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

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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.

Introduction. *The Singapore radar project.* Owing to the absence of quantitative information on the distribution, size, and frequency of storms in equatorial regions and the need of such data for planning the operation of Concorde and other supersonic transport aircraft, radar observations were made and recorded systematically at Singapore from mid 1968 to early 1971 with a Plessey 43S 10-cm radar which had just been installed near the RAF airfield at Changi. It was originally hoped that useful data would be collected over a period of three years but mechanical and other technical problems proved difficult to surmount and it was not until August 1969 that a high level of instrumental performance and general reliability was established. Consequently the data that have been studied most carefully are those collected between September 1969 and December 1970 although earlier results have been reviewed in a more qualitative manner.

The collection of data was spread over a series of shifts, the roster being drawn up at the beginning of each month quite independently of the meteorological situation. The night shifts were restricted to six per month and similarly the basic programme only called for six morning and six evening shifts, but it was found advantageous to increase the size of the sample by working supplementary shifts whenever possible. Hence although the night sample is about 15–20 per cent of possible per month, the day sample (from 0700 to 2200 local time*) is up to twice as large (see Table I). Unfortunately it became necessary for one of the observers to be transferred from this project to synoptic duties in October 1970, so that the sample size is reduced from then on.

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* All times quoted in this paper are local station time, which was 7½ hours ahead of GMT.

TABLE I—NUMBER OF ECHO-TOP CHECKS MADE EACH HOUR

Hour of day (local time)

		00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1969	Sept.	12	12	12	12	12	12	12	23	24	22	22	22	23	30	29	21	19	18	18	20	24	24	18	12
	Oct.	12	12	12	12	12	12	13	18	27	29	30	30	31	33	30	27	20	16	16	16	24	24	18	12
	Nov.	10	10	10	10	10	10	10	20	22	21	18	15	18	27	25	20	20	18	16	16	18	18	14	10
	Dec.	12	12	12	12	12	12	12	15	17	19	19	18	17	27	27	21	20	17	16	16	22	22	17	12
1970	Jan.	10	10	10	10	10	10	14	22	22	17	17	16	18	24	23	25	25	20	20	20	24	24	17	10
	Feb.	8	8	8	8	8	8	10	16	16	14	16	14	17	22	21	20	18	14	14	14	16	16	12	8
	Mar.	10	10	10	10	10	10	12	20	20	20	20	20	20	21	22	20	18	16	16	16	22	22	16	10
	Apr.	10	10	10	10	10	10	12	15	14	17	20	20	20	21	23	20	17	16	16	16	20	20	15	10
	May	12	12	12	12	12	12	12	19	19	18	18	18	21	22	22	22	20	18	18	19	26	26	19	12
	June	12	12	12	12	12	12	16	22	20	21	22	22	21	24	23	22	21	20	20	20	24	24	18	12
	July	12	12	12	12	12	12	13	20	20	20	20	19	19	21	22	22	22	22	22	22	24	24	18	12
	Aug.	10	10	10	10	10	10	10	16	18	18	18	18	17	24	24	24	23	20	20	20	22	22	16	10
	Sept.	12	12	12	12	12	12	13	24	22	22	22	22	22	25	25	24	23	22	22	23	22	22	17	12
	Oct.	12	12	12	12	12	12	12	18	18	18	16	14	14	14	14	15	16	16	16	16	18	18	15	12
	Nov.	12	12	12	12	12	12	12	12	11	12	12	12	12	14	14	12	12	12	12	12	16	16	13	12
	Dec.	10	10	10	10	10	10	10	10	10	10	10	10	10	14	18	17	13	10	10	10	11	16	10	10

The work-programme consisted of :

(a) at each hour during the main shifts, taking a sequence of photographs of the 240-nautical mile (n. mile) range display at 1° elevation-steps from 0° to 11°;

(b) during all shifts, making measurements every half hour of all high tops within 120 n. mile and the maximum intensities of these echoes;

(c) every 15 minutes or so, taking photographs at two or three different elevations to show the main features of the distribution and development of the echo;

(d) comparing the radar evidence with synoptic observations and with any aircraft reports.

The photographs taken in (a) were required for plotting on a grid for subsequent analysis by computer so that information could be obtained on the distribution of weather-echoes at low and middle levels; this will be the subject of a separate study. Consequently the main concern here is only with the high tops measured in (b), obtained directly from a plan position indicator (PPI) display, using swept-gain normalized at 108 n. mile or 200 km. ('Swept-gain' is a device incorporated in the radar which produces an automatic inverse-square-law reduction of intensity for all echoes received from within 108 n. mile; this means that, provided they fill the radar beam, all targets of the same reflectivity should produce signals of the same intensity on the screen for all distances up to 108 n. mile.) The method of finding and measuring these high tops is fundamental to much of what follows, so it will be described in detail. Each 10-n. mile range interval was examined in turn, from the outermost inwards, for any echoes appearing at a critical elevation angle which was different for each range interval and chosen so that all tops above 40 000 ft were certain to be recorded. (These critical angles and their implied ranges of height are illustrated in Figure 1; in fact, a large proportion of the tops above 35 000 ft were also measured.) Each echo was followed upwards by increasing the angle of elevation of the aerial until it just disappeared; the height of the top of the echo was then obtained from its slant range and maximum angle of elevation by use of tables which incorporated allowances for the curvature of the earth and the variation with height of the refractive index in a standard tropical atmosphere.

At the time of writing, the echo-top data are also being put into machinable form so that a more thorough analysis of the records, including comparisons with computed heights made using the Singapore upper-air soundings (cf. Roach and James[1]) will then be possible; in the meanwhile, however, the authors believe that the necessarily limited results of the preliminary analysis described in this paper will nevertheless be of interest.

Accuracy of the measurements. It has become accepted over the last decade that the height of cumulonimbus (Cb) tops in tropical areas may exceed 50 000 ft, a figure which previously might have been thought improbably large. Although Concorde may cruise well above active weather in middle and high latitudes, its expected cruising level of about 55 000 ft may bring it dangerously near such giant Cb in the tropics; it is important therefore that sources of error in the heights measured in this radar project should be carefully considered, and that these heights should if possible be shown to be consistent with measurements made directly from aircraft.

The most serious errors in the measurements of echo-tops are likely to be due to the return of the outer parts of the main lobe or the side-lobes from intensely reflective parts of the storm below the actual top. Donaldson[2] has calculated probable errors in echo-top measurements for model storms of different intensities, shapes and vertical profiles for two types of radar, one of which had characteristics similar to those of the 43S. It appears from his work that maximum reflectivities need to be of order $10^6 mm^6 m^{-3}$ before radar measurements are consistently in excess of the true tops. Fortunately, the highest reflectivities observed at Changi were only about $10^5 mm^6 m^{-3}$ and the storms there were not so intense in their upper parts as the models in Donaldson's paper that gave the largest errors; the models that are more typical of the Singapore storms give radar tops to within 5000 ft of the true top out to 100 n. mile and in some storms the radar top can be below the true top.

