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SCIENTIFIC PAPERS

No. 31 The three-dimensional analysis of meteorological data

By R. Dixon, B.Sc. and E. A. Spackman, M.Sc.

The advent of modern observational devices such as satellites and long-life free drifting balloons has greatly complicated the process of data analysis by computer. This paper presents a possible method for effecting this data analysis by fitting a high-power polynomial to all the observations from within a large volume of the atmosphere.

37½p (40p by post)

No. 32 The Bushby-Timpson 10-level model on a fine mesh

By G. R. R. Benwell, M.A., A. J. Gadd, Ph.D., J. F. Keers, B.Sc., Margaret S. Timpson, B.Sc., and P. W. White, Ph.D.

A full description is given of the 10-level numerical weather prediction model which has been developed by the Meteorological Office during the past few years for use in investigating the dynamics of fronts and in predicting rainfall. The formulation includes representation of the effects of surface friction, topography surface exchanges of sensible and latent heat, sub-grid-scale convection, and lateral diffusion. An example of a recently computed forecast is included.

55p (57½p by post)

METEOROLOGICAL OFFICE Met.O.854

THE METEOROLOGICAL MAGAZINE

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RETIREMENT OF MR V. R. COLES

Mr V. R. Coles, Deputy Director of the Meteorological Office responsible for forecasting services, retired on 9 September 1973 after 36 years' service. He graduated in mathematics and physics at Reading University in 1934 and was then awarded a Henry Fellowship for a year's study and research at Yale University in the U.S.A. On returning to England he continued his research at Reading University, taking the Master of Science degree, and accepted an appointment in the Meteorological Office in April 1937. His career was to be spent almost entirely in synoptic meteorology — weather forecasting, the organization of forecasting services and research into the problems of synoptic meteorology.

During the first decade of his career in the Office Roy Coles served with the Royal Air Force in a variety of posts, at the headquarters of Bomber Command, at flying stations, at the School of Air Navigation and on an overseas tour in Iraq. In 1947 he was posted to the Central Forecasting Office, then in Dunstable, and he spent the next eight years on the Senior Forecasters' roster. He then went to Cyprus on promotion to Senior Principal Scientific Officer for a tour of duty as Chief Meteorological Officer to the Royal Air Force in the Near East.

On returning home towards the end of 1957 Mr Coles was appointed Assistant Director responsible for research in synoptic meteorology, a post he held for four years, and then became the Assistant Director in charge of the Central Forecasting Office. In 1966 he was promoted to Deputy Chief Scientific Officer and, as a Deputy Director of the Office, assumed responsibility for all its forecasting services, not only in the Central Forecasting Office but also at the outstations serving the defence forces and civil aviation and at the weather centres serving the general public, industry and commerce. His period as Deputy Director marked the transition to a highly centralized forecasting organization based on computerized techniques using a very powerful computer as well as modern communications facilities.

With all this experience in weather forecasting and with his ever-widening responsibilities, Roy Coles naturally became prominent in international affairs and on several occasions was leader of the British delegation to meetings of WMO's Technical Commission for Synoptic Meteorology, now called the Commission for Basic Systems. He also played a leading role in the intergovernmental meetings on the North Atlantic Ocean Station scheme.

In a career devoted to synoptic meteorology and its applications to weather forecasting, it was very plain that Roy's talents were being used to the best advantage and this conferred on him a degree of leadership and influence that were to be of wide extent and of great value. His enthusiasm burned brightly throughout his career, showing no diminution in later years but rather a greater insight into the problems that still have to be faced. Roy was a fine sportsman in his day, particularly at cricket, and subsequently a mine of information on a variety of sporting topics. Always relaxed and approachable, he will be greatly missed. We wish him and Mrs Coles many years of happiness and good health in their retirement.

P. J. MEADE

AWARD OF IMO PRIZE TO MR J. S. SAWYER

The World Meteorological Organization has awarded the International Meteorological Organization Prize, its highest honour, to Mr J. S. Sawyer, F.R.S., Director of Research in the Meteorological Office for his outstanding researches in dynamical meteorology and for his important contributions to international collaboration in meteorological research. A similar award has been made to Dr C. H. B. Priestley, F.R.S., of the Commonwealth Scientific and Industrial Research Organization, Australia, who worked as a research scientist in the Meteorological Office from 1939 to 1946.

Mr Sawyer's researches, mainly devoted to analytical and theoretical investigations of the structure and dynamics of weather systems, ranging in scale from lee waves to the global circulation of the atmosphere, have always been motivated by a strong desire to improve the standards of weather forecasting. He played a key role as a research scientist in pioneering numerical weather prediction in the Meteorological Office and it was under his direction that the current 10-level hemispheric models were developed and brought into operational service.

He has done a great deal of work over the years for international relations in meteorology, on behalf of both the World Meteorological Organization and the International Council of Scientific Unions. In particular, he has been a member of the Joint Organizing Committee for the joint WMO/ICSU Atmospheric Research Programme since its inception, and is currently President of the WMO Commission for Atmospheric Sciences.

Of the 18 IMO Prizes awarded since their inception in 1956, no fewer than four have been awarded to members of the Meteorological Office and Mr Sawyer joins the distinguished company of Mr E. Gold (1958), Dr R. C. Sutcliffe (1963) and Sir Graham Sutton (1968). It is hoped that the presentation of the medal, certificate and prize will be made at a ceremony in Bracknell early next year.

This high and well-deserved honour will give widespread pleasure to Mr Sawyer's colleagues within the Office and in the meteorological community at large.

B. J. MASON

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NEW INDICES TO LOCATE CLEAR-AIR TURBULENCE

By R. BROWN

Summary. A test of the effectiveness of two indices for locating areas of clear-air turbulence on 12 days of widespread aircraft reports is presented. These indices were suggested by Roach as a modification of an earlier index derived by him on theoretical grounds, but which has proved to be impracticable for direct use in locating clear-air turbulence. The tests suggest that the indices are better than the Richardson number in locating clear-air turbulence and are promising enough to warrant further development. One of the days tested is presented as a case study.

Introduction. Although during the last few years there has been considerable progress in understanding the physical mechanism of clear-air turbulence (CAT) there has been little corresponding improvement in its routine forecasting. Forecasts are usually produced by associating certain upper-air patterns with the occurrence of CAT and by empirical associations between wind shears (both horizontal and vertical) and CAT occurrence. The turbulent areas forecast by these methods are large and it is an important problem to try to reduce the areas in which CAT is forecast without sacrificing accuracy. Roach[1] derived an index to locate areas where CAT is likely from a theoretical consideration of the synoptic processes involved in the production of CAT. Unfortunately it proved impossible to evaluate fields of this index by using synoptic upper-air data because of the poor spatial resolution of these data. This led Roach (unpublished note) to propose two modified forms of his original index which could be more easily evaluated from conventional synoptic data. This paper examines the effectiveness of these modified indices in locating areas of CAT on 12 days when moderate or severe turbulence was reported. A detailed case study is presented of one of these days when an exceptional number of turbulence reports was received.

Theoretical considerations. It is now generally accepted that Kelvin–Helmholtz instability (KHI) occurring in regions of large vertical wind shear is a major cause of CAT. When a large shear exists between two layers of a fluid with a stable density configuration the boundary can become distorted into an amplifying wave or billow which finally breaks down into turbulence. This process has been observed in the laboratory (Thorpe[2]), in the ocean (Woods[3]) and, by using a sensitive radar, in the atmosphere (Browning;[4] Browning, Watkins, Starr and McPherson[5]). A large static stability can inhibit the onset of KHI unless the shearing stress associated with the wind shear is sufficient to predominate. The Richardson number (*Ri*) is a measure of the relative size of these two opposing effects. This may be written in pressure co-ordinates :

$$Ri = -\frac{1}{\rho\theta}\,\frac{(\partial\theta/\partial p)}{(\partial \mathbf{V}/\partial p)^2}, \qquad \ldots(1)$$

where

ρ = density,

θ = potential temperature, and

$\dfrac{\partial \mathbf{V}}{\partial p}$ = vertical shear of horizontal wind.

It has been shown from theoretical considerations (Howard[6]) that $Ri < \frac{1}{4}$ is a necessary but not sufficient condition for the onset of KHI. Attempts have been made to locate areas of CAT using *Ri* fields produced from routine upper-air soundings. The correlation between *Ri* produced in this way and reports of CAT is rather poor mainly because of the poor vertical resolution of the upper-air data. Typically, upper winds are averaged over a vertical depth of about 750 m, yielding *Ri* over 1·5 km to 2 km, whilst 95 per cent of turbulent patches are less than 500 metres thick (Anderson[7]). When *Ri* is calculated from data of a finer vertical resolution, for example, data from a specially instrumented aircraft (Roach and Axford — submitted to the *Quarterly Journal of the Royal Meteorological Society*), there is a closer correlation, suggesting that the association of CAT with KHI is basically correct.

Roach attempted to avoid the problem of evaluating *Ri* from synoptic data by identifying areas where *Ri* was being reduced by the large-scale flow. Assuming hydrostatic, adiabatic, inviscid flow he obtained an expression for the rate of change of the logarithm of *Ri* (Reference 1, equation 10) which can be written in the following form :

$$\Phi \equiv -\frac{D}{Dt} \ln Ri$$

$$= (2\,Ri - 1) \left|\frac{\partial \mathbf{V}}{\partial p}\right| \left|\nabla_\theta p\right| \cos\beta$$

$$+ \left(\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}\right) \cos 2\alpha - \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right) \sin 2\alpha \qquad \ldots (2)$$

where $\mathbf{V}$ = horizontal wind vector

$\nabla_\theta p$ = the horizontal pressure gradient in an isentropic surface

u = orthogonal component of $\mathbf{V}$ directed east

v = orthogonal component of $\mathbf{V}$ directed north

α = angle between $\frac{\partial \mathbf{V}}{\partial p}$ and north measured in a clockwise direction

β = angle between $\frac{\partial \mathbf{V}}{\partial p}$ and $\nabla_\theta p$ (which is 90° in geostrophic flow).

