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THE DISTRIBUTION AND FREQUENCY OF HIGH CUMULONIMBUS TOPS NEAR SINGAPORE AS MEASURED BY 10-CENTIMETRE RADAR (PART II)

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Summary. Radar measurements of storms near Singapore, made during 1969 and 1970, are discussed and analysed. Especial attention is given to tops above about 50 000 ft because of their importance to supersonic transport aircraft. A marked preference for development of giant cumulonimbus in certain favoured areas is described, as also are diurnal and seasonal variations of some importance.

Spatial and diurnal distribution of the higher tops. (Continued from Part I.*) It should be pointed out here that except perhaps for periods during the north-east monsoon the wind flow is rarely uniform over the whole area. The equator is only 80 n.mile south of Singapore and hence the winds over the southern portion of the area may well have a different characteristic direction from those farther north. In the south-west monsoon, for instance, the winds over Singapore and farther south are usually south-easterly and turn round into a south-westerly over Johore, often at a well-marked shear-line. (The description 'SE monsoon' is indeed sometimes used at Singapore, especially in older literature where the surface wind was the only guide.) The frequencies of surface winds from various directions for the periods September, October, and November–December 1969 are shown in Figure 12 for the three places Singapore, Malacca, and Mersing. Similar diagrams, for Singapore only, for the remaining combinations of months used for displaying distributions of echo-tops are given in Figure 13.

The formation of storms in the Singapore area is influenced by the shape of the Malay peninsula and the long, narrow strait between Malaya and Sumatra so that storms are distributed along lines rather more frequently than may be typical of equatorial regions in general. Figure 14 illustrates three examples of lines which soon become familiar. Of these, the third is the least common and least likely to be associated with high tops; it is occasionally seen in the late night and early morning when the low-level winds over the China Sea have an easterly component, and a katabatic westerly drift from the mainland sets up a convergence zone some distance off-shore. It is likely to decay

* HILL, F. F. and LEWIS, R. P. W.; The distribution and frequency of high cumulonimbus tops as measured by 10-centimetre radar (Part I). *Met Mag, London,* 103, 1974, pp. 29–48.

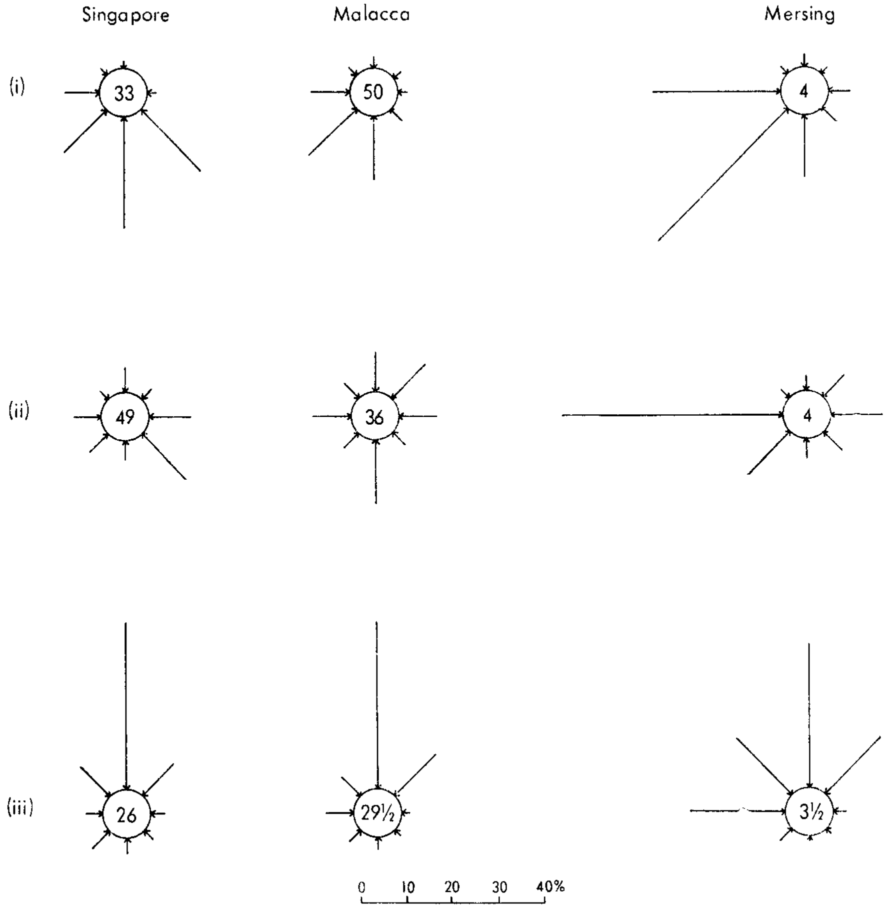


FIGURE 12—PERCENTAGE FREQUENCIES OF WINDS FROM DIFFERENT DIRECTIONS AT SINGAPORE, MALACCA AND MERSING

(i) September 1969; (ii) October 1969; (iii) November and December 1969.
Lengths of arrows are proportional to frequencies and the percentage frequencies of calms are shown in the central circles.

quickly. The second type is of frequent occurrence and the main generator of high tops. This type is subject to a variety of wind influences as already mentioned but its further development and movement should be broadly predictable.

The first figure illustrates the 'Sumatra' storm which is a night-time development and a source of major problems for the forecaster. The formation of a 'Sumatra' is largely due to convergence initiated by katabatic sinking between the parallel mountainous spines of Malaya and Sumatra. The existence of a light southerly or south-easterly wind over the strait between Singapore and Sumatra accentuates this convergence and the storms may then become a major feature with their future movement depending on the wind at low and middle levels; consequently, during the south-west monsoon the storms are likely to affect Malaya during the night or early morning.

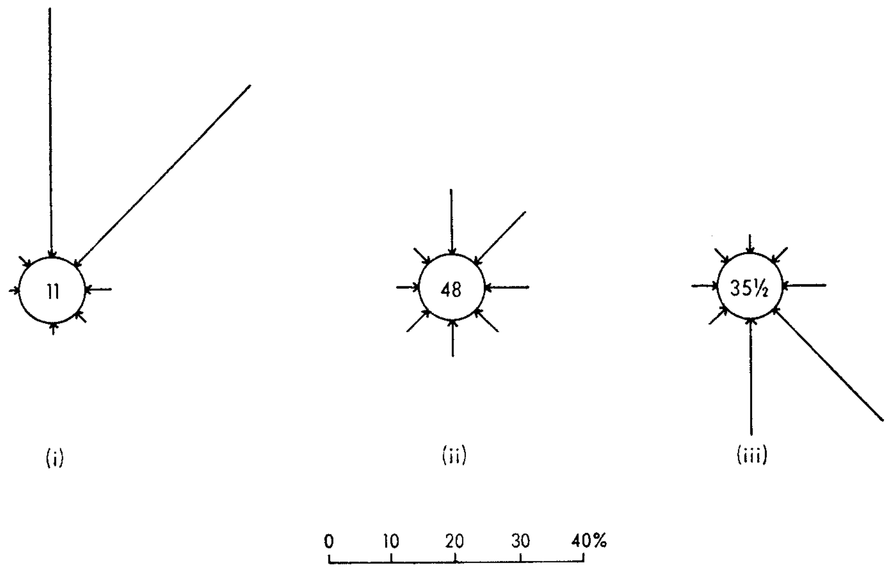


FIGURE 13—PERCENTAGE FREQUENCIES OF WINDS FROM DIFFERENT DIRECTIONS AT SINGAPORE

(i) January, February and March 1970. (ii) April and May 1970. (iii) August and September 1970.

See note under caption to Figure 12.

The main point of interest is, however, that the highest tops seem to be generated over the straits and near the coast only and thus have the appearance of propagating eastwards or south-eastwards in an irregular movement while the existing storms move north or north-eastwards overland and decay.

The following table gives frequencies of various types of night-time development for the period May to October in 1969 and 1970:

TABLE IX—FREQUENCY OF CERTAIN NOCTURNAL CONVECTIVE DEVELOPMENTS FOR THE PERIOD MAY TO OCTOBER IN 1969 AND 1970

Night-time echo distribution over Malacca Strait	Number of nights May–October 1969	Number of nights May–October 1970	Total
Nil or only isolated echoes	14	19	33
Several echoes, some strong, but no line	9	7	16
Numerous echoes, including formation of a line	9	9	18
Total	32	35	67

Of the 18 lines, 13 moved into Malaya. Not all the lines yielded high tops: it seemed that the more mobile the line, the less likely were they to do so; on the other hand, some of the more scattered developments generated giant Cb.

Since night-time observations were made on only about 40 per cent of possible occasions, it follows from these figures that either areas or lines of major storms with a possibility of giant Cb may be expected on about $(34/2)\times(100/40)\approx 40$ nights during the period May–October with the main activity usually occurring between 0100 and 0600 local time.

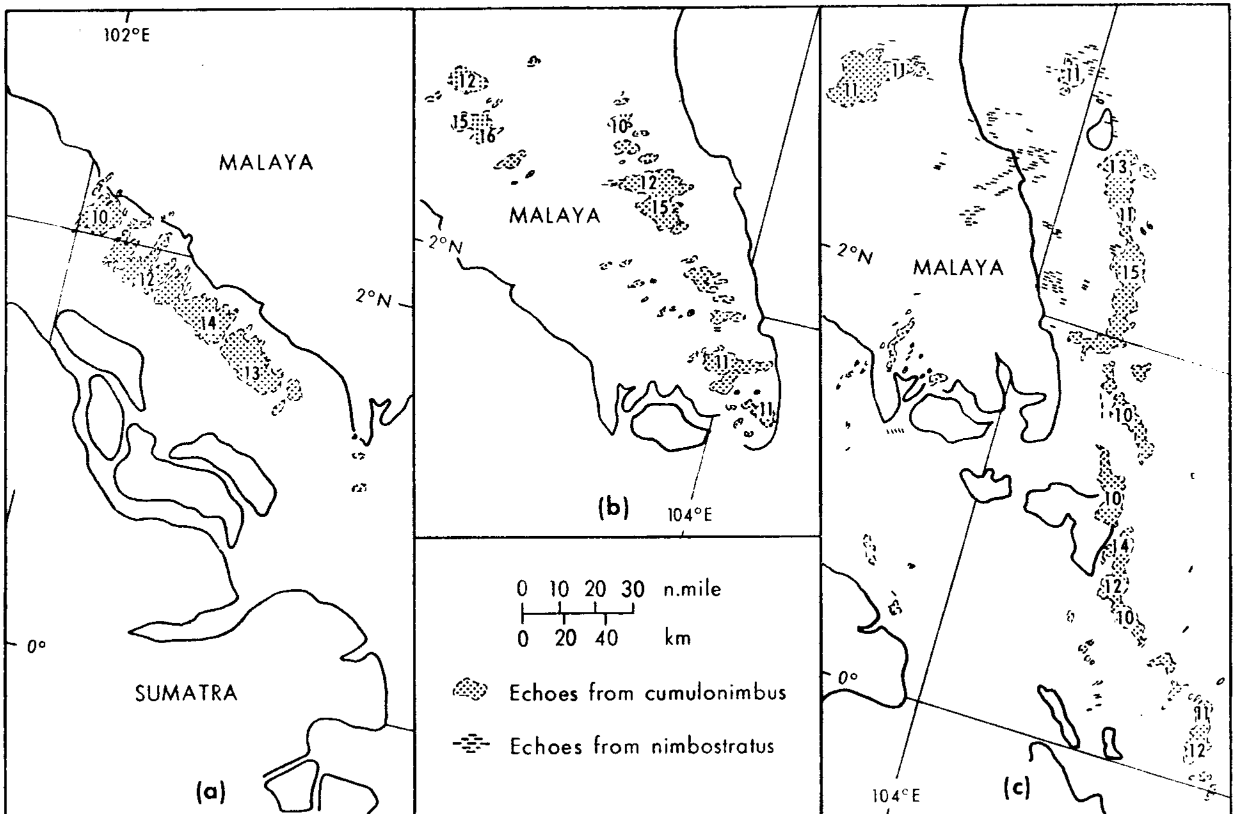


FIGURE 14—TYPICAL EXAMPLES OF BROKEN LINES OF ECHOES SOMETIMES ASSOCIATED WITH HIGH TOPS

(a) 8 October 1970 at 0318; (b) 22 April 1970 at 1615; (c) 2 December 1969 at 0920.
Heights of echo-tops are quoted to the nearest kilometre.