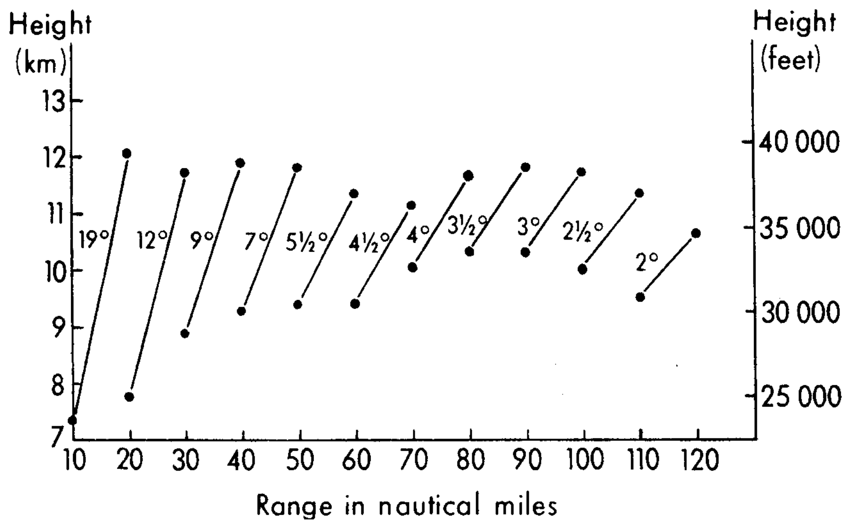

FIGURE 1—ELEVATION AND RANGE CRITERIA USED FOR ROUTINE MEASUREMENTS OF ECHO-TOPS DURING PERIODS OF WIDESPREAD ACTIVITY

The elevation angles of echo-tops were measured to the nearest ¼°; neither the specification of the elevation control nor the clarity of the elevation dial permitted greater accuracy to be attempted and human errors and bias could influence the data. Such errors are most likely to cause doubt in the measurements of the more distant echoes; at 120 n. mile an error of ¼° is equivalent to 3000 ft. One might expect the number of echo-tops above a certain height to have a greater density at long range since errors due to side-lobe effects and beam-width will be positive. The following table gives the numbers of echo-tops above 50 000 ft recorded within stated ranges between September 1969 and December 1970 (inclusive).

TABLE II—NUMBERS OF ECHO-TOPS ABOVE 50 000 FEET RECORDED BETWEEN SEPTEMBER 1969 AND DECEMBER 1970

Range *n. mile*	Number of tops observed	Number of tops expected on assumption of even density
31–60	207	200
61–90	381	332
91–120	410	466

This table yields a value of χ^2 of 14·2 with two degrees of freedom, which is significant at less than the 0·1 per cent level. The distribution of recorded tops is therefore almost certainly not random, but the cause of the non-randomness cannot be accurately diagnosed; the distribution of land and sea round Singapore is far from homogeneous and this influences the distribution of areas of strong convection. It is also possible that the relative deficiency of tops in the outer annulus may be due to the failure of distant clouds to fill the beam completely, or to an excessively cautious measurement of the distant echoes; it is interesting in this connection to note that Lee and McPherson[3] comment on the smallness of the diameter of Malaysian storms compared with those of similar height over Oklahoma.

During October 1968, flights using two aircraft were made over southern Malaya on 21 afternoons (Lee and McPherson[3]); one aircraft could fly above the tops, which helped to establish their heights more accurately, and both aircraft could be directed toward storm areas by guidance from the Changi radar operator. During this project there was a small number of occasions when aircraft and radar measurements of tops could be compared and these demonstrated good agreement as may be seen from the following table.

TABLE III—COMPARISON OF HEIGHTS OF CUMULONIMBUS TOPS AS MEASURED FROM AIRCRAFT AND BY RADAR

Date 1968	Aircraft height *km*	Radar height *km*
2 Oct.	16	15
2 Oct.	16	15–16
2 Oct.	14	14
3 Oct.	15 (anvil)	13
3 Oct.	16	16–13 (decaying)
16 Oct.	15	14
16 Oct.	17	16

The 'aircraft heights' were those measured by altimeter and subsequently corrected for the *D*-value* difference between ICAN heights and those appropriate to the actual upper-air structure over Singapore on the day in question; they were originally given in thousands of feet. Radar performance was very variable at this time owing to a fault in the equipment but on the days in question it appeared to be satisfactory. It is clear that the radar heights tend to be lower by about 1 km than the aircraft heights.

* The *D*-value is the difference, *D*, between the actual height above mean sea level of a particular pressure surface and the pressure altitude (the height of the same surface in the International Civil Aviation Organization Standard Atmosphere).

Indirect support for the accuracy of the radar measurements is given in the paper by Roach and James[1] in which it is shown that calculations of the maximum parcel-top height from the Singapore upper-air soundings agreed well with the observed radar tops during the period September–November 1969.

Overall, therefore, we may say that the radar height estimates are probably fairly realistic and should be correct to within at most 6000 ft (2 km) of the true top and often within 3000 ft. Larger errors are likely to be more numerous beyond about 80 n. mile but the heights are not necessarily exaggerated — indeed the reverse may well be more likely. Because the radar was insensitive to very small droplets the agreement between true and measured tops is closest during the periods of growth and maximum development, and hence the figures to be reviewed refer to the tops of Cb at their most vigorous stages. The true frequencies of Cb tops at a given level, including those that are decaying, are thus likely to exceed the values given.

Overall frequency of high tops. A general idea of the distribution of high tops may be obtained from Tables IV–VIII. Table IV shows the variation throughout the day of the mean height of the highest echo-top recorded at the regular half-hourly checks for each of the 16 months from September 1969 to December 1970. (The mean heights for 15 and 45 minutes past each hour are further averaged to give one mean height for the complete hour of 60 minutes.)

It is necessary to state here that before January 1970 the entry 'Nil Sig' was made if there were no echoes satisfying the criteria for measuring tops. These criteria were originally designed to ensure that all tops over 30 000 ft were recorded, but after the correction of a long-standing instrumental fault in August 1969 it was found necessary to raise the limit to 40 000 ft during periods of widespread activity. (See also above and Figure 1.) The staggered form of these criteria result in about 60 per cent of the tops above 35 000 ft also being recorded and these minima were 'stretched' whenever possible so that the losses at the upper distances of each range-step were reduced. It is clear from the records that 'Nil Sig' was not entered if any tops were higher than about 9 km; further, it is likely that there were almost always Cu present somewhere within 120 n. mile of Singapore at heights of at least 3 km which would not necessarily be recorded on the radar screen since the base of the beam rose to nearly 3 km at a range of 120 n. mile. Consequently, for the calculation of the mean highest top, a nominal substitution of 6 km was made for an entry of 'Nil Sig', and 3 km for one of 'Nil Echo'. The month mainly affected by these substitutions was December 1969; after the beginning of January 1970 the highest top was recorded irrespective of any lower limit.

It was also unfortunate that a reduction in sample size became necessary from October 1970 onwards because the previous October had been very active. It is known from other radars and weather reports that several days of substantial activity were missed on this account so that the records for October 1970 may not be as typical of a transitional month as they should; by contrast in October 1969 a run of storms in the second half of the month was smapled more completely than usual.

The area scanned by the radar to which the present results apply is about 45 000 (n. mile)^2. It contains an interesting configuration of land and sea

