1	3				
≥90·0					1	1				
August										
70·0–74·9	2	11	8	16	17	15	4	3	1	
75·0–79·9	1	7	7	7	3	5	8			
80·0–84·9	1	2	1	7	2	1	1		1	
85·0–89·9	1	1	1		1					
≥90·0				1						
September										
70·0–74·9	6	7	12	9	5					
75·0–79·9		1	2	2		1				
80·0–84·9	1	1	1	1						
85·0–89·9					1					
≥90·0			1	1						

The higher temperatures (85°F and above), in general, show smaller differences between the two exposures than the lower ranges of temperature, but the number of occasions is small. Days of high temperature are generally those with little or no cloud and therefore will have greater than average differences between the temperatures, but often the days with the strongest radiation (those giving the greatest differences) will occur when the temperatures are comparatively low: for example, on days of clear polar air.

The greatest difference during the period 1900–09 was −4·2°F which occurred with a Stevenson screen maximum of 74·8°F in July 1908. Unfortunately, August 1911 does not come within this period, but the difference between the maxima on 9 August (Glaisher maximum 100·0°F) has been quoted as −3·4°F (Harding, 1911). The average difference between the Stevenson screen and Glaisher stand maximum temperatures at Greenwich during the summer months is seen to be about 2°F.

REASSESSMENT OF PUBLISHED EXTREME TEMPERATURES

Table I summarized the mean differences in maximum temperatures recorded on Glaisher stands and in Stevenson screens, as found in the various investigations.

The values obtained at Greenwich and Kew are similar, while those for Camden Square, Croydon and Strathfield Turgiss are nearly 1°F smaller. However, as the periods are not the same, a strict comparison cannot be made.

To make a comparison of the temperatures of the summer of 1976 with the published maxima for the United Kingdom (100·0°F in August 1911 and 100·5°F in July 1868) some corrections must be applied to the old recordings.

The summer of 1868

In 1868 Dr G. Hunsley Fielding (1869) was keeping weather records at Tonbridge, Kent. His description of that summer could easily be applied to 1976:

> The intense heat, combined with great scarcity of rain, was most fatal in its effects both upon the animal and vegetable world. The Registrar-General's returns for the quarter ended September 30 showed a fearful increase, in England alone, of 21,000 deaths. In the garden . . . nothing whatever came to perfection, either in size or flavour. Peaches and nectarines, apricots, apples and pears dropped half-developed from the trees; raspberries, currants and gooseberries hung shrivelled on the bushes and the beans and peas hung dwarfed or with empty pods. The lawns were burnt quite brown, as were the neighbouring pastures, and often split into deep furrows, the stock being obliged to feed on winter provender. The springs in many places were quite dried up, occasioning great inconvenience and expense in obtaining water.

His thermometers were mounted in a 'box stand, double with venetian sides' (Fielding, 1869) and he gives the following description of the site:

> My abode is at Tunbridge [*sic*], in the valley of the Medway; it is nearly surrounded by hills, but the immediate vicinity is flat and marshy, the river winding through, at a distance of about a quarter of a mile. . . . A small tributary of the Medway flows at the bottom of the garden to the eastward and southward, on which last there is a millpool through which it runs. The kitchen-garden is at the back of the house, and in it, entirely detached from the house, is my thermometer-stand. The stand faces to the north-east, a narrow gravelled path separating it from the vegetable beds, and about fifty feet distant is a fruit wall. It is double at the back and top, air circulating freely between the pieces. Behind it is a piece of lawn, and about 20 feet distant a low wall and laurel-hedge fencing off the millpool. The instruments . . . are 4 feet from the ground and 75 feet above mean sea-level.

The maximum temperature recorded at Tonbridge was 100·5°F on 22 July 1868, and on the same date Greenwich recorded 96·6°F. Other maximum temperatures recorded on this day are listed in *Symons's Meteorological Magazine* (1868) with descriptions of the types of stand used. F. W. Stow's records at Tunbridge Wells produced a maximum of 92·4°F in a modified Glaisher stand, but that site was 403 feet above mean sea level, considerably higher than Dr Fielding's. Two records from Stevenson screens were quoted: 83·0°F at Worthing and 92·6°F at Audley End, Esssex.