Relative frequency of heights of high tops. Figure 15 shows the relative monthly frequencies of heights of the highest top at each routine check for all tops above 6 km with separate plots for the 'afternoon' (1200–1800 local time) and for 'other times'. The curves have been subjectively smoothed to eliminate variations in the original graphs which were plotted in 0·5-km steps. A figure within the curves indicates the percentage of checks at which there was at least one top above 6 km (20 000 ft).

The graphs for 'other times' show a marked peak of frequency in most months at a height varying from 10 to 12·5 km (33 000 ft to 41 000 ft). In some months this level is the most frequent for the highest tops in the afternoon also, but the formation of giant cumulonimbus overland causes at least one secondary peak to appear at from 14 to 16 km (46 000 to 52 000 ft) and this level becomes the principal one in the more active months; in several months there was also substantial activity at even higher levels (16–18·5 km, or 52 000–60 000 ft).

In Table VIII (p.40) the numbers of echo-tops above 40 000, 50 000 and 60 000 ft are given as percentages of the number of tops above 35 000 ft, a height which is near the normal cruising level for subsonic passenger aircraft and is also near the height attained by most cumulonimbus tops over the sea and by the tops of many of the less vigorous cumulonimbus occurring over the land; again, separate figures are given for the 'afternoon' and for 'other times'. Although this method of presentation eliminates the month-to-month variation of total activity (plausibly measured by the number of tops over 35 000 ft), the table still shows some significant variations at high levels: the percentages at 50 000 ft, for example, vary from 0 to 18 per cent in the afternoons, and from 0 to 12 per cent at other times. Both zero values occurred in February 1970, the last three weeks of which were rainless in Singapore and over much of southern Malaya. It is likely therefore that convective activity was much less in this month than usual; however, relative frequencies at 50 000 ft were below 5 per cent in some other months which were not particularly dry, for example December 1969. It is consequently not possible to give one distribution curve for all months and times of day that would be of much practical use or meteorological relevance, and so two curves are illustrated in Figure 16, one of which is typical of the night, morning, and the quieter afternoons and has a decrease of frequency with height which is roughly exponential, with zero-level at about 61 000 ft; the other curve shows a distribution of frequency more typical of afternoon in the more active months: the percentages above 45 000 ft are from two to three times as high as those given by the first curve and fall to zero at about 63 000 ft.

Comparison of densities of high tops over land and sea. As the frequency distribution of heights of echo-tops for times other than 1200–1800 local time is dominated by the tops occurring in the period 0001–1200, and as most of the tops observed in this period are over the sea and coastal areas rather than inland, it is likely that the peak shown on the graphs in Figure 15 for 'other times' gives a good indication of the most usual height of the highest cumulonimbus over sea areas, i.e. typically 11–12 km (36 000–40 000 ft); this estimate is well supported by aircraft reports on the route between Singapore and Gan.

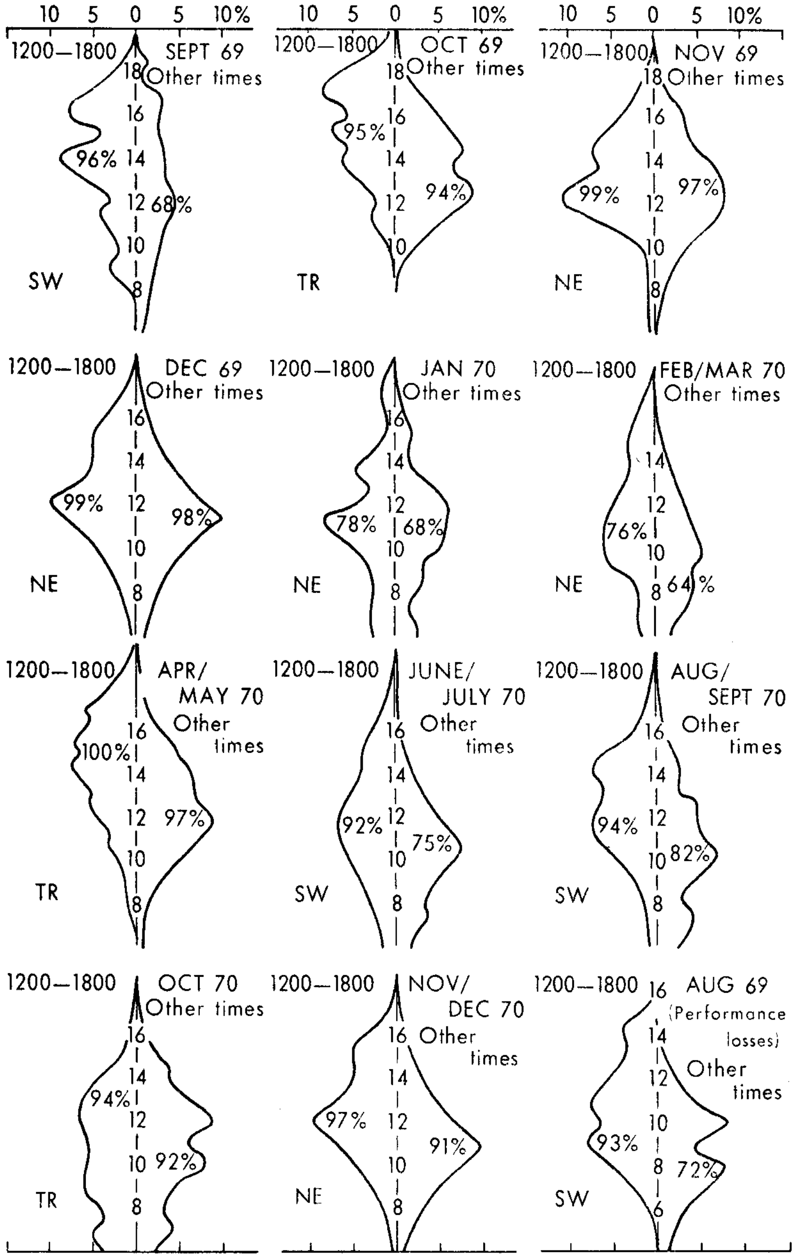
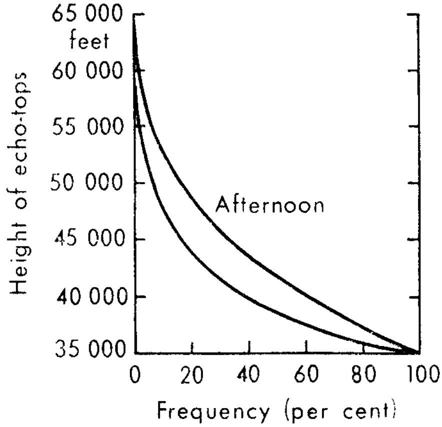


FIGURE 15—FREQUENCY DISTRIBUTIONS OF HEIGHTS OF HIGHEST ECHO-TOP OBSERVED AT EACH ROUTINE CHECK, BOTH FOR 'AFTERNOONS' (1200–1800) AND 'OTHER TIMES' FOR VARIOUS MONTHS AND COMBINATIONS OF MONTHS

Numbers on vertical axes represent heights in kilometres.
SW south-west monsoon; NE north-east monsoon; TR transitional.



Afternoons per cent	Other times per cent
0	0
1½	½
6	2
16	6
32	16
62	40
100	100

FIGURE 16—CUMULATIVE FREQUENCY DISTRIBUTIONS OF ECHO-TOPS EXCEEDING 35 000 FEET IN HEIGHT FOR 'AFTERNOONS' AND FOR 'OTHER TIMES'

The curves are applicable to the more active months.

So that the frequency of occurrence of high tops over the open sea might be estimated separately, a special area was defined lying to the east of a boundary which ran from north-north-west to south-south-east about 20 nautical miles off the east Malayan coast and avoided the large islands to the south; this area lay over the China Sea and had a size of about 13 000 $(\text{n.mile})^2$. During 15 months of good radar performance this area was surveyed on nearly 6000 occasions and 125 tops of 50 000 ft or above were recorded; this is roughly equivalent (assuming homogeneity in time and space) to a density of one top of 50 000 ft or higher per 600 000 $(\text{n.mile})^2$. If such tops were scattered randomly (which is not necessarily true) then an aircraft on a flight of 2000 n. mile over the open sea with a safety margin of 10 n.mile on either side would encounter such a top on 1 flight in 15. However, over 80 per cent of these tops occurred between 0001 and 1200 local time, suggesting a considerably higher incidence within this period over the open sea; this contrast may not be so evident well away from land influences because it is possible that day-time ascent and night-time subsidence causes a reciprocal effect over the China Sea within the area scanned by the radar. For the sake of comparison, the corresponding figures for the number of tops over Malaya were also derived: these were found to be one top of 50 000 ft or higher per 110 000 $(\text{n.mile})^2$ over the whole 24 hours and one top per 30 000 $(\text{n.mile})^2$ in the afternoon. One might have expected this last density to be greater, but the frequency of high tops is variable at all seasons, even in the south-west monsoon and transitional months, and is particularly so in the north-east monsoon.

Variation of height of storm-tops with time. The height of the top of a vigorous cumulonimbus will vary rapidly with time, especially while the cloud is still growing; of particular importance is the growth of individual high tops in or near an area of existing storms. Time–height sections (Figure 17) have been compiled from measurements made at two-minute intervals of the principal tops of cells associated with a slow-moving storm cluster on each of two occasions. The wind-fields for one of these occasions (4 March 1970) are illustrated in Figure 18. Low-level north-easterlies over the China Sea extended across Malaya but backed to north over south Malaya and over the Malacca Straits so that there was convergence over the west coast due both to deceleration and to curvature; the main winds were light enough to allow westerly sea-breezes over this coast. The upper winds veered slowly with height, with south-easterlies established (as usual at this season) at mid-tropospheric levels. This type of pattern is common during the north-east monsoon, but it can be seen that whether storms will develop depends largely on the strength of the low-level winds. In this case, small convection cells formed well inland from the west coast, but it was not until late afternoon that the main storms developed and propagated slowly south-eastwards along the coast.

During most of the period of three or four hours during which each case was observed there were cells reaching 30 000–40 000 ft, but at intervals of

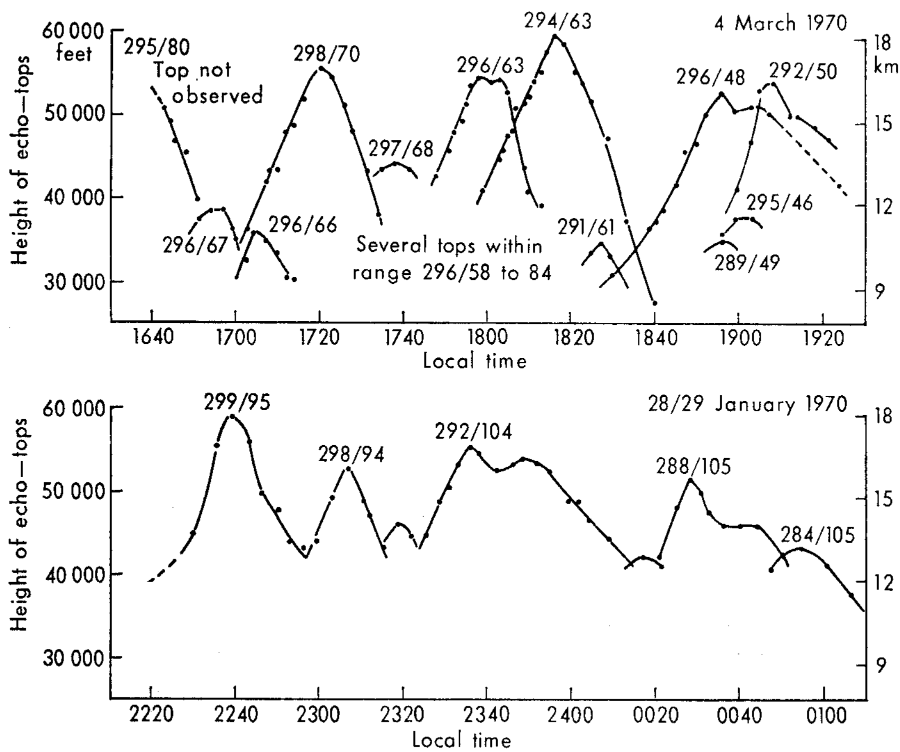


FIGURE 17—VARIATION WITH TIME OF HEIGHT *H* OF PRINCIPAL ECHO-TOPS OVER THE WEST COAST OF JOHORE ON TWO OCCASIONS

Bearings in degrees true and ranges in nautical miles are given in the form 295/80.