It was hoped that synoptic evaluation of Φ would delineate areas in which *Ri* was being rapidly reduced (Φ large and positive) until it fell below some small critical value and turbulence was initiated by KHI. Roach compared fields of Φ evaluated by hand from synoptic data with aircraft reports of severe turbulence and found little correlation between them, Φ sometimes being negative in the vicinity of the turbulence. He observed that the magnitudes of the multipliers $(\partial u/\partial x - \partial v/\partial y)$ and $(\partial u/\partial y + \partial v/\partial x)$ tended to be large in CAT areas. Roach also discussed the energetics of CAT production based on the principle that if the synoptic-scale deformation processes reduce *Ri* across a layer below its critical value the resultant turbulence tends to increase *Ri* across that layer. The turbulence will decay unless *Ri* can be maintained below its critical value by the deformation processes. An expression for the energy dissipation ε was derived by assuming that the turbulence (increasing *Ri* across the layer) works against the deformation processes (reducing *Ri* across the layer), the net result being that *Ri* across the layer is held to a small limiting value.

The resulting expression was :

$$\varepsilon = \Phi \frac{(\Delta \mathbf{V})^2}{24} \text{ for all positive } \Phi , \qquad \ldots (3)$$

where $\Delta \mathbf{V}$ denotes the velocity difference across the turbulent layer. The performance of ε as a locator of CAT was not examined by Roach and equal emphasis is placed in this paper on evaluating ε and a modified version of Φ.

Modified turbulence indices. It can be seen from equation (2) that the value of the index Φ is sensitive to the orientation of the vertical wind shear vector which can change rapidly with height, especially near the tropopause. Examples of this are shown as looped hodographs in References 4 and 8. Fields of the angles α and β cannot be derived from synoptic data with any degree of accuracy because of the poor spatial resolution of these data. It is believed that this is the cause of the rather random pattern of the Φ-fields obtained in the original tests. The index Φ has been modified to remove the effects of fluctuations in the orientation of the vertical wind-shear vector. The modified index Φ_m is derived in the Appendix and takes the form :

$$\Phi_m = (0{\cdot}3\ \zeta_a{}^2 + D_S{}^2 + D_T{}^2)^{\frac{1}{2}} \qquad \ldots (4)$$

where $\zeta_a = \partial v/\partial x - \partial u/\partial y + f$, the vertical component of absolute vorticity,

$D_S = \partial u/\partial y + \partial v/\partial x$, the shearing deformation, and

$D_T = \partial u/\partial x - \partial v/\partial y$, the stretching deformation.

A modified version of the index ε can be evaluated from equation (3) with Φ replaced by Φ_m. A difficulty arises in evaluating ε synoptically in that CAT is usually distributed as an ensemble of patches of various thickness throughout a region of the atmosphere of synoptic dimensions. $\Delta \mathbf{V}$, which should be evaluated across a turbulent layer, will depend strongly on the layer thickness. In this paper $\Delta \mathbf{V}$ has been evaluated between standard pressure levels appropriate to the heights of the turbulence reports. Thus the depth of the layer across which $\Delta \mathbf{V}$ is evaluated varies from 1400 m to 4200 m. To make comparison of the results possible it is necessary to normalize $\Delta \mathbf{V}$ to some standard thickness which in this paper is taken to be 500 m. As previously noted 95 per cent of turbulence patches are less than 500 metres thick. The resultant ε is designated ε_{500}.

Comparison of indices with turbulence reports on 24 November 1971. A special request for CAT reports near the British Isles resulted in 45 reports of moderate or severe turbulence being received on this day for times between 10 and 22 GMT. The high-power Defford radar was operational from 10 to 18 GMT and a large billow event was observed at 1113 GMT.

(a) *Synoptic situation.* The midday surface chart for the British Isles and immediate vicinity is shown in Figure 1. A ridge from a stationary high over the Atlantic covered the British Isles. As a deep low near Jan Mayen moved south-eastwards towards western Norway an associated warm front moved steadily south-eastwards across the British Isles. A north-north-easterly jet between 250 mb and 300 mb lay along the line Aughton–Camborne at midday. A ridge from an upper high to the west of the British Isles extended over the British Isles during the day as the jet weakened and moved away south-eastwards. A cross-section for midday from Long Kesh to De Bilt is shown in Figure 2. A notable feature of the midday ascents is a shear of 90 knots between 400 mb and 300 mb at Hemsby. This is associated with an upper frontal zone.

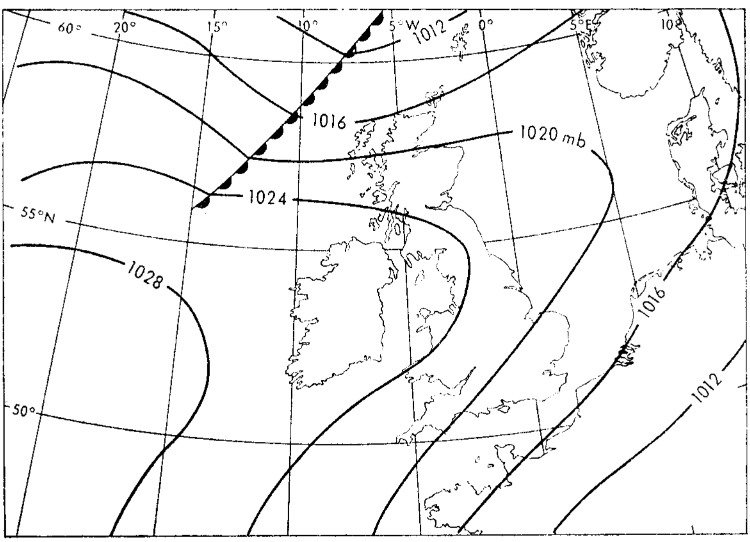

FIGURE 1—SURFACE CHART FOR 12 GMT, 24 NOVEMBER 1971

(b) *Indices and turbulence reports.* Fields of the indices Φ_m and ε_{500} have been evaluated for 12 GMT and 18 GMT at 400 mb and are reproduced in Figures 3–6. Richardson numbers for 12 GMT have been computed and are shown in Figure 7. The indices have been produced by hand analyses of the wind fields, $\Delta\mathbf{V}$ for ε_{500} being evaluated across the layer 500–300 mb. Many stages are involved in the analyses making it difficult to estimate the accuracy of the final product. Assuming that the winds are accurate to 1 m/s, taking the Coriolis parameter as 10^{-4} s^{-1}, and evaluating the wind gradients over 1000 km, the maximum error for $\Phi_m = 10^{-4}$ s^{-1} has been estimated at approximately 25 per cent. Small values of ε_{500} are very susceptible to errors in the winds because of the factor $(\Delta\mathbf{V})^2$. Using the assumptions made above the maximum error for $\varepsilon_{500} = 0{\cdot}25$ cm^2 s^{-3} has been estimated at 50 per cent, whilst for $\varepsilon_{500} = 2{\cdot}5$ cm^2 s^{-3} this is reduced to 26 per cent. These figures suggest that it is probably unwise to believe the smaller-scale features of the

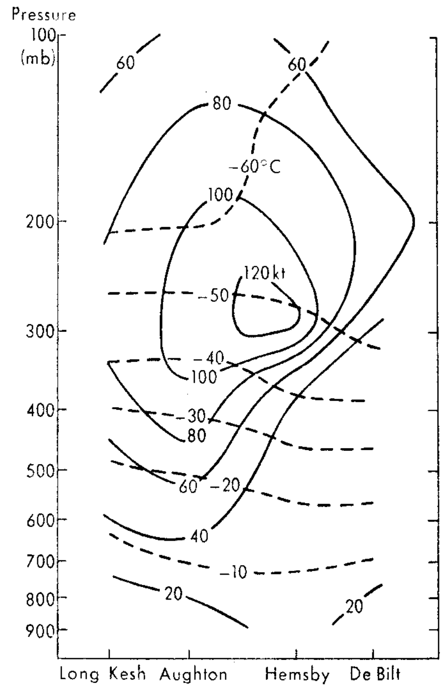

FIGURE 2—VERTICAL CROSS-SECTION OF WIND SPEED AND TEMPERATURE FROM LONG KESH TO DE BILT FOR 12 GMT, 24 NOVEMBER 1971

——— Wind speed perpendicular to section, in knots.
- - - - Temperature in degrees Celsius.

fields. There is a general coherence of shape and position of the fields between 12 GMT and 18 GMT making the gross features of the fields believable. All aircraft turbulence reports between 500 mb and 300 mb for two hours either side of 12 GMT and 18 GMT are superposed on Figures 3–7 to illustrate their positions relative to the fields of the indices and Richardson number. It can be seen that as the maxima of the fields of the indices move south-eastwards between 12 GMT and 18 GMT there is a corresponding displacement of the turbulence reports. It is not possible to observe the movement of the *Ri* field because no temperatures are available for its computation at 18 GMT. Considering the 12 GMT and 18 GMT data together the isopleth $\Phi_m = 10^{-4}\ s^{-1}$ encloses 83 per cent of the turbulence reports and 20 per cent of the chart area. Similarly the isopleth $\varepsilon_{500} = 0{\cdot}5$ encloses 83 per cent of the turbulence reports and 22 per cent of the chart area. At midday the isopleth $Ri = 5$ encloses 73 per cent of the reports and 26 per cent of the chart area. For this day Φ_m and ε_{500} are equally good at locating CAT and both seem slightly better than *Ri*. Time–height sections of the Φ_m and ε_{500} fields have been constructed for Malvern to make a comparison with the billow events observed there. These are shown in Figures 8 and 9. Besides data from the main synoptic hours some additional data have been used from special ascents made at Malvern.

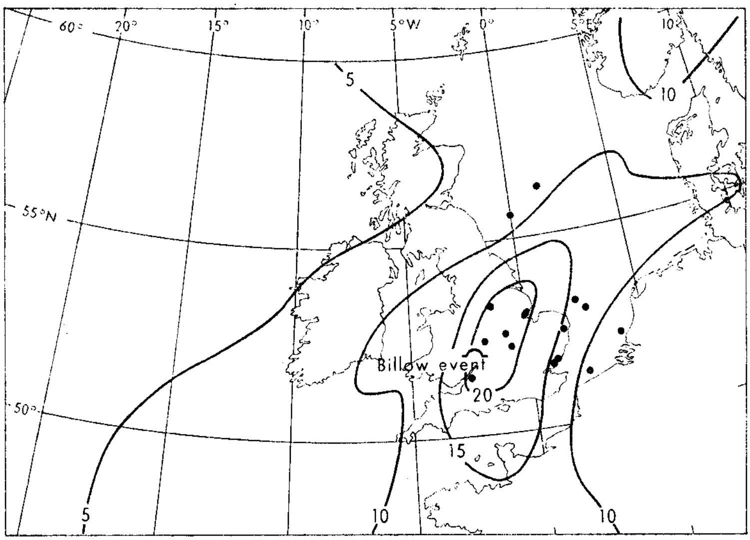

FIGURE 3—FIELD OF Φ_m AT 400 mb FOR 12 GMT, 24 NOVEMBER 1971 IN UNITS OF $10^{-5}\ s^{-1}$

● Aircraft turbulence reports for 10 GMT to 14 GMT between 500 and 300 mb.
The billow event was observed at Malvern at a height of 7·9 km at 1113 GMT.