TABLE IV—MEAN HEIGHT OF HIGHEST TOP AT EACH CHECK

	Hour of day (local time)																								
	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Overall
	kilometres																								
1969																									
Sept.	7·3	7·9	7·8	8·0	11·7	12·9	12·9	11·3	11·2	10·6	10·3	11·0	12·4	13·3	14·6	15·5	14·3	12·9	12·0	11·5	8·7	8·5	7·7	7·9	10·9
Oct.	13·4	13·7	13·5	13·1	13·9	14·2	13·2	14·1	13·9	14·8	13·0	13·3	14·7	14·9	15·8	16·7	15·1	13·1	13·0	12·5	12·1	10·1	11·3	13·0	13·6
Nov.	12·9	12·1	11·8	12·2	11·8	10·1	11·3	12·8	12·5	12·1	12·9	12·4	13·3	12·8	13·0	13·4	14·0	14·0	13·3	13·4	11·5	11·2	10·7	11·7	12·4
Dec.	10·8	10·5	10·5	11·7	11·4	11·3	11·5	10·7	10·2	10·9	10·6	9·1	10·1	11·2	12·1	12·1	12·1	10·9	10·2	10·8	11·3	10·5	11·0	10·7	10·9
1970																									
Jan.	10·1	9·3	8·4	8·3	8·0	8·0	7·4	7·9	8·3	8·1	7·7	8·2	8·3	9·2	9·3	10·1	10·2	9·2	8·4	8·5	9·2	9·1	9·4	10·2	8·8
Feb.	5·1	5·4	6·8	6·4	6·3	5·9	5·7	4·4	4·4	4·7	4·9	4·7	6·0	7·2	6·9	7·0	7·3	7·2	6·6	5·8	5·8	5·4	6·3	5·2	5·9
Mar.	11·3	10·8	11·5	10·4	9·5	9·8	8·8	9·1	8·8	9·2	8·8	8·7	8·4	12·2	12·1	12·8	14·3	13·0	11·0	9·0	8·5	6·8	7·6	9·8	10·1
Apr.	11·9	12·7	11·9	12·8	13·5	13·8	12·1	11·8	11·3	10·9	11·5	12·7	13·7	14·2	14·7	15·6	15·8	13·0	11·4	11·0	12·8	12·6	12·5	12·1	12·8
May	11·4	12·0	13·2	14·6	13·6	13·3	13·5	12·1	11·7	12·0	11·6	11·5	12·0	13·3	14·0	15·1	15·2	14·3	13·4	11·9	11·3	10·7	11·3	11·5	12·7
June	6·6	6·5	8·0	10·3	10·2	10·3	9·7	10·6	10·7	10·1	10·4	11·2	10·7	9·7	11·2	11·4	12·0	10·6	9·6	9·7	8·8	7·3	7·8	6·5	9·6
July	6·5	8·9	9·2	8·8	8·7	7·6	8·1	10·7	10·6	9·8	9·5	9·5	10·4	11·1	11·8	11·6	11·7	11·0	9·9	8·3	7·0	6·0	5·0	6·3	9·1
Aug.	7·1	8·4	7·6	7·0	10·0	9·7	10·9	11·1	11·4	10·1	10·4	10·6	10·2	11·1	12·1	13·1	12·7	12·6	11·1	9·3	8·0	7·8	7·0	5·6	9·8
Sept.	6·3	8·2	9·5	11·7	10·9	11·4	11·7	10·5	10·0	9·9	9·7	10·7	12·0	10·5	12·1	12·9	12·6	11·6	9·9	8·4	6·7	6·8	6·7	7·3	9·9
Oct.	10·9	11·5	10·9	10·9	10·7	11·3	10·6	12·2	11·7	10·6	10·4	9·8	9·3	10·4	9·5	10·8	10·9	11·6	10·8	11·3	9·7	8·1	8·5	11·1	10·6
Nov.	11·7	12·9	13·5	12·1	11·6	11·5	10·2	11·5	12·0	11·3	10·2	10·3	10·8	10·3	12·3	13·2	12·4	12·9	11·9	12·0	10·7	10·8	10·1	11·2	11·6
Dec.	9·8	10·9	10·9	9·6	9·2	9·1	7·6	8·9	7·8	7·0	7·6	8·2	8·8	10·0	10·9	11·7	12·5	11·9	10·5	10·6	9·1	9·1	9·5	9·2	9·6

TABLE V—HEIGHT OF HIGHEST TOP OBSERVED IN EACH MONTH

	Hour of day (local time)																								
	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Ex-treme
												kilometres													
1969																									
Sept.	16·3	16·7	15·9	14·1	18·0	18·7	18·8	18·3	17·6	17·0	16·6	16·9	16·6	17·3	19·7	20·2	18·3	17·3	16·8	18·2	19·9	21·4	16·7	16·6	21·4
Oct.	15·2	17·6	18·8	15·8	15·9	20·1	16·6	17·7	18·7	20·3	18·4	17·8	19·8	18·7	19·9	20·9	19·3	17·8	18·7	17·3	18·7	16·2	17·4	16·3	20·9
Nov.	14·7	16·4	17·5	17·5	18·7	17·1	15·9	17·1	16·5	16·1	15·6	18·5	16·9	21·0	17·1	16·3	17·4	20·6	16·3	16·7	19·0	18·5	16·9	16·5	21·0
Dec.	16·6	16·4	16·5	16·7	16·0	17·6	17·9	15·9	17·5	15·4	16·3	16·1	16·0	16·7	18·7	15·8	16·2	14·8	14·5	14·2	16·3	15·0	13·9	15·2	18·7
1970																									
Jan.	14·0	14·4	15·7	14·2	12·5	12·9	12·5	12·8	12·7	12·3	12·6	11·2	13·7	14·9	15·5	17·1	17·9	16·3	16·5	18·2	17·7	16·7	15·4	16·2	18·2
Feb.	7·5	10·3	13·4	12·3	12·8	9·7	11·0	10·1	10·5	10·4	10·3	9·3	12·3	12·5	13·6	12·3	12·3	12·9	11·0	9·4	11·6	10·4	12·6	8·1	13·6
Mar.	13·9	14·2	13·7	14·0	13·9	14·9	13·1	14·7	13·3	15·9	13·1	14·8	14·8	17·2	16·7	17·2	18·0	16·5	17·6	15·2	14·1	13·4	14·3	14·2	18·0
Apr.	14·2	14·9	14·1	15·6	17·8	16·3	15·7	15·0	15·1	14·6	15·1	15·4	16·0	18·3	19·6	18·7	19·3	17·2	17·2	19·4	17·7	18·9	15·7	16·7	19·6
May	12·9	17·2	15·5	17·3	15·4	16·3	17·3	16·8	16·0	17·3	15·0	14·5	16·0	17·6	17·4	19·3	20·3	17·9	17·2	18·5	18·0	15·5	15·4	15·2	20·3
June	11·5	12·5	15·7	16·1	17·2	16·3	14·5	16·4	15·7	13·5	14·3	15·1	13·1	15·5	16·1	16·7	16·2	14·5	14·3	14·3	11·6	12·6	12·9	12·6	16·7
July	13·9	15·6	15·3	16·5	14·9	12·9	13·1	15·0	16·5	14·5	16·1	13·3	14·0	15·9	18·3	18·3	18·4	18·0	19·7	16·4	14·2	15·2	12·8	15·2	19·7
Aug.	13·6	18·5	14·5	14·6	14·4	12·1	15·5	16·7	16·9	15·8	15·9	14·0	13·9	16·5	17·5	17·8	17·8	18·7	18·3	14·5	17·5	16·2	13·9	9·5	18·7
Sept.	12·1	13·7	13·7	14·3	13·8	15·9	15·4	15·2	15·5	14·5	13·5	16·6	14·7	14·3	17·3	18·7	19·3	17·3	15·5	17·2	11·5	15·9	11·4	11·9	19·3
Oct.	14·9	15·2	16·2	14·8	15·7	13·4	16·1	15·9	14·6	13·9	14·4	14·3	13·4	15·9	16·5	15·0	14·3	17·9	16·1	17·2	15·1	13·0	14·5	14·8	17·9
Nov.	16·5	17·6	16·8	17·0	13·7	15·0	14·0	13·9	13·9	14·5	11·7	13·3	15·5	15·8	16·8	17·1	16·1	16·0	15·9	15·7	15·5	12·6	16·3	16·9	17·6
Dec.	13·0	15·2	14·3	12·7	12·8	13·9	12·2	11·7	10·3	10·2	12·7	12·1	13·1	13·3	14·0	14·5	14·7	15·3	14·5	13·6	14·9	14·6	15·3	12·6	15·3
Ex-treme	16·6	18·5	18·8	17·5	18·7	20·1	18·8	18·3	18·7	20·3	18·4	18·5	19·8	21·0	19·9	20·9	20·3	20·6	19·7	19·4	19·9	21·4	17·4	16·9	

permitting much opportunity for a variety of developments either initiated or distorted by orographic influences. Although land forms only about 30 per cent of this area, it thus exerts some effect on a much larger proportion — perhaps 60 per cent to 80 per cent — the effect being most pronounced during the season of the south-west monsoon and the transitional periods, i.e. from April to October. The results of the present investigation may therefore give an exaggerated impression of the amount of storm activity in the equatorial zone in general, especially in oceanic areas; however, the sort of activity seen here is not likely to be worse than would be seen over Sumatra, Borneo, or several of the large islands that lie on or near the air-routes from south-east Asia to Australia.