It is difficult to make any comparison of the Tonbridge temperatures with present-day values as it is not entirely clear how much shelter the Tonbridge stand afforded. Dr Fielding's description implies that it was an open stand, while Symons's list suggests that it was similar to Stevenson's screen with louvers all round. The description of the site is rather vague on whether the thermometers were over grass, but the obvious proximity of the gravel path and vegetable beds (especially that year when all vegetation was dried up) must have increased the amount of radiation reaching the thermometers if the stand was at all open.

Both Stevenson screens were in very different localities and no direct comparison can be made with these limited data. The high value at Tonbridge, compared with other maxima on that day, would seem to indicate that it was recorded in an open stand. If this was the case, we can perhaps assume that the same differences occurred between the exposures as at Greenwich where an average of −2·1°F has been calculated for July. This would give a value comparable with a louvered screen exposure of 98·4°F. On the other hand, when in 1911 Greenwich had a similar maximum temperature (100·0°F), the difference between the two exposures was −3·4°F. Applying this correction to the Tonbridge maximum gives a value of 97·1°F.

Daily values of maximum temperature are available for Tonbridge and Greenwich for July 1868 which show that Tonbridge was about 3°F higher, on average, in that month. The Stevenson screen equivalent of the reading of 96·6°F at Greenwich seems likely to be between 93·2 and 94·5°F. Applying a 3°F correction to these figures leads to a Tonbridge value of between 96·2 and 97·5°F. The most probable Stevenson screen equivalent of the Tonbridge maximum temperature would therefore seem to lie between 97 and 98°F.

The summer of 1911

Harding (1912) described the summer of 1911 when a maximum of 100·0°F was recorded at Greenwich. Although temperatures in the south-east were high, London was not affected by the water shortage which was more severe in the north Midlands and caused many people to be thrown out of work. In the same article (page 21), Harding quoted a letter from a Dr F. S. Arnold who wrote about an extraordinary amount of 'unrest in the labour world' and 'police and mob violence . . . which will make the year 1911 long memorable', and who attributed this to the hot weather.

Both the Glaisher stand and the Stevenson screen at Greenwich at that time were located in the Magnetic Pavilion enclosure, about 15 ft apart. On 9 August 1911, when the maximum temperature in the Glaisher stand was 100·0°F, the Stevenson screen maximum was 96·6°F (Harding, 1912), a difference of −3·4°F. Other maximum temperatures recorded on the same date and published in the *Monthly Weather Report* (Meteorological Office, 1911) were 98°F at Epsom (Surrey), Raunds (Northants) and Canterbury (Kent), all in Stevenson screens. A value of 99°F at Isleworth (Middlesex) was quoted in the *Report* (and also by Harding, 1912). An article in *Symons's Meteorological Magazine* (1911) quotes a maximum temperature of 98·8°F from a Kew-verified Six's thermometer in a Stevenson screen at Ponders End (Middlesex).

POSSIBLE ADJUSTMENTS TO EXTREME MAXIMUM TEMPERATURES FOR THE UNITED KINGDOM

From descriptions of the various types of structure for mounting thermometers and the comparisons between them, it is concluded that the measurements of the maximum temperatures currently accepted as the extreme United Kingdom values are higher than they would have been if present-day methods were used. While the thermometers in a Stevenson screen are always and automatically sheltered from direct radiation, this is not always the case for a Glaisher stand, and thus values from an open stand must be rejected as unrepresentative of ambient temperature.

No direct comparison with the maximum temperature of 100·5°F at Tonbridge in 1868 and the present type of exposure is available, and there is some doubt as to the exact positioning and screening of the thermometers. However, assuming the same differences as those calculated for Greenwich, it seems most probable that the equivalent Stevenson screen maximum temperature at Tonbridge on 22 July 1868 was between 97 and 98°F, which is in excess of the 1976 maximum. Since 1868 very warm spells have occurred in 1881, 1911 and 1932.

In 1881 a temperature of 101·0°F was observed in an open stand at Alton, Hants (Symons, 1881) but this has apparently never been considered as a record extreme; indeed, on the same day, 15 July 1881, the nearby station at Alresford had a maximum of only 89·4°F in a Stevenson screen. The highest Stevenson screen maximum for this period reported in Symons (1881) was 95·0°F at Camden Square.