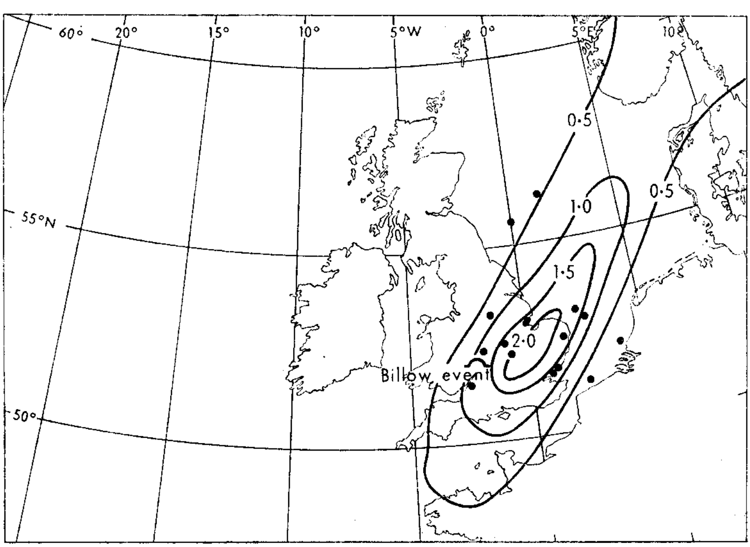

FIGURE 4—FIELD OF ε_{500} AT 400 mb FOR 12 GMT, 24 NOVEMBER 1971 IN UNITS $cm^2\ s^{-3}$

See notes under Figure 3 for explanation of aircraft turbulence reports and billow event.

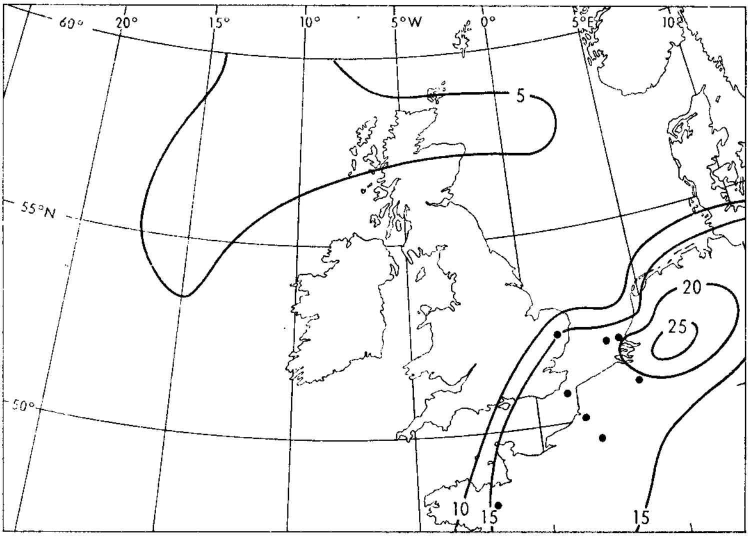

FIGURE 5—FIELD OF Φ_m AT 400 mb FOR 18 GMT, 24 NOVEMBER 1971 IN UNITS OF 10^{-5} s^{-1}

● Aircraft turbulence reports for 16 GMT to 20 GMT, between 500 and 300 mb.

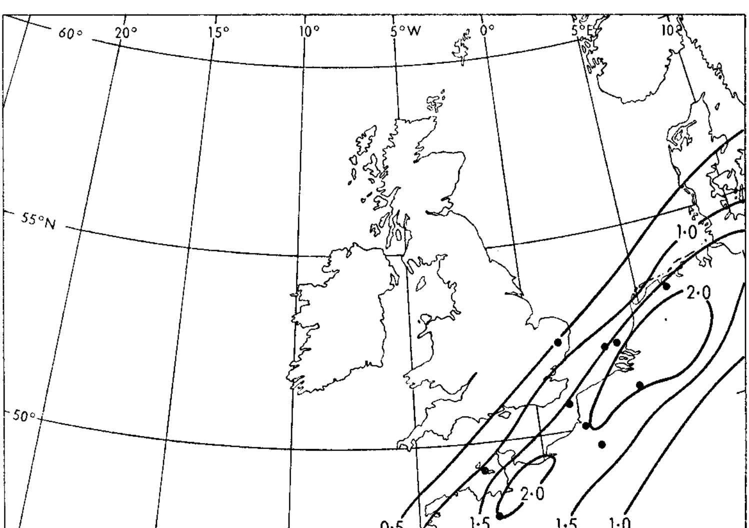

FIGURE 6—FIELD OF ε_{500} AT 400 mb FOR 18 GMT, 24 NOVEMBER 1971 IN UNITS cm^2 s^{-3}

See note under Figure 5 for details of aircraft turbulence reports.

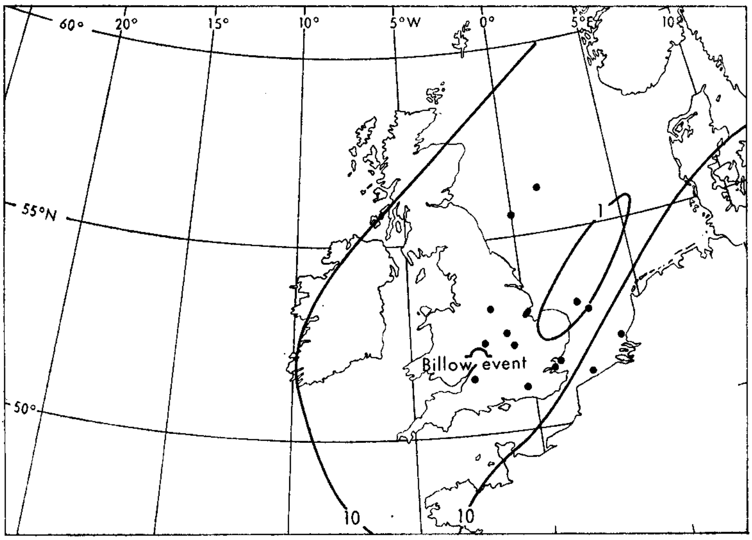

FIGURE 7—FIELD OF RICHARDSON NUMBER *Ri* EVALUATED BETWEEN 500 AND 300 mb FOR 24 NOVEMBER 1971

See notes under Figure 3 for explanation of aircraft turbulence reports and billow event.

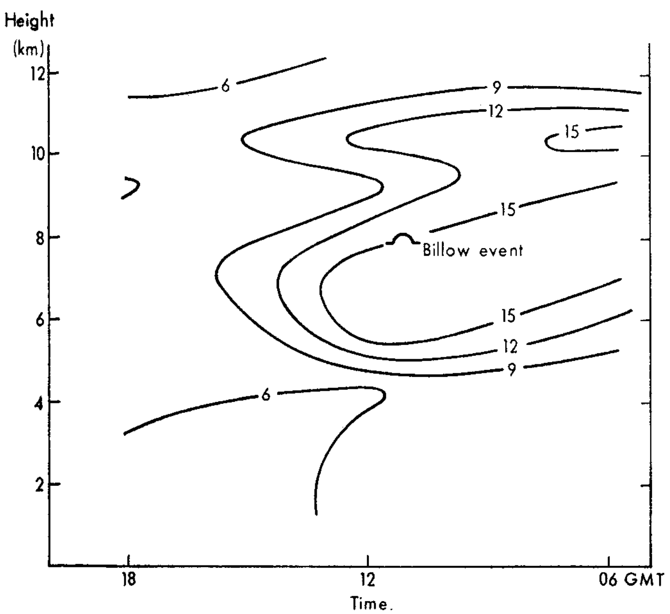

FIGURE 8—TIME–HEIGHT CROSS-SECTION OF Φ_m FOR MALVERN ON 24 NOVEMBER 1971 IN UNITS OF 10^{-5} s^{-1}

See note under Figure 3 for details of billow event.

A word of explanation is needed here concerning a billow event as observed by the Defford high-power radar. The Defford radar receives echoes from optically clear air which are attributed to temperature or humidity inhomogeneities occurring on a scale of half the radar wavelength, i.e. approximately 5 cm. These inhomogeneities are the result of turbulence caused by small-scale KHI. It is possible for KHI billows to occur in the atmosphere simultaneously on several scales, the largest having amplitudes of several hundred metres. The radar has a resolution of 100–200 m and if the larger-scale KHI billows do not exceed this in amplitude the radar echoes are observed to be featureless layers. When billows of a larger amplitude occur a certain degree of their structure is resolved by the radar and their amplitude and wavelength can be measured.

Such an event was observed on 24 November 1971 and its position is marked on the time–height sections. It occurred in a region of above-average Φ_m and ε_{500} values. As the radar was out of use during the earlier part of the day when the largest Φ_m and ε_{500} values occurred other billow events may have taken place unobserved.

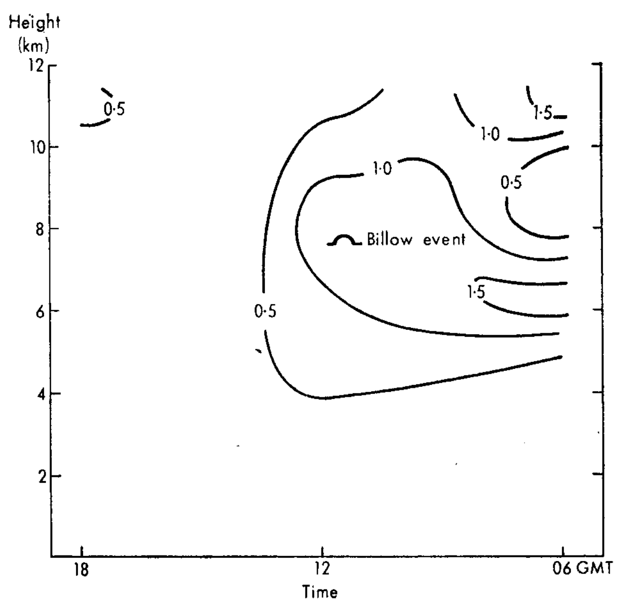

FIGURE 9—TIME–HEIGHT CROSS-SECTION OF ε_{500} FOR MALVERN ON 24 NOVEMBER 1971 IN UNITS $cm^2\ s^{-3}$

See note under Figure 3 for details of billow event.