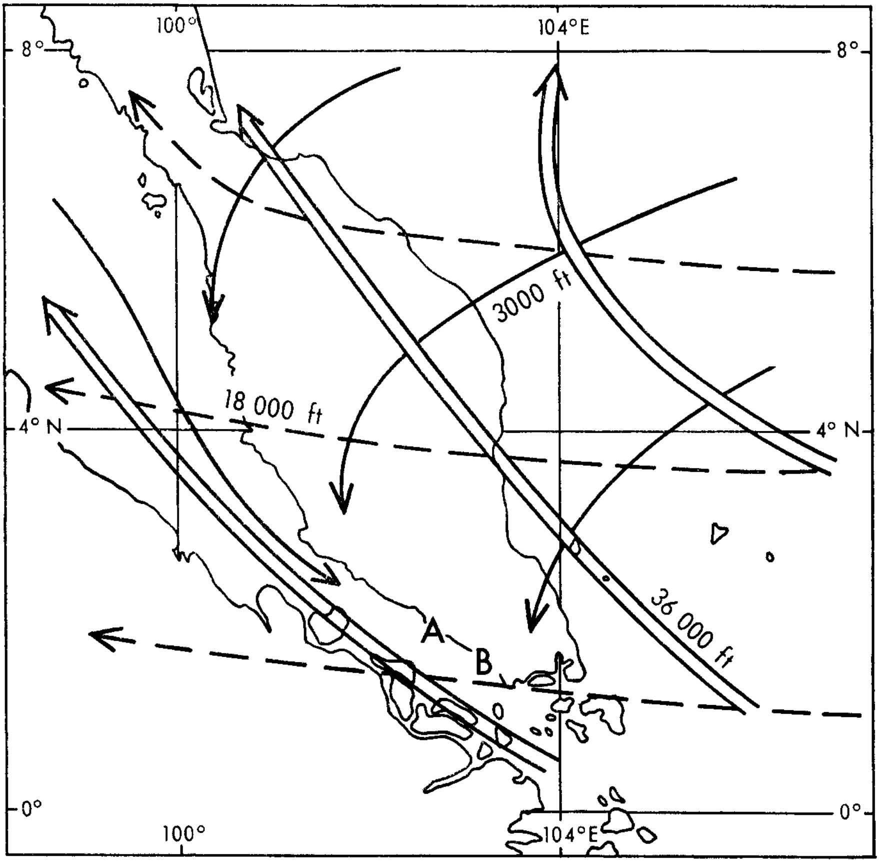


FIGURE 18—STREAMLINES AT THREE LEVELS OVER MALAYA ON 4 MARCH 1970

High tops formed between A and B and propagated south-eastwards. See also upper curves in Figure 17.

half an hour or so, individual cells grew well above the general top and reached 50 000–60 000 ft for short periods (typically 10 minutes) before subsiding. As the radar would not detect cloud left behind during decay and subsidence a good deal of cirrus and cirrostratus would probably remain for some time to hide the main cells from the view of pilots, especially if the latter were approaching from the west.

The slopes of the graphs of the ascending echo-tops suggest rates of ascent of about 1000–1500 ft a minute; this may be a useful figure for aviators to bear in mind even if more vigorous growth may occasionally be observed. (Rates of rise exceeding 1 km or 3000 ft a minute have in fact been observed on a small number of occasions.)

Relationship of echo-tops to tropopause. The highest tops observed during the periods of frequent measurement described in the last section coincided closely with the tropopause, the height of which can vary from 14·5 to 18·5 km (48 000 to 60 000 ft) but which usually lies between 16 and

17 km. However, the height of vigorous cumulonimbus can exceed that of the tropopause by a considerable margin as may be demonstrated by considering some of the highest tops observed during the present investigation. Sixteen echo-tops of at least 19·0 km in height were selected, and the height of the tropopause at the time of observation of each one was estimated from the upper-air soundings at Singapore at the beginning and end of the day in question. The mean echo-top height was 19·8 km (ranging from 19·0 to 21·0 km) while the tropopause was on average 3·5 km lower, the difference in height ranging from 1·3 to 5·4 km.

Conclusions. Although the present study is based on a relatively small proportion of the data accumulated during the investigation at Singapore, and although only methods of visual examination of the original records have been used (as distinct from computerized studies of digitized versions of the data), nevertheless some conclusions can be drawn that are of general interest to pilots and operators of aircraft flying over and near south Malaya.

Cumulonimbus tops at 55 000 ft and above may occur at any time of day or night, but are rare except during the afternoon; to have more than 2 or 3 tops over 50 000 ft occurring simultaneously within a circular area of radius 120 nautical miles is rare at any time. A few tops may penetrate the tropopause, thus exceeding 21 km (or 69 000 ft) at times; the number of tops, however, drops off rapidly with height above 12 km (or 40 000 ft) which is the most common height of tops over land during the afternoon, although tops tend to be higher by a few kilometres during inter-monsoon periods. Activity is more prevalent over the sea during the night and early morning, and over the land during the afternoon; the density of cumulonimbus over the sea, however, is at no time of day as great as it is over the land during the afternoon. Activity over Malaya tends to be concentrated on the lee side when the wind has a consistent direction, and this effect is particularly marked during the north-east monsoon.

The tops of developing cumulonimbus often rise at the rate of from 1000 to 1500 ft a minute and occasionally at rates exceeding 1 km or 3000 ft a minute.

Acknowledgement. The authors wish to express their gratitude to Mr Teo Teck Kiang for his invaluable assistance in making a large proportion of the measurements discussed in this paper.

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INDICATORS OF MONTHLY MEAN TEMPERATURE AND RAINFALL FOR ENGLAND AND WALES BASED ON ANTECEDENT MONTHLY PRESSURE ANOMALIES OVER THE NORTHERN HEMISPHERE

By R. MURRAY

Summary. From an analysis of nearly 100 years of monthly mean pressure data over the northern hemisphere, objective indices representing anomalous features of the atmospheric circulation in the preceding three months are shown to be related to monthly mean temperature and monthly rainfall over England and Wales. Useful predictions of rainfall and temperature on the monthly time-scale can be made objectively.

Introduction. In three recent papers[1,2,3] the author has employed monthly mean pressure anomalies over the northern hemisphere to obtain empirically based predictors of seasonal rainfall and temperature for England and Wales. The same method has been employed to derive statistical relationships between simple parameters based on monthly mean pressure anomalies in antecedent months and monthly rainfall (in terciles) for England and Wales, and monthly mean temperature (in quintiles) for central England. The procedure used in the present investigation is exactly as described in detail in Murray[1] and need not be fully repeated here.

Briefly, for each class of month (e.g. as specified by quintiles of monthly mean temperature in central England), the composite monthly mean pressure anomaly maps for the three antecedent months were examined for areas where the monthly mean pressure anomaly (PA) or the PA difference between two grid points (PAD) is apparently different from zero. These PAs and PADs constitute potential predictors. Individual PAs and PADs were then selected as primary indicators, provided that they satisfied certain criteria as given in Murray,[1] but also repeated below for convenience. The pressure anomaly data in the antecedent months were ranked in order of magnitude and related to the quintiles of temperature or terciles of rainfall in the forecast month. The PA and PAD indicators were then selected from classes of the ranked pressure anomaly distribution provided that the following conditions were satisfied :

(a) The class must contain at least 15 years; (the only exception was in connection with November temperature, see Table I).

(b) If both ends of the distribution of pressure data appear to have an association with subsequent monthly rainfall or temperature then the Sutcliffe Score (see Murray[1]) for each class must be equal to or greater than 1·2.

(c) If only one end of the ranked pressure distribution appears to have an association with subsequent monthly rainfall or temperature then the Sutcliffe Score for each class must be equal to or greater than 1·4.

(d) For practical purposes the pressure class was taken so that the critical pressure anomaly boundary was a whole number (e.g. pressure anomaly >4 mb) provided also that (a) and (b) or (c) were satisfied.

The selection procedure for primary PA or PAD indicators was objective in most respects. However, on some occasions PA (or PAD) indicators, clearly representing similar features of anomalous circulation, were derived from different grid points in the same general region; in such cases a subjective selection of the indicators was made. On a few occasions, notably prior to September and October, there was an excessive grouping of all or nearly all the years of the data within the class in certain areas and in certain epochs, and these cases were omitted. This clustering of data was probably due to serious uncertainties in the basic data in some cases (e.g. in the Pacific in the nineteenth century) but may also have been a result of longer-period secular changes in circulation.

The predictive rules. The primary PA and PAD indicators were combined to produce predictors of monthly rainfall. Calling D, A and W the numbers of primary indicators of 'dry' (actually satisfying the critical pressure anomaly for a bias to tercile 1 in the distribution of rainfall terciles in the forecast month), 'average' (i.e. bias to tercile 2) and 'wet' (i.e. bias to tercile 3), then simple relationships involving mainly the number D and W but occasionally A were derived for use as predictive criteria. One example, for use in forecasting April rainfall, is given in Table I.

TABLE I—RULES FOR PREDICTING MONTHLY RAINFALL IN TERCILES FOR ENGLAND AND WALES FOR APRIL, BASED ON MONTHLY MEAN PRESSURE ANOMALY PARAMETERS IN SOME OR ALL OF THE THREE ANTECEDENT MONTHS

I		II	III	IV		V	Terciles		
							1	2	3
January	1	30 50	>3W	January	1	D=0, W≥3	5	1	14
	2	65 70	<−5W		2	W=0, D≥1	17	16	4
	3	65 70	>3D						
	4	35 50–65 70	<−3D						
	5	35 50–65 70	≥2W						
	6	60 20E–65 70	<−6D						
	7	60 20E–65 70	>7W						
February	1	80 60E	<−1W	February	1	D=0, W≥3	1	2	12
	2	80 60E	>4D		2	W=0, D≥1	20	13	3
	3	35 20	>5W						
	4	25 150	>2W						
	5	40 20–80 40E	≤−2D						
	6	40 20–80 40E	≥4W						
March	1	25 140	<−1D	March	1	D=0, W=1	6	5	14
	2	35 10	<−3D		2	W=0, D≥2	13	8	1
	3	35 10	>1W	January					
	4	60 30E	>5D	+February	1	D−W≤−2	4	5	29
	5	35 10–60 30E	<−6D			(D−W≤−5)	(1)	(1)	(13)
					2	D−W≥−1	30	24	5
						(D−W≥4)	(10)	(5)	(1)
				February					
				+March	1	D−W≤−3	1	0	16
					2	D−W≥2	20	9	1
				January					
				+February					
				+March	1	D−W≤−3	2	1	26
					2	D−W=−2/−1	4	6	6
					3	D−W≥0	28	22	2
					4	W≥2, D=0	0	0	16
					5	D≥1, W=0	12	6	0

Headings I–V have the following meanings :

I Month and reference number of pressure anomaly (PA) indicator.

II Position of PA or PA difference (PAD); 60 30 is 60°N 30°W, 75 100E is 75°N 100°E.

III PA or PAD at position given in column II required to be satisfied to give the indicated bias (D=dry, A=average, W=wet) in the forecast month.

IV Reference number of forecast rule based on the specified month or months.

V Here D, A and W are the numbers of PA or PAD indicators which are satisfied in the specified month or months in column IV and have the bias given by the specified letter in column III. When the criteria shown under V are satisfied, the forecast probability is suggested by the distribution of monthly rainfall terciles in the last column headed 'Terciles'.

The use of the rules is illustrated in Table I. Similar tables for use in predicting general rainfall for other months of the year for England and Wales (and also for predicting mean monthly temperature for central England) are also available in an unpublished paper by Murray.[4]

Concluding remarks. Once more it should be stressed that the details of the general procedure and the underlying arguments for using monthly mean pressure anomalies as simple indices of broad-scale anomalous circulation are given fully in an earlier paper by the author.[1] The method is empirical and can give only a statistical indication of rather broad categories of weather.