On 9 August 1911 the maximum temperature in the Stevenson screen at Greenwich was 96·6°F (Glaisher stand maximum 100·0°F) which is equal to the 1976 maximum. However, higher values recorded in Stevenson screens were reported: 98°F at Epsom, Raunds and Canterbury. A value of 99°F has been quoted for Isleworth (Meteorological Office, 1911) but no details of the siting of the thermometers are available, nor was it included in Symons (1911) with other high temperatures on that day. This station was administered by the Royal Meteorological Society and had been operating for many years, although the readings were not published regularly in the *Monthly Weather Report.* A temperature of 98·8°F at Ponders End was recorded in a Stevenson screen but the thermometer was not standard and there are no details of the site, except for a comment that it was 'in standard conditions' (Symons, 1911).

In 1932, although it was a generally dull summer, there were some high maximum temperatures in southern England in August. Maxima of 97°F were recorded in standard exposures at many places on 19 August including Camden Square, Regent's Park, Tottenham and Enfield in the London area, and Halstead in Essex.

Accepting the strict conditions that are now required for the siting and recording of air temperatures, only those values recorded by standard thermometers in a Stevenson screen in an unsheltered site should be considered for the extreme maximum temperature. However, a careful comparison of Glaisher stand and Stevenson screen readings suggests that the Stevenson equivalent of some of the old Glaisher maxima still maintain a place in the 'top ten' extreme temperatures.

A realistic estimate of the extreme maximum temperature so far recorded in the United Kingdom is 98°F (37°C)—most of the stations recorded the extreme temperatures in whole degrees Fahrenheit—and the ranking order seems to be as follows:

98°F (37°C)	9 August 1911	Raunds, Epsom, Canterbury;
97–98°F (36–37°C)	22 July 1868	Tonbridge;
97°F (36°C)	9 August 1911	Hillington, Wokingham;
	19 August 1932	Camden Square, Enfield, Regent's Park, Tottenham, Halstead;
96·6°F (35·9°C)	9 August 1911	Greenwich;
	3 July 1976	Cheltenham.

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ORGANIZATION OF THE COST 72 TECHNICAL CONFERENCE AND EXHIBITION AT THE UNIVERSITY OF READING, SEPTEMBER 1976

By K. J. T. SANDS

SUMMARY

A Technical Conference and Exhibition on Automatic Weather Stations was held at the University of Reading in September 1976. Most of the organization of this event was the responsibility of Meteorological Office staff. This article summarizes the work involved.

In September 1973 a contract was arranged between governments participating in European Co-operation in Science and Technology (COST) and the Director-General of the Meteorological Office, to carry out a study of the use of automatic weather stations in COST participating countries. The study was to be concluded by a technical conference and exhibition to be organized by the British Meteorological Office. The study group consisted of delegates from ten countries and the Chairman was Mr G. J. Day, then in charge of surface instrument development in the Office. A sub-group consisting of three members was formed to make arrangements for the running of the conference and exhibition: Mr J. H. Rietman (Netherlands), Dr C. V. Dake (West Germany), and Mr K. J. T. Sands (UK) who was appointed Chairman.

The first meeting of the sub-group took place at the Meteorological Office College, Shinfield Park in September 1975. Two members of the EEC Secretariat attended the meeting. It soon became obvious that, although the overall plan would be decided by the sub-group, the majority of the work involved would have to be undertaken by the UK representative (the Chairman).

The sub-group originally considered holding the Conference at the Meteorological Office College. However, the only period available, mid July, is a popular holiday time for the EEC countries. Reading University was able to offer suitable accommodation, and it was agreed to hold the event there during the third week of September 1976. An offer to help in the organization of the Conference by the International and Planning Branch (Met O 17) was accepted. The advice of other UK Government Departments was sought on the problems of organization and, on their recommendation, a specialist contractor was asked to supply the furnishings.

Concurrently, questionnaires were sent to the official COST representative of each participating country, requesting abstracts of papers to be presented at the Conference and details of exhibits from their commercial and national organizations. Eventually sufficient information was at hand to enable a draft Conference program to be drawn up, along with exhibition-stand layout design.

A further meeting of the sub-group took place in March 1976 and the Conference program and exhibition layout were agreed. Accommodation for the delegates was booked at the University. The Conference was to be presented in three working languages, namely English, French and German; simultaneous translation listening facilities were arranged in the lecture theatre for all delegates.