Table VI indicates that it was rare to have more than 2 or 3 tops over 50 000 ft simultaneously except during the afternoons of September and October in 1969 and of April and May in 1970 when from 5 to 8 were observed. There were several months when, with a good sample, the numbers were small even in the afternoon. It will also be seen that although the morning samples were substantially bigger in most months than the night samples, the greatest number of tops observed at given levels was frequently less, suggesting that a significant lull occurred during the early morning. In most months quite a small sample was enough to produce highest tops of about 14 km (45 000 ft) in height at each hour. Given a complete set of measurements hour by hour throughout each month it would seem that a maximum height of about 17 km (55 000 ft) might occur at any time but there are some hours at which such an occurrence is much more frequent than at others; in consequence the mean height of highest top (Table IV) shows a large diurnal variation.

So that random fluctuations may be smoothed out to some extent while any significant seasonal variations are preserved, it is worth while combining figures for individual months from Table IV according to the main seasons apparent at Singapore. Figures 2(a) to 2(d) show mean diurnal variations of height of highest echo-top for the south-west monsoon period, the north-east monsoon period, the combined transitional periods, and for the complete set of 16 months being considered. Some significant properties of the diurnal variations are immediately obvious: the biggest diurnal range of height occurs during the south-west monsoon with a very marked depression of activity round midnight; heights are considerably greater during the transitional months when low-level winds tend to be lighter and more variable in direction than at other times of year; and activity has a more noticeable subsidiary night-time peak during the north-east monsoon than during the rest of the year.

The presence of a semi-diurnal (i.e. 12-hour) component in the variations for all seasonal groupings is also obvious. If the results for the whole 16-month period are harmonically analysed the phase of the semi-diurnal component is such that maxima occur at times (having allowed for the difference between local clock time and true local mean time) of 0330 and 1530 which are very close to the times of minima of the travelling component of the semi-diurnal pressure wave, viz. 0344 and 1544 (Chapman and Lindzen[4]). There may possibly, therefore, be a link between convective activity at Changi and atmospheric tidal action as suggested by the work of Brier and Simpson[5]; on the other hand, night-time cooling effects, both at low levels (producing

TABLE VI—GREATEST NUMBER OF TOPS AT ANY ONE CHECK OVER 15·3 km (50 000 ft)

		Hour of day (local time)																							
		00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1969	Sept.	1	2	1		3	3	2	2	2	1	1	1	2	3	4	7	3	2	1	2	3	4	2	1
	Oct.		3	1	1	2	1	1	3	4	4	2	2	4	7	8	5	4	2	2	2	1	1	1	1
	Nov.		1	2	1	2	1	1	1	1	1	1	1	2	1	5	1	2	2	1	2	1	2	3	2
	Dec.	2	1	2	1	2	2	3	1	1	1	1	1	1	1	1	1	1				1			
1970	Jan.			1												1	2	5	1	1	1	1	1	1	1
	Feb.																								
	Mar.										1				1	2	2	2	3	1					
	Apr.				1	2	1	1					1	1	6	3	5	4	2	1	2	3	1	1	1
	May		1	1	1	1	1	2	1	1	1			1	2	6	5	2	3	2	2	2	1	1	
	June			1	1	1	1		1	1					1	1	1	1							
	July		1	1	1					1		1			1	2	4	3	2	1	1				
	Aug.		2					1	2	2	2	1			1	2	1	2	1	1		1	1		
	Sep .						1	1		1			1			1	3	2	1	3	2		1		
	Oct.			2		1		1	1						1	1			3	1	1				
	Nov.	1	1	2	1									1	1	1	2	2	2	1	3	1		1	1
	Dec.																		1					1	

TABLE VII—GREATEST NUMBER OF TOPS AT ANY ONE CHECK OVER 18·3 km (60 000 ft)

		Hour of day (local time)																							
		00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1969	Sept.						1	1	1							1	1	1				1	2		
	Oct.			1			1			1	2	1		1	1	1	1	1		1		1			
	Nov.					1							1		1				1		1	1	1		
	Dec.															1									
1970	Jan.																								
	Feb.																								
	Mar.																								
	Apr.														1	1	1	1			1		1		
	May																1	1			1				
	June																								
	July															1	1	1		1					
	Aug.		1																1	1					
	Sept.																1	2							
	Oct.																								
	Nov.																								
	Dec.																								

TABLE VIII—FREQUENCIES OF TOPS AT OR ABOVE VARIOUS LEVELS AS PERCENTAGES OF NUMBERS EXCEEDING 35 000 ft IN HEIGHT

(a) Afternoons (1200–1800 local time)

	1969				1970											
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
								per cent								
60 000 ft	0·2	1·6	0·5	0·3	0·0	0·0	0·0	1·5	0·9	0·0	1·7	0·3	1·1	0·0	0·0	0·0
50 000 ft	15	15	6	4	9	0	11	18	17	5	15	6	8	7	8	1
40 000 ft	60	58	44	40	44	33	50	67	60	49	62	46	55	44	52	45

(b) Other times (1800–1200 local time)

	1969				1970											
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
								per cent								
60 000 ft	1·6	0·8	0·6	0·0	0·0	0·0	0·0	0·4	0·2	0·0	0·5	0·8	0·0	0·0	0·0	0·0
50 000 ft	12	8	5	4	6	0	1	7	6	3	6	8	5	2	6	1
40 000 ft	58	49	43	35	36	50	33	55	48	38	44	49	44	42	45	41

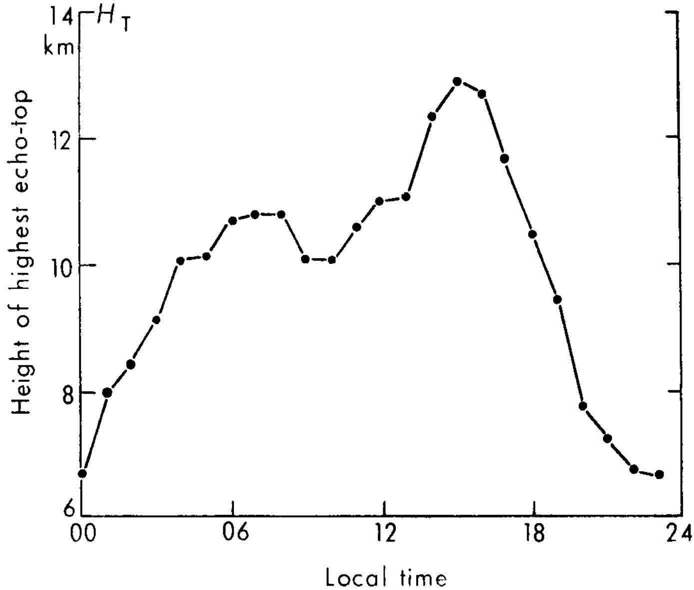

FIGURE 2(a)—DIURNAL VARIATION OF HEIGHT H_T OF HIGHEST ECHO-TOP WITHIN 120 NAUTICAL MILES OF CHANGI FOR THE SOUTH-WEST MONSOON PERIOD (SEPTEMBER 1969, JUNE 1970, JULY 1970, AUGUST 1970 AND SEPTEMBER 1970)