By the nature of the selection process it is not possible to apply the usual statistical tests of significance to the various distributions of terciles and quintiles. Most of these distributions would of course be highly significant if statistical tests (e.g. chi-square test) were applied on the assumption that the degrees of freedom were, say, 8 for a 3×5 table or 4 for a 3×3 table.

As the various rules began to be developed they were put to the test in the actual situations which arose in preparing the operational *Monthly Weather Survey and Prospects*. The forecasts based only on these rules, but made before the event from January 1972 to March 1973, have provided a mean Sutcliffe Score of 1·8 for rainfall and also 1·8 for temperature. In the individual forecasts it is worth mentioning that only in one month, namely September 1972, were rainfall and temperature predictions simultaneously seriously wrong (i.e. as defined by negative Sutcliffe Scores). September 1972 was a very cool (quintile 1) dry (tercile 1) month (only 1894 and 1912 in the past 100 years were similar in the rainfall and temperature combination); the rules suggested incorrectly that September 1972 would be rather warm with average rainfall. It is possible that unusual combinations of rainfall and temperature will be difficult to predict by this method. However, the evidence for this is not clear. For instance, the rather cool, dry August of 1972 was correctly predicted, although rather cool (quintile 2) Augusts are usually associated with average or wet (tercile 2 or 3) weather and dry (tercile 1) Augusts with warm or very warm (quintile 4 or 5) weather.

Simple statistical methods like the present anomaly procedure can at best give only a rough indication of the likelihood of the broad patterns of rainfall and temperature on the monthly time-scale. Many other physical factors need to be taken into account. There is every expectation of a radical improvement in long-range forecasting on the monthly time-scale provided that we can increase our rudimentary understanding of the physical processes involved in the production of large-scale weather anomalies. Understanding should go hand in hand with improved numerical models of the global circulation of the atmosphere and oceans.

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THE METEOROLOGICAL TRANSMISSION SYSTEM OPERATING BETWEEN BEAUFORT PARK AND METEOROLOGICAL OFFICE HEADQUARTERS

By K. J. T. SANDS and D. G. WILKINSON

Summary. A data-transmission system has been developed by the Operational Instrumentation Branch for the display of meteorological data from remote sites. This is known as the Continuous Automatic Remote Display system. The first equipment has been operating between the official observing site at Beaufort Park and the main Headquarters building in Bracknell. The system is versatile and will have wider applications within the Meteorological Office.

Introduction. Before work started on the new Richardson Wing at Meteorological Office Headquarters Bracknell, temperature measurements had been taken from a thermometer screen located to the east of the Headquarters building, and the data displayed on dials in the entrance hall of this building, and on a potentiometric recorder in the Central Forecasting Office (CFO). Wind-speed and direction data were obtained at the Experimental Site (now Beaufort Park) and transmitted by an experimental telemetry system to dials in the entrance hall and to an anemograph in CFO. The loss of the observing site near the Headquarters building and the poor performance of the wind telemetry system led to a requirement being stated for a new system which would permit several variables to be measured at Beaufort Park and to be transmitted to the Headquarters building.

This new requirement called for :

(a) Local display of data for the observing staff at Beaufort Park.

(b) Remote recording of values of wind and temperature data in CFO.

(c) Remote indication of values of wind, temperature and, possibly, visibility data in the entrance hall at Headquarters.

It was subsequently agreed that the entrance hall display would incorporate an indication of visibility and the value and time of the maximum gust in each hour.

The general approach adopted to meet the requirement was to use commercially available telemetry equipment which had already been incorporated by the Operational Instrumentation Branch into other instrument systems, together with techniques recently developed for the Mk V wind system[1] and the Digital Anemograph Logging Equipment (DALE). The standard telemetry modules known as Teleshift, Teleducer and Telecode permit data to be transmitted over a single, permanently connected, Post Office private line. Other cables of similar electrical performance could be used but repeaters would be required if the distance were greater than 30 miles. The new system has been designated the Continuous Automatic Remote Display (CARD) system.

General description. The equipment consists of three main parts (see Plates II–IV):

(a) The data transmitter.

(b) The data receiver and CFO display.

(c) The entrance hall display.

The temperature measurements are made in a standard enclosure at Beaufort Park. The wind data are derived from a Mk V cup generator and a Mk IVG wind vane mounted on a 10-m mast to the west side of the site. Visibility measurements are obtained from the transmissometer on the site. The CARD transmitting equipment is housed in a room in a new block at Beaufort Park overlooking the observing area. A local display of the data being transmitted is provided for the observing staff of the Observational Requirements and Practices Branch at Beaufort Park.

The receiving equipment is housed in a wooden console in the Central Forecasting Office. Two recorders are provided :

(a) A dual-pen chart recorder for wind speed and direction.

(b) A 12-channel recorder for the remaining data.

No meter display is provided in CFO, but there is ample capability in the equipment if this is required at a later date.

Processed data are fed via a multicore cable from CFO to the Headquarters entrance hall display. Here the data are scaled to a suitable format for display on digital meters. The extraction of the speed and time of the maximum gust from the raw wind-speed data also takes place in the equipment located in the entrance hall. Spare capacity has been provided for additional data at a later date. The resolution of the system is ±0·1 per cent of full scale; the corresponding accuracy is not worse than ±0·2 per cent and will usually be better.

The data transmitter. A block diagram of the data transmitter is shown in Figure 1. The a.c. output from the cup generator is processed by circuits developed for the Mk V wind system.[1] Since the frequency is linearly related to wind speed, it is used in preference to the amplitude of the voltage. In the Mk IV wind system, which is an improved version of the Mk II wind system,[2] rectification of the signal leads to a non-linear relationship at low speeds. A frequency-to-voltage conversion of the generator output gives a voltage range of 0–10 volts for a wind-speed range of 0–200 knots. This voltage is fed to the Teleducer unit via a potential divider. The Teleducer unit converts the voltage input to a frequency output of 5–25 Hz, which is used to modulate the frequency of the 2340-Hz carrier of the Teleshift unit. In this way, wind speed is transmitted continuously over the Post Office line, thus meeting one of the requirements of the user.

The remaining data channels are not transmitted continuously; an electronic switch (known as a multiplexer) being used to switch them sequentially. Each of the sensor outputs, including wind direction, is processed to give an analogue voltage in the range 0–10 volts. Wind-direction data are derived from a Mk IVG wind vane, again using circuits developed for the Mk V wind system, by measuring the difference in phase between the waveform obtained from the magslip rotor and a pre-set reference. When a local three-phase oscillator is connected to the stator windings of the magslip, the phase of the induced voltage is proportional to the angular position of the rotor. To avoid full-scale swings of the output indicator when the direction changes through north, the range of the direction scale is increased to 540 degrees. When the indicated direction reaches either end of the 540-degree scale, electronic switching adds or subtracts 360 degrees.

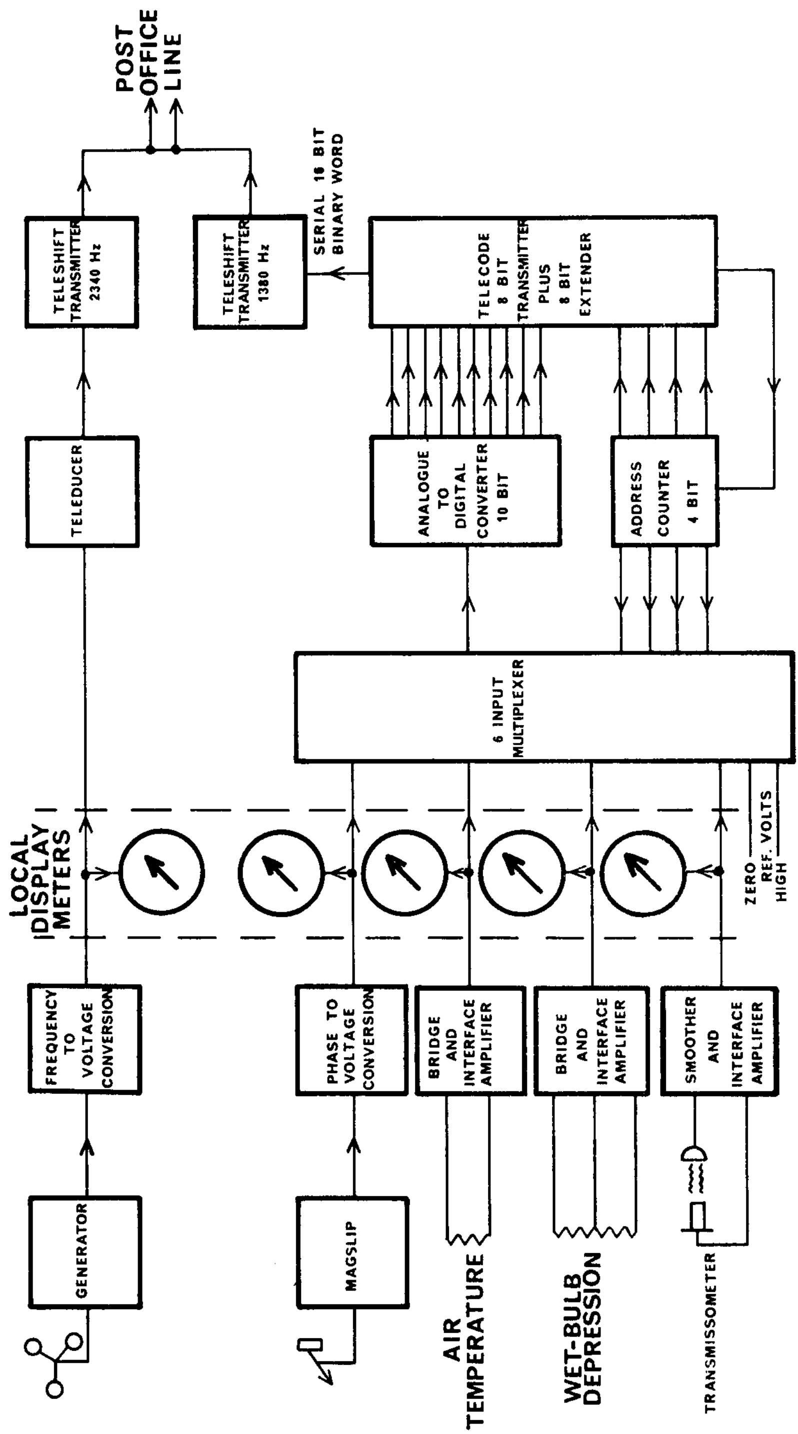

FIGURE 1—CARD DATA TRANSMITTER

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Photograph by courtesy of Plessey Radar Limited

PLATE I—PLESSEY 43S 10-CENTIMETRE RADAR

A radar of this type was used for the Singapore radar project described on pp. 61–70.

PLATE II—CARD TRANSMITTER UNIT

See page 74.