Further tests of the indices. Fields of the indices have been produced by hand for another 11 days when either aircraft reports of severe CAT were received or billow events were observed using the Defford high-power radar. The indices have been evaluated at the standard levels appropriate to the heights of the turbulence reports and over the same chart area as that used for the 24 November 1971 case study. Typically the number of reports varied from one to five so that no individual day is worth a case study. Considered together they give an indication of the performance of the indices. Tables I, II and III show the number of turbulence reports occurring where Φ_m and ε_{500} are larger than certain values and Ri is less than certain values. To see these figures in perspective one must consider the fraction of the chart area covered on average by various values of the indices and this is shown in the second column of the tables. In Figure 10, which summarizes Tables I–III, the number of turbulence reports, converted to a percentage of the total, is plotted against the corresponding percentage chart area. A line bisecting the angle between the axes of this graph represents no skill at locating CAT, i.e. by chance one would expect to find 50 per cent of the reports on average in 50 per cent of the chart area. The significance of the figures in the first two columns of the tables has been examined statistically. There is a small probability of finding any one turbulence report in a given area of the chart and hence it has been assumed that the probability of a certain number of the reports falling by chance in a fraction of the chart area is governed by a

TABLE I—NUMBER OF TURBULENCE REPORTS LOCATED WHERE Φ_m IS LARGER THAN CERTAIN VALUES, THE FRACTIONAL CHART AREA WHERE Φ_m IS LARGER THAN THESE VALUES ON AVERAGE, AND THE SIGNIFICANCE LEVEL OF THESE FIGURES, BASED ON A TOTAL OF 24 TURBULENCE REPORTS

$\Phi_m \times 10^5$	Number of turbulence reports (X)	Fraction of chart area (A)	Significance level
s^{-1}			*per cent*
$\geqslant$10	17	0·39	1·5
$\geqslant$15	7	0·10	1·0
$\geqslant$20	2	0·024	12
$\geqslant$25	1	0·011	26

TABLE II—NUMBER OF TURBULENCE REPORTS LOCATED WHERE ε_{500} IS LARGER THAN CERTAIN VALUES, THE FRACTIONAL CHART AREA WHERE ε_{500} IS LARGER THAN THESE VALUES ON AVERAGE, AND THE SIGNIFICANCE LEVEL OF THESE FIGURES, BASED ON A TOTAL OF 24 TURBULENCE REPORTS

ε_{500}	Number of turbulence reports (X)	Fraction of chart area (A)	Significance level
cm^2 *s*$^{-3}$			*per cent*
$\geqslant$0·1	17	0·48	5
$\geqslant$0·2	10	0·36	36
$\geqslant$0·5	10	0·18	1
$\geqslant$1·0	9	0·08	0·02
$\geqslant$2·0	5	0·024	0·04
$\geqslant$3·0	2	0·006	0·5

TABLE III—NUMBER OF TURBULENCE REPORTS LOCATED WHERE Ri IS LESS THAN CERTAIN VALUES, THE FRACTIONAL CHART AREA WHERE Ri IS LESS THAN THESE VALUES ON AVERAGE, AND THE SIGNIFICANCE LEVEL OF THESE FIGURES, BASED ON A TOTAL OF 24 TURBULENCE REPORTS

Ri	Number of turbulence reports (X)	Fraction of chart area (A)	Significance level
			per cent
$\leqslant$20	17	0·55	16
$\leqslant$10	10	0·35	33
$\leqslant$5	9	0·23	11
$\leqslant$1	1	0·02	9

Poisson distribution. If m is the mean number of reports found in a fraction A of the chart area ($m = NA$, where N is the total number of CAT reports) and $P(x)$ the probability that x reports will fall at random in a fraction A of the area then

$$P(x) = \frac{e^{-m}\, m^{x}}{x!} \qquad \ldots (5)$$

A more meaningful statistic in this case is the probability P that x or more reports will fall at random in a fraction A of the chart area, and this is given by the summation

$$P(x) = \sum_{J=x}^{J=\infty} \frac{e^{-m}\, m^{J}}{J!} \qquad \ldots (6)$$

The columns headed 'significance level' in Tables I–III show the values of P expressed as a percentage for the corresponding X and A values in the tables. Values of P less than 5 per cent may be taken as showing a significant departure from a random distribution. The most outstanding feature of the results can be seen by referring to Table II. The number of CAT reports found where $\varepsilon_{500} \geqslant 0{\cdot}5$ cm^2 s^{-3} is significantly larger than that expected

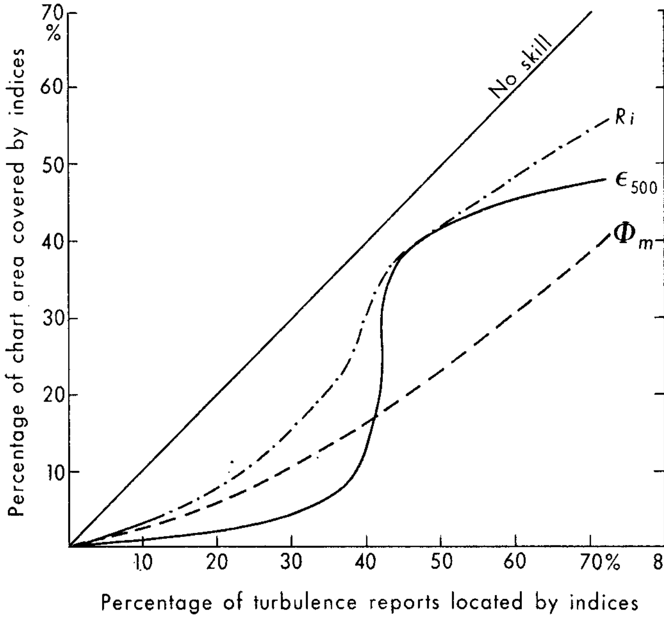

FIGURE 10—SUMMARY OF TABLES I–III

The number of turbulence reports converted to a percentage is plotted against the fractional chart area also converted to a percentage.

by chance. In Table I it can be seen that there is a significant tendency for CAT reports to be located where $\Phi_m \geqslant 10^{-4}\ s^{-1}$. The results for $\varepsilon_{500} \leqslant 0{\cdot}2$ $cm^2\ s^{-3}$ and those for $\Phi_m \geqslant 2 \times 10^{-4}\ s^{-1}$ do not differ from those expected purely by chance. Both indices are superior to *Ri* in locating the turbulence reports, and the performance of the latter is not noticeably different from that expected purely on the basis of chance. The areas required by Φ_m and ε_{500} to locate the majority of the turbulence reports are large. The fields of the indices have been evaluated over an area extending from 48°N to 60°N and 20°W to 10°E. If turbulence occurs within this region it is likely to cover approximately a third of the chart area. The indices have only been evaluated when turbulence was reported within this region. It is possible that if the indices had been evaluated over a much larger area the fractional values in Tables I–III would have been reduced.

Conclusion. The tests described in this paper are open to criticism on the grounds that they are only based on positive reports of CAT. To relate the indices to the probability of encountering CAT it is necessary to have a substantial body of nil reports for the days that CAT was not reported. These were not available at the time this work was performed. It is believed that the tests do show a qualitative relationship between the indices and reports of CAT. These reports are not randomly distributed but are preponderant in areas of large ε_{500} values and above-average Φ_m values. The performance of the indices seems sufficiently encouraging to warrant their further development. This will involve the evaluation of the indices by computer from the output of the Bushby–Timpson 10-level model and comparison with a large body of specially commissioned aircraft observations of CAT and its absence.

Acknowledgement. The author is most grateful to Dr W. T. Roach for his helpful suggestions during the course of this work.

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Appendix I — The derivation of the expression (4) **for the index Φ_m.** By referring to equation (4) it can be seen that there are three terms within parentheses in the expression for Φ_m. The first of these terms is derived from the first term on the right-hand side of equation (2). Removing the factor $2Ri$ from within the parentheses, using equation (1) and noting that

$\nabla_p\theta = -\left(\frac{\partial\theta}{\partial p}\right)\nabla_\theta p$ one may write

$$(2\,Ri - 1)\,\frac{\partial \mathbf{V}}{\partial p}\,.\,\nabla_\theta p = 2(1 - 0{\cdot}5\,Ri^{-1})\,\frac{(\partial\mathbf{V}/\partial p).\nabla_p\theta}{\rho\theta\,(\partial\mathbf{V}/\partial p)^2}\,. \qquad \ldots (1\text{A})$$

Using the gas equation, the equation for hydrostatic equilibrium in the form $\frac{\partial p}{\partial\varphi} = -\rho$ (where φ is the geopotential), and noting that $\frac{\nabla_p\theta}{\theta} = \frac{\nabla_p T}{T}$

one can show that

$$\frac{\nabla_p\theta}{\rho\theta} = -\frac{\partial}{\partial p}(\nabla_p\varphi)\,. \qquad \ldots (2\text{A})$$

The thermal wind equation may be written in terms of the geopotential in the following way :

$$\frac{\partial}{\partial p}(\nabla_p\varphi) = -f\mathbf{k}\times\frac{\partial\mathbf{V}_g}{\partial p} \qquad \ldots (3\text{A})$$

where f is the Coriolis parameter, $\mathbf{k}$ the unit vector along the vertical, and $\mathbf{V}_g$ the geostrophic wind.

Eliminating $\frac{\partial}{\partial p}(\nabla_p\varphi)$ from equations (2A) and (3A) and using the result

to eliminate $\frac{\nabla_p\theta}{\rho\theta}$ from equation (1A) one may write

$$(2\,Ri - 1)\,\frac{\partial \mathbf{V}}{\partial p}\,.\,\nabla_\theta p = 2(1 - 0{\cdot}5\,Ri^{-1})\,\frac{\partial\mathbf{V}}{\partial p}\,.\,\frac{f\mathbf{k}\times\partial\mathbf{V}_g/\partial p}{(\partial\mathbf{V}/\partial p)^2}$$

$$= 2(1 - 0{\cdot}5\,Ri^{-1})\,\frac{f\,\partial\mathbf{V}_g/\partial p}{\partial\mathbf{V}/\partial p}\sin\gamma \qquad \ldots (4\text{A})$$

where γ is the angle between $\frac{\partial\mathbf{V}}{\partial p}$ and $\frac{\partial\mathbf{V}_g}{\partial p}$.