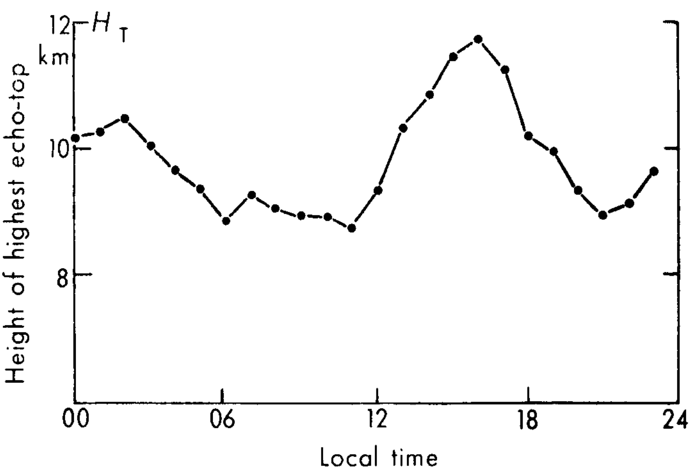

FIGURE 2(b)—DIURNAL VARIATION OF HEIGHT H_T OF HIGHEST ECHO-TOP WITHIN 120 NAUTICAL MILES OF CHANGI FOR THE NORTH-EAST MONSOON PERIOD (NOVEMBER 1969, DECEMBER 1969, JANUARY 1970, FEBRUARY 1970, MARCH 1970, NOVEMBER 1970 AND DECEMBER 1970)

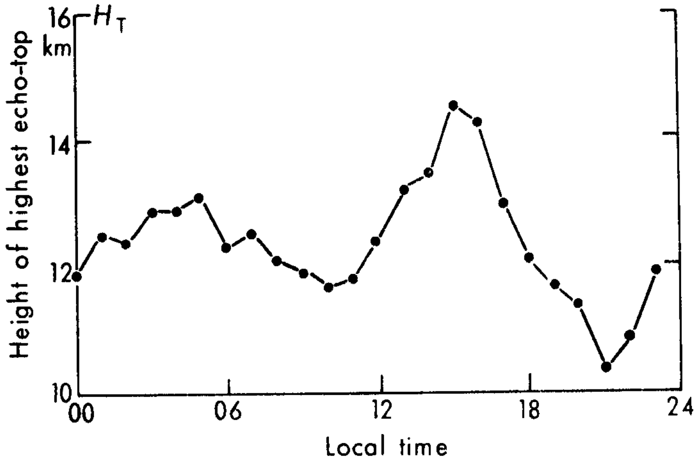

FIGURE 2(c)—DIURNAL VARIATION OF HEIGHT H_T OF HIGHEST ECHO-TOP WITHIN 120 NAUTICAL MILES OF CHANGI FOR TRANSITIONAL PERIODS (OCTOBER 1969, APRIL 1970, MAY 1970 AND OCTOBER 1970)

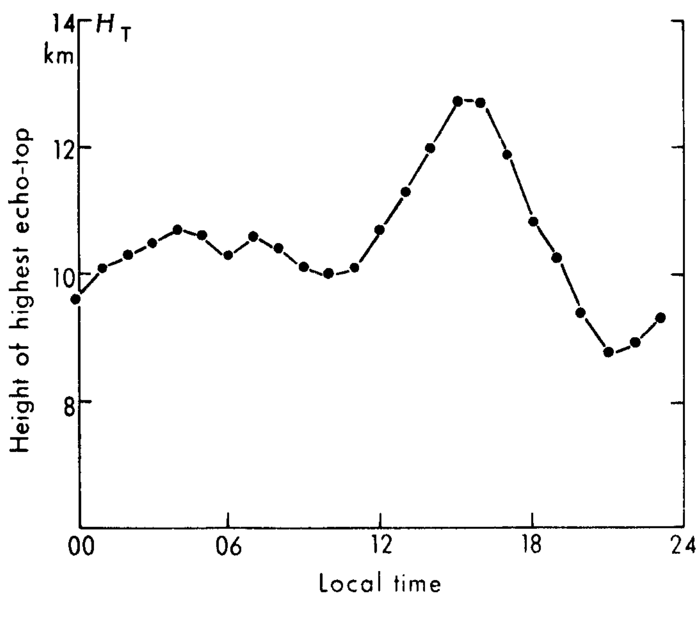

FIGURE 2(d)—DIURNAL VARIATION OF HEIGHT H_T OF HIGHEST ECHO-TOP WITHIN 120 NAUTICAL MILES OF CHANGI FOR ALL 16 MONTHS (SEPTEMBER 1969–DECEMBER 1970) areas of convergent katabatic winds in the complex mixture of sea and mountainous land surrounding Singapore) and at high levels (leading to upper instability) may be the true, or at least a more important, cause.

It is of interest to compare the diurnal variation of height of highest echo-top with that of thunderstorm activity at Singapore which is illustrated in Figure 3; the general resemblance is obvious. We may similarly compare the run from September 1969 to December 1970 of monthly mean values of the average height of highest echo-top taken over the whole day (shown in Figure 4(a)) with the corresponding figures for thunderstorm activity (Figure 4(b)).

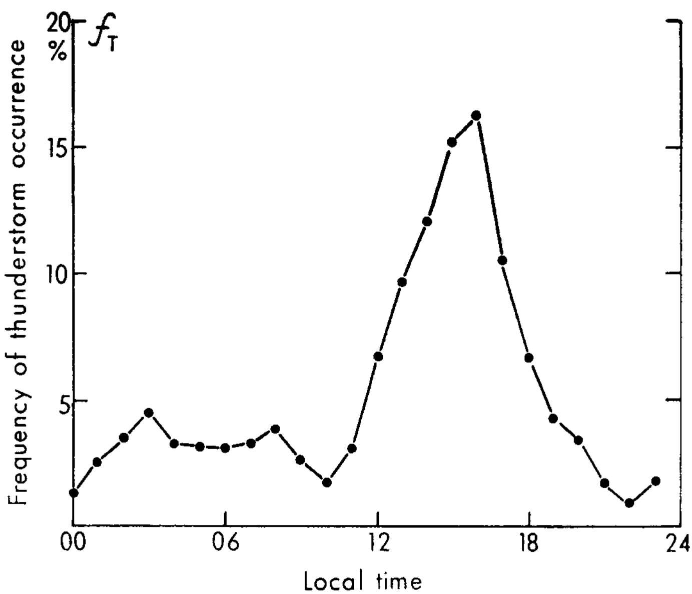

FIGURE 3—DIURNAL VARIATION OF MEAN PERCENTAGE FREQUENCY f_T OF THUNDERSTORM OCCURRENCE AT SINGAPORE, SEPTEMBER 1969–DECEMBER 1970

Spatial and diurnal distribution of the higher tops. Figures 5 to 11 show the position of the echo-tops over 50 000 ft in certain months or combinations of months plotted for three periods of the day. Because the numbers of checks in these periods were not necessarily the same they are stated on the diagrams; so also is the sample size which is given as a percentage of the total number of half-hourly observations possible in each period per month (or combination of months). The months for which plots are given were selected because good samples were available and because they conveniently illustrate the changes in distribution and density that occurred as the south-west monsoon (September 1969) was replaced by the north-east monsoon (transitional and moist from October to December, markedly drier from January to March), whereas the April and May figure (Figure 9) shows the south-west monsoon becoming re-established.

