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RETIREMENT OF MR R. H. CLEMENTS

Mr R. H. Clements, Deputy Director of the Meteorological Office responsible for the communications and computing organization, retired on 31 July 1972, after 34 years' service. He read mathematics at Oxford University and after taking his degree was a schoolmaster for a few years before joining the Meteorological Office in 1938. The first 14 years of his new career were spent on forecasting duties, first at a variety of outstations and then from 1942 at the Central Forecasting Office at Dunstable. In his 10 years at CFO, Mr Clements became one of the best-known Senior Forecasters and he is still well remembered as one of the Office's 'ace' forecasters.

In 1952 he left Dunstable for a 3-year tour as Chief Meteorological Officer with the Royal Air Force in Germany and on returning home was engaged for some years in forecasting research. In 1958 he transferred to climatology and shortly afterwards became the Assistant Director responsible for Climatological Services. During the next 8 years he initiated many important developments in the applications of climatology to a wide range of activities and also played a prominent part in the international field, notably with the World Meteorological Organization Technical Commissions for Climatology and for Hydrology. In 1966 Mr Clements was promoted to Deputy Director with overall responsibility for applied climatology, including hydrometeorology and argicultural meteorology, and for observational systems and for data processing. Subsequently, with the acquisition of a very powerful new computer and with the modernization of the telecommunications organization, Mr Clements took charge of a new Deputy Directorate responsible for the operation and systems development of these advanced facilities.

Thus Mr Clements's career occupied three main phases — forecasting, climatology, and data acquisition and processing. In each phase he was highly successful and of international reputation. Doubtless he will count among the major milestones of his career the years of planning, studying and assessing that culminated in the purchase, installation and rapid progress to full operational use of the Office's giant computer.

'Clem' was widely known in the Office and most popular. Never one to look on the dark side, his cheerfulness and optimism were infectious. For him retirement from the Office will merely mark a new beginning in other activities and we wish him and Mrs Clements many years of happiness and good health.

P. J. MEADE

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THE MEASUREMENT OF ATMOSPHERIC TURBULENCE FROM A CAPTIVE BALLOON

By C. J. READINGS and H. E. BUTLER

Summary. This paper describes an instrument which has been designed to measure wind and temperature fluctuations from the flying cable of a tethered kite balloon. Its performance has been evaluated from measurements close to the ground with the probe mounted on a fixed support. These enable both its reproducibility and its performance relative to a sonic anemometer to be assessed.

Some preliminary studies of the effect of the balloon motion were carried out using a reference instrument mounted on a 43-metre tower. These showed that though variances were not much affected, quite serious errors may be introduced into the flux measurements but that these might be reduced by adequate vertical separation of the instrument and the balloon. A more comprehensive series of measurements is required to establish these features.

Introduction. Although the structure and properties of the constant-stress layer are now quite well understood, the relative inaccessibility of the rest of the earth's boundary layer means that quite the converse is true of this part of the atmosphere, despite its obvious relevance to the energetics of the troposphere. Furthermore, this situation cannot be remedied just by studying the structural details revealed by applying some of the recent developments in the field of remote probing (e.g. frequency-modulated-continuous-wave radar, see Gossard *et alii*[1]); direct measurements are essential if the effects of the fine structure are to be correctly interpreted and the terms in the various balance equations evaluated.

Though aircraft and tall towers have been extensively used in studying these lower regions of the atmosphere, neither of them provides the perfect 'platform' from which to make measurements. A less familiar technique is to mount the instruments on the flying cable of a tethered balloon. This paper describes a turbulence probe which has been designed to operate in such a fashion (it does not discuss the use of tethered balloons in general for scientific studies — for which the reader may care to consult another article[2]).

The paper is divided into three main parts — first the probe is described, then its performance on a fixed support is assessed and finally the complications introduced by the balloon's movement are considered.

Description of the probe. An article by Jones and Butler[3] describes the first instrument used to study in detail the vertical component of turbulence from the flying cable of a tethered kite balloon. The present instrument (see Figure 1) is a development from this and is designed to measure with adequate response the fluctuations required for evaluating heat and momentum fluxes:

(a) *Temperature.* The sensor consists of 180 cm of platinum wire (25 μm in diameter) wound non-inductively on a plastic former. It is connected to an amplifier (mounted in the vane) which gives a linear output of 0·5 volt/degC over a range of ± 10 degC; the three switches at the bottom of the vane enable the centre zero to be adjusted in 3-degC steps between − 3°C and + 18°C.

(b) *Total wind speed.* As the vane is free to rotate about the flying cable, the probe is kept facing into wind and the anemometer measures the instantaneous values of the total wind speed. The anemometer is

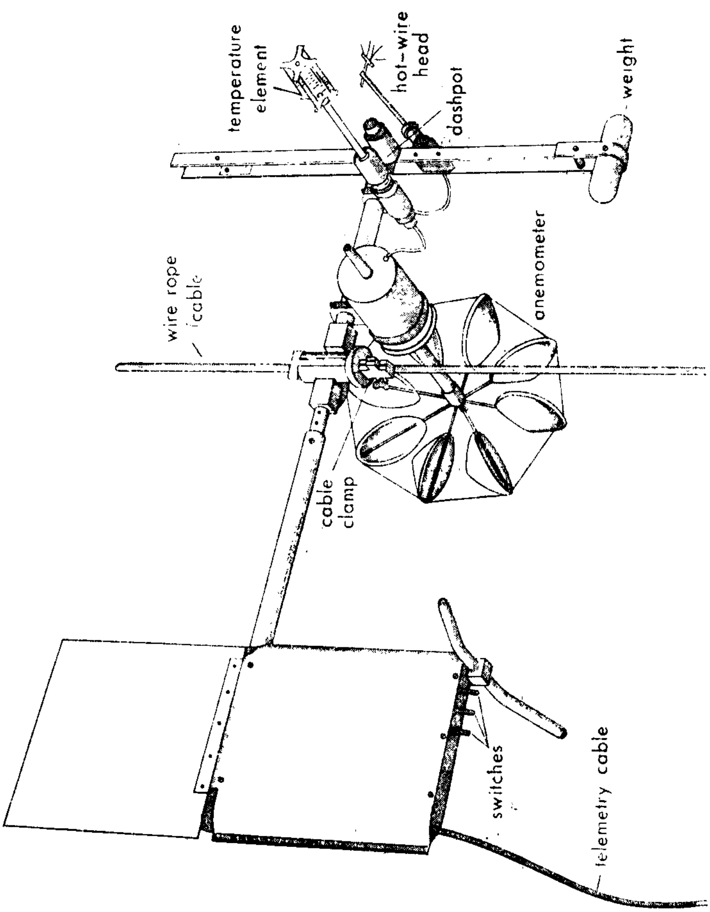


FIGURE 1—THE CARDINGTON PROBE

fitted with an 8-cup polystyrene rotor,[4] the pulses from which are converted to an analogue voltage by a ratemeter located in the laboratory — 120 pulses being produced per revolution.

(c) *The inclination of the wind to the horizontal.* A hot-wire yawmeter consisting of two V-shaped platinum wires (of diameter 13 μm and each containing an angle of 120°) making an angle of 80° (Jones[5]) is attached to the vertical upright pivoted at the front of the probe. This is kept vertical despite any tilting of the balloon cable, by the combination of the weight at its lower end and an oil dashpot which damps oscillations, hence enabling the yawmeter to measure the instantaneous inclination of the wind relative to some fixed reference which is near the vertical (see later). The yawmeter is connected to a bridge situated inside the vane which gives a sensitivity of 0·5 volts/radian. Its output is linear over ± 40° and it will accept lateral flow variations of ± 30° (with respect to the vane) without any errors being introduced.

A battery box is attached to the flying cable just below the probe. This provides the stabilized voltage necessary to operate the two bridges and also acts as a link from which the signals are relayed to the ground by cable (a radio system is being tested at present). There they are sampled once a second by a data-logger whose output is recorded on paper tape. This logger has a resolution of one part in a thousand which corresponds to 0·01 degC, 2 cm/s or 0·02 radians. The higher-frequency fluctuations of inclination and temperature are studied with the aid of a series of band-pass filter units.[6]

Although at present the probe does not measure the instantaneous direction of the wind in the horizontal, it is hoped to remedy this in the near future by the addition of a second yawmeter and a magnetic flux-gate device providing an azimuth reference. Furthermore, by early 1973 it is planned to record all the information on magnetic tape, hence eliminating the sampling restriction referred to above.

The electrical and mechanical parts of the system were subject to certain tests in both the laboratory and the wind-tunnel. However, in view of the complexity of the system and of the environment in which it has to operate, it was necessary to carry out a series of field trials to establish that the atmospheric variables were being measured properly.

The performance of the probe on a fixed support.

Comparison of probes. As a first step in this evaluation, two of these probes were mounted on fixed vertical rods so that they were 2 m apart at a height of about 8·5 m at the Cardington, Bedfordshire, field station — a suitably flat and unobstructed site for low-level work. A series of one-hour runs were carried out with the horizontal boom to which the rods were attached approximately perpendicular to the mean wind direction during each run. Thirty-three runs were carried out under various stability conditions; z/L at 8·5 m varied between 0 and − 2·0 (z being the height above the ground and L the Monin-Obukhov length).

Unfortunately many of the quantities of interest are sensitive to slight rotations of the frame of reference;[7] so, as the axes of these probes cannot be determined with sufficient accuracy using only instrumental techniques, it was decided to fix them by assuming that the value of the mean vertical wind speed, $\overline{W}$, was zero during each run. This produced an axial reference reproducible to within 0·3 degrees and even this uncertainty may well be atmospheric in origin as the mean inclinations of the flow derived from the two probes invariably agreed to within 0·1 degrees.

Although some slight troubles were experienced with the cup anemometers and their associated circuitry, these were not serious and it would be fair to conclude that normally the mean winds would be expected to agree within a few centimetres per second. It was also found that the 20-minute temperature differences were consistent to ± 0·02 degC after correcting for the difference in the resistances of the two temperature elements at 0°C.

The degree of agreement between the other variables was assessed by plotting the cumulative differences on probability paper — a Gaussian distribution would produce a straight line. Some examples of the sort of results obtained are shown in Figure 2 (a) and (b) for the 20-minute values.