Assume now that the horizontal wind $\mathbf{V}$ is given by the gradient wind equation

$$\mathbf{V}^2 K = f(\mathbf{V}_g - \mathbf{V}) \qquad \ldots (5\text{A})$$

where K = curvature of trajectory.

Differentiating equation (5A) with respect to pressure,

$$f\frac{\partial \mathbf{V}_g}{\partial p} = \frac{\partial \mathbf{V}}{\partial p}(f + 2K\mathbf{V}) + \mathbf{V}^2\frac{\partial K}{\partial p}. \qquad \ldots (6A)$$

The following assumptions are now made concerning equation (6A) :

(a) $\mathbf{V}^2 \dfrac{\partial K}{\partial p}$ may be neglected in comparison with the other terms.

(b) Noting that the vertical component of absolute vorticity may be written $\zeta_a = f + \dfrac{\partial \mathbf{V}}{\partial r} + K\mathbf{V}$ (where $K = \dfrac{1}{r}$) and assuming that $K\mathbf{V}$ and $\dfrac{\partial \mathbf{V}}{\partial r}$ are of the same sign and roughly the same size then from equation (6A) :

$$f\frac{\partial \mathbf{V}_g}{\partial p} \approx \zeta_a \frac{\partial \mathbf{V}}{\partial p}. \qquad \ldots (7A)$$

Combining equations (7A) and (4A) :

$$(2\,Ri - 1)\frac{\partial \mathbf{V}}{\partial p}.\nabla_\theta p \approx 2(1 - 0{\cdot}5\,Ri^{-1})\,\zeta_a \sin\gamma. \qquad \ldots (8A)$$

The term $(1 - 0{\cdot}5\,Ri^{-1})$ is assumed to be of order unity to avoid a separate evaluation of Ri. The angle γ cannot be evaluated meaningfully synoptically and the factor 2 sin γ is accordingly omitted, leaving ζ_a as an approximation to the first term of Φ. Originally $\zeta_a{}^2$ appeared as the first term within the parentheses in the expression for Φ_m. This dominated the other terms in regions of calm where ζ_a tends to f. In order to reduce this spurious effect the first term was reduced by an arbitrary factor to $0{\cdot}3\,\zeta_a{}^2$. The derivation of the terms $D_S{}^2$, $D_T{}^2$ within parentheses in the expression for Φ_m is now considered. Looking at the right-hand side of equation (2) it can be seen that the value of the second and third terms depends strongly on the angle α.

It became clear during the trials of Φ that the angles change rapidly with height, producing a quasi-periodic oscillation in the magnitude of these terms of an amplitude determined by the multipliers $(\partial u/\partial x - \partial v/\partial y)$ and $(\partial u/\partial y + \partial v/\partial x)$. The multipliers themselves also change with height, but rather less rapidly so that a characteristic profile of the last two terms of equation (2) would appear as in Figure 11 with the dotted curve forming the modulus of the oscillations. Roach, in a private communication, has suggested that it would be more meaningful to estimate this modulus as an indication of the general intensity of the deformation processes in a region of synoptic dimensions. This modulus is given by the expression $(D_S{}^2 + D_T{}^2)^{\frac{1}{2}}$. The square of the total deformation has been used by others, notably Endlich,[9] as a CAT forecasting index. In formulating the modified index Φ_m the first term of Φ has been effectively approximated by $(0{\cdot}3)^{\frac{1}{2}}\,\zeta_a$ and the second and third terms by $(D_S{}^2 + D_T{}^2)^{\frac{1}{2}}$. The approximate terms contain no information about the sign of the equivalent terms in the original index, which even if large may be of the opposite sign. To avoid producing unrealistically large values Φ_m is not formed from the algebraic sum of $(0{\cdot}3)^{\frac{1}{2}}\,\zeta_a$ and $(D_S{}^2 + D_T{}^2)^{\frac{1}{2}}$ but in the following manner :

$$\Phi_m = (0{\cdot}3\ \zeta_a{}^2 + D_S{}^2 + D_T{}^2)\ . \qquad \ldots (9A)$$

Finally the index ε_{500} is defined by

$$\varepsilon_{500} = \Phi_m \frac{(\Delta \mathbf{V})^2}{24}\ , \qquad \ldots (10A)$$

where $\Delta \mathbf{V}$ is the velocity difference normalized across a 500-metre layer.

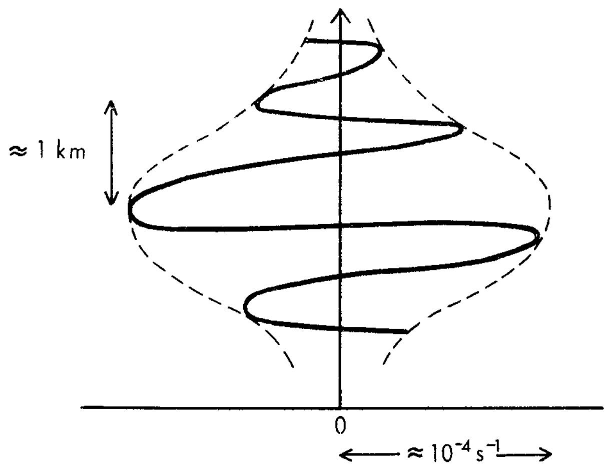

FIGURE 11—IDEALIZED ILLUSTRATION OF RELATIONSHIP BETWEEN $(D_T \cos 2\alpha - D_S \sin 2\alpha)$ AND $(D_T{}^2 + D_S{}^2)^{\frac{1}{2}}$ WHEN VECTOR $\partial \mathbf{V}/\partial p$ IS ROTATING WITH HEIGHT

——— $(D_T \cos 2\alpha - D_S \sin 2\alpha)$
- - - - $(D_T{}^2 + D_S{}^2)^{\frac{1}{2}}$
α is the angle between $\partial \mathbf{V}/\partial p$ and North.

551.577.37:551.589.1(420+429)

HIGH VALUES OF DAILY AREAL RAINFALL OVER ENGLAND AND WALES AND SYNOPTIC PATTERNS

By E. N. LAWRENCE

Summary. Seasonal and secular variation of the higher values of daily areal rainfall is examined in relation to synoptic patterns. During recent years, there has been an increase in the number of days with high values of areal rainfall and also an increase in the frequency of days of cyclonic weather type. Seasonal variation suggests that thermal instability is an important factor.

Introduction. Daily values of areal rainfall over England and Wales were calculated for the period 1950–72, mainly for the purpose of obtaining synoptic-type rainfall averages. In this note, the seasonal and secular variation of the higher values of daily areal rainfall is discussed in relation to synoptic patterns.

Method. The method of calculating daily areal rainfall over England and Wales is described elsewhere.[1] For various rainfall thresholds, the annual variation, by month and by quarter, is shown in Table I and the individual quarterly and yearly values are given in Table II. Occasions of daily areal rainfall of 20 mm (0·79 inches) or more are listed in Table III which shows the associated synoptic type[2] and the mean midday surface pressure.

Results. From the number of occurrences of daily values of areal rainfall $\geqslant$10, $\geqslant$15, $\geqslant$20 and $\geqslant$25 mm, presented in Table I, it can be seen that for thresholds up to and including $\geqslant$20 mm, the number of occurrences is highest in November and lowest in April (but zero in May for daily values $\geqslant$20 mm). For daily values of rainfall $\geqslant$25 mm, two occasions occurred in July and the other four in April, September, October and December. Two of the three occasions of daily rainfall $\geqslant$30 mm occurred in July (the other occasion being in October) and the absolute maximum value of daily rainfall also occurred in July.

Days of areal rainfall $\geqslant$10 mm occurred with various synoptic types as follows: 149 cyclonic days, that is, 13·0 per cent of all cyclonic days; 82 days (5·7 per cent) of straight-westerly type; and 20 days (7·0 per cent) of cyclonic-westerly type. These synoptic types refer to the Lamb catalogue of daily synoptic types.[2] For the threshold $\geqslant$20 mm (see Table III), the corresponding percentages are 1·0, 0·3, 0·3; and for the threshold $\geqslant$25 mm, the percentages are 0·3, 0·07 and nil (that is, for cyclonic, straight-westerly, and cyclonic-westerly types, respectively). Clearly, the synoptic type most strongly associated with the higher values of daily areal rainfall is the cyclonic type.

It can be seen from the indication of pressure level (Table III), that high values of daily areal rainfall tend to occur with about average pressures in summer and reflect the effects of thermal convection or thermal lows.[3] In contrast, the cyclonic pressure levels on occasions of high daily rainfall during the winter half-year are generally associated with baroclinic lows of well-below-average pressure.

The yearly values of the number of occurrences of areal rainfall exceeding 20 mm per day (Table II) increased markedly during the period; for example, there are 4 occasions in the 1950s, 12 occasions in the 1960s and 6 in the period 1970–72: again, daily values exceeding 25 mm occurred only in the years 1960, 1967, 1968, 1969, 1971 and 1972, while daily values exceeding 30 mm occurred only in 1967, 1968 and 1969. The results of a variance ratio analysis (F-test) on the three equal periods of seven years in the 21 years ending at 1972 show that the annual frequency of days with 25 mm or more has period differences which are significant at the one per cent level (that is, less than one chance in a hundred of the series occurring by accident). The series for 20 mm or more shows a corresponding significance at the five per cent level.

The yearly frequencies of days with cyclonic type are shown in Figure 1. It can be seen that the period from 1952 onwards indicates a change (which can be best represented by a linear term) which has less than one chance in 50 of arising by accident in the sampling of such data.