The Conference, planned to last three days, was divided into four sessions, each dealing with a different aspect of automatic weather stations and having a different Chairman, a specialist in that particular aspect. It had originally been planned to send a complete set of papers to the EEC Secretariat in Brussels for duplication prior to the Conference, and a bound set of papers was to be sent to each registered Conference participant four weeks before the Conference date. The deadline for receipt of papers was 1 June 1976 but by then only about one quarter of the thirty papers promised had arrived, and so a decision was made to duplicate, collate and bind the papers locally as soon as they came in. The duplicating section of the Meteorological Office responded magnificently and in a very short time produced 92 000 copies. The bound volume of papers consisted of 356 pages. Six papers arrived too late for inclusion and were published as a supplement. All the papers were published in the original language, but English translations were prepared and made available at the Conference. A program of the Conference and Exhibition was also prepared for issue at the Conference.

The organization of the Exhibition became very demanding as the event drew closer. Each overseas exhibitor was informed of the procedures to be followed when dealing with the British Customs and Excise. With display material coming from many different countries it was perhaps inevitable that some difficulties would arise but it was nevertheless surprising that large organizations failed to act on the information sent to them and consequently fell foul of our Customs regulations. After much late-night telephoning by the organizers, two exhibitors breathed long sighs of relief when their display material was released from bond at London Airport and delivered to them a few hours before the opening of the Exhibition. Even the use of internationally known forwarding agents did not guarantee a safe passage: one consignment of valuable equipment disappeared from a 'sealed container' on the return journey to Italy, and some weeks later it had still not been traced.

The Conference and Exhibition were formally opened on 22 September by Dr B. J. Mason, Director-General of the Meteorological Office, and Mr C. L. Silver, Chairman of the COST Senior Officials. Twenty-nine papers were presented during the first two and a half days of the Conference, the afternoon of the third day being devoted to a discussion on the opportunities for standardization and co-operation in the development and use of automatic weather stations. Twenty-three stands from eight countries displayed a variety of equipment in the Exhibition and several exhibitors had instruments set up on the grassed area adjacent to the building; the Meteorological Office stand was organized independently by members of the Operational Instrumentation Branch (Met O 16) and is shown in Plate IV.

The Conference office remained open throughout the Conference and dealt with delegates' and exhibitors' problems as they arose; the telephone was in great demand, many lengthy calls being made by foreign exhibitors to their home base.

Co-operation by the staff of the University was first-class and contributed greatly to the success of the event.

The Conference and Exhibition closed at 1600 hours on 24 September. Dismantling of the stands and equipment started immediately and was completed the following morning. A sight typical of the end of a successful Conference and Exhibition was that of an obviously satisfied overseas exhibitor holding an impromptu farewell party for his UK Agent in the grounds of the University, surrounded by his crated exhibits.

REVIEW

Statistical fluid mechanics: mechanics of turbulence, Volume 2, by A. S. Monin and A. M. Yaglom, edited by J. L. Lumley. 230 mm × 160 mm, pp. xi + 874, *illus.* MIT Press, 126 Buckingham Palace Road, London SW1W 9SD, 1975. Price: £25.00.

This volume completes the outstanding *tour de force* of the two Russian authors in which they present an account, without an equal, of the current theory and understanding of turbulence. The first volume had discussed the nature of laminar and turbulent flows in which it can be described statistically.

In over 800 pages this volume goes into the mathematical description in great detail and considers special turbulence fields (homogeneous, isotropic, locally isotropic, etc.) and the theories and hypotheses that have developed around them. The propagation of waves through turbulent fields, and other problems, are considered in detail. Possibly the parts of greatest interest to meteorologists are:

(a) A clear and interesting account of the earlier work on closure schemes for the basic equations governing momentum, heat and moisture. Although these schemes have advanced significantly since the writing of the book, nevertheless it would be no waste of time to read, for example, the detailed background to the Millionshchikov hypothesis that velocity fourth-order cumulants can be put equal to zero. The authors discuss in detail the consequences and why to some degree it fails.

(b) A fairly full account (60 pages) of some of the theoretical and experimental work on diffusion. This is very good reading indeed for the research worker in this field, but it is not intended as a practical manual for the man concerned with the height of his factory chimney!

The translation and editing has been done with great competence by Professor John Lumley of Pennsylvania State University, one of the most respected names in turbulence theory in the world. Generally the printing is satisfactory, and the occasional large changes in print size over several pages at a time, which at first sight seem rather extraordinary and presumably occur as a result of last-minute changes in the text, turn out in practice to be of no consequence or irritation.