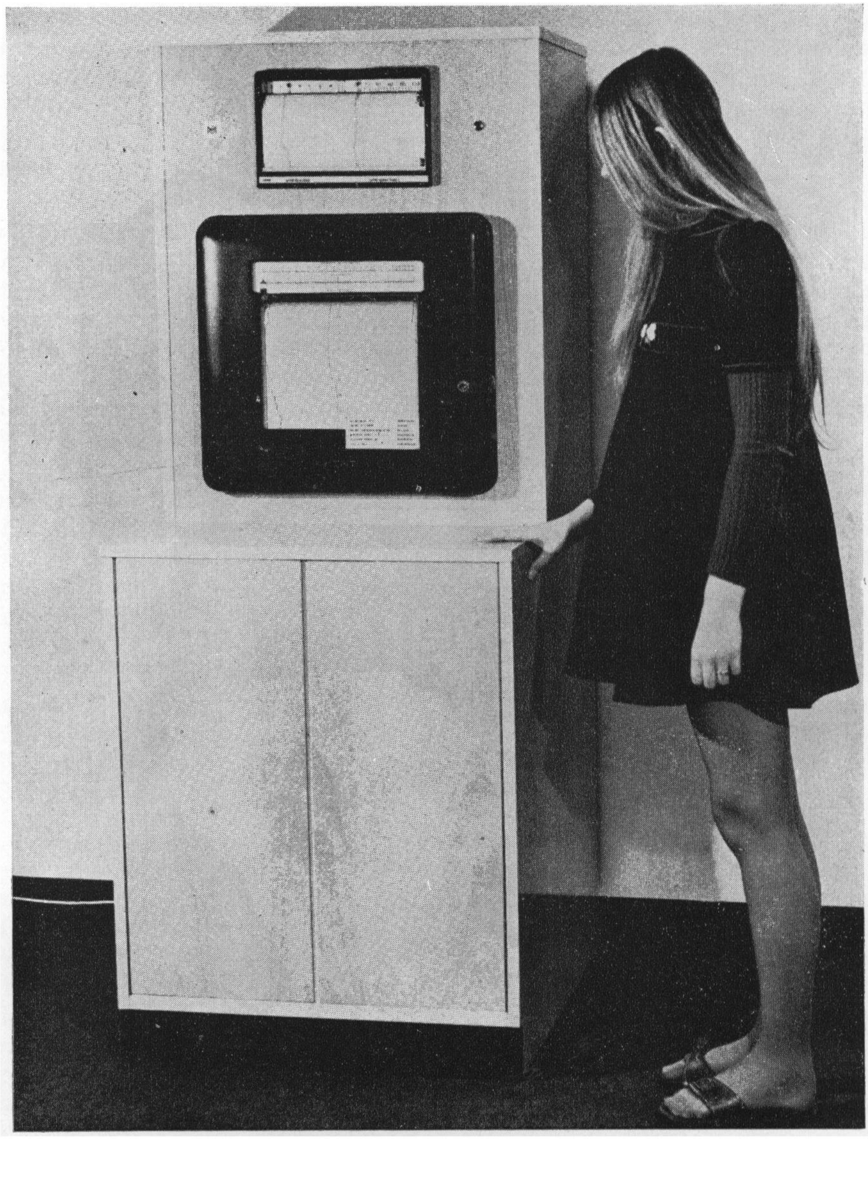

PLATE III—CARD RECEIVING UNIT AND DISPLAY IN CENTRAL FORECASTING OFFICE, BRACKNELL

See page 74.

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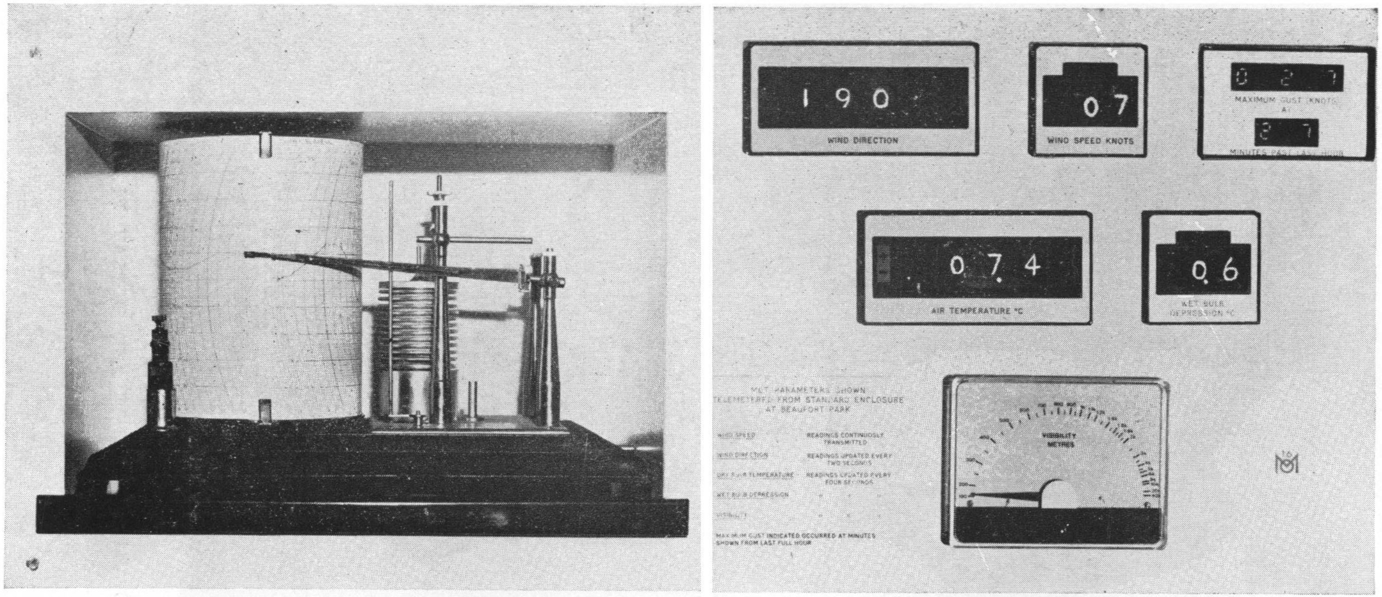

PLATE IV—DISPLAY IN ENTRANCE HALL AT METEOROLOGICAL OFFICE HEADQUARTERS, BRACKNELL

See page 74.

Air temperature is measured by an electrical resistance thermometer[8] in a Kelvin bridge; the resulting signal is converted by an operational amplifier to give an output of 0–10 volts for the range −20°C to +40°C.

Wet-bulb depression is measured by two electrical resistance thermometers in a comparison bridge; the resulting signal is converted by an operational amplifier to give an output of 0–10 volts for the range 0–12 degC.

The output from the transmissometer, in the range 0–10 volts, is fed to a smoothing circuit to remove rapid fluctuations of signal and then to an operational amplifier.

The multiplexer is an electronic 16-way switch which is controlled by an address counter. Pulses at one-second intervals from the Telecode unit are combined into a 4-bit address code which is used to switch the input signals, to identify the channel being transmitted and to synchronize the operation of the analogue-to-digital converter. The input channels in the multiplexer are interconnected to give wind direction at 2-second intervals, and temperature, wet-bulb depression and visibility at 8-second intervals. Two reference voltages are also fed to the multiplexer, one at 0 volts, the other at 9 volts; these are transmitted at 16-second intervals.

The analogue voltages are converted into 10-bit binary words by the analogue-to-digital converter and combined, in the Telecode unit, with the appropriate 4-bit address code to form serial words of 16 bits in length (the extra two bits are sent as zeros). A complete conversion takes approximately one second. The 16-bit word is used to modulate a second Teleshift transmitter working at a centre frequency of 1380 Hz, a binary '0' being 1350 Hz and a binary '1' being 1410 Hz.

The outputs of both Teleshift transmitters are fed continuously into a private Post Office line. In the event of a failure on either transmission channel, a warning light at the receiver will indicate a fault condition. The Post Office line is terminated in the Richardson Wing of Meteorological Office Headquarters.

The data receiver and CFO display. A block diagram of the data receiver is shown in Figure 2. The basic function of the receiving equipment is to re-form the coded signals from the transmitter into analogue voltages. The incoming data signals on the Post Office line are fed to two Teleshift receivers, each tuned to accept signals within a set frequency band. Thus the wind-speed data transmitted on a carrier frequency of 2340 Hz are detected, demodulated and passed to the Teleducer receiver as a signal varying between 5 and 25 Hz. The Teleducer converts this signal into a voltage varying between 0 and 10 volts. An amplifier provides sufficient power to drive the pen-chart recorder which displays the data in CFO and also the meters in the entrance hall display.

The remaining data channels are detected by the 1380-Hz Teleshift receiver and then fed to the Telecode receiver as a series of 16-bit binary words. Each word is held in a multistage shift-register while a circuit checks that the correct number of bits has been received, and is then fed in parallel to the digital-to-analogue converter and address decoder. While the conversion is taking place, the address decoder causes the de-multiplexer to switch its output to the appropriate sample-and-hold circuit where the analogue signal is held until it is updated. The contents of the sample-and-hold circuits are

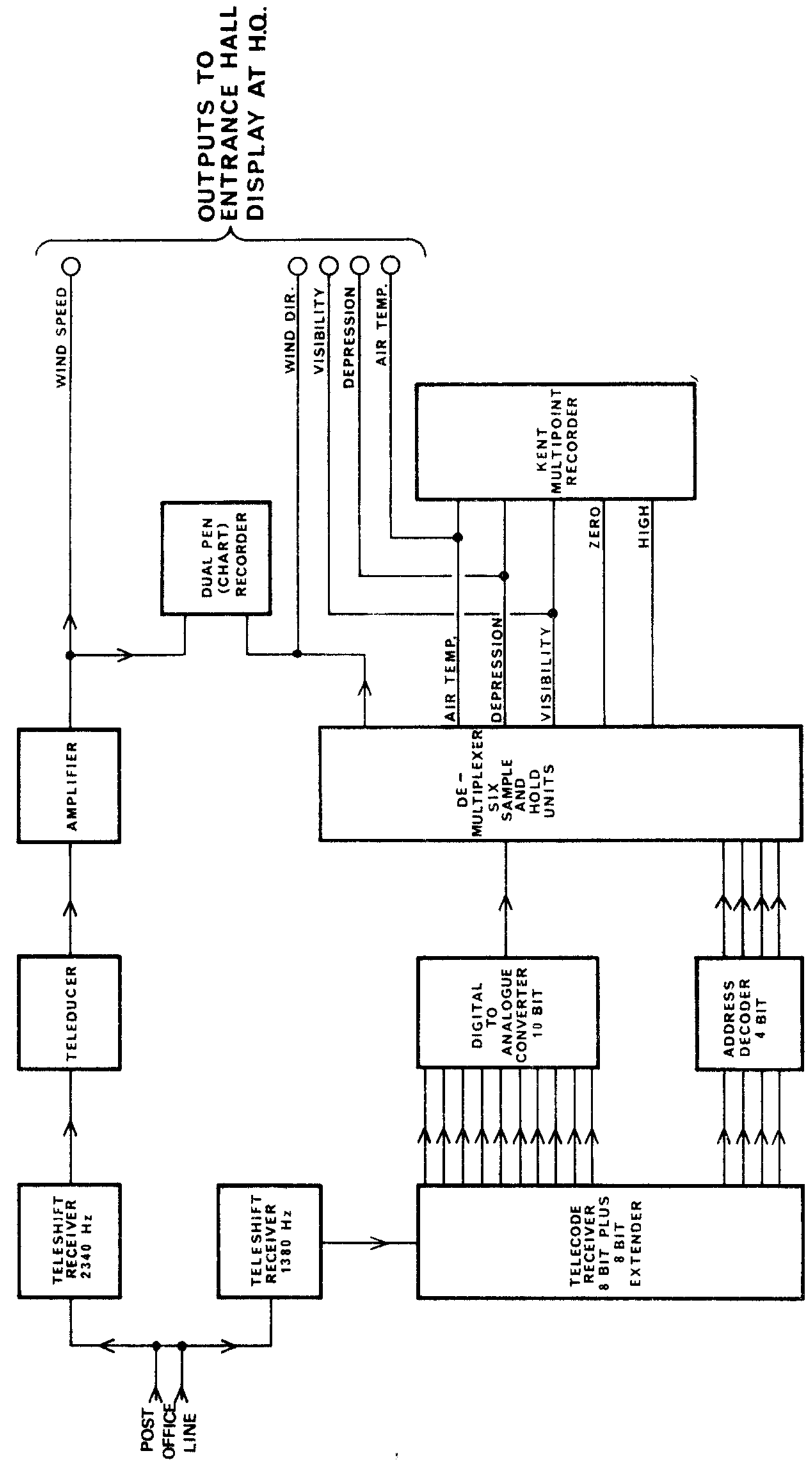

FIGURE 2—CARD DATA RECEIVER

displayed on the wind-direction chart or on the 12-channel recorder in CFO, and also on the entrance hall display. The 12-channel recorder display of air temperature, wet-bulb depression, visibility and the two reference voltages has a different colour for each trace.

The entrance hall display. A block diagram for the Meteorological Office Headquarters entrance hall display is shown in Figure 3. With the exception of visibility, all the displays are by digital panel meters. Data in the form of analogue voltages in the range 0–10 volts are fed from CFO via a multicore cable. The inputs to the digital panel meters are not compatible with these voltages and scale-changing is required as listed in the table below.