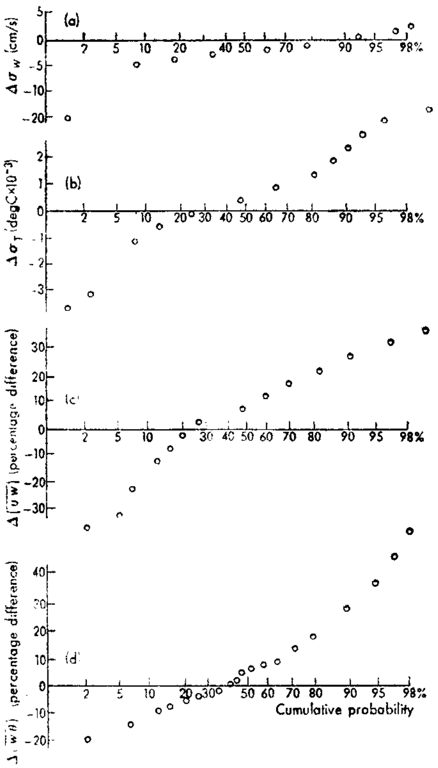


FIGURE 2—COMPARISON OF THE PERFORMANCE OF TWO INSTRUMENTS ON FIXED SUPPORTS AT A HEIGHT OF 8·5 METRES AND 2 METRES APART (20-MINUTE SAMPLES)

See Table I for definitions of symbols.

Although the spread in the differences between the standard deviations (or between the mean vertical winds) is larger than would have been expected from the preliminary laboratory and wind-tunnel tests, the complexities of the full operating system in the natural airflow mean that it would be

TABLE I—THE ACCURACIES IMPLIED BY THE COMPARATIVE RUNS ON FIXED SUPPORTS (USING 20-MINUTE VALUES)

Quantity	Mean difference ± standard error
Mean vertical wind, $\overline{W}$ (cm/s)	0·0 ± 0·3
Standard deviation of temperature fluctuations, σ_T (degC)	0·006 ± 0·001
Standard deviation of horizontal wind fluctuations, σ_u (cm/s)	0·0 ± 0·3
Standard deviation of vertical wind fluctuations, σ_w (cm/s)	− 1·7 ± 0·3
Momentum flux, $\overline{uw}$ (per cent)	9 ± 2
Heat flux, $\overline{w\theta}$ (per cent)	8 ± 2

unsafe to conclude that the discrepancies are purely atmospheric in origin. However, it seems fair to state that these quantities can be measured *at least* to the statistical accuracies implied by these comparisons (see Table I).

With the two vertical fluxes the situation is complicated by their dependence on the frame of reference used and the large variations in their absolute values. This makes it more sensible to compare the percentage differences as is done in Figure 2 (c) and (d). Though it is well known that the two vertical fluxes vary considerably in both space and time,[8] the additional uncertainty introduced by the frame of reference makes it even more unwise to state that the spread merely reflects atmospheric variability; though it is relevant to note that the more extreme differences vanish when 'hour' as opposed to '20-minute' values are compared. However, it does seem reasonable to conclude that statistically the individual fluxes may be determined to within 10 per cent *or better* (see Table I). These conclusions may be considered to be quite general as during the course of these tests a whole series of sensors and circuit elements were used, thus making them a comparison of a series of probes.

Comparison with profile estimates of the friction velocity. During some of these comparative runs a vertical wind profile was available from three single-slot photo-electric anemometers mounted 4·3, 8·5 and 17·1 m above the ground, ordinary Sheppard anemometers with metal cups being used. Estimates of the friction velocity, u_*, were obtained by applying the method described by Webb[9] to the hourly means, and in Figure 3 these results are compared with those derived from one of the probes (i.e. $\sqrt{-(\overline{uw})}$ where $\overline{uw}$ is the momentum flux), the comparison being restricted to occasions when z/L at 8·5 m was greater than −0·10. The agreement is very encouraging and it is interesting to note that the scatter of the differences between the estimates is not much different from that found when two probes are compared.

A similar exercise was carried out by applying the formulation discussed by Dyer and Hicks[10] to the results — the profile winds being used in conjunction with the z/L values from one of the probes (no temperature profile being available at that time). These estimates also agreed very well with the probe values.

Comparison with a sonic anemometer. During October 1969 one of these probes was compared in Boston, U.S.A., with the Air Force Cambridge Research Laboratories' three-component sonic anemometers which have been described by Haugen.[8] These tests were carried out by mounting the two instruments about 2 m apart on the top of a 15·5-m tower — a vertical rod supporting the Cardington probe. Owing to obstruction around the site, runs could

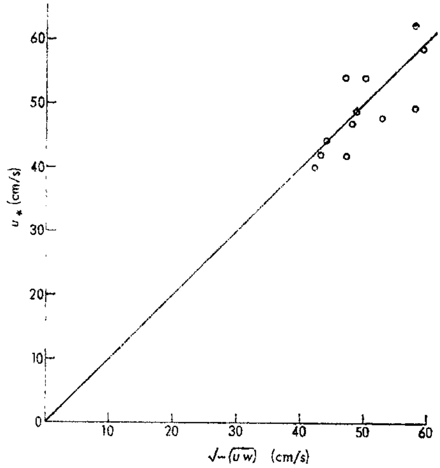


FIGURE 3—COMPARISON OF THE HOURLY VALUES OF $\sqrt{-(\overline{uw})}$ AND u_* OBTAINED FROM PROFILE MEASUREMENTS USING WEBB'S TECHNIQUE

$\overline{uw}$ is momentum flux and u_* the friction velocity.

only be done when the wind was coming from the west so it was only possible to do sixteen 10-minute and four 5-minute runs in the time available. The signals were processed on data-logging equipment with a frequency cut-off at 10 Hz and a sampling rate of 20 samples per second.[8]

Although the definition $\overline{W} = 0$ was used to determine the reference axes for the Cardington probe, the sonic anemometer was lined up using purely instrumental techniques. Thus the sonic-anemometer values refer to gravitation axes while those of the Cardington probe refer to the $\overline{W} = 0$ axes. This means that the two sets of values are not strictly compatible and that the spread in the difference between the estimates of u_* may be greater than was found at Cardington, especially as the uncertainty in the axes was a degree or two in this case (probably because of the poorer nature of the site in Boston). A further complication may have been introduced by the relatively slow response of the cup anemometer which would cause the Cardington probe to underestimate the momentum flux if there were a significant high-frequency contribution. (Incidentally this should not matter at the heights for which the captive balloon system is designed.) The rather small heat fluxes precluded any meaningful comparison of the heat fluxes or the temperature fluctuations.

In comparing the results of these tests (Figure 4) with those obtained from the mast runs (see Figure 2 and Table I) it is important to remember that only 18 values (the four 5-minute runs making 2 values) were available on this occasion; thus no significance can really be attached to the tails of the distribution. It would therefore seem reasonable to conclude that the results are roughly compatible, though the agreement between various values of σ_w, the standard deviation of vertical wind fluctuation, is slightly improved and that between the various values of σ_u, the standard deviation of horizontal wind fluctuation, and of u_* is slightly worse; these small changes are probably no more than a reflection of the shorter averaging period and the points raised in the previous two paragraphs.

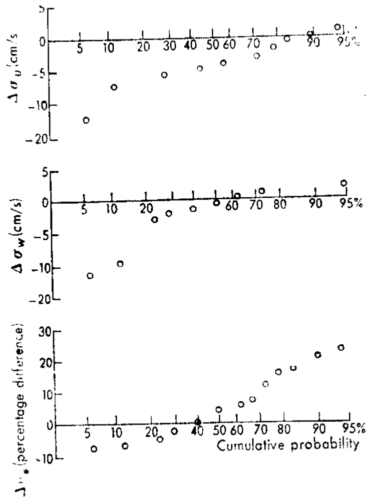


FIGURE 4—DISTRIBUTION OF THE DIFFERENCES BETWEEN THE SONIC ANEMOMETER AND THE CARDINGTON PROBE (10-MINUTE SAMPLES)

Comparisons were made at Boston, U.S.A., in October 1969.

It is relevant to note that the 10-minute wind speeds agreed to within a few centimetres per second, so these results were not biased by overspeeding (see Readings[11]). Furthermore, on the few occasions when a second sonic was available, the correlation between the two sonics was slightly less than that between the Cardington probe and each of them individually — the Cardington probe being positioned midway between them. This also points to the instruments having equivalent performances.

A preliminary study of the effects of balloon movement. The movement of a tethered balloon is transmitted to any instrumental packages attached to the cable. As these motions can be quite appreciable there is a strong possibility that they may introduce 'apparent' contributions to the measured turbulence variables, though mean values of variables such as wind speed and temperature should not be affected provided that the averaging period is long enough. For a given balloon/cable system, the motion of the balloon will depend mainly on the structure of the atmosphere and the position of the balloon in it. The movements of the actual instrument will also depend on its position on the cable relative to the balloon and may well be a scaled-down version of the balloon motion. However, the measurement errors will depend not only on these movements but also on any corresponding changes in temperature or wind in the vicinity of the instrument.

Although at present it is not possible to predict the magnitude of the errors, the equations relating them to the motion of the instrumental package can be written down :

$$\Delta\sigma_u = \frac{50}{\sigma_u^2}\left[\overline{\left(\frac{dx}{dt}\right)^2} - 2\,\overline{U_t\left(\frac{dx}{dt}\right)}\right] \qquad \ldots (1)$$

$$\Delta\sigma_w = \frac{50}{\sigma_w^2}\left[\overline{\left(\frac{dz}{dt}\right)^2} - 2\,\overline{W_z\left(\frac{dz}{dt}\right)}\right] \qquad \ldots (2)$$

$$\Delta\overline{uw} = \frac{100}{\overline{uw}}\left[\overline{\left(\frac{dx}{dt}\right)\left(\frac{dz}{dt}\right)} - \overline{U_z\left(\frac{dz}{dt}\right)} - \overline{W_z\left(\frac{dx}{dt}\right)}\right] \qquad \ldots (3)$$

$$\Delta\sigma_T = \frac{50}{\sigma_T^2}\left[\overline{z^2}(\Gamma^2 + 1) - 2\Gamma\overline{zT_z'}\right] \qquad \ldots (4)$$

$$\Delta\overline{w\theta} = \frac{100}{\overline{w\theta}}\left[\overline{T_z'\left(\frac{dz}{dt}\right) + \Gamma z\left(W_z - \frac{dz}{dt}\right)}\right] \qquad \ldots (5)$$

where Δ = the difference between the apparent value and the true value expressed as a percentage of the true value; x and z are the instantaneous co-ordinates of the instrument relative to its mean position, and subscript z denotes value of atmospheric quantity at height z; U is the horizontal wind, and u and w are fluctuations in the horizontal and vertical wind respectively; Γ is the mean lapse rate (a positive quantity); σ_T is the standard deviation of temperature fluctuations; $w\theta$ is the heat flux, θ being a temperature fluctuation; T_z' is the temperature fluctuation relative to the mean profile; t is time; and the horizontal bars refer to time-averaging. In deriving these equations it has been assumed that σ_T does not vary rapidly with height at 43 m, but this assumption is unlikely to be important as it involves only a small correction.

Approximate estimates of the effect of these motions on measurements of momentum flux have been made by Thompson (unpublished) who used two theodolites to monitor the movement of a fore-runner of the present Cardington probe as it recorded the instantaneous values of u and w. His analysis showed that the probe tended to underestimate the momentum flux. However, this examination only took into account the second term in equation (3).