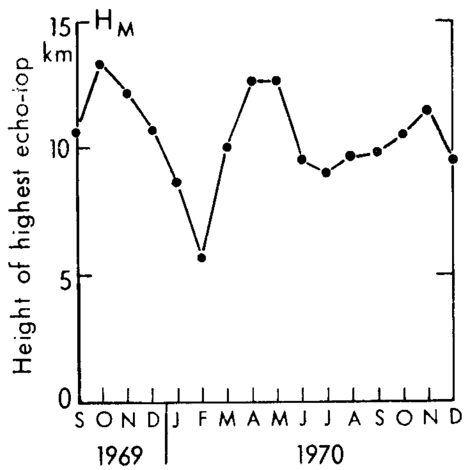

FIGURE 4(a)—MONTHLY MEAN HEIGHT H_M OF HIGHEST ECHO-TOP WITHIN 120 NAUTICAL MILES OF CHANGI, SEPTEMBER 1969–DECEMBER 1970

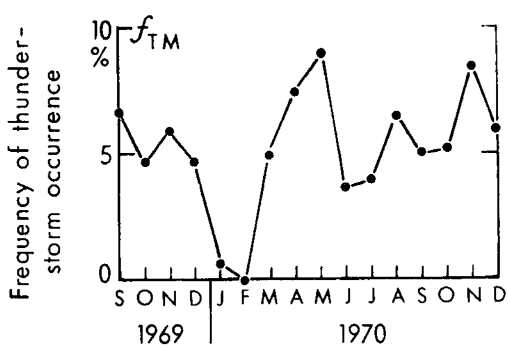

FIGURE 4(b)—MONTHLY MEAN PERCENTAGE FREQUENCY OF THUNDERSTORM OCCURRENCE AT SINGAPORE FOR SAME PERIOD AS IN FIGURE 4(a)

A marked feature of the distributions is that activity occurs mainly over the land during the afternoon and evening, and over the sea during the night and morning; even at the 40 000-ft level (see Figure 10 for April and May, 0001 to 1200 only) most of the echoes over Malaya shown as occurring in the morning formed in fact after 1100 (local time) so that the contrast between land and sea is still dominant.

Since the number of checks made between 0001 and 1200 was in all months greater than in either of the two six-hour periods 1200 to 1800 and 1800 to 2359, the diagrams also demonstrate that the frequency of tops above

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PLATE I—SITE OF THE PILOT EXPERIMENT OF A METEOROLOGICAL/ENTOMOLOGICAL STUDY AT SHINFIELD PARK, NEAR READING

See page 53.

PLATE II—MAJOR AND MRS K. G. GROVES WITH SQUADRON LEADER N. LAMB, MASTER AIR LOADMASTER M. W. BAILEY AND FLIGHT LIEUTENANT P. WALLIS

See page 55.

PLATE III—SQUADRON LEADER N. LAMB, METEOROLOGICAL RESEARCH FLIGHT, WINNER OF THE METEOROLOGICAL OBSERVER'S AWARD

See page 56.

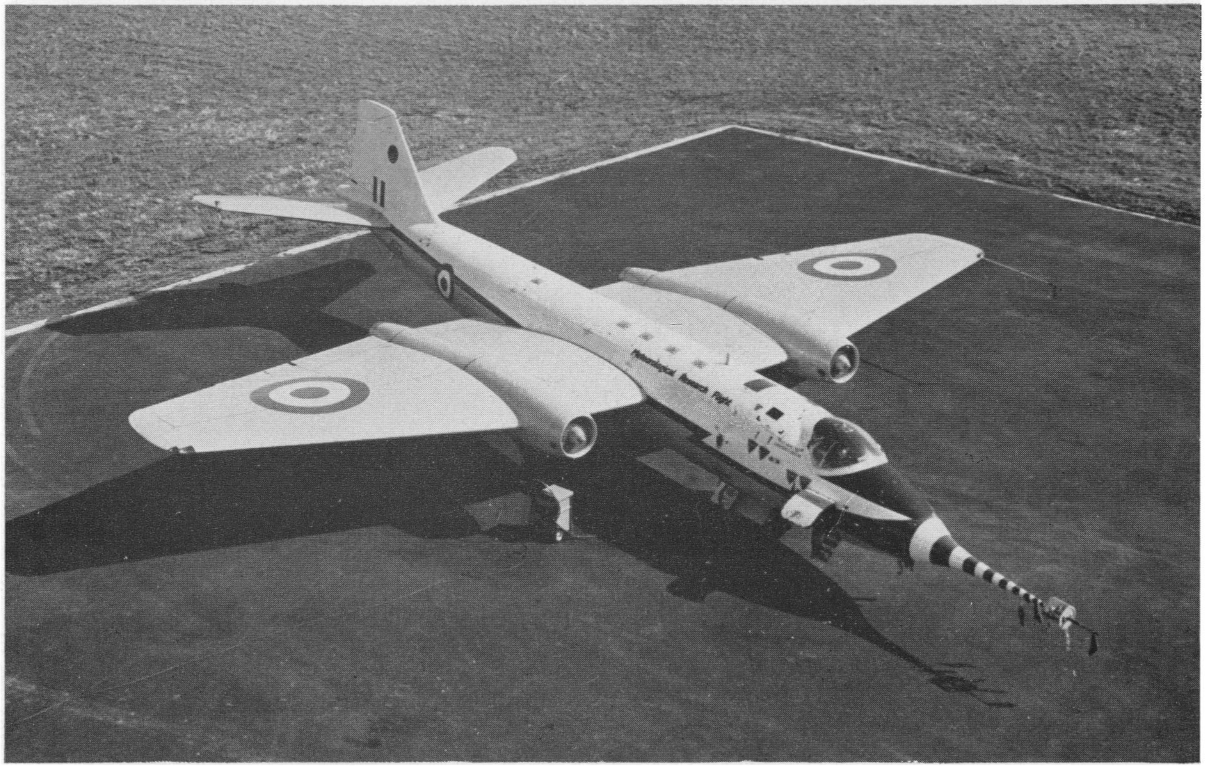
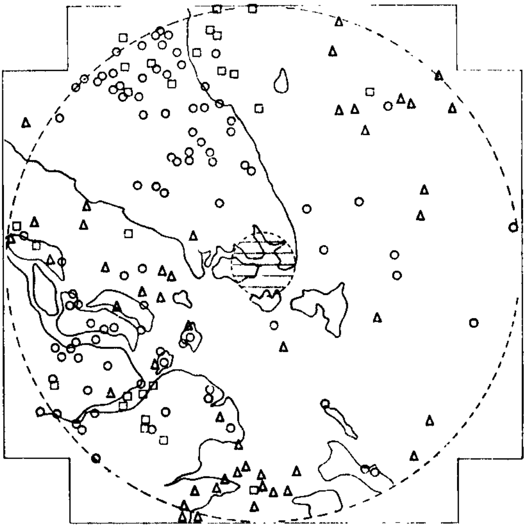


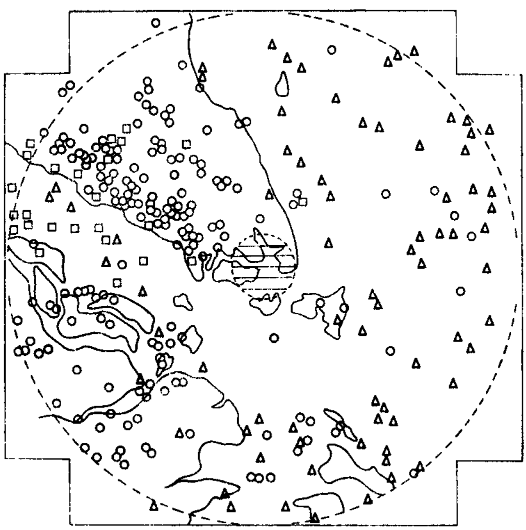
PLATE IV—CANBERRA AIRCRAFT OF THE METEOROLOGICAL RESEARCH FLIGHT PHOTOGRAPHED AT JEFFERSON COUNTY AIRPORT, COLORADO, WHILST DETACHED ON PROJECT WAMFLEX

See page 56.