Element	Line input *volts*	Range covered	Meter input	Range displayed
Wind speed	0–10	0–200 kt	0–2 V	0–199 kt
Wind direction	0–10	90°–630°	0–180 mV	0–360°
Air temperature	0–10	−20° to +40°C	0–300 mV*	−20° to +40°C
Wet-bulb depression	0–10	0–12 degC	0–1·2 V	0–12 degC
Visibility	0–10	100 m–40 km	0–10 mA†	100 m–40 km

* An offset voltage is provided to give negative readings when required.

† An analogue meter is used with a series resistor.

The wind-speed scale-changing circuit uses an operational amplifier to change voltage levels and incorporates the facility for producing mean wind speeds if required. This is not used for the entrance hall display.

The wind-direction scaling circuit is more complex since the range of direction covered by the incoming signal is 540°. Operational amplifiers are used with offset and comparator functions to sense when the wind direction passes through north (360°), and to add correcting voltages to the display.

Air-temperature scaling requires a potential-divider network and an offset voltage for negative readings. The wet-bulb depression requires a potential divider only.

The visibility display is by a 0–10-mA analogue meter. The visibility scale is non-linear beeause the signal relates to transmittivity rather than to meteorological optical range. The display of this element by a digital meter is under consideration, but a sufficiently simple technique has not yet been devised because of the complex form of the transfer function between visibility and sensor signal.

The presentation of the maximum gust and the times of occurrence uses techniques developed for the Digital Anemograph Logging Equipment (DALE). The wind-speed data are fed to an 'upcount' analogue-to-digital converter. This device stores the maximum value presented to it in digital form and will only update when the previous maximum value is exceeded. When updating occurs, a pulse is produced which allows the time display to update also. A crystal clock provides one-minute pulses into the time store. The time store resets to zero at a count of 60 and at the same time resets the upcount analogue-to-digital converter to zero. The maximum gust value in the store is displayed, along with the time of its occurrence.

The digital indicators may give an impression that the data are being sampled at a greater rate than is actually occurring; this is due to the digital meter scanning the output of the sample-and-hold circuits approximately once per second.

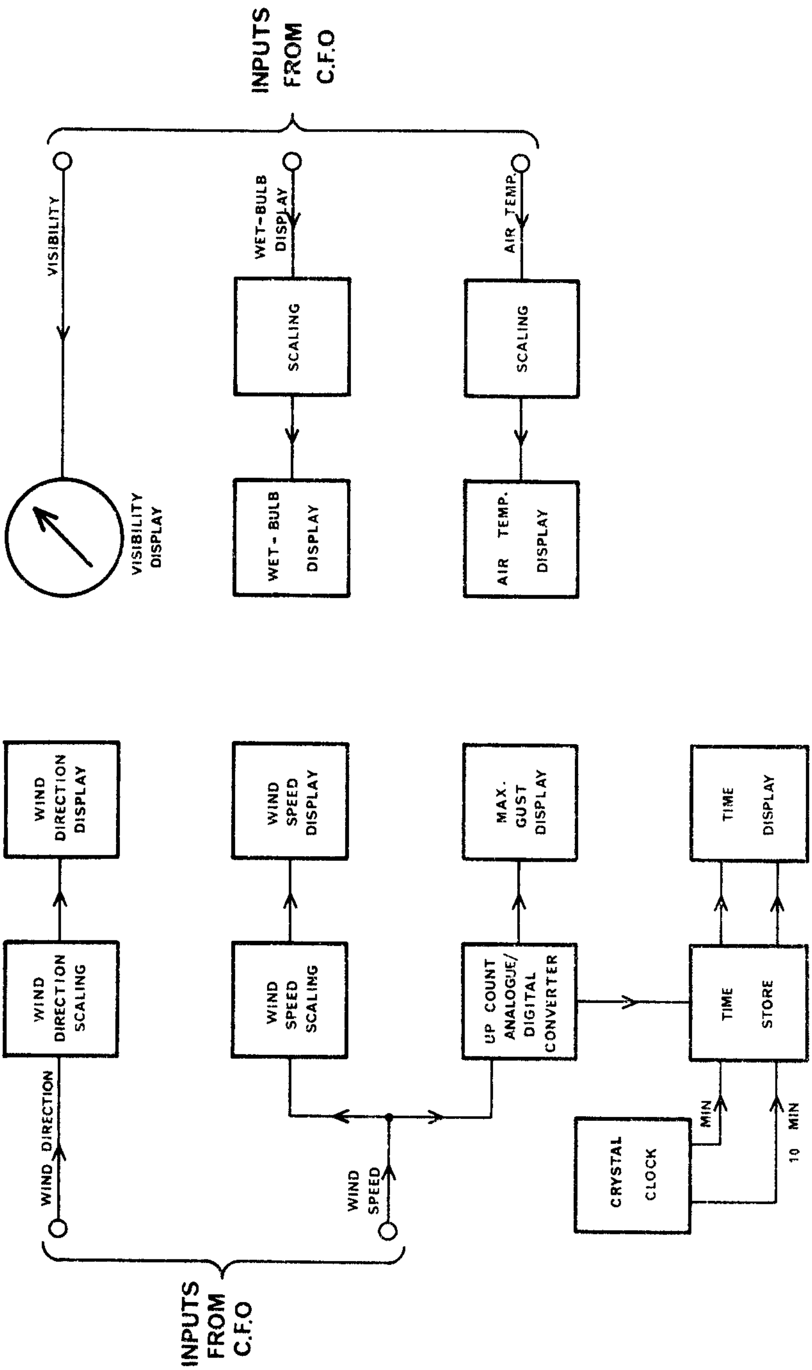

FIGURE 3—ENTRANCE HALL DISPLAY AT METEOROLOGICAL OFFICE HEAD-QUARTERS, BRACKNELL

Other applications. The CARD equipment, described in an earlier paragraph, can handle up to 16 analogue channels of information. It can, however, be expanded to accommodate up to 64 channels. The normal rate of transmission is one channel per second. By increasing the bandwidth of the system and using high-speed Telecode and Teleshift, a channel rate of six per second is possible.

The transmitted data may be processed in several ways :

(a) Mean values can be calculated and displayed.

(b) As is shown in the entrance hall display, maximum values can be stored and updated when necessary.

(c) It is also possible to provide a print-out of data or to feed the output direct into a computer.

Several receivers may be run from one transmitter in order to provide displays at widely separated locations. In such an arrangement, each receiver would be linked to the transmitter by a single telephone line.

CARD has obvious applications on airfields where sensors may have to be remote from the observing office, and where runways and taxi-tracks may make the laying of multicore cables difficult and expensive. CARD merely requires a single telephone cable which may be as long and as indirect as circumstances require. It would also be a simple matter to switch the output from a transmitter to a distant collecting station when an airfield was closed.

The next application of CARD is to be between the Post Office Tower in London and London Weather Centre. Readings taken from sensors measuring wind speed and direction, air temperature, humidity and sunshine high up on the tower, will be displayed and recorded in the forecast room of the Weather Centre.

CARD provides the user with facilities which in some respects are similar to those provided by the Mk II Meteorological Office Weather Observing System (MOWOS). Although the latter is only interrogated when data are required, the structure of Post Office line-rental charges and the relative capital costs of the two systems are such that it could be more economical to use CARD over short distances (say, less than about 30 miles). On the other hand, MOWOS has the advantage that any remote station can be interrogated by any station equipped with the necessary receiving equipment.

The present CARD system requires a 240-volt mains supply but the circuits could be further developed for operation from batteries if necessary.

Acknowledgement. The help and advice of Mr C. V. Else, who initiated the project, is gratefully acknowledged.

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THE DETERMINATION OF LARGE-SCALE VERTICAL MOTION BY A MODIFIED ISENTROPIC TECHNIQUE

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Summary. A modified technique for the determination of vertical motion by isentropic analysis is described which takes account of the diabatic effect of radiative cooling of the atmosphere. The method is applied to a case study of anticyclonic conditions and the computed vertical motion is shown to be consistent with the synoptic changes; little variation with height is evident for some distance above the top of the boundary layer. Limitations of the method are discussed.

Introduction. During recent studies of the convective boundary layer over land[1] it has become evident that an essential part of boundary-layer budgeting is the determination of the large-scale vertical motion $\bar{\omega}$ at the top of the layer. This is particularly important for the computation of the rates of entrainment into the layer of heat, moisture and mass from the 'free atmosphere' above. In a more general context, however, the problem of obtaining $\bar{\omega}$ can be considered as part of the more basic meteorological problem of the construction of air trajectories within the atmosphere. Because of the quasi-isentropic nature of air motion above the convective boundary layer, airflow in surfaces of constant potential temperature gives useful approximations and analyses of air motion in such surfaces have been used by many authors (e.g. Green *et alii*[2] and Danielsen[3]) in estimating trajectories. However, limitations to the approach can be expected to arise from the presence of non-adiabatic processes operating within the atmosphere as well as from intrinsic errors in the reported data. Of the non-adiabatic processes, the most important are turbulent mixing in the boundary layer, moist convection and long-wave radiative cooling. Others such as adjustments following Kelvin–Helmholtz instability may only rarely be significant. Above the boundary layer and away from regions of moist convection, the principal diabatic process is long-wave radiative cooling which leads to motion through isentropic surfaces towards lower potential temperature; in the following note we incorporate the effect of long-wave radiative cooling into an isentropic approach in the context of obtaining a representative value of large-scale vertical motion appropriate to a level just above the boundary layer by using routine synoptic data. The technique proves particularly suitable when lapse rates are small, as is often found for some distance above the inversion which frequently marks the convective boundary-layer top.

Isentropic analysis. The basic technique employed in isentropic analysis is to draw streamline and isotach patterns in a chosen surface of constant potential temperature, θ_1, at successive observation times t, $t + \Delta t$, $t + 2\Delta t$ . . . by using observations of wind speed and direction at each station in the radiosonde network. From such a sequence of charts an isentropic trajectory can be inferred, assuming that the time interval Δt is short enough for the streamlines to be taken as trajectories during this period, i.e. that the field of motion is adequately described by charts Δt apart. The vertical

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motion of the air along the trajectory between two successive times, t, $t + \Delta t$ is then given by the change in the level of the parcel on the isentropic surface, i.e. by

$$[p(\theta_1, t + \Delta t) - p(\theta_1, t)]_{\text{(following parcel)}}.$$

The assumption that the air remains in the surface neglects the presence of long-wave radiative cooling and a more realistic estimate of parcel trajectories, and hence of vertical motion, can be made by including its effect. If the radiative cooling of air in the time Δt is $\Delta\theta_R$ at the level of interest, then we modify the above approach and follow air for the first half of the interval Δt on the chosen isentropic surface θ_1 plotted for time t, and for the second half of the interval on the isentropic surface $\theta_1 - \Delta\theta_R$ for time $t + \Delta t$. The average vertical motion of the parcel during this time along the estimated trajectory is, in this case, given by

$$\bar{\omega}\Delta t = \overline{\frac{Dp}{Dt}}\,\Delta t = [p(\theta_1 - \Delta\theta_R, t + \Delta t) - p(\theta_1, t)]_{\text{(following parcel)}}.$$

This procedure is shown schematically in Figure 1.

As mentioned above, the value of $\bar{\omega}$ obtained is a mean value for a *parcel*. In practice, it is often desirable to obtain values of $\bar{\omega}$ representative of some selected location P and we have here adopted the convention of ascribing the value of $\bar{\omega}$ to a position of the parcel in space midway between chart times. In practice this differs little from its mean position along the trajectory and simplifies the analysis, since the starting level $p(\theta_1, t)$ of the parcel can be simply located by backwards projection from P on the θ_1 chart over a distance equivalent to a time of travel $\Delta t/2$ whilst forwards projection from P on the $\theta_1 - \Delta\theta_R$ chart gives the finishing level $p(\theta_1 - \Delta\theta_R, t + \Delta t)$ and hence $\bar{\omega}$.