Conclusion. There has been an increase in the number of days with high values of areal rainfall ($\geqslant$20 mm) over England and Wales during recent years. During the same period, there has also been an increase in the frequency

TABLE I—MONTHLY AND SEASONAL DISTRIBUTION OF HIGH VALUES OF DAILY AREAL RAINFALL EQUALLING OR EXCEEDING VARIOUS LIMITS, OVER ENGLAND AND WALES DURING THE PERIOD FROM 1950 TO 1972

	Jan.	Feb.	Mar.	Jan.–Mar.	Apr.	May	June	Apr.–June	July	Aug.	Sept.	July–Sept.	Oct.	Nov.	Dec.	Oct.–Dec.
								Number of days								
⩾10 mm (0·39 in)																
1950–59	17	19	9	45	5	8	10	23	16	21	18	55	13	29	16	58
1960–69	16	10	10	36	4	8	13	25	16	16	22	54	20	23	22	65
1970–72	4	0	3	7	3	1	3	7	0	3	1	4	2	16	3	21
1950–72	37	29	22	88	12	17	26	55	32	40	41	113	35	68	41	144
⩾15 mm (0·59 in)																
1950–59	2	2	1	5	1	3	5	9	4	4	4	12	5	8	1	14
1960–69	2	1	2	5	0	2	4	6	4	2	6	12	5	5	5	15
1970–72	0	0	1	1	1	0	2	3	0	2	1	3	0	6	1	7
1950–72	4	3	4	11	2	5	11	18	8	8	11	27	10	19	7	36
⩾20 mm (0·79 in)																
1950–59	0	1	0	1	0	0	0	0	0	0	0	0	1	2	0	3
1960–69	1	1	2	4	0	0	0	0	2	1	1	4	2	1	1	4
1970–72	0	0	0	0	1	0	2	3	0	0	1	1	0	2	0	2
1950–72	1	2	2	5	1	0	2	3	2	1	2	5	3	5	1	9
⩾25 mm (0·98 in)																
1950–59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1960–69	0	0	0	0	0	0	0	0	2*	0	0	2	1†	0	1	2
1970–72	0	0	0	0	1	0	0	1	0	0	1	1	0	0	0	0
1950–72	0	0	0	0	1	0	0	1	2	0	1	3	1	0	1	2

* 32·3 mm (1·27 in) and 39·1 mm (1·54 in).
† 31·2 mm (1·23 in).

TABLE II—NUMBER OF OCCASIONS OF DAILY AREAL RAINFALL OVER ENGLAND AND WALES EQUALLING OR EXCEEDING VARIOUS LIMITS DURING EACH QUARTER AND EACH YEAR FROM 1950 TO 1972

	1950	'51	'52	'53	'54	'55	'56	'57	'58	'59	'60	'61	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72
											Number of days												
⩾10 mm																							
Jan.–Mar.	7	7	1	3	3	6	3	4	6	5	6	3	4	3	3	2	5	4	2	4	1	4	2
Apr.–June	1	2	0	3	5	6	0	1	3	2	1	4	1	2	2	2	2	5	3	3	1	4	2
July–Sept.	11	7	6	5	5	0	7	6	6	2	8	5	6	7	1	6	4	4	9	4	1	2	1
Oct.–Dec.	3	6	7	3	13	5	4	3	5	9	12	5	3	3	3	9	8	8	7	7	10	4	7
Year	22	22	14	14	26	17	14	14	20	18	27	17	14	15	9	19	19	21	21	18	13	14	12
⩾15 mm																							
Jan.–Mar.	1	0	1	0	0	0	0	0	1	2	1	0	0	0	1	0	0	1	1	1	0	1	0
Apr.–June	0	1	0	1	3	1	0	0	2	1	1	0	0	0	0	1	1	2	1	0	0	3	0
July–Sept.	2	2	0	0	1	0	3	2	1	1	1	1	3	0	0	3	1	0	2	1	1	1	1
Oct.–Dec.	2	2	1	0	3	0	1	1	2	2	4	1	0	2	1	3	1	2	0	1	4	1	2
Year	5	5	2	1	7	1	4	3	6	6	7	2	3	2	2	7	3	5	4	3	5	6	3
⩾20 mm																							
Jan.–Mar.	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	1	0	1	0	0	0
Apr.–June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
July–Sept.	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	1	0	0	1
Oct.–Dec.	0	1	0	0	0	0	0	1	0	1	2	0	0	1	0	0	0	1	0	0	1	0	1
Year	0	1	0	0	0	0	0	1	1	1	3	0	2	1	1	0	0	2	1	2	1	3	2
⩾25 mm																							
Jan.–Mar.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apr.–June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
July–Sept.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1
Oct.–Dec.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
Year	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1*	1*	1*	0	1	1

* Values ⩾30 mm: 31·2 mm (1·23 in); 32·3 mm (1·27 in); 39·1 mm (1·54 in), respectively.

TABLE III—OCCASIONS OF DAILY AREAL RAINFALL OVER ENGLAND AND WALES EQUALLING OR EXCEEDING 20 mm DURING THE PERIOD 1950–72

Year	Month	Day	Rainfall *mm*	Rainfall *in*	Synoptic type*	Surface pressure† *mb*
1951	Nov.	5	23·1	0·91	C	994
1957	Nov.	3	20·3	0·80	W	986
1958	Feb.	24	20·1	0·79	C	994
1959	Oct.	26	22·4	0·88	W	1009
1960	Jan.	23	20·1	0·79	SW	996
1960	Oct.	8	21·6	0·85	C	996
1960	Dec.	3	29·0	1·14	W	1000
1962	Aug.	6	24·1	0·95	C	1006
1962	Sept.	29	20·8	0·82	S	996
1963	Nov.	17	20·8	0·82	C	998
1964	Mar.	14	21·6	0·85	S	998
1967	Feb.	27	20·3	0·80	W	1000
1967	Oct.	16	31·2	1·23	C	1006
1968	July	10	32·3	1·27	CE	1016
1969	Mar.	12	20·1	0·79	U	1003
1969	July	28	39·1	1·54	C	1015
1970	Nov.	1	21·1	0·83	CW	1012
1971	Apr.	23	25·7	1·01	C	1003
1971	June	10	23·6	0·93	CNE	1010
1971	June	18	24·1	0·95	C	1016
1972	Sept.	8	27·7	1·09	U	1014
1972	Nov.	12	20·1	0·79	C	1002

* C = cyclonic, CNE = cyclonic north-easterly, etc., U = unclassified.
† Pressure at 53°N 2°W at midday on *Daily Weather Report* chart.

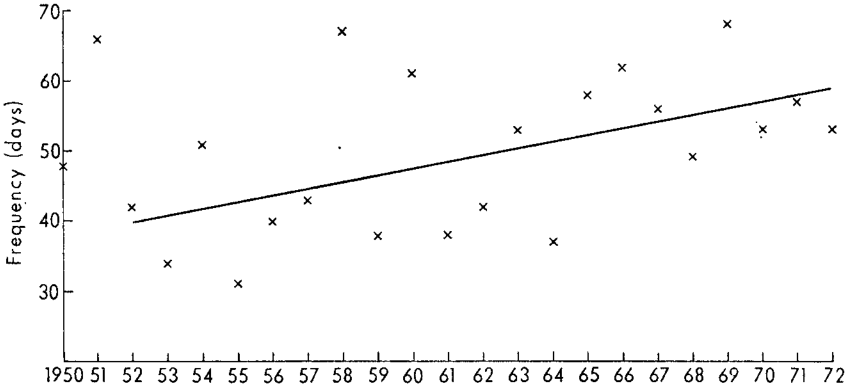

FIGURE 1—YEARLY FREQUENCY OF CYCLONIC TYPES (LAMB CLASSIFICATION) 1950 TO 1972, AND THE LINEAR COMPONENT FOR 1952 TO 1972

of days of cyclonic weather type, thus confirming the association of high areal rainfall with cyclonic weather, though high values of areal rainfall occur with other synoptic weather types and especially when thermal instability is an important factor. This study describes the fluctuations that have occurred in the recent past but does not indicate the changes to be expected in the near future; indeed, it is not possible to say that the indicated 'trends' will continue.

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REVIEWS

Introduction to the nonlinear theory of mesoscale meteorological processes by L. N. Gutman. 240 mm × 175 mm, pp. vi + 224, *illus.*, (translated from the Russian by the Israel Program for Scientific Translations, Jerusalem), John Wiley & Sons Ltd, Baffins Lane, Chichester, Sussex, 1972. Price: £10·35.

Many aspects of the weather such as fog, showers, sea breezes and frontal phenomena, which affect people and communities, are on a small scale, less than hundreds of kilometres in horizontal extent. The local weather forecasts issued by state meteorological services are often interpretations of the synoptic-scale forecasts in terms of these smaller-scale, or mesometeorological, events and these forecasts are of extreme importance to those who must endure the weather. Mesometeorological research is not new; forecasters have been trying to understand local weather conditions almost since forecasting began and descriptions and theories are to be found in the great meteorological texts of a hundred years ago. Since then the literature has abounded in rules for description and prediction but little of the research has been on a connected basis, concerned with generalities. The substantial progress that has been made with numerical prediction on the synoptic and global scales suggests that the numerical approach to mesometeorological processes may be expected to yield success; at the same time the synoptic numerical forecasts provide the background against which the mesometeorological systems develop. There is little doubt that expression of the physics of mesometeorological phenomena in terms of mathematics for introduction into numerical weather prediction will be a major preoccupation of research in the next decade.

Dr Gutman's book, which was published in the U.S.S.R. in 1969, is therefore very timely. It seeks to provide the mathematical abstractions of some of the main mesometeorological processes and it indicates obliquely how these abstractions might be used to provide numerical forecasts. The author considers six main topics; in each he follows the same pattern — a short introductory history of the problem, the simplified equations with some solutions and then some rather fuller equations which are usually insoluble in analytic terms except in rather special cases. The topics are topographical effects, fronts, thermals, cumulus clouds, whirlwinds and tornadoes, and sea-breezes and other local winds. The longest chapter is that on wave motions produced by topography and though it differs in detail from the well-known WMO *Technical Note* No. 34 the development is rather similar. The problems attacked in the other chapters are, of course, much harder because the heat and energy sources and sinks become much more important than in the mountain wave problem and the non-linear effects are considerably increased. The first simplifications, generally having the effect of linearizing the mathematics, give analytic solutions which are at best illustrative and at worst misleading. The second simplifications which include some of the non-linear effects, usually of the dynamical advective terms rather than the physical terms, lead to computed solutions which must be more realistic and these results are well worth looking at.

Perhaps one of the most welcome features of the book is that it provides a résumé of recent Russian research into mesometeorological problems which may not otherwise be easily available. Dr Gutman is well aware also of the work of western authors, as his text and bibliography show. There is no comparable text published in English and the book is bound to be read with great interest as providing a good theoretical basis for attacking meso-meteorological problems.

The translation reads easily and the odd misprint is not likely to mislead. The book is beautifully produced, but alas its price is high even by today's standards and most people will have to be content with referring to a library copy.