In view of the relevance of this problem to balloon-borne measurements it was decided to try and measure the errors directly by comparing measurements made from a fixed support at the top of the 43-m tower at Cardington with those made simultaneously with another instrument mounted at the same height on the flying cable of a tethered balloon. A series of one-hour runs were done with the balloon at one of four standard heights (60, 150, 300 and 600 m) above the instruments. However, from the outset it was clear that these measurements must be regarded as very preliminary in nature, as they were only made at 43 m and facilities for monitoring the movements of the balloon-borne probe were not available at that time. Their aim was therefore limited to ascertaining whether the errors were large enough to warrant a full-scale investigation.

It had been hoped to use the tower-mounted probe to provide the 'true' values but unfortunately the $\overline{W} = 0$ assumption did not enable the axial reference to be fixed to better than a few degrees. Furthermore, this variability could not be reduced by doing a 'calibration' run at 8·5 m above the ground because the probe had to be dismantled to get it into position on top of the tower. As this uncertainty in the reference axes could well mask any effects due to balloon movement, it was decided to apply the $\overline{W} = 0$ assumption for the tower instrument when the balloon was at its maximum height (i.e.

600 m above the two probes). Then the axial reference of the balloon probe was determined by forcing the hourly-mean momentum fluxes to be equal during these runs. These two sets of axes were used for all the other runs carried out on that particular day — a 600-m run always being done.

The effect of balloon motion on the turbulence quantities was assessed only in respect of the variation of the motion of the instruments with the separation between the balloon and the instruments by comparing the difference curves (i.e. balloon minus tower values) for the other balloon heights with those obtained with the 600-m spacing. It does, however, seem likely that the 600-m balloon values were less affected by balloon movement and that therefore the foregoing comparison provides a first approximation to the absolute effect. Some evidence supporting this assumption was provided later by making some single theodolite observations of changes in the elevation of a probe attached to a balloon cable at the same height as during the runs. The elevation angle was recorded every 15 seconds and measurements were made with the balloon at all the standard heights used during the original experiments. Figure 5 is typical of the results obtained with the balloon in

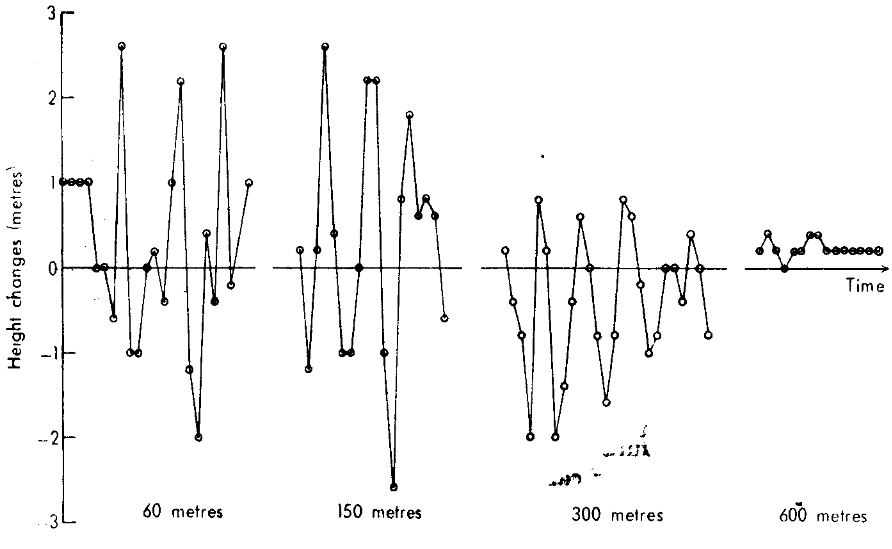


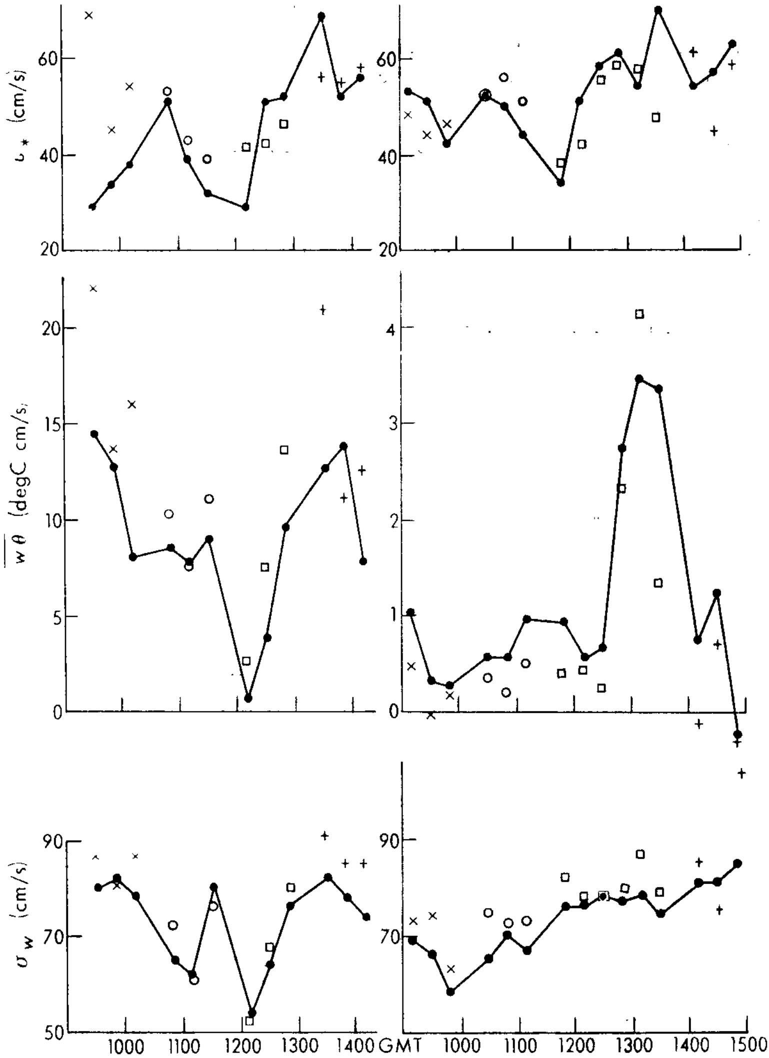
FIGURE 5—EXAMPLE OF THE VARIATION WITH TIME IN THE HEIGHT OF A PROBE ABOVE THE GROUND AS A FUNCTION OF ITS DISTANCE BENEATH THE BALLOON

Measurements were made every 15 seconds with a separation between balloon and probe of 60, 150, 300 and 600 metres.

the atmospheric turbulence layer and shows how the amplitude of the probe's vertical motion decreases as the vertical separation increases. However, it must be realized that although it seems reasonable to assume that the 600-m runs were less (if not negligibly) affected by balloon motion than were the others, it does not necessarily follow that the motion of the instrument decreased steadily as the vertical separation increased.

In all some 24 usable one-hour runs were done under various atmospheric conditions with z/L at 43 m varying between $-1{\cdot}0$ and $-0{\cdot}03$; though on three of the four days $z/L \approx -1{\cdot}0$. The probes were about 50 m apart and the tower was downwind of the balloon on all but one day when there was a crosswind.

As a first step in the analysis the successive 20-minute values of σ_u, σ_w, σ_T, $\overline{uw}$ and $\overline{w\theta}$ were compared on a day-to-day basis; two examples are shown in Figure 6. It was found that although the values did not agree as



• Tower × 60 m ○ 150 m □ 300 m + 600 m

(a) $z/L = -0{\cdot}5$ (b) $z/L = -0{\cdot}03$

FIGURE 6—A COMPARISON OF TWO EXAMPLES OF VALUES MEASURED AT 43 METRES ON A TOWER AND AT THE SAME HEIGHT ON A BALLOON WITH FOUR SEPARATIONS BETWEEN BALLOON AND PROBE (20-MINUTE SAMPLES)

Separations between balloon and probe were 60, 150, 300 and 600 metres.

closely as during the mast runs described earlier, they nevertheless tended to follow each other quite well. Also, the scatter between the two sets of values seemed less on the non-convective day. However, as it was impossible to discern any correlation between the degree of agreement and the vertical distance between the probes and the balloon, it was decided to combine the results of all days and compare the percentage differences as a function of balloon height (these results are summarized in Figure 7 and Table II).

TABLE II—MEAN PERCENTAGE DIFFERENCES BETWEEN VARIOUS TURBULENCE QUANTITIES, AS MEASURED AT 43 M ON A FIXED SUPPORT AND ON THE BALLOON CABLE, AS A FUNCTION OF THE HEIGHT OF THE BALLOON ABOVE THE INSTRUMENTS

Quantity	Height of balloon above instruments				Mast runs
	60 m	150 m	300 m	600 m	
σ_u	9 ± 3	7 ± 3	6 ± 3	3 ± 2	−0·1 ± 0·3
σ_w	1 ± 3	−4 ± 4	4 ± 2	3 ± 4	−3·3 ± 0·5
$\overline{uw}$	51 ± 48	2 ± 22	−6 ± 11	3 ± 10	9 ± 2
σ_T	14 ± 5	−1 ± 3	3 ± 5	4 ± 7	1·9 ± 0·6
$\overline{w\theta}$	27 ± 31	−22 ± 12	−4 ± 13	33 ± 21	8 ± 2

Tabulated figures are mean percentage difference ± standard error.

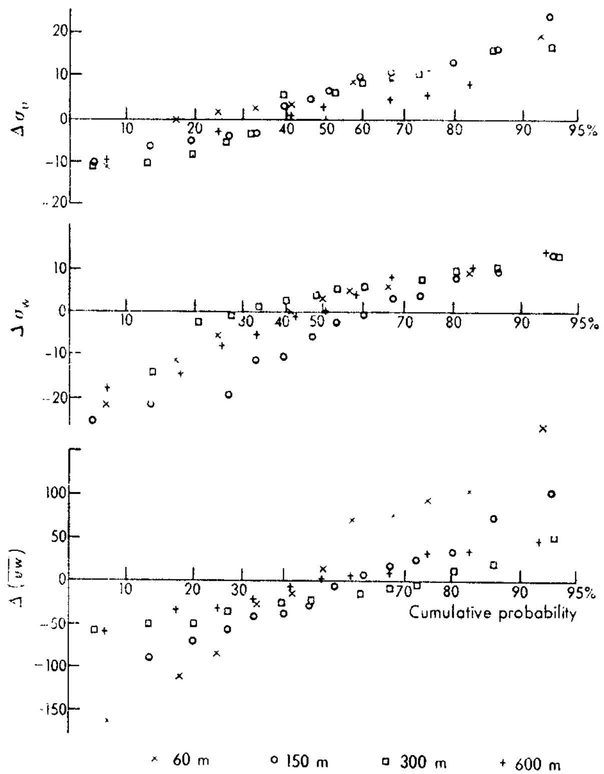


FIGURE 7—COMPARISON OF ALL VALUES MEASURED AT 43 METRES ON A TOWER AND AT THE SAME HEIGHT ON A BALLOON WITH FOUR SEPARATIONS BETWEEN BALLOON AND PROBE (20-MINUTE SAMPLES)

Separations between balloon and probe were 60, 150, 300 and 600 metres. Results are all expressed as percentage differences.