For practical application Δt is taken to be 12 hours, the interval between available radiosonde information. Typically in our studies, the length of a 12-hour trajectory is about 150 km and the end-points lie well within the British radiosonde network. However, the open nature of this network means that little smoothing can be applied in constructing the isentropic pressure-height and wind fields, with the result that any erroneous or unrepresentative sounding is likely to affect strongly the inferred value of $\bar{\omega}$. Figure 2 illustrates the errors in determining the pressure-height as a function of the lapse rate through a layer (within which the lapse rate is assumed constant) arising from a likely error of 0·5 degC in the temperature at all levels. Note that the errors increase with increase of lapse rate, becoming intolerably large as the lapse rate approaches the dry adiabatic. If we further reasonably assume that wind directions may be in error by $\pm 10°$ and wind speeds by ± 2 m/s then by reference to typical isentropic charts, we can infer that an error of ± 10 mb $(12\ \text{h})^{-1}$ may arise from a likely error in the trajectories. Combining this with an error of ± 10 mb $(12\ \text{h})^{-1}$ typical for a lapse rate through the lower troposphere (cf. Figures 2 and 3 below) suggests that the total probable error in $\bar{\omega}$ is likely to be of the order of ± 15 mb $(12\ \text{h})^{-1}$ (root-mean-square

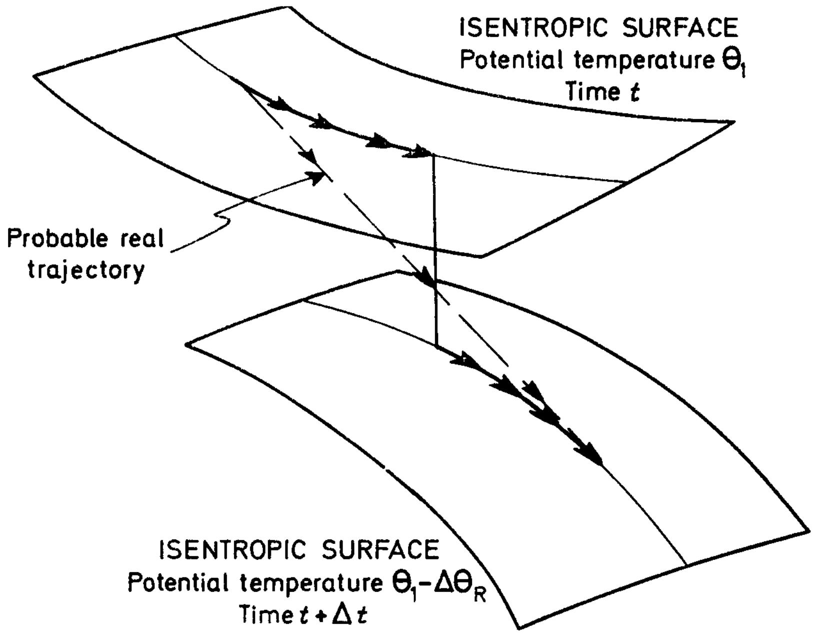

FIGURE 1—A SCHEMATIC REPRESENTATION OF THE METHOD OF DETERMINING THE AVERAGE VERTICAL MOTION OF A PARCEL

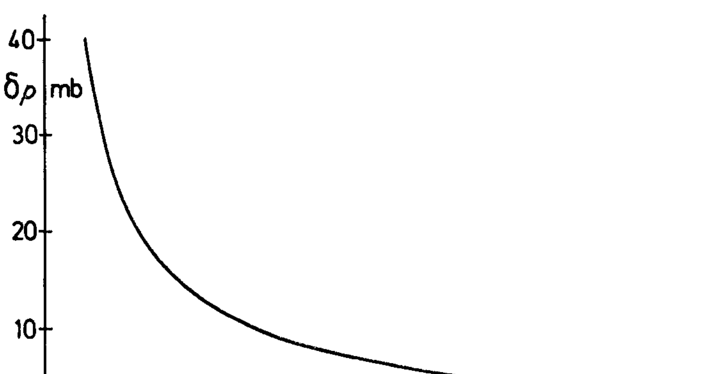

FIGURE 2—THE ERROR IN PRESSURE-HEIGHT (δp) OF AN ISENTROPIC SURFACE AS A FUNCTION OF LAPSE RATE ($\partial T/\partial p$) FOR AN ERROR IN THE TEMPERATURE SOUNDING OF 0·5 degC

Dry and wet adiabatic lapse rates (dalr, walr) are indicated.

combination). Whilst not insignificant, as shown below such an error is still smaller that the correction which must be applied to take account of radiative cooling.

An application of the method. We applied the technique outlined above to an occasion of settled anticyclonic conditions over the British Isles and initially determined the vertical motion a little way above the top of the boundary layer. The period chosen for analysis was 3–8 September 1971, routine significant-level data from the British network of radiosonde stations being used throughout. Figure 3 shows a sounding typical of the period, with the top of the boundary layer at 840 mb.

By using an Elsasser radiation chart,* the cooling rate of the lowest layer of the free atmosphere through a depth of 100 mb was estimated as 2 degC/day with day-to-day variations an order of magnitude smaller than this and so considered negligible. Consequently, for our analysis with $\Delta t = 12$ hours, we have taken $\Delta\theta_R$ to be 1 degC throughout.

In Figure 4 we show time sequences of the computed vertical motion at 12-hourly intervals at two locations in the south of the British Isles: Silwood Park (Ascot) and a place in the Bristol Channel, together with the pattern of vertical motion at Silwood Park computed without allowance for radiative cooling. The potential temperatures used in the computation were chosen to lie just above the inversion at the top of the boundary layer and so the air is not affected by convection. As an anticyclone intensified over England on the 4th the figure shows descent to take place at both locations, continuing until the 7th when the anticyclone moved away north-eastwards to Scandinavia. Note that trends are shown to occur earlier at the more westward location; descent begins earlier there on the 4th and also weakens there earlier between the 6th and 7th. The maximum rate of descent is about 40 mb $(12\ h)^{-1}$ (≈ 1 cm/s). The form of the time sequences of vertical motion computed with and without allowance for radiative cooling are predictably similar, but values for subsidence rates are smaller by about 20 mb $(12\ h)^{-1}$ when radiative cooling is not included; indeed the implied direction of the vertical motion may even be upwards rather than downwards. The size of the difference depends primarily on the lapse rate in the layer.

We illustrate the variation of mean vertical motion with height by choosing a second (higher) potential temperature, appropriate to approximately the 650-mb level, and applying the method as before. Figure 5 compares the mean vertical motion at Silwood Park at this higher level with that at the lower level (about 800 mb) already displayed in Figure 4. The pattern of vertical motion is similar at both levels, but on the 4th the results indicate that descent begins first at the upper level. Thereafter there is descent at both levels until the 7th. During the period of descent, there appears to be little variation of $\bar{\omega}$ with height for some distance above the boundary-layer top. However, there is a suggestion of greater variability at the upper level, probably as a result of greater errors incurred with generally steeper lapse rates aloft (cf. Figure 3).

* A chart which, by providing a graphical method of numerical integration of the equations of radiative transfer in the atmosphere, permits of the calculation of the upward and the downward fluxes of radiation at any level, the vertical distribution of temperature and humidity being known.

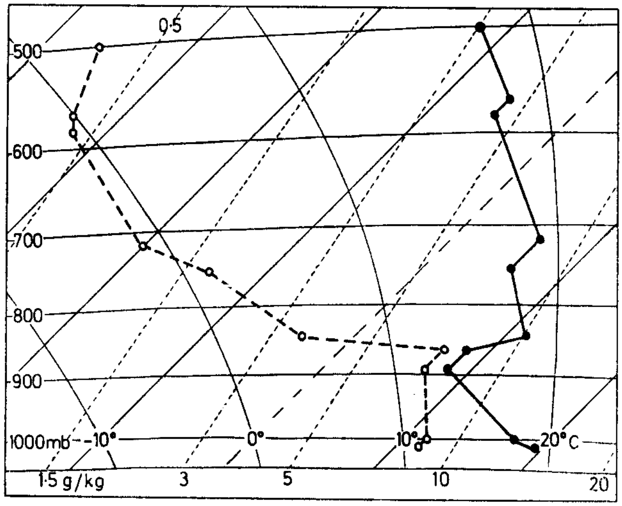

FIGURE 3—CRAWLEY RADIOSONDE SOUNDING, 12 GMT, 5 SEPTEMBER 1971

●——● Dry-bulb temperature ○— — —○ Dew-point temperature

The sounding is typical of subsidence conditions.

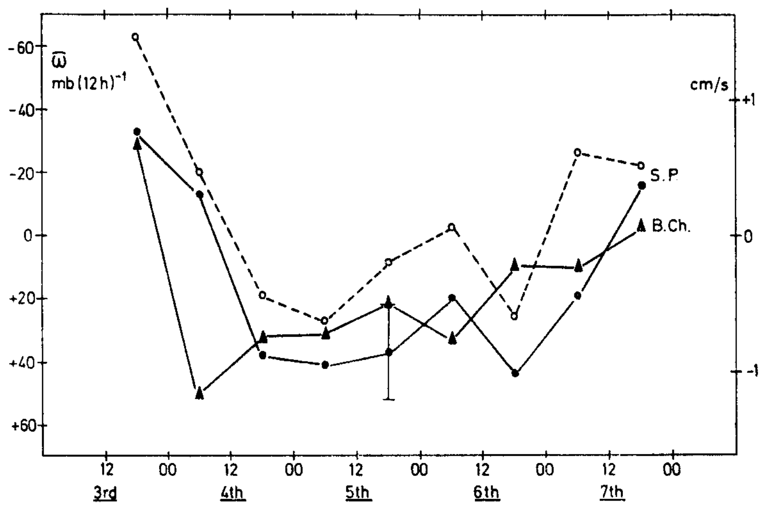

FIGURE 4—THE COMPUTED VERTICAL MOTION ($\overline{\omega}$) JUST ABOVE THE BOUNDARY-LAYER INVERSION, 3–8 SEPTEMBER 1971

▲——▲ Bristol Channel ●——● Silwood Park, Ascot

○- - -○ Silwood Park, without allowance for radiative cooling

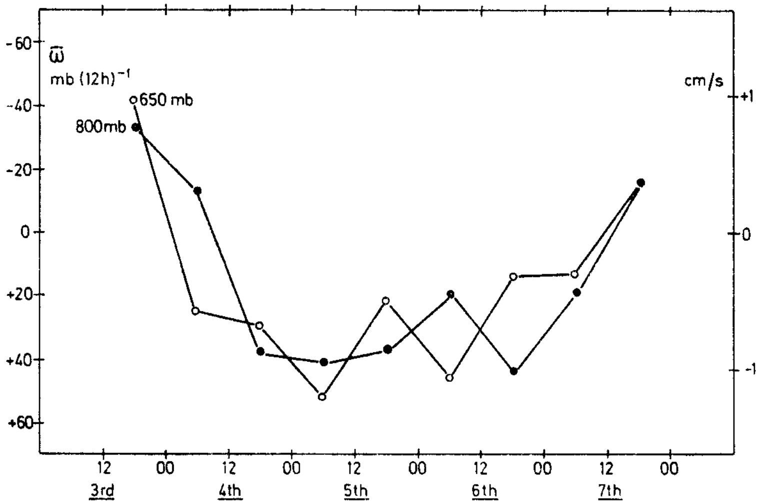

FIGURE 5—THE VERTICAL MOTION ($\bar{\omega}$) AT SILWOOD PARK, 3–8 SEPTEMBER 1971

●——● $\bar{\omega}$ just above the boundary layer (approximately 800-mb level)
○——○ $\bar{\omega}$ at approximately 650 mb

Large-scale vertical motion over a short period. The shortest period over which a value of $\bar{\omega}$ can be determined using routinely obtained radiosonde data is 12 hours. To consider the applicability of such a value to periods shorter than this we have examined sequential radiosonde observations made approximately hourly at Silwood Park on a day when warming through the first 200 mb or so above the boundary layer due to horizontal advection was negligible (as deduced from the upper-air synoptic network), and compared the observed changes in the temperature profiles with time with those expected using the 12-hour mean value of $\bar{\omega}$, due allowance being made for radiative cooling. The computation of $\bar{\omega}$ was made independently of the Silwood Park data. The sequential soundings show a definite trend, temperatures increasing at all levels through the day (implying subsidence), which can be broadly accounted for by the mean vertical motion. Figure 6 shows a typical comparison of measured and predicted changes, in this case between radiosondes launched 5 hours apart (1130 GMT and 1646 GMT respectively). The predicted and observed profiles for the 1646 GMT radiosonde are generally in good agreement; the largest difference of about 1 degC occurs around the 750-mb level where the observed temperature increase is 3 degC and the predicted value is 2 degC. These differences between observed and predicted warming do not vary systematically with height over the period of sequential soundings as a whole and so cannot be accounted for by a steady change with height of the 12-hourly mean vertical motion. They may, in part, be attributed to measurement errors between successive radiosondes; otherwise we must infer either variations in $\bar{\omega}$ or differential horizontal advection over these levels on time and space scales considerably