E. KNIGHTING

Atmospheric energetics, by Jacques van Mieghem. 235 mm × 155 mm, pp. ix + 306, *illus.*, Clarendon Press: Oxford University Press, 37 Dover Street, London W1X 4AH, 1973. Price: £7·50.

The outward show of the atmosphere is weather — temperature, cloud cover, rain and so on — and locally this is the most important aspect. Yet weather is a product of the motions resulting from the uneven solar heating of the earth/atmosphere system which presents the system with the problem of transferring energy from the equatorial to polar regions and it is not until it is known how this energy is transferred that one can claim to understand atmospheric processes. The general mechanisms, the Hadley circulation and the large-scale atmospheric vortices are well known from observations but need considerable clarification before they become acceptable explanations of the energy transfer. Professor van Mieghem sets out in this book to provide a systematic account of this transfer of kinetic, potential and thermal energies.

He starts by carefully treating in the first half-dozen chapters the fundamental equations of motion and the idea of resolving motions into a basic and fluctuating part and the application to turbulent flow. Two chapters follow on forced and free convection; they are a concise treatment of turbulence near the ground, very necessary because there are important sources and sinks of energy in the boundary layer. The remainder of the book deals with the energy in the free atmosphere. Following normal practice the flow at any given instant is separated into a zonal period average, obtainable from climatology, and departures from this average, the latter usually being termed eddy motions. Equations can then be developed for the energetics of the system, the rates of change of the mean and eddy kinetic and potential energies and their northward transfer. Because the equations of motion are non-linear there must be considerable interaction between waves of different wavelength, e.g. between the weather-bearing systems and the general circulation, and formal expressions are obtainable for the way in which energy is passed from scale to scale. The study of these equations along with the observations allows one to see the inner working of the atmosphere, the cycle of energy conversions and transfers. The equations are particularly suitable for use with the computed results from atmospheric models of the general circulation and provide insight into the atmospheric behaviour in regions where there are few observations.

Professor van Mieghem leads us through all the difficulties in his impeccably logical style and his reduction of the papers in the literature to a readable concision is quite a *tour de force*. Of course, the book is highly mathematical with a large number of equations because the subject matter is highly numerate; however, it is essentially all the same kind of mathematics and not difficult to follow. It is a particularly opportune moment for publication, since the energetics of the atmosphere will be closely studied over the next few years when the Atlantic Tropical Experiment of the Global Atmospheric Research Programme (GARP) and the First GARP Global Experiment (FGGE) will provide a great deal of extra observational data.

E. KNIGHTING

Turbulent diffusion in the environment, by G. T. Csanady. 240 mm × 160 mm, pp. x + 248, *illus.*, D. Reidel Publishing Company, P.O. Box 17, Dordrecht, Holland, 1973. Price: Dfl. 40.– –. (hard-cover edition Dfl. 70.– –).

Dr Csanady's book is concerned primarily with the theoretical and mathematical treatment of turbulent diffusion problems and has sprung from courses given to engineering graduate students specializing in environmental fluid mechanics. It consists of seven chapters dealing with the following topics: molecular diffusion and Fick's 'constant diffusivity' law, statistical theory in the context of Brownian motion and random-walk processes, statistical theory applied to turbulent diffusion in laboratory and atmospheric flows, growth of plume elements especially in water, dispersion in shear flow, effects of density stratification and behaviour of buoyant plumes, and the fluctuation in the concentration of dispersed material.

The most novel sections of the book are in the last three chapters, the content of which is drawn substantially from the author's own original papers. His apologies for the preference given to his own contributions are unnecessary, as they are enlightening and stimulating of further thought, as indeed is the book as a whole. Generally speaking, the reader is steered skilfully through the subtleties which abound in the basic concepts. There will be finer points on which specialists in the field will be ready to argue, but on the whole a balanced and realistic view is presented. Obviously, the air pollution meteorologist must not expect the book to provide him with a full background of the observational experience in respect of atmospheric turbulence and dispersion or with detailed working rules. Nevertheless the more mathematically inclined will find it a valuable component of his library and one which will undoubtedly repay selective study.

The style is concise and neat and there are very few misprints. Absence of an index is, however, an important omission and one which will be a disadvantage in sustained use of the book. Editions are available in both limp or hard covers. In both cases the price is high, but judged from the limp-covered version reviewed here the production is of excellent quality as regards paper, printing and general layout.

F. PASQUILL

Earth's voyage through time, by David Dinely. 215 mm × 135 mm, pp. 320, *illus.,* Hart-Davies, MacGibbon, 3 Upper James Street, Golden Square, London W1R 4BP, 1973. Price: £3·95.

This book describes the story of our planet from its formation some 4600 million years ago right up to the present time, with some brief speculations on the next 5000 million years.

It is well written and well illustrated and contains very few errors either of fact or in the production. Almost any scientist will find the book fascinating since the author's knowledge clearly extends over a wide range of scientific disciplines. He considers among other things the origin of the solar system, the nature of the interior of the earth, the composition of the earth's atmosphere and how it has varied over geological time, the possible origin of life on earth, and how it has evolved. However, the book is inevitably mainly about geology in the widest sense including how the structure of the earth's surface has changed throughout its history and is still changing today and how the various forms of life have evolved from their early beginnings.

To the present reviewer the most interesting chapters were those dealing with the continental drift theory originally propounded by Wegener (a meteorologist!). The author produces most convincing evidence that some 100 million years ago all the land masses of the earth were contained in one huge continent which broke up into 'plates' (likened to ice floes) which have subsequently drifted apart. Apparently the mechanism for this, best observed in the Atlantic, is that there is virtually continuous up-motion going on in some areas followed by lateral spreading of the earth's crust. This results in an expansion of the ocean floor which amounts, in the Atlantic, to about 2 cm/year. This must of course be compensated for in some way since the earth as a whole is not getting bigger. What apparently happens is that at the deep ocean trenches (the ultimate in waste disposal?) one section of the ocean floor is sinking under another and becomes reabsorbed in the earth's core so that the whole forms a sort of giant slow convection system. Among the evidence for this sort of mechanism are the facts that the rocks of Brazil and Africa are similar and of similar age in the region where the two continents originally fitted together; the rocks on either side of the ridge on the floor of the North Atlantic Ocean are of similar age, and the age of all rocks on the ocean floor is less than 70 million years. This would represent the time the continents have been drifting apart at about 2 cm/year.

World geography as we now know it has thus developed from a single continent in about 70 million years which is only about 1½ per cent of geological time. It is suggested that the process of formation and break-up of land masses has taken place at least once before in the history of the eart

Against this background it becomes easier to understand many geological puzzles. It is here that the meteorologist may become interested: if there was only one continent, clearly world climate would be different. The author suggests a super monsoon type with outflow from the continent in winter and extreme conditions in the continental interior. In other epochs more like our own, climates would be more equable in many areas and more variable generally. There is scope for thought here and for some original work by meteorologists. It would be interesting for instance to work out what the general circulation would have been like at the time of one world continent and how it would have reacted as North and South America gradually drifted apart from Europe and Africa.

However, apart from a little on the possible causes of ice ages, there is not much in the book of direct interest to meteorologists. Nevertheless I can thoroughly recommend it as a fascinating study of what science has been able to deduce of the earth's history.

R. A. S. RATCLIFFE

Determination of the water equivalent of snow cover, edited by L. K. Vershinina and A. M. Dimaksyan. 245 mm × 172 mm, pp. iv + 142, *illus.*, (translated from the Russian by the Israel Program for Scientific Translations, Jerusalem). Keter Press Ltd, 15 Provost Road, London NW3 4ST, 1971. Price: £5·50.

In 1962 the Applied Geophysics Institute of the Main Administration of the Hydrometeorological Service, U.S.S.R., proposed a new method for the determination of the water equivalent of snow by aerial surveying. The method is based on attenuation of the natural gamma radiation of the earth by the snow cover. The first experiments were carried out in January 1963 and showed the method to be feasible. They were followed by further trials during the winter of 1963–64, and then from 1964 to 1968 the scale of the studies was extended to several different regions, over courses and areas of various sizes, and to cover a number of typographical types. The work included investigation of the discrepancies, sometimes large, between the water equivalents obtained by airborne gamma surveying and those from control measurements of high standard on the ground. Measures for minimizing the errors were developed and introduced.

This collection of 11 papers discusses the main results. It is dedicated to the memory of V. A. Uryvaev, Director of the State Hydrological Institute and 'leading organizer of experimental hydrological studies' at the time of his death. It had been his responsibility to direct and develop the work under field conditions; he had written the introductory paper and was co-author of 6 of the 10 following papers. There are seven authors in all. One of them, Vershinina, also an editor, should be specially mentioned. She appears as individual author of two papers, including the second longest, and co-author of five others. With Uryvaev she produced the longest paper, occupying just over one-third of the volume. Any question of quantity against quality does not arise, and there is no doubt that the total could be fairly labelled: Uryvaev, Vershinina *et alii*. The volume contains a large amount of information, but taken as a single whole it is not as easy to read as it might have been.

The difficulty does not arise from any individual paper and certainly not from the translation; the English is quite clear and as simple as it could be for writing of this kind; the style might with advantage be taken as a model by some of our own writers. The weakness is that the papers overlap and link several topics in a way that is neither entirely co-ordinated, nor sufficiently indicated by the titles and abstracts immediately below them. Again, the introductory paper, though a very useful brief summary (little more than four pages), is not a good guide to all the information in the other ten. A second reading, with notes and cross-references prepared during the first, is therefore helpful to get maximum value from the book, at least for a reviewer whose sometime approach to a high-resolution photographic memory is beginning to suffer, with age and in the spate of current scientific literature, from more or less fogged plates.

Nearly every paper deals in some way with errors of assessment and accuracy of results. But there is no compact numerical summary, all on one page, of the main conclusions in this respect. It appears, on widely separated pages, that in the most favourable circumstances the airborne gamma survey provides results with an accuracy well within 10 per cent, slightly better than the usual ground survey methods as at present developed and in regular use; whilst in the least favourable conditions the airborne survey can underestimate by 30 per cent or more, or overestimate by 90 per cent or occasionally much more (unusually bad but not extreme examples from the lengthy comparative tables). The largest percentage discrepancies tend to occur, as one might expect, with the smaller absolute values, whilst apart from this the most important single source of error (for which useful corrective measures have not been devised) is that the gamma survey assesses the water equivalent of snow with, in addition, the water (or some of it?) in the upper soil layer. Thus: 'The method cannot be employed in a swampy locality' though 'during stable thawless winters . . . the error of airborne surveys is . . . close to that of ground surveys, but . . . somewhat lower'.