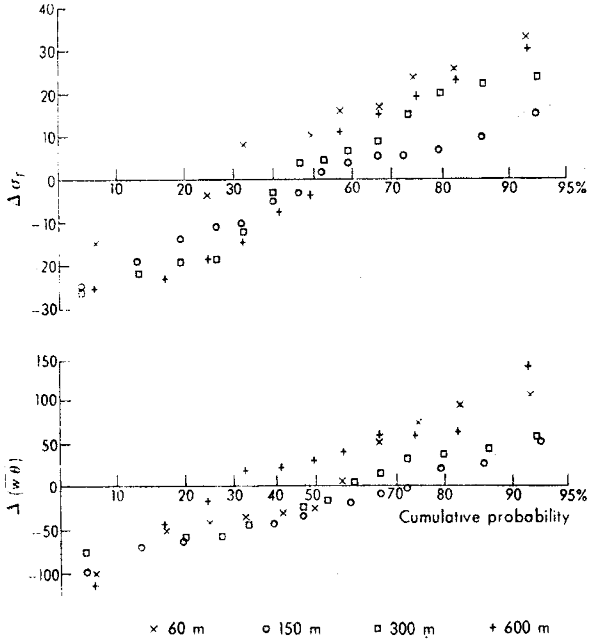


FIGURE 7—*continued*

In considering these results it is important to realize that even if there were no effects of balloon motion, the 600-m curves would not be straight lines of zero mean and zero slope as the two probes were about 50 m apart — for reference the corresponding figures for the mast runs are also listed in Table II. Furthermore, the distributions could be affected either way by the balloon motion (i.e. the apparent agreement may improve or worsen according to which terms dominate the appropriate equation).

Although $\Delta\sigma_u$ and $\Delta\sigma_w$ show a slight dependence on the vertical distance between balloon and instruments (Figure 7) the changes are only a few per cent and are therefore of not much concern, though they do imply that while the first term dominates equation (1) (i.e. the more positive values of Δ at lower separations) both terms contribute to equation (2). However, with $\Delta\overline{uw}$ quite large differences are observed and it appears that the balloon-borne measurements could be in error by 100 per cent or more in *either sense*. This implies that at least two of the terms in equation (3) can be significant and that if Thompson had been able to measure the other two terms, his results could have been drastically changed — as he pointed out at the time. However, the smaller range of $\Delta\overline{uw}$ for both 600 and 300-m curves raises the possibility of making the error insignificant by positioning the equipment sufficiently far below the balloon.

The curves of $\Delta\sigma_T$ are probably the most intriguing as the irregular way their shapes vary as the vertical distance between balloon and probe increases implies that both terms in equation (4) are significant — this means that local changes in temperature are associated with upward movements of the balloon, probably through the action of convective elements. However, the errors are not really large except for the 150-m spacing. The $\Delta\overline{w\theta}$ curves are also separated and the sense of this separation implies that the last term in equation (5) is probably very important. The errors are quite significant even with the 300-m spacing.

Concluding remarks. From the preceding discussions it may be concluded that on a fixed support the Cardington probe measures the various turbulence quantities *at least* to the accuracies summarized in Table I. Furthermore, the upper limits to the accuracy of the probe may well reflect atmospheric variability rather than instrumental inaccuracies. Thus the use of this relatively inexpensive instrument on fixed supports as well as on the tethering cable of a balloon becomes a very attractive proposition.

The preliminary studies of the effects of balloon motion seem to show that though σ_u, σ_w and σ_T are only marginally affected, the momentum and heat fluxes could be seriously in error if the instrument is mounted too close to the balloon. They point therefore to the necessity for carrying out an extensive series of measurements at greater heights above the ground with continuous monitoring of the probe and balloon movements. However, until these measurements have been made and analysed, it is advisable to fly the instruments as far below the balloon as possible and to monitor their motions.

Acknowledgements. The authors would like to acknowledge Dr D. A. Haugen for permission to refer to the Boston experiment and the help of all members of the Meteorological Research Unit at Cardington especially Mr R. Rayment and Mr R. H. Marles. They also benefited from many useful discussions with Dr F. Pasquill.

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551.5:06(b):37

THE METEOROLOGICAL OFFICE COLLEGE

By D. H. JOHNSON

Early days. Systematic centralized training began in the Meteorological Office in 1935. It took place in a special section of the Overseas Division at Croydon Airport. With the outbreak of war four years later, more elaborate arrangements became necessary and on 15 September 1939 the Meteorological Office Training School came into being at Berkeley Square House, London. Professor (later Sir David) Brunt was released temporarily from Imperial College, London, to take charge of the training programme. During the next decade the School had several moves until it found a more permanent home at Stanmore, Middlesex, on 22 August 1951. The development of the training programme up to that time was traced by P. J. Meade, who was then Head of the School, in the *Meteorological Magazine* in 1952.[1]

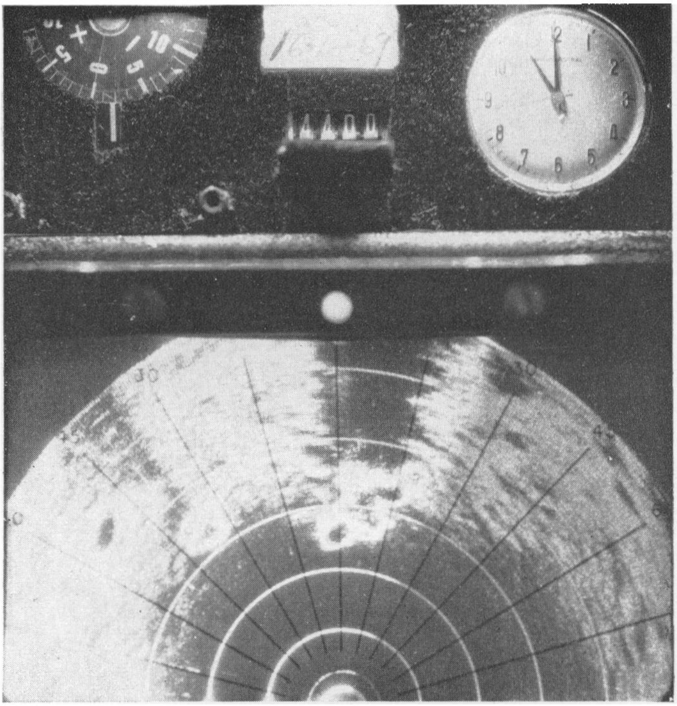
Training at Stanmore. At Stanmore professional training flourished, a stable pattern of instruction developed, and pride in the quality of the courses grew. The School acquired an international reputation. Students came from 75 countries and they could be trained for work in any region of the globe. A. H. Gordon has described[2] the expansion in the scope of the courses which took place over the years up to 1959. Since then the overall pattern of training has not greatly changed, but the courses themselves have kept pace with the quick development of the science. The principal courses, at the present time, are described in an Office leaflet issued annually (see page 301).

The Meteorological Office College. The establishment of training facilities at Stanmore in 1951 was a great step forward at the time. However, as general development took place in the area and accommodation standards changed, the restrictions on teaching imposed by the old wartime buildings and their environment were increasingly felt. In 1961 the various scattered units of the Meteorological Office Headquarters were brought together in a new building at Bracknell. It was intended[2] that the Training School would also be rehoused in the new Headquarters, but due to pressure of growth in other branches the move of the School to Bracknell did not take place. Weight was added to the case for re-location by a recommendation of the Parliamentary Estimates Committee in the third report of the Session 1966–67. It was felt that specialists working in the various branches of the science at the Headquarters at Bracknell should be able to participate more fully in the lecturing programmes. The search for a suitable site came to an end a year or two later when the Royal Air Force vacated the Flying Training Command Headquarters at Shinfield Park, near Reading. The Meteorological Office was offered a substantial part of the site. After a period of planning, work commenced in September 1970 on the conversion and extension of existing buildings to provide accommodation for a new Meteorological Office College. Training ended at Stanmore on Friday, 15 October 1971 and recommenced without break at Shinfield Park on the 18th. Photographs of some of the College facilities can be found at Plate II (others in the *Meteorological Magazine* for March 1972 and the Meteorological Office *Annual Report* for 1971).

Comparison of these pictures with those accompanying the articles by Meade[1] and Gordon[2] shows clearly the improvement in the quality of the teaching accommodation.

At Shinfield Park, skilful conversion has minimized the limitations imposed by the need for adaptation of the existing buildings. Two of these contain all the instructional facilities. In the Main Building, a former airmen's mess, there are seven spacious classrooms each equipped with light-tables, projectors and other aids for practical instruction in weather analysis and forecasting. Five of them are housed in a specially built extension to the original building and are grouped around an instruments lobby in which are continuously recorded atmospheric pressure, wet- and dry-bulb screen temperatures, surface wind speed and direction, cloud base, rainfall, total and direct incoming solar radiation, reflected solar radiation, the radiation balance, earth temperatures to a depth of one metre, and the temperature profile in the lowest metre of the atmosphere. Also within the Main Building is a tiered lecture theatre, the library, communications room, instructors' common room and administrative offices. School House, once an airmen's dormitory block, is used for training in the use and maintenance of meteorological instruments, weather observing, coding and plotting. There are also excellent facilities for the lectures in basic meteorological physics which form part of the syllabuses of the majority of the courses for Assistants (now Assistant Scientific Officers). In addition to three synoptic classrooms, offices and a students' common room, there is an outstation-routine room, a small tiered lecture theatre, an instruments classroom and a workshop. A cinema seating 94 has been built as an extension to School House. It is comprehensively equipped for lecturing as well as for showing the instructional films which form an important part of the curricula, and the acoustics are very good. The Services Kinema Corporation advised in its design.