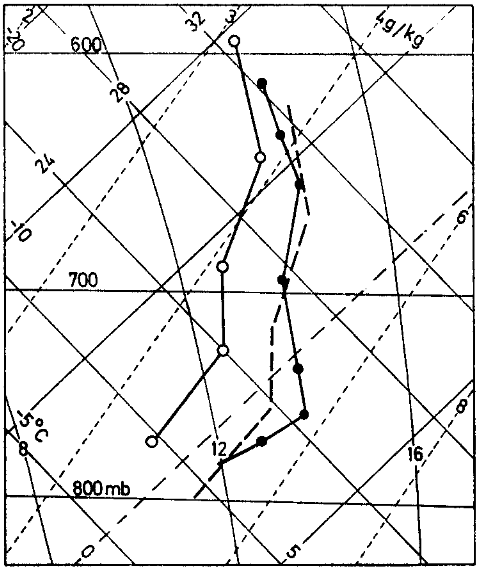

FIGURE 6—COMPARISON OF OBSERVED AND INFERRED PROFILES

Two soundings made at Silwood Park on 16 June 1972 are shown by continuous lines: 1130 GMT (○ —— ○) and 1646 GMT (● —— ●). The pecked line shows a sounding appropriate to the later time inferred from the first sounding and using the mean value of the vertical motion computed for Silwood Park.

smaller than that of the synoptic network (or, additionally, small variations may also arise from associated variable cooling rates if the moisture content is particularly non-uniform — not observed on this occasion). They are, however, on average only about 20 per cent of the large-scale trend, so that on this occasion it appears that variations on time scales less than 12 hours were relatively small and diurnal variations can be considered unimportant, changes in the value of $\bar{\omega}$ being primarily on the synoptic time scale.

Concluding remarks. It is evident that the diabatic process of radiative cooling should not be neglected in estimating trajectories and the associated mean vertical motions. Although expected errors in the technique as described are not likely to be small, the internal consistency between time sequences of vertical motion at different locations gives confidence in the method, strengthened by systematic day-to-day changes in the patterns of the isentropic charts. This, together with our consideration of hourly sequential radiosonde observations, further suggests that variations of $\bar{\omega}$ are primarily on the synoptic scale. As we have indicated, however, a severe limitation in the method exists where the lapse rate of temperature approaches the dry adiabatic, it being most suitable for application in more stable layers.

Acknowledgement. This work was carried out under a Natural Environment Research Council research contract for studies of the convective boundary layer over land.

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REVIEWS

Air pollution and atmospheric diffusion, edited by M. E. Berlyand (translated by the Israel Program for Scientific Translations, Jerusalem). 240 mm × 165 mm, pp. v + 220, *illus.*, John Wiley and Sons Ltd, Baffins Lane, Chichester, Sussex, 1973. Price: £7·00.

Although an up-to-date appraisal of Russian contributions in atmospheric and oceanic physics is well provided for in the regular translations organized by the American Geophysical Union, the developments in the practical contexts of air pollution are not so readily accessible. Even at the recent IUTAM–IUGG Symposium on Turbulent Diffusion in Environmental Pollution (Charlottesville, U.S.A., 8–14 April 1973), there were no contributions in these particular contexts. It is useful therefore to have this collection of translated papers from the Israel Program for Scientific Translations.

Mr Berlyand is a leading figure in the practice of air pollution meteorology in the U.S.S.R., who has already provided several survey papers in translated form, including an extensive appendix in W.M.O. *Technical Note* No. 121, and the present volume of which he is editor now provides an opportunity of studying various individual papers on work of the last few years. There are 19 altogether, of which seven are concerned with diffusion theory and observational studies of dispersion, five with various relevant aspects of boundary layer structure and the remainder with methods of sampling and analysis of pollutants.

The opening paper, by Berlyand and Onikul, is by far the most extensive of the collection and cites a long list of references, largely of the work of Berlyand and various co-authors. Many of the references are to reports in the G.G.O. (Main Geophysical Observatory) series available in original form in the Meteorological Office Library. This particular paper quotes the formulae used in practice for estimating concentrations of pollution from power stations and industrial emissions. It has been evident for some time that the Russian workers favour a rather formal approach, and the basis for the formulae referred to lies in solutions of the classical three-dimensional equation of diffusion, incorporating vertical and lateral eddy diffusivities and an arbitrary speed of sedimentation for particles of pollution.

It is interesting to note that some progress is claimed to have been made for the very important practical case of near-calm conditions, though the reader will need to seek out other references for further details of this work. Also, for the case of a power-station plume it is noteworthy that the Russian treatments include the familiar simple representation of the opposing effects of wind speed on plume rise and dilution, prescribing a 'most dangerous wind speed' at which the ground-level concentration is a maximum. In the recent power-station studies in England this simple result has not been confirmed and indeed a much more complex variation with wind speed has been observed, showing high values of the maximum (with respect to distance from the source) for light winds by day and also for strong winds by day or night. The Russian calculation of a 'dangerous velocity' is claimed to be supported by observations reported (on p. 92) in one of the shorter papers in this collection. However, these observations contain so much scatter that it is difficult to see how it has been possible for any conclusion to be drawn about a systematic variation with wind speed.

The foregoing are examples of attitudes and results which are somewhat surprising on first encounter and it is fairly obvious that a realistic appraisal of the Russian work in this field will require close study, not only of the present papers but also of the various papers which are cited in support.

F. PASQUILL

The world in figures, by Victor Showers. 260 mm × 175 mm, pp. xii + 585, *illus.*, John Wiley and Sons Ltd, Baffins Lane, Chichester, Sussex, 1973. Price: £6·50.

What a task the author undertook in compiling this book of nearly 600 pages, mainly of numbers, giving geographical, physical and demographic statistics for the world, for while some of his material is the hard rock of fact, such as the heights of mountains, other material is as shifting sand, as political divisions alter and populations grow! To bring the updated task to a successful conclusion in November 1972 and achieve publication in less than a year is more than creditable.

Clearly the author had to make a choice of the subjects he would include and he has wisely aimed at those whose numerical values are not likely to change rapidly, either by revision or by development. He has chosen to cover three aspects of the world, namely the numerical aspects of the physical features, the population statistics and climatic statistics where available. The first of these is dealt with in more detail than is commonly found in gazetteers, atlases or reference books and there are extensive tables of the largest seas, longest rivers, highest mountains, and so on. The population statistics are given country by country and city by city along with historical information for each of the more than 1600 cities.

The climatic data give for each city the latitude and longitude, the period of the meteorological records from which the data were extracted, the mean yearly temperature, the means for the warmest and coldest named months, the absolute maximum and minimum temperatures, the annual mean maximum and minimum temperatures and the mean annual rainfall; the statistics for extreme temperatures and for rainfall may be drawn from longer-period records than are used for the mean temperatures. The entry also gives an elevation which is 'that of the city centre or principal business district or an average of elevations at several points of the city: otherwise it is that of the meteorological station'. The bibliography gives the sources for the information and some comparisons with the sources show that the transcription and proof-reading have been excellent. A surprising feature is that the climatological tables are given *twice*, once in feet, inches and on the Fahrenheit scale and again in metres, millimetres and on the Celsius scale: it is difficult to believe that this is necessary and if desirable that the most economic method of presentation has been used. Meteorologists may well wonder what use can be made of these restricted data, since almost all climatological inquiries ask for more data than are given here, and so be led to wonder whether demographers too find that the data with which they are familiar are too scantily reproduced.

From its very nature the book is not aimed at a well-defined group of readers; it is essentially a reference book and will find its way into libraries rather than on to personal bookshelves.

E. KNIGHTING

OFFICIAL PUBLICATIONS

The following publications have recently been issued:

Geophysical Memoirs

No. 118. Northern hemisphere monthly and annual mean-sea-level pressure distribution for 1951–66, and changes of pressure and temperature compared with those of 1900–39. By H. H. Lamb, M.A., P. Collison, B.Sc. and R. A. S. Ratcliffe, M.A. (London, HMSO. Price: £2·60.)

This publication is intended to draw attention to the small but significant changes that have taken place in the atmospheric circulation of the northern hemisphere and in the mean temperature over much of Europe since the early part of the 20th century.

Changes in the level of monthly average temperature over much of Europe reflect the pressure changes; there is clear evidence that winters (particularly January and February) have been colder in the more recent period and there are smaller but interesting changes in other months.

No. 119. A climatology of the stratosphere over north-west Europe. By R. A. Hamilton, O.B.E., M.A., F.R.S.E., B.D. Mason, B.Sc. and G.C. Bridge. (London, HMSO. Price: £2·10.)

The results of over 200 meterorological rocket soundings made from West Geirinish, Outer Hebrides, during the period 1964–72 are discussed. Monthly data comprising temperatures and zonal and meridional wind components at various stratospheric levels are statistically analysed. Stratospheric warmings are discussed, and simultaneous temperature and wind data from a three-station network are presented. There is an account of the diurnal variation with due consideration being given to the difficulty of obtaining accurate day-time temperature values because of radiation error.

British Rainfall 1966. (London, HMSO. Price: £10.)

This publication provides a comprehensive summary of the rainfall of 1964 with discussion of both the incidence of rainfall and its variation from place to place, based on data from about 6000 observers. It contains numerous tables, graphs and maps.

The 'general table of rainfall' forms Part I of the volume and contains annual and monthly rainfall totals and the rainfall of the wettest day where daily values are available. Part II discusses the main characteristics of the year and contains sections dealing with monthly, annual and seasonal rainfall, spells of rainfall deficiency and excess, frequency distribution of daily amounts of rainfall, heavy falls on rainfall days and in short periods, also Penman estimates of potential evapotranspiration. Part III contains the annual report of the 'Snow Survey of Great Britain' for the season 1965–66 by R. E. Booth, 'Potential Evapotranspiration Data, 1966' by F. H. W. Green, and 'A study of magnitude, frequency and distribution of intense rainfall in the United Kingdom' by John C. Rodda.

Marine climatological summaries for the Atlantic Ocean east of 50°*W and north of* 20°*N*, 1963 and 1966. (London, HMSO. Price: £6·85 (1963) and £6·70 (1966).)

These summaries are part of a series of similar summaries covering the oceans of the world, which are to be published by nine countries, including the United Kingdom, in accordance with an internationally agreed scheme sponsored by the World Meteorological Organization. The summaries for 1964 and 1965 have already been published and it is intended eventually to publish similar summaries for each of the remaining years from 1961 onwards.

The information in the tables relates entirely to observations made aboard ships on passage, or at Ocean Weather Stations, by observers of countries participating in the scheme. The results included in the tables depend upon large numbers of observations, and production of the tables was facilitated by processing the data by means of programs written for the KDF9 computer at the Meteorological Office, Bracknell.

OBITUARY

Sir Robert Watson-Watt, C.B., LL.D., D.Sc., F.R.S.

We regret to learn of the death in his 82nd year on 5 December 1973 of Sir Robert Watson-Watt. He was one of a band of distinguished people who started their careers in the Meteorological Office at about the time of the First World War and who subsequently found fame in other disciplines. Robert Watson-Watt joined the Meteorological Office in 1915 when he was appointed Senior Professional Assistant to C. J. P. Cave to study radio-waves from lightning at South Farnborough, and he became Meteorologist-in-Charge at the Royal Aircraft Establishment in 1917. His formal connection with the Office ceased in 1921 when he became Superintendent, Radio Research Stations, Department of Scientific and Industrial Research, but his interest in meteorology continued through the years and he became President of the Royal Meteorological Society in 1950, the centenary year of the Society.

Sir Robert's enduring work was of course the discovery and development of radio-location, and he was widely known as the 'father of radar'. His career was lustrous and attended by many honours; his work was of signal benefit to mankind.

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NOTICES

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