There is no comparison of costs or effort for airborne and ground surveys (a fairly thorough search suggests that this was not given on one of the fogged plates). 'The (former) method is promising for use in little-populated regions with a steady winter' (page 46), implying perhaps that it might be relatively too expensive for areas where ground survey teams can be recruited. The reader is expected to know about the objects of such work, except for an occasional generalized explanation that snow data are 'widely used in various hydrologic calculations' (page 1) and 'for operational purposes of hydrological forecasts' (page 84). It is to be assumed that, according to circumstances, the information is used both to estimate the potential dangers from snowmelt floods, and to assess future water resources for all purposes, including navigation and hydroelectric power.

Work was continuing at the time of the Russian publication. If the refinements hoped for are achieved, we may perhaps look forward to a correspondingly improved systematic account of the technique; yet this volume, despite its shortcomings as a unified treatment, may then become a classic, and within its field a fitting tribute to V. A. Uryvaev, a man who was deservedly well known, respected and liked at international meetings, as well as in his own country.

A. BLEASDALE

Environment and plant life, by S. A. Searle. 220 mm × 140 mm, pp. 278, *illus.*, Faber and Faber, 3 Queen Square, London WC1N 3AU, 1973. Price: £4·50.

This book is based upon the study of the individual environmental factors of plant growth and development in the hope that their integration may provide 'clues to some of the mysteries that confront us today'. The integration is the difficulty and Mr Searle can hardly expect to succeed where so many have failed; nevertheless there is much of value in his book. For example, the meteorologist has his attention focused on many interesting applications of his subject to the cultivation of plants, while the farmers, growers and gardeners may well gain insight into the effect of weather and climate on their efforts to produce food or provide decoration. One could perhaps complain that there is too much emphasis on the atmospheric environment and too little on the soil. The author concedes that these are equally important but the chapter on the soil occupies less than one-tenth of the book.

The chapters on the aerial environment for plants are arranged in a somewhat unconventional order. In a book dealing with plant life there is much to be said for treating soil temperature before air temperature but still more for starting at the very beginning, with solar radiation. These chapters outline the basic facts concerning the distribution of the individual elements in time and space, linking these where possible with plant response. Also, both the instruments and standard methods of measurement are described.

A number of the following chapters emphasize the ways in which the environment may be modified to the advantage of plant production. These are well known to agricultural meteorologists and include principally the use of various types of windbreaks, irrigation, protection against frost and, more generally, the selection of suitable sites. Although practical details are not given, these form a useful introduction to those unfamiliar with the ideas. In this respect it is interesting that one of the major manipulations of the environment to improve production is unrelated to meteorology, viz., the manipulation of day-length by providing light or shade for chrysanthemums in the greenhouse to produce blooms at any time of the year. Another (but accidental) example of the control of the photoperiodic response of plants occurs just outside Wormwood Scrubs Prison where the floodlights are providing effective long days to parts of the plane trees which line the pavement.

The book is easy to read but in places there is a somewhat uneasy balance between the straightforward presentation of facts and the adjectives used to describe processes. For example, on page 23 Mr Searle refers to the 'tremendous wave of heat' in relation to soil temperature and a little later to the 'far vaster seasonal wave'. Again, on page 51 he talks of water 'falling in a reasonable manner upon the soil surface' and there are many other places where rephrasing would have led to improvements. But these are minor points which may be overlooked when assessing the merits of the book, which will be of interest to many who work in the fields of ecology and plant production.

The publishers are to be congratulated on the attractive appearance of the book. It is extremely clear, the diagrams and plates are of high quality and there are useful appendices with an adequate index.

W. H. HOGG

Meteorology for seamen, by C. R. Burgess. 210 mm × 130 mm, pp vii + 249, *illus.*, Brown, Son and Ferguson, Ltd, Publishers, 52 Darnley Street, Glasgow, 1973. Price: £4.

This is the third edition of a book first issued in 1950. Although many amendments and additions have been made, and the sections on cloud physics and upper-air charts have been rewritten and enlarged, the layout remains essentially the same. There are four parts :

I Factors which go to make up the weather;

II The climates of the oceans;

III Weather forecasting;

and IV Observing and recording the weather.

The primary aim is to provide the seaman with all he needs to know about meteorology, and a little more besides, without using any mathematics. This aim has been substantially achieved, the author having managed to condense a great deal of useful information into a relatively small volume, with the aid of many, albeit rather small, photographs and diagrams and a number of maps and tables. Two subjects of special interest to the mariner, namely cargo ventilation and ship routing might have received more attention however.

The reviewer found the chapters on climates and the one on sea and swell particularly good. For a third edition the number of misprints is rather high and although the writing is generally clear and sound a number of obscurities and errors were noted.

An unfortunate first impression is given in the second sentence of the opening chapter where it is stated that 'These (oxygen and nitrogen) and other, rarer, gases of which the atmosphere mainly consists have no effect on the weather, but some other bodies often present in the air, namely water vapour, salt and certain products of combustion, have a considerable effect . . .'. The important effects of carbon dioxide and of ozone appear to have been overlooked. On page 26 the explanation given for the occurrence of rain from clouds whose tops do not reach the freezing level is difficult to follow and probably incorrect, and on page 144 the opening sentence in a section on the effects of topography on wind reads 'Air, unless unstable, as indeed it usually is (in the lower levels) near the equator, objects to rising over high ground so that much of it escapes round the ends'. Although it is claimed in the preface that apart from horizontal distances which are still given in nautical miles, the metric system has been adopted almost entirely, there are still several examples of the use of mixed units, e.g. metres and feet for heights and °F and °C for temperatures, on the same pages. On page 11 reference is made to p. 224 which is a blank page (p. 236 is probably intended) and on page 209 the reader is referred to Tables 6 and 7 of Appendix I when Tables 7 and 8 are the relevant ones.

Despite these shortcomings this is a book which continues to fill a need, although, at more than five times the price of the first edition published 22 years earlier it seems a little less reasonable than its original version.

H. C. SHELLARD

NOTES AND NEWS

Negative surge warnings*

In September 1973 the Storm Tide Warning Service at Bracknell started to issue warnings of 'negative surges' in the North Sea. The need for this service is clearly indicated by tidal records from coastal tide gauges. For example, measurements at Southend over a period of two years show that the level of the sea was 2 feet or more below predicted levels on 51 occasions — on six of these it was 6 feet or more below them. Such differences resulting from 'negative surges' could be critical when tankers are operating with keel clearances of only a few feet in the eastern part of the English Channel and the southern North Sea.

Initially the new service will be experimental, providing only rudimentary warnings to shipping broadcast from coastal radio stations. The negative surge warnings will be given whenever tide levels are expected to be half a metre or more below the levels predicted in tide tables. The message will simply be that 'abnormally low tidal levels are expected' in a given area. The service will be experimental until two problems have been solved : the relation between coastal tide-readings and open-sea tide levels, and the forecasting of non-progressive surges. The first requires the installation of an offshore tide gauge. The second arises because 25 per cent of negative surges do not progress predictably southwards down the east coast of England. Instead, they occur simultaneously at all points on the east coast. These rogue surges cannot at present be forecast.

Numerical forecasting for the tropics

The first major experiment of the Global Atmospheric Research Programme (GARP) is the GARP Atlantic Tropical Experiment (GATE) scheduled to take place in the tropical Atlantic during the summer of 1974. The experiment was motivated by the recognition of the crucial part played by the tropics in the global circulation of the atmosphere and of the many unresolved problems regarding the tropical atmosphere. The principal aims of GATE are to observe the tropical atmosphere in detail by using all possible methods (e.g. ships, buoys, aircraft, and meteorological satellites) so as to establish the nature and the behaviour of the various scales of tropical weather systems and the interactions between them. The detailed scientific, operational and logistical planning of the experiment is being undertaken by a group of scientists known as the International Scientific and Management Group (ISMG) located at Bracknell.

In order that the Meteorological Office should be in a position to derive the maximum benefit from the GATE experiment, an additional research group has been established within the Dynamical Climatology Branch

* This news item was originally published in the issue of *New Scientist, London,* dated 20 September 1973.

(Met O 20) specially to work on the problems of applying numerical models of the atmosphere to the tropics. Apart from studying and attempting to improve the tropical performance of the existing models, the group is setting up a high-resolution model (1-degree grid and 11 levels) suitable for short-period forecasting (up to two days) over the GATE area during the period of the experiment in 1974. This objective calls for a system of data processing and tropical analysis which is already the subject of collaborative effort with the Forecasting Research Branch (Met O 11).

OBITUARY

Mr James Paton

It was a great shock to everybody associated with meteorology in Scotland to hear of the death of Mr James Paton on 26 August 1973, only a few weeks before he was due to retire from his post of Reader in Meteorology in Edinburgh University.

Mr Paton graduated M.A. (Honours Mathematics and Natural Philosophy) in 1925 and B.Sc. (Honours Physics) in 1926 at Edinburgh University. After a spell of about a year in the Meteorological Office he accepted an invitation from the Professor of Physics to return to Edinburgh as a lecturer. He maintained his association with meteorology by serving in the Royal Air Force Volunteer Reserve before ill-health forced him to resign. Shortly after the war, under his guidance, Edinburgh became the first university in Britain to introduce courses in meteorology for undergraduates in the Faculties of Arts and Science and in 1954 Mr Paton was appointed Reader in Meteorology. In 1964 he became the head of the newly formed Department of Meteorology.

Throughout his career he had a keen interest in meteorological optics and he was a well-known authority on aurora and noctilucent clouds. For many years he assembled and published reports of these phenomena and since 1957 he had been in charge of the Balfour Stewart Laboratory which was formed in Edinburgh, with financial help from the Royal Society, to carry on this work. He was elected a Fellow of the Royal Society of Edinburgh in 1946, and he was a member of the Meteorological Research Committee and the Advisory Committee on Meteorology for Scotland for many years.

Mr Paton chose to live in Scotland whose hills and mountains were a source of great enjoyment to him and during his life he did much to advance the cause of meteorology in this country. He will be remembered with gratitude by his students not only for his ability as a lecturer but also for his patience and helpfulness in resolving their problems. He will be greatly missed by his countless friends who enjoyed his company and benefited from his advice.

D. R. GRANT


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NOTICES

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