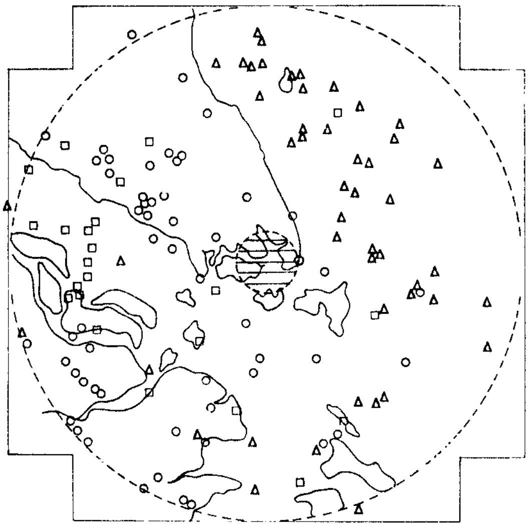
△ 00–12 h	No. of checks 197	Size of sample 27%
○ 12–18 h	No. of checks 140	Size of sample 39%
□ 18–24 h	No. of checks 116	Size of sample 32%

FIGURE 5—DISTRIBUTION OF ECHO-TOPS OVER 50 000 FEET IN SEPTEMBER 1969



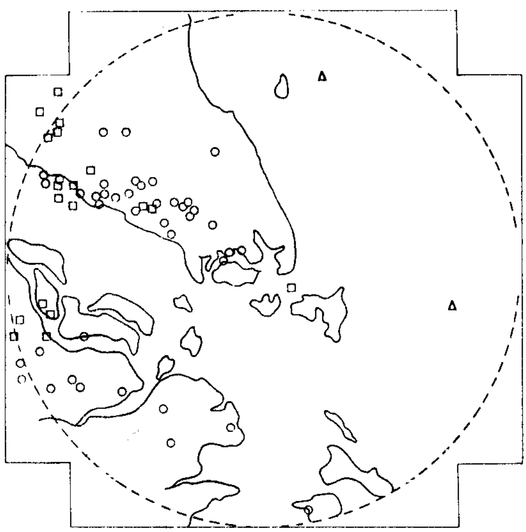
△ 00–12 h	No. of checks 219	Size of sample 29%
○ 12–18 h	No. of checks 157	Size of sample 42%
□ 18–24 h	No. of checks 111	Size of sample 30%

FIGURE 6—DISTRIBUTION OF ECHO-TOPS OVER 50 000 FEET IN OCTOBER 1969



Δ 00 – 12 h	No. of checks 338	Size of sample 23%
o 12 – 18 h	No. of checks 257	Size of sample 35%
□ 18 – 24 h	No. of checks 197	Size of sample 27%

FIGURE 7—DISTRIBUTION OF ECHO-TOPS OVER 50 000 FEET IN NOVEMBER AND DECEMBER 1969



Δ 00—12 h	No. of checks 474	Size of sample 22%
o 12 —18 h	No. of checks 364	Size of sample 34%
□ 18 —24 h	No. of checks 297	Size of sample 27%

FIGURE 8—DISTRIBUTION OF ECHO-TOPS OVER 50 000 FEET IN JANUARY, FEBRUARY AND MARCH 1970

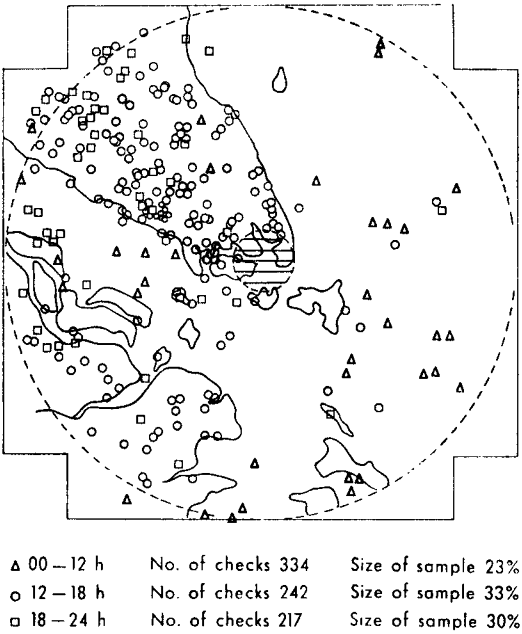


FIGURE 9—DISTRIBUTION OF ECHO-TOPS OVER 50 000 FEET IN APRIL AND MAY 1970

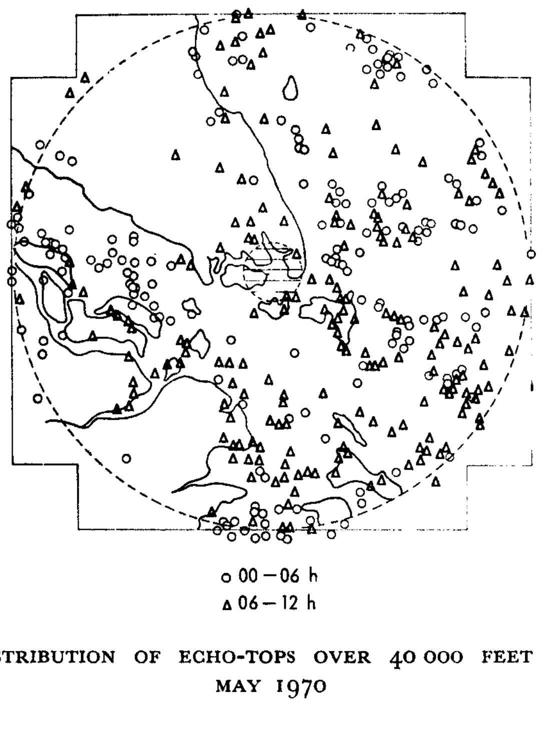
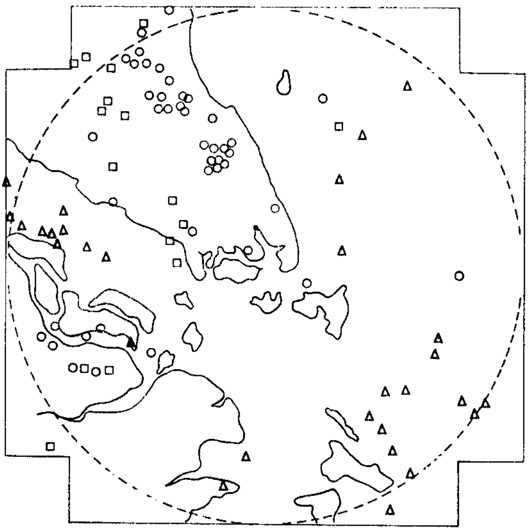


FIGURE 10—DISTRIBUTION OF ECHO-TOPS OVER 40 000 FEET IN APRIL AND MAY 1970



Δ 00–12 h	No. of checks 355	Size of sample 24%
o 12–18 h	No. of checks 273	Size of sample 37%
□ 18–24 h	No. of checks 228	Size of sample 31%

FIGURE 11—DISTRIBUTION OF ECHO-TOPS OVER 50 000 FEET IN AUGUST AND SEPTEMBER 1970

50 000 ft over the sea is much less than over the land even at the times most favourable for their occurrence; only over the Malacca Strait is there a density comparable with that over Malaya, and the China Sea (apart from coastal waters) is often free of all but a thin sprinkling of isolated tops.