In the early weeks of their courses students are taught to plot weather data and to analyse weather situations from the past. As the courses develop, however, it becomes necessary, in simulating operational working conditions, for current weather information to be available. The College is directly linked with the Telecommunications Centre at Bracknell by several teleprinter channels. The Bracknell centre is a hub of the global telecommunications circuit and can provide current data for all parts of the world. These data are raw material for courses in analysis and forecasting, not only for the Atlantic and European areas, but also for the Mediterranean countries, the Middle East, the Far East and many parts of the tropics. Thus the course for, say, the Seychelles staff is able to work with current material for the Indian Ocean and bordering countries, and to become familiar with the operational working of the proper local regional procedures. Two facsimile broadcasts are received from Bracknell by landline and the College takes radio-facsimile transmissions from overseas areas as required. Cloud and radiation pictures are received at the College from satellites via the ground station at Beaufort Park, near Bracknell, as they are broadcast. Satellite data have become an essential adjunct to the standard chart sequences selected and printed for the students' use. The main instruments enclosure is situated within an open area of grassland well clear of the College buildings, but there is also an array of teaching screens close to School House and the roof of the cinema serves as an observing platform. The many acres of parkland allow ample space



Photograph by courtesy of Royal Aircraft Establishment, Bedfor

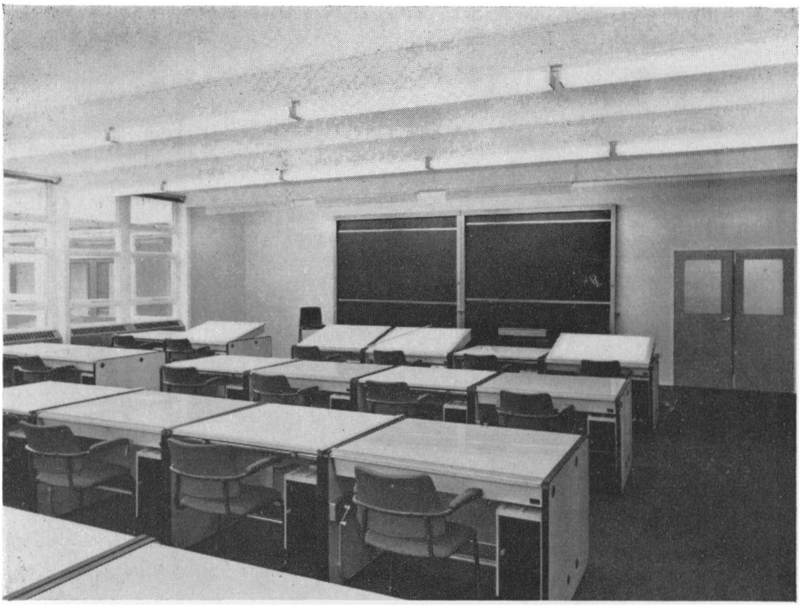
PLATE I—AIRBORNE 30-mm RADAR SHOWING 'SHADOW' CAST BY SHOWERS

The aircraft was at 20 680 ft (6·3 km) near 22° 25′N, 83° 37′E at 1630 IST (GMT + 5½ hours). The radar antenna was depressed 2° below the horizontal. Ground returns appear at ranges greater than 30 n.miles (55 km) except where they are masked by the showers. (Range markers are at intervals of 10 n.miles.) See page 304.

(a) The Main Building

PLATE II THE METEOROLOGICAL OFFICE COLLEGE AT SHINFIELD PARK

See page 299.



(b) Classroom in the Main Building equipped with light-table and working tables in pairs. Slopes of table tops are adjustable.

(c) School House. The staircase leads to the observing platform on the roof of the cinema.

PLATE II—*continued*

To face page 301

Photograph by D. Tribble

PLATE III HAZE IN THE AUSTRIAN TIROL, LATE AFTERNOON ON 9 AUGUST 1954

See page 312.

for the field work which now forms an important part of the Scientific Officers Course, and for multiple theodolite pilot-balloon observations. Unrestricted base lines are available for such instruments as the cloud-base recorder, visibility lights and transmissometer.

At Shinfield Park the courses have become fully residential, the College being designed to accommodate 110 students, each of whom has a compact but bright and well-furnished study/bedroom which allows for quiet evening work. This represents a very considerable advance. Dependence at Stanmore on lodging accommodation meant that course members were hampered in their studies by unsatisfactory working and living conditions. Overseas students in particular had complaints of unheated rooms, inadequate diets and lack of sympathy in health problems. These difficulties are now of the past and the benefits of the new facilities have quickly been felt; course members are getting through more work with greater success and less stress. Domestic arrangements at the College are the responsibility of the Bursar, assisted by an Accounting Officer, Catering Officer and Matron. Social activities centre upon the Lodge, a small, early nineteenth century residence with extensions housing the dining room, games and television rooms and bar. The last amenity derives from the building's previous function as an officers' mess. Squash and tennis courts within the grounds have also been retained.

The future. The training programme must respond to changing circumstances and it is not difficult at this time to see directions from which pressure for change may come. Internationally, there is the world-wide problem of the effects of the pace of development of the science, and there is the trend to centralization of certain of the meteorologists' functions in response to the growth of the computer's role. Nationally, in the United Kingdom, recruitment during the past year has become, for one reason or another, more selective and academic standards are higher than in the past. There has also been the introduction into the Meteorological Office, in common with other departments of the Civil Service, of a new scientific class structure, combining the former Scientific Officer, Experimental Officer and Scientific Assistant classes. It is a little too soon to predict here what changes may result. Certain it is, however, that the new College facilities have come none too soon.

Shinfield Park is situated within a mile or two of the University of Reading, so the opportunity exists for co-operation with the Department of Geophysics in training projects of potential mutual benefit. In February 1973, students will arrive at Shinfield Park to embark upon the first phase of a new sandwich course leading to an honours bachelors degree in meteorology. The course will offer unique advantages in vocational training over the normal academic syllabus.

A leaflet giving the College calendar and the syllabuses for current courses is available on request from The Principal, Meteorological Office College, Shinfield Park, Reading, Berkshire, RG2 9AU.

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551.501.81:551.507.352

A NOTE ON THE USE OF AIRBORNE 30-MILLIMETRE RADAR AT LONG RANGES

By S. G. CORNFORD

Summary. The radar beam of a cruising supersonic transport aircraft will sometimes be attenuated by showers at lower levels. Storms at the flight level may lie in the radar shadow of lower-level showers and may not be detected when they first come into radar range. The effect, due to the curvature of the earth, is alleviated somewhat by refraction.

Introduction. It is well established[1,2] that cumulonimbus clouds sometimes extend to heights of over 18 km, rising 3 or more kilometres into the stratosphere. Where they occur, such tall clouds may present a hazard to supersonic transport aircraft (SST). The SST pilot will need to begin avoiding action when the storms are still a long way ahead, perhaps 400 km or more, because of the large accelerations inherent in any but gentle manœuvres at supersonic speeds. Allowing time for decision making and so on, he will need to detect storms when they are even farther ahead. So that he may do this the aircraft will carry radar. For practical reasons this will operate on a wavelength of 30 mm, the wavelength used in most airborne radars. At the ranges involved in storm detection from SSTs, however, two factors become important which are usually ignored by users of airborne radar. They are the curvature of the earth and refraction of the radar beam. The factors are, of course, well known[3,4] but their importance in these circumstances may be of interest to aircrew and the meteorologists who advise them.

Geometry on a spherical airless earth. Consider Figure 1. Suppose an observer at O, at height z above a spherical and airless earth of radius R, wishes to see an object S at the same height above the earth's surface as himself. He must look not along the horizontal OHS but along the chord OMS. His line of sight passes through M at a depth d below him. The geometry of Figure 1 gives the depression d as $d \approx l^2/2(R + z)$ where $2l$ is the range of S from O along the arc OHS. The only approximation involved is that $\varphi \approx \sin \varphi$. Since l will not exceed a few hundred kilometres and

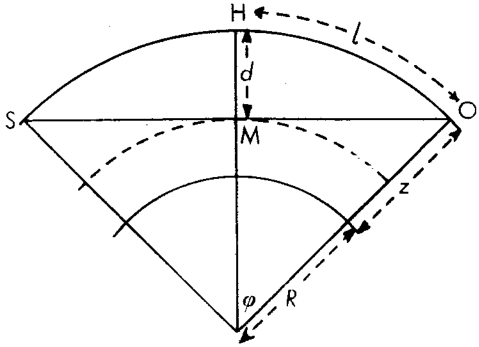

FIGURE 1—GEOMETRY ON A SPHERICAL AIRLESS EARTH

O Observer S Object being observed R Radius of earth

$(R + z) \approx 6000$ km, φ is small and is indeed approximately equal to $\sin \varphi$. The relationship between d and $2l$ is shown by the full curve in Figure 2. As may be expected since $z \ll R$, d is insensitive to variations in z of a few tens of kilometres and is almost proportional to l^2.

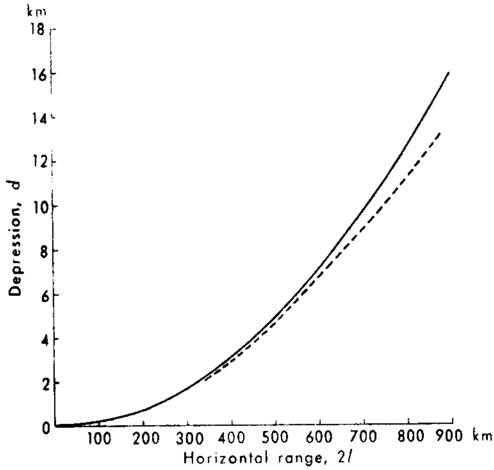

FIGURE 2—MAXIMUM DEPRESSION OF MICROWAVE BEAMS WITH RANGE

——— On a spherical airless earth with $R = 6377$ km. The depression, d, is insensitive to variations in the height, z, of the observer.

- - - For beams aimed from 100 mb at a target at the same level through air with the mean temperature and humidity profiles of a period when storm tops rose to over 18 km.

Refraction of microwaves in the atmosphere. The refractive index, n, of air for microwaves with wavelengths of tens of millimetres depends[3,4] upon the pressure, temperature and water-vapour pressure. The variation of n with height produces bending of microwave beams; see Figure 3.

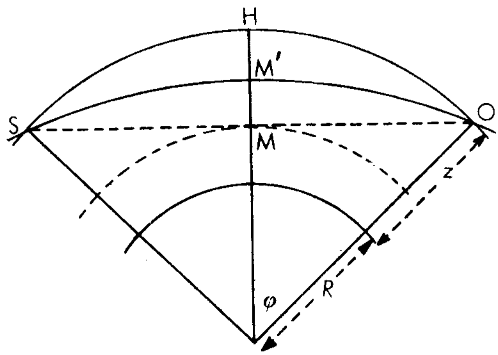

FIGURE 3—REFRACTION OF MICROWAVES IN THE ATMOSPHERE

Because the atmosphere forms a spherical shell, a beam which is horizontal at M′ passes into higher layers of air where n is smaller. At each higher level the beam is refracted 'away from the normal', although the curvature of the beam is smaller than that of the earth. Conversely a beam from O will travel along a path OM′S where M′ is above M. (On a smaller scale *n* may sometimes decrease quickly with height, e.g. at the base of an inversion, to give rise to anomalous propagation. Here, though, the rays pass through considerable depths of atmosphere.)