In summary, this book is a very valuable piece of work intended for the turbulence specialist and has no competitor of equal standing at the present time.

F. B. SMITH

NOTES AND NEWS

Retirement of Mr R. A. S. Ratcliffe

Mr R. A. S. Ratcliffe, Assistant Director (Synoptic Climatology), retired on 26 May 1977. He had held this post since 1966, and it is as the man responsible for the monthly forecasts that he has become best known, both inside the Meteorological Office and, through his numerous appearances on radio and television, to a wider audience in the general public. The long-range forecaster's task is not easy. Faced with one of the most intractable problems in the whole of science he is, nevertheless, called upon to produce a diagnosis and prognosis to a grinding half-monthly schedule. The margin of success is small; near misses and much insight go by unrecognized, while failures attract more than their fair share of criticism. To maintain one's enthusiasm and conviction over a long period takes more than ordinary resilience and tenacity of purpose. These are qualities that Mr Ratcliffe has brought to long-range forecasting to a striking degree. He has consistently been a formidable apologist for the concept of long-range forecasting and a strong defender of the methods used within the Meteorological Office.

Earlier in Mr Ratcliffe's career he had also been required to face difficult situations and bear his share of heavy responsibilities. Coming into the Meteorological Office in 1938 with a first-class honours degree in Natural Sciences from Cambridge University, he was soon plunged into the maelstrom of agonizing decisions and frequent postings that the Second World War brought to most meteorologists of his generation. Within a few months he found himself responsible for forecasts for aircraft undertaking very long flights over the Atlantic and the Norwegian Sea, at times when observations were few and the forecaster had to make most of his deductions from surface observations. His experience at this time led to his being selected to join the pioneering group set up at Dunstable in 1943 under Dr Sverre Petterssen to provide a unified upper-air forecasting service. Its output was used in many contexts, but most notably perhaps in providing meteorological data for Bomber Command raids on Germany. It was during this time that the basic methods of upper-air forecasting were developed; pressure levels were chosen in preference to fixed heights as the basis for the charts and the 'gridding' technique which became standard practice in the Meteorological Office until the advent of computer methods.

When the sphere of military operations moved to the Far East, Mr Ratcliffe went to the Joint Meteorological Centre in Colombo, and later to Calcutta. After hostilities were over, there came a spell in the United Kingdom, first on the upper-air roster once more, and then as senior meteorologist in RAF Training Command, but he was soon abroad again in Cyprus. His spell of duty there coincided with the worst period of the EOKA campaign and included such traumatic events as the British withdrawal from Egypt, the 1956 Suez campaign, and the upheavals in Iraq and Jordan.

Returning home in 1959, Mr Ratcliffe spent the next eight years as a senior forecaster at Heathrow and then at the Central Forecasting Office, Bracknell. During this time he earned an enviable reputation for his forecasting skill and dependability. One highly competent judge considered him to be 'among the best three or four forecasters ever to have served in the Central Forecasting Office'. In 1966 he was promoted to Senior Principal Scientific Officer and turned his mind from the relatively tangible concepts of 24 and 48 hour prediction to the nebulous uncertainties of atmospheric developments over a month. Once again he quickly made his mark, and in 1970 was awarded (jointly with R. Murray) the L. G. Groves Memorial Prize for Meteorology for his research on the influence of sea-surface temperature anomalies in the Atlantic on weather conditions near the British Isles.

Outside his official duties, Mr Ratcliffe has maintained a particular interest in the activities of the Horticultural Society of which he has been Chairman for most of his time at Bracknell. At flower shows his exhibits, and those of Mrs Ratcliffe, have been outstanding and a source of pleasure and admiration to all the Meteorological Office staff. He has been active on the cricket field and on the tennis courts. Indeed, he is currently Secretary of the Royal Ascot Tennis Club, and still plays occasional matches for them.

A man of wide-ranging interests and enthusiasms, Mr Ratcliffe approached his departure from the Meteorological Office not as an end to activity but as an opportunity to intensify existing pursuits and to take up new ones. To him and to his charming wife Hilary we extend our heartfelt wishes for a long, happy and full retirement.

A. GILCHRIST

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NOTICES

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