One of the parts of the world where storms are known to extend up to SST flight levels is north-east India (report by S. G. Cornford and C. S. Spavins, to be published). Because it was available from other work, a mean refractive-index profile based on soundings made from Calcutta during the pre-monsoon season of 1969 was used to trace rays such as OM′S. The soundings were made during a period when storm tops were observed at 18 km and above. A selection of rays is shown in Figure 4. They all start

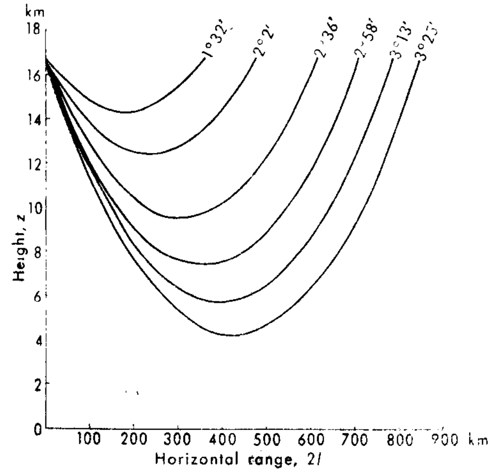

FIGURE 4—CALCULATED PATHS OF MICROWAVE BEAMS

The initial angle of depression is shown for each path.

and end at a height corresponding to 100 mb and, for ease of illustration, are shown relative to a flat earth. (The real sense of the curvature is that shown in Figure 3.) Although soundings from a storm-prone area were used, the paths of the rays are not very different from those in a standard atmosphere. Figure 4 has been used to derive the pecked curve on Figure 2. Comparison of the two curves of Figure 2 shows that refraction reduces the depression, *d*, of rays towards the earth by an amount which exceeds 1 km for ranges beyond 700 km.

Conclusions. Figure 4 shows that a Concorde pilot flying just below 17 km and using his radar to detect storms ahead of him must depress the radar below the horizontal. For a storm 600 km ahead, for example, the depression amounts to 2½° and the axis of the radar beam (and so most of the microwave energy) passes through air below 10 km. To detect storms 800 km ahead the axis of the beam would need to pass through air at between 5 and 6 km, where showers are often more frequent than at 17 km. Because they attenuate 30-mm radar beams, showers effectively cast radar 'shadows' and may mask more distant high-level storms; see Plate I. This effect appears to be a potential hazard and its implications (taking into account effects of beam-width, for example) should be worth exploring further. An assessment of its real importance must depend partly on an assessment of the relative probabilities of beams at different levels encountering one or more showers. If the radar were caused to nod continually over a range of a few degrees downwards from the horizontal, high-level storms could be spotted as soon as they came out of the radar shadows.

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551.509.334:551.524.36:551.589

MONTHLY MEAN TEMPERATURE RELATED TO SYNOPTIC TYPES OVER BRITAIN SPECIFIED BY PSCM INDICES

By R. MURRAY

Summary. The seasonal and spatial variations of monthly mean temperature over Britain are discussed in relation to the main broad-scale synoptic types given by the *PSCM* indices of Murray and Lewis.

Introduction. The *PSCM* indices of Murray and Lewis,[1] based on the Lamb[2] catalogue of daily synoptic types, have been shown to be good indicators of broad-scale circulation near the British Isles. For instance, Murray and Benwell[3] presented some examples showing the close relationship between the indices in quintile form and the mean pressure anomalies over one, two and three months over the eastern Atlantic and western Europe. When the indices differ appreciably from average (quintile 3), pairs of P, S and C usually delineate fairly definite broad-scale types of synoptic situation near the British Isles; these synoptic types tend to be associated with characteristic temperature distributions. Murray and Benwell[3] also presented numerical correlations between the indices and monthly mean temperatures, and they briefly discussed the seasonal variations and the spatial variations over the United Kingdom. However, it is felt that to be of practical use these variations need to be described more explicitly.

The indices cover the period 1861 to 1969. The quintile boundaries (based on 100 years, 1865–1964) are given in Murray and Benwell,[3] together with information on monthly mean temperature.

Pairs of P, S and C indices. Blocked and progressive synoptic types are represented by P_{12} (quintiles 1 or 2 in P index) and P_{45} (quintiles 4 or 5 in P index) respectively. Synoptic types with a bias to north and south are given by S_{12} and S_{45} respectively. Anticyclonic and cyclonic synoptic types are represented by C_{12} and C_{45} respectively. When two indices, for example P_{12} and C_{45}, are taken together a blocked cyclonic type which is represented as $P_{12}C_{45}$ is obtained. Pairs of the P, S and C indices can be combined in a meaningful way to represent broad-scale synoptic types on the monthly time-scale. The frequencies of occurrence of various combinations of the indices in relation to the synchronous distribution of quintiles of monthly mean temperature in central England were readily obtained in percentage form. The actual frequencies of synoptic types varied between pairs of indices and also seasonally, but usually there were around 20 cases (14 to 28) per month for each pair.

The 12 subsections contained in Table I show how the monthly mean temperature varies according to the broad-scale synoptic type.

TABLE I—MONTHLY PERCENTAGE FREQUENCY DISTRIBUTION OF QUINTILES OF MONTHLY MEAN TEMPERATURE IN CENTRAL ENGLAND FOR COMMON SYNOPTIC TYPES,* 1861 TO 1969

Quintiles	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
(a) $P_{12}S_{12}$ (blocked northerly)												
1	**63**	**60**	**65**	**40**	**30**	22	33	24	**60**	**54**	**82**	**42**
2	22	35	30	26	25	22	33	24	17	13	13	23
3	10	5	5	20	25	22	14	24	17	13	5	31
4	5	0	0	7	10	22	10	16	6	20	0	4
5	0	0	0	7	10	12	10	12	0	0	0	0
(b) $P_{45}S_{12}$ (progressive northerly)												
1	6	0	0	17	**56**	41	**58**	33	17	14	16	5
2	22	32	19	**38**	32	0	8	**39**	39	**36**	26	25
3	22	10	27	33	6	41	17	22	39	32	**32**	20
4	22	16	27	6	6	6	17	6	0	6	16	25
5	**28**	**42**	27	6	0	12	0	0	5	14	10	25
(c) $P_{12}S_{45}$ (blocked southerly)												
1	18	28	15	5	0	15	6	0	0	5	7	25
2	**34**	14	25	25	17	23	6	7	11	14	7	15
3	24	22	25	**30**	11	15	29	36	22	19	20	20
4	24	**36**	25	20	17	**32**	18	0	**39**	10	**46**	15
5	0	0	10	20	**55**	15	**41**	**57**	28	**52**	20	25
(d) $P_{45}S_{45}$ (progressive southerly)												
1	0	0	0	0	0	14	10	12	0	0	0	0
2	0	0	0	7	6	18	25	19	6	0	10	13
3	17	12	7	0	25	27	15	**25**	25	18	5	13
4	25	19	36	36	31	9	25	19	**38**	36	35	20
5	**58**	**69**	**57**	**57**	**38**	**32**	25	25	31	**46**	**50**	**54**
(e) $P_{12}C_{12}$ (blocked anticyclonic)												
1	**50**	**50**	29	20	10	16	14	12	30	26	**54**	**48**
2	29	25	**41**	25	10	11	14	8	9	13	7	25
3	13	11	18	25	15	21	14	20	13	13	14	9
4	8	14	12	15	15	21	14	12	17	13	21	9
5	0	0	0	15	**50**	**31**	**44**	**48**	30	**35**	4	9
(f) $P_{45}C_{12}$ (progressive anticyclonic)												
1	0	0	0	0	6	7	7	8	0	8	9	0
2	7	0	8	22	**35**	21	7	0	**45**	**31**	27	29
3	36	22	8	17	18	21	20	31	22	23	9	21
4	14	22	**46**	17	18	14	27	**38**	11	15	9	**36**
5	**43**	**56**	38	**44**	23	**37**	**40**	23	22	23	**46**	14
(g) $P_{12}C_{45}$ (blocked cyclonic)												
1	29	**50**	**45**	25	23	23	25	21	29	25	**43**	**35**
2	21	42	11	19	**38**	23	**31**	**36**	29	8	21	29
3	**43**	0	22	19	23	12	25	29	13	17	7	6
4	7	8	11	12	8	**30**	13	14	29	**33**	21	12
5	0	0	11	25	8	12	6	0	0	17	7	18

Maximum percentages are bold if they are at least 3 per cent greater than the next highest percentage.

*Synoptic type is indicated by pairs of *P*, *S* and *C* indices.

TABLE I—*continued*

Quintiles	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
(h) $P_{45}C_{45}$ (progressive cyclonic)												
1	6	0	0	12	**35**	**43**	39	32	14	14	5	6
2	6	11	22	29	5	14	39	**42**	24	9	18	11
3	11	32	17	29	20	29	16	21	**48**	**29**	14	11
4	**44**	21	**33**	24	25	5	6	0	9	24	**36**	17
5	33	**37**	28	6	15	9	0	5	5	24	27	**55**
(i) $S_{12}C_{12}$ (northerly anticyclonic)												
1	**33**	**43**	25	21	16	11	25	25	**50**	33	**68**	29
2	22	29	**40**	**42**	32	6	25	15	31	**40**	18	**38**
3	11	14	15	16	32	**33**	20	**35**	6	7	9	14
4	17	5	15	5	10	28	15	15	13	13	0	19
5	17	9	5	16	10	22	15	10	0	7	5	0
(j) $S_{45}C_{12}$ (southerly anticyclonic)												
1	23	14	0	0	0	8	0	6	0	6	0	23
2	31	7	21	0	6	15	0	0	7	11	15	12
3	31	33	29	20	6	15	12	12	20	22	8	18
4	8	33	21	20	23	23	18	13	27	0	**46**	23
5	8	14	29	**60**	**65**	**38**	**70**	**69**	**46**	**61**	31	24
(k) $S_{12}C_{45}$ (northerly cyclonic)												
1	27	18	**67**	36	**72**	**62**	**50**	33	**40**	**40**	**36**	**46**
2	20	**27**	8	21	11	13	33	**50**	30	10	29	23
3	27	23	25	36	11	13	8	6	30	30	21	8
4	13	14	0	7	6	6	9	11	0	10	7	15
5	13	18	0	0	0	6	0	0	0	10	7	8
(l) $S_{45}C_{45}$ (southerly cyclonic)												
1	0	7	11	6	0	**29**	16	12	0	5	0	6
2	25	7	0	22	15	19	**37**	18	14	5	10	18
3	19	7	21	11	**35**	19	26	**46**	29	16	5	12
4	**31**	**50**	31	**44**	30	19	16	18	**50**	37	**45**	12
5	25	29	**37**	17	20	14	5	6	7	37	40	**52**

The first four types show combinations of P and S. Not unexpectedly, blocked northerly (a) and progressive southerly (d) types show markedly different temperature distributions, especially in the winter half-year. Progressive northerly (b) and blocked southerly (c) types have more complicated patterns. The next four types involve P and C. The blocked anticyclonic type (e) shows a pronounced seasonal variation, being cold in winter and warm in summer, whereas the progressive cyclonic type (h) shows broadly the reverse temperature pattern during the year. The progressive anticyclonic (f) and blocked cyclonic (g) types are also the reverse of each other in temperature pattern but they do not show such a strong seasonal change as do the blocked anticyclonic and progressive cyclonic types. The last four types in Table I involve the S and C indices. The southerly anticyclonic type (j) is generally warm except in winter; the opposite type, i.e. northerly cyclonic (k) is usually cold, especially in March, May and June. The northerly anticyclonic type (i) has a strong bias to cold from September to April; on the other hand, the southerly cyclonic type (l) tends to be warm from September to April.

Correlations between indices and temperature. Correlation coefficients between the individual indices and monthly mean temperature *(T)* at several places were given in Murray and Benwell.[3] The data for Braemar in north Scotland and Plymouth in south-west England are plotted in Figure 1 in order to illustrate seasonal and geographical differences and similarities.

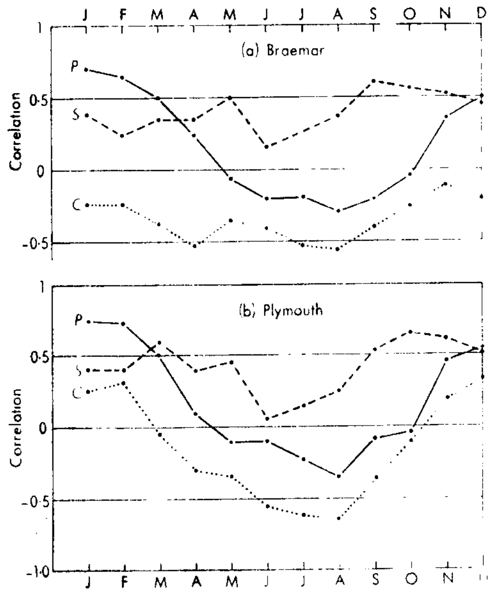

FIGURE 1—CORRELATION COEFFICIENTS BETWEEN INDICES AND MONTHLY MEAN TEMPERATURE FOR BRAEMAR AND PLYMOUTH (From Murray and Benwell[3])

At both places the correlations between P and T are positive in winter and negative in summer and this broad relationship applies in other parts of the United Kingdom. The correlations between S and T are positive throughout the year at both stations, although there is a seasonal variation with a minimum correlation in June and a maximum in autumn. At Braemar the correlations between C and T are always negative but at Plymouth they are negative only from March to October.

The seasonal variation of the correlations between C and T at Plymouth are quite typical of those in most other parts of England and Wales, as shown by the statistics for Kew (London), Oxford, Cambridge and Aberystwyth (Wales) and, in a weak form, for Stoneyhurst (Lancashire) and York. It is probable that the C and T correlations at Braemar are fairly typical of north and west Scotland (from Aberdeen and Dumfries data) and Northern Ireland (from Armagh data).

Multiple correlations have been computed between P, S and C indices and T for several stations. Examples involving central England and Edinburgh monthly mean temperatures were given in the paper by Murray and Benwell.[3] The regression equations for central England for January and August may be employed to illustrate the variation of monthly mean temperature according to the way in which the P, S and C indices in quintiles are combined.

The multiple regression equations for January (1) and August (2) are :

$$T(^\circ C) = 2{\cdot}753 + 0{\cdot}058P + 0{\cdot}054S + 0{\cdot}006C, \qquad \ldots (1)$$

$$T(^\circ C) = 15{\cdot}816 - 0{\cdot}009P + 0{\cdot}077S - 0{\cdot}035C. \qquad \ldots (2)$$

Each of the P, S and C indices may be divided into three classes, namely quintiles 1 and 2 (e.g. P_{12}), quintile 3 (e.g. P_3) and quintiles 4 and 5 (e.g. P_{45}). The values of each index at the quintiles 1 and 2 boundaries (given in Murray and Benwell[3]) may be taken as representative of P_{12}, S_{12} and C_{12} and at the quintiles 4 and 5 boundaries as representative of P_{45}, S_{45} and C_{45}. P_3 may be allocated the mean of the boundary of quintiles 2 and 3 and of quintiles 4 and 5, and similarly for S_3 and C_3. There are 27 combinations of the three subdivisions of indices *P*, *S* and *C*; these give 27 synoptic types, such as $P_{12}\ S_{12}\ C_{12}$, $P_{12}\ S_3\ C_{12}$, etc. The type $P_{12}\ S_{12}\ C_{12}$ is, of course, blocked northerly anticyclonic and can be equated to the anticyclonic north-easterly type in terms of monthly mean pressure anomalies. Similarly the other types can be described in simple and meaningful synoptic terms.

By using equation (1), typical or representative monthly mean temperatures may be allocated to each of the 27 synoptic types. A similar procedure can be carried out using equation (2) to give typical values for August. Table II shows the 27 synoptic types ranked according to the rank of the mean temperatures typically associated with them.

Table II shows several synoptic climatological features of interest. In January the coldest type is $P_{12}\ S_{12}\ C_{12}$ (blocked northerly anticyclonic) and the warmest is $P_{45}\ S_{45}\ C_{45}$ (progressive southerly cyclonic); in August the coldest is $P_{45}\ S_{12}\ C_{45}$ (progressive northerly cyclonic) and the warmest is $P_{12}\ S_{45}\ C_{12}$ (blocked southerly anticyclonic). In determining monthly mean temperature the primary index is clearly *P* in January, but *S* and *C* are more significant than *P* in August. It is also of interest that the $P_3\ S_3\ C_3$ or normal type is in the middle of the order in August but slightly on the warm side in January when the mean temperature distribution is negatively skew.

It must be remembered that the data in Table II were derived from quintile boundary values of the three indices. Quintiles 1 and 2 in, say, the *P* index covers a wide range of possible values each month. For example, taking the extreme values of *P*, *S* and *C* in January listed in Appendix II of Murray and Benwell[3] the regression equation (1) gives a likely minimum of $-1{\cdot}7$°C and a maximum of 7·9°C. The likely extreme temperatures in August derived from equation (2) are 12·0°C and 18·9°C. The two estimated maxima are slightly higher that the highest recorded monthly mean temperature; the estimated minimum is higher in January and lower in August than the minimum monthly mean temperature recorded during the period of the *PSCM* indices (i.e. since 1861).

In practical work, temperatures are mostly used in their quintile form. Figure 2 gives the relationship between the 27 main synoptic types and their characteristic temperature quintiles in diagrammatic form. The diagram shows quite clearly that in January the warm types are between north-west ($P_{45}\ S_{12}$) and south-west ($P_{45}\ S_{45}$), irrespective of cyclonicity. There are almost temperature discontinuities between north-west and north types and also between south-west and south types. Figure 2 emphasizes the importance of the *C* index in August. The warmest types are C_{12} from the south or south-east and the coldest type is C_{45} associated with roughly north-west flow.

It must be emphasized again that Figure 2 shows only typical temperature quintiles associated with values of *P*, *S* and *C* at the boundaries between quintiles 1 and 2 and between quintiles 4 and 5 and at roughly the mid-point of quintile 3. For example, if the type is $P_4\ S_1$ in January, with P_4 nearly equal to P_3 and S_1 well into the quintile 1 range, then the mean temperature will probably be quintile 2 rather than quintile 4 as shown in Figure 2. As another example, in a case of marked blocking in January, with *P* well into

TABLE II—SYNOPTIC TYPES* TYPICALLY ASSOCIATED WITH RANKED MONTHLY MEAN TEMPERATURES IN JANUARY AND AUGUST IN CENTRAL ENGLAND, DERIVED FROM REGRESSION EQUATIONS

Index	Temperature rank 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
(a) January													*subscript of index*														
P	12	12	12	12	12	12	3	3	12	3	12	12	3	3	3	3	3	3	45	45	45	45	45	45	45	45	45
S	12	12	12	3	3	3	12	12	45	12	45	45	45	45	45	3	3	3	12	12	3	3	3	3	45	45	45
C	12	3	45	12	3	45	12	3	12	45	3	45	12	3	45	12	3	45	12	3	45	12	3	45	12	3	45
(b) August																											
P	45	3	45	12	45	3	3	12	45	45	12	45	3	3	3	12	12	45	45	12	3	3	12	12	45	3	12
S	12	12	3	12	12	3	12	3	3	45	12	12	45	3	12	45	3	45	3	12	45	3	45	3	45	45	45
C	45	45	45	45	3	45	3	45	3	45	3	12	45	3	12	45	3	3	12	12	3	12	3	12	12	12	12

In January, Rank 1 = 2·16°C and 27 = 5·47°C. In August, Rank 1 = 14·45°C and 27 = 16·65°C.

* Synoptic types are indicated by indices.

the lowest quintile, the $P_1 S_3$ type is likely to be associated with temperature quintile 1 rather than with quintile 2. In other words the diagrammatic representation in Figure 2 must be interpreted sensibly. The likely temperature quintile can of course be assessed more accurately from the regression equations if the actual values of P, S and C are known or estimated.

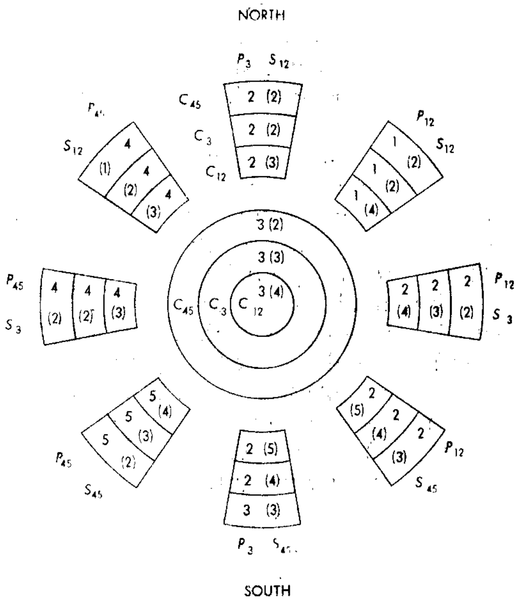

FIGURE 2—RELATIONSHIP BETWEEN THE 27 SYNOPTIC TYPES AND THEIR CHARACTERISTIC TEMPERATURE QUINTILES IN DIAGRAMMATIC FORM FOR JANUARY AND AUGUST

Typical quintiles of monthly mean temperature in central England in January and August (latter in brackets) associated with the 27 main synoptic types as given by combinations of P, S and C indices in their quintile form. Combinations of P and S give roughly the direction of the anomalous flow ($P_3 S_3$ indicates normal flow); the cyclonicity (C) associated with each pair of P and S varies from C_{12} in the inner sector to C_{45} in the outer sector of each box.

A diagram similar to Figure 2 can be prepared for Edinburgh from the regression equation given in Murray and Benwell.[3] However, the discussion in this note of Figures 1 and 2 and Table I should be enough for qualitative assessments of the monthly mean temperature distribution over the United Kingdom associated with different broad-scale synoptic types.

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HAZE TOP IN THE AUSTRIAN TIROL

By E. N. LAWRENCE

The haze photograph, Plate III, was taken at about 16 GMT on 9 August 1954, from the top of Hahnenkamm (Austrian Tirol), altitude 1700 m (5500 ft), looking about north-north-west. The range of mountains in the background reaches about 2300 m (7500 ft) and the valley floor is at about 800 m (2500 ft). Small amounts of small cumulus cloud may be seen 'near' the mountains, at about the level of the haze top but projecting slightly above this level.

The synoptic pressure situation (at 18 GMT) shows the area to be in a feeble ridge between a small depression over Holland and a frontal trough from Sweden to the Adriatic. The area is situated at about the nodal point of the front joining these two systems. Some associated upper cloud is shown in the photograph. At 700 mb (at 15 GMT) winds were south-westererly about 35 knots to the north-west and light to the south-east.

The haze top is probably associated with the stable, inversion layer shown on the Munich (Riem) upper-air ascent for 15 GMT on 9 August (Figure 1). At Munich, some 100 km (60 miles) to the north-west of the site of the photograph, the height of the inversion layer is 870–846 mb and the top of the inversion is 1450 m (4750 ft) above MSL, that is, somewhat below the top of the mountain ridge shown in the photograph.

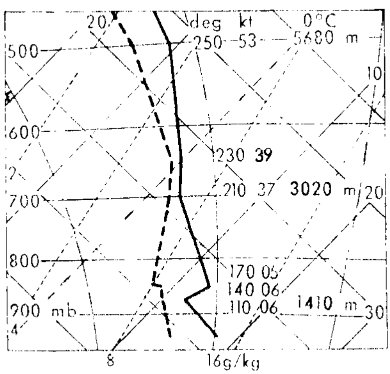

FIGURE 1—UPPER-AIR TEMPERATURES AND WINDS AT MUNICH AT 15 GMT ON 9 AUGUST 1954

——— Temperature - - - Dew-point

Heights refer to standard levels.

NOTES AND NEWS

Dr K. A. Browning — Special merit promotion to Senior Principal Scientific Officer

It is a pleasure to record that Dr K. A. Browning has been promoted to Senior Principal Scientific Officer under the scheme for promotion of scientists of special research ability. Dr Browning has been concerned with the application of radar to meteorological research throughout his career. His early research was at Imperial College, London, under the direction of Professor F. H. Ludlam in the early 60s. He continued his studies in the U.S.A. at the Air Force Cambridge Research Laboratories but returned to the United Kingdom in 1966, taking charge of the Meteorological Research Unit at Malvern, first as a Principal Research Fellow but from 1969 as a Principal Scientific Officer.

Dr Browning's researches have covered many aspects of atmospheric physics and cloud structure. His studies of the structure of severe storms, of the detailed structure of fronts, of clear-air turbulence and of the structure of hailstones have been particularly noteworthy. In all of them he has exploited the potentialities of radar to the full. As leader of the small team of meteorologists and radar specialists engaged on meteorological problems, he has been able to digest the voluminous data from the radars in a remarkably short time, and to present a graphic and understandable picture of the atmospheric system observed, whether it be a cumulonimbus, clear-air turbulence or a mountain wave.

The Meteorological Office is fortunate that his promotion permits Dr Browning to continue to lead the Malvern group and to exploit the powerful radars available there for meteorological research.

J.S.S.

REVIEWS

Inadvertent climate modifications. Report of the Study of Man's Impact on Climate. 220 mm × 155 mm, pp. xxi + 308, *illus.* The M.I.T. Press, 126 Buckingham Palace Road, London, SW 1, 1971. Price: £5·85, paperback £1·40.

This book presents the results of an international symposium held in Stockholm in 1971. Thirty of the world's leading atmospheric scientists from 14 countries met to discuss and study the impact of man on climate. The study was intended as a follow up of an earlier Study of Critical Environmental Problems (SCEP) held in the U.S.A. in 1970.

The 30 scientists include many famous names, Budyko, Flohn, London, Machta, Manabe, Van Mieghem, G. D. Robinson and Twomey, for instance, and there is no doubt that they have produced a thoroughly worthwhile and most timely report.

The report is directed at the scientific community in general, partly in the hope that young scientists will be stimulated to study some of the unsolved problems to which the report draws attention. Even more important, it is hoped that the conclusions and recommendations will influence the international scientific community so that progress towards their implementation may be made. In this latter respect it was clearly intended that the report should be studied carefully by delegates to the recent United Nations Conference on the Human Environment. It is recognized that only by airing the problems involved at such a unique forum is the necessary research effort likely to be allocated by governments.

The layout of the book leads to a good deal of repetition. One would not complain at the collection in Part I of the major conclusions and recommendations of the whole study, but Parts II, III and IV also contain a good deal of repetition. Part II describes climatic changes which have taken place in the geological past from 550 million years ago right up to the 20th century and this is followed by some discussion of the various ways in which it is possible that man may be influencing climate. Part III describes in more detail the factors which govern climate — radiative processes, ocean/atmosphere transport processes, hydrological processes, etc. — and then goes on to describe the general theory of climate and the progress which has been made towards producing a satisfactory mathematical model to represent the way in which climate is determined. Part IV discusses in some detail the possible ways in which man is, or may be, changing the climate as a result of the changes he is making. This part is divided into three sections :

(a) *At the surface.* Urban effects; changing the earth's albedo by the increase of agriculture, deforestation, etc.; changing the surface water area, and hence evaporation, by means of artificial lakes, drainage of swamps, etc.; changes in the hydrological cycle due to control of run-off; the mining of ground water, etc.
(b) *In the troposphere.* Addition of particulate matter, aerosols, gaseous products such as carbon dioxide and sulphur dioxide, and water vapour which may effect cloud formation, etc.
(c) *In the stratosphere,* where, owing to their longer residence time, any contaminants may have more chance of seriously influencing photochemistry, especially that involving ozone.

Throughout the book the authors stress the importance and probable instability of the polar ice; a 1 per cent change of incoming solar radiation, keeping mean cloudiness constant, is likely to change the mean global temperature by 1·5 degC and that of the Arctic by about 5 degC. A 1 per cent change in global albedo is also likely to change the mean global temperature by 2·3 degC — more in high latitudes — so that it is clear that polar ice is extremely sensitive to changes in the global radiation budget. If the polar ice once melted completely it is considered very doubtful whether it would re-form, because the change in the albedo would lead to greater absorption of heat by oceans in high latitudes.

The importance of carbon dioxide is also stressed; it seems likely that the increase to 375 parts per million expected in the atmosphere by 2000 AD would lead to about a 0·5-degC global temperature rise which would be enhanced by absorption of heat due to the increased water vapour in the atmosphere. However, if mean cloudiness increased by 1 per cent this rise of global temperature would probably be more than counterbalanced by a fall due to the changed albedo. From these sorts of arguments it is clear that the study has served a very useful purpose in drawing attention to the need for much more research and in spelling out the most profitable areas for carrying out this research.

This volume is very readable with generally good diagrams and it is thoroughly up to date with many references to work done in 1970 and 1971, and even to work not yet published. Apart from H. H. Lamb, however, British meteorologists get scant reference. Errors in the text are few although the reference to Lamb's long series of January and July charts on p. 41 should be for the period since 1750 and not since 1790 as stated. More seriously the scale of Figure 3.5, showing the changes in the frequency of westerly weather types since 1860 over Britain, is completely wrong, indicating a year-to-year variability from 70/170 instead of about 70/120.

Nevertheless, the study is thoroughly recommended as a balanced view, based on the current state of knowledge, of the possibilities of inadvertent climatic change. It makes it clear that man may possibly have reached the stage when he could be influencing the climate on a global scale, but the accent throughout is cautious and stresses the necessity for further knowledge before a proper judgement can be made.

R. A. S. RATCLIFFE

New Zealand: the physical environment, by D. J. Hooton (editor). 245 mm × 155 mm, pp. 70, *illus.*, Auckland University Press, and Oxford University Press, Ely House, 37 Dover Street, London W 1, 1970. Price: £1 (paperback).

Anyone entering the Geological Museum in South Kensington, London, at the appropriate moment will be faced by a rotating globe showing almost a hemisphere of water — the Pacific Ocean — liberally sprinkled with islands, the largest of which are the North and South Islands of New Zealand. Their nearest continental neighbours are Australia, about 1100 miles (1770 km) to the west, and South America, some 5000–6000 miles to the east.

This extreme isolation is the result of earth movements which gradually separated New Zealand from its parent continent, Australia and Antarctica combined. In the first century of European colonization, New Zealand, with its biological affinities with Australia, South America and Antarctica, was a paradise for the natural scientists, but less so for the physical scientists.

Recent developments in meteorology and geophysics have now shown that New Zealand offers unique opportunities for research in these fields as well, its very isolation from continental masses being a valuable asset in certain important fields, such as the circulation of air and water currents and the electron content of the ionosphere.

The booklet under review consists of a series of six lectures delivered at Auckland in the (southern) winter of 1969 by specialists in geology, physics, geophysics, meteorology and oceanography.

As Professor Hooton says in his preface, these six lectures 'range from outer space to the hot interior of the earth' and on the way they mention some of the special fields of research in which New Zealand is engaged. The Director of the New Zealand Meteorological Office, Dr J. F. Gabites, describes how New Zealand fits into the global scheme and shows a striking picture of the track of a balloon — launched from Christchurch, New Zealand, during the GHOST project (Global Horizontal Sounding Technique) — which had travelled more than seven times round the hemisphere in 102 days at a height of 12 km.

The ionosphere is being investigated by means of signals radiated from satellites, and another figure shows the electron content, on 11 days in winter and summer 1965, along a path between a geostationary satellite (at a height of 30 000 km over the equator north of New Zealand) and Auckland.

New Zealand has also been prominent in the study of 'whistlers'—disturbances of radio reception due to distant lightning flashes. The dispersion of the whistler signal between one hemisphere and the other was first demonstrated experimentally in 1955 between Wellington, New Zealand, and Unalaska in the Aleutian Islands.

Of about 800 volcanoes now active on the face of the earth, 62 per cent are situated in the narrow 'Girdle of fire' round the Pacific Ocean. Volcanic eruptions and earthquakes can give rise to the destructive ocean waves known as 'tsunamis', which travel enormous distances at recorded speeds of up to 600 miles/h, according to the depth of the ocean. The wavelength is typically tens of miles long and waves of more than 100 ft in height have built up on some shores.

Because of its isolated position, New Zealand is ideally situated to record, by hydrophone, underwater volcanoes, earthquakes likely to produce tsunamis and man-made signals in the SOFAR channel, along which underwater sound can travel many thousands of miles before being lost in the general background noise. Instances are given of projects exploiting this capability (Neptune, Chase V).

T. C. MARWICK

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