The last point demonstrated by these diagrams is that over Malaya the location of the highest afternoon tops during months with a dominant wind-flow is to the lee side of the land mass. The existence of this lee effect first became apparent during the north-east monsoon of 1968–69 when, although heavy rain often affected the eastern half of Malaya, the high tops were found to be mostly confined to the west. The diagrams for the combinations November–December 1969 and January–February–March 1970 confirm this feature of the distribution; similarly, in the afternoons of September 1969 and August–September 1970, during the south-west monsoon, high tops occurred mainly over the eastern half of Malaya.

Part II of this paper will be published in March.

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551·515·33

TORNADO IN SOUTH-EAST ESSEX ON 7 AUGUST 1973

By C. I. GRIFFITHS
(Meteorological Office, Shoeburyness)

Summary. The writer was alerted by the passage of a tornado, and describes the local effects, collating some evidence along its track. He suggests that heat-sources downwind may have triggered off the phenomenon, and concludes his note by discussing the meteorological situation.

The Thorpe Bay–Foulness area of south-east Essex was crossed by a tornado on 7 August 1973. The disturbance passed through a garden within 50 yards of the writer, who thereby became most interested in ascertaining its track.

It was possible to plot the tornado's path quite accurately, as the trail of damage was fairly narrow, and deviated little from a slightly curved line over the 8-mile route. Some sighting reports helped fill in gaps over open country. It is rather remarkable that the path is very similar to that of the Shoeburyness whirlwind of October 1949, as described by Hemens.[1] A sketch map of the area showing the path of the tornado is shown in Figure 1.

Damage was most severe between points A and B, and again at C. In the Thorpe Bay area (A–B) several large trees bordering the golf course were uprooted, though the roots proved to be fairly shallow. Chimney pots, roof tiles, garden walls and television aerials were brought down, and one car was reported to have been overturned. There was little evidence between B and C, though the passage of the tornado over the main A13 road south of Wakering was betrayed by numerous broken branches.

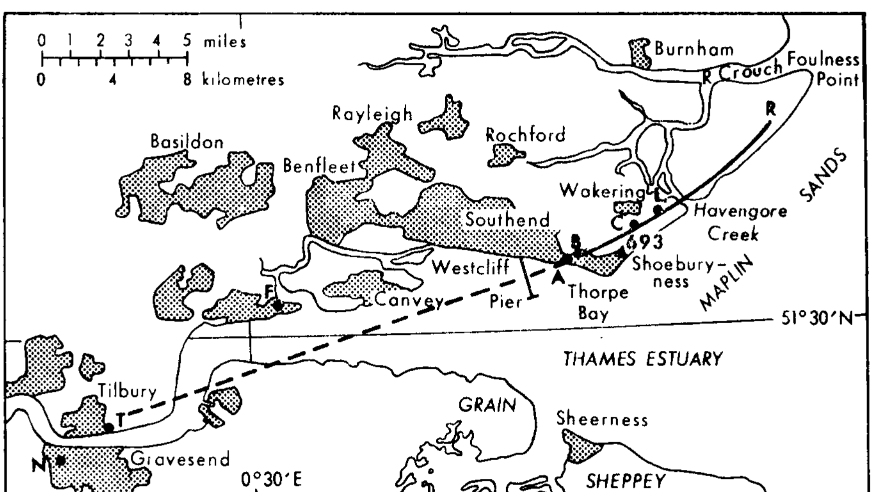

FIGURE 1—PATH OF TORNADO ON 7 AUGUST 1973

——— known track — — — suggested 'backtrack' to power stations on banks of River Thames

F position of flares at Shellhaven Refinery T Tilbury Power Station
N Northfleet Power Station
See text for explanation of other letters and figures on track of tornado.

The writer, near point C, recorded the passage of the disturbance at 0749 GMT. Cloud appeared to be swirling fairly low overhead, though it was not possible to discern a funnel cloud. Some trees, bushes, and even grass were flattened almost to the horizontal in the wind blast which preceded the whirlwind itself. It was subsequently discovered that debris was mainly deposited to the north-east of points of pick-up. One fairly large tree was broken off just above ground level, and several others were decapitated. A garden shed was shifted some 30 feet, and panes and wooden framing of adjacent glasshouses suffered severely.

Meteorological staff on duty at Shoeburyness radiosonde office (L) observed a short-lived waterspout as the tornado passed over Havengore Creek, at about 0755 GMT. The final trace was slight structural damage at Rugwood (R), some 8 miles from Thorpe Bay, at about 08 GMT.

The occurrence is of considerable interest in that it is possible that the tornado may have been produced partially by artificial means. Heat-sources are available at the flares at Shellhaven Refinery, near Canvey Island, and at power stations on the Thames Estuary. There was some backing of the known track between points A and B, rather more obvious on a larger-scale map than on the one which is reproduced here. This backing was possibly the result of increased friction over land. Rough backtracking, indicated by the dashed line in Figure 1, leads to the power station at Tilbury (T), some 16 miles west-south-west of Thorpe Bay. Inquiries have elicited the fact that pilots of light aircraft frequently report turbulence in this area. Unfortunately, no reports could be discovered of tornado sightings south-west of Thorpe Bay, nor was there any sign of damage to Southend Pier, which must have been in the tornado's path (see Figure 1). The extrapolated track is largely over water, and with showers in the area, the tornado may have travelled unobserved.

Hoddinott[2] describes funnel clouds near Chester in 1958 and 1959, to the lee of coke furnaces, and more recently Heighes[3] has discussed the formation of miniature funnel clouds suspended beneath smoke plumes from certain factory chimneys. It would seem that observers downwind of such sources in meteorological conditions similar to those described below may well be rewarded by seeing these somewhat unusual phenomena.

Meteorological situation. A well-marked cold front had passed at 1530 GMT on the previous day, leaving the Shoeburyness area in a very unstable west-south-westerly airstream. The temperature sounding made at Shoeburyness (Landwick), only a few minutes after the waterspout had been seen, is reproduced as Figure 2. At Shoeburyness synoptic office (693) at 0756 GMT, the following conditions were reported: surface wind 260° 20 kt; rain showers; dry-bulb temperature 14·8°C; dew-point 13·4°C; barometer 1010·6 mb. Between 0745 and 0750 GMT the barograph trace showed a temporary depression of approximately 1 mb; also at this time the wind veered by some 60° and a 48-kt gust was recorded, indicating the passage of a trough. Barograph and anemograph records are reproduced as Figures 3 and 4. A thunderstorm was observed about 5 miles to the north of the area at the time of the tornado. Showers occurred at Shoeburyness throughout the morning with a thunderstorm at 1207 GMT. The sea temperature at Southend Pier was 18·5°C.

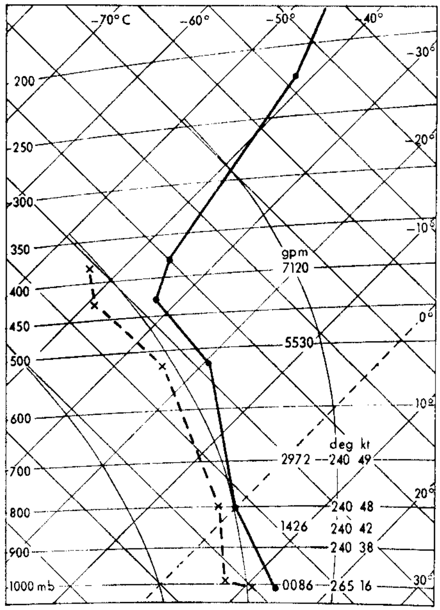

FIGURE 2—SHOEBURYNESS ASCENT DATA FOR 7 AUGUST 1973 AT 0805 GMT

· —— · dry-bulb temperature x – – x dew-point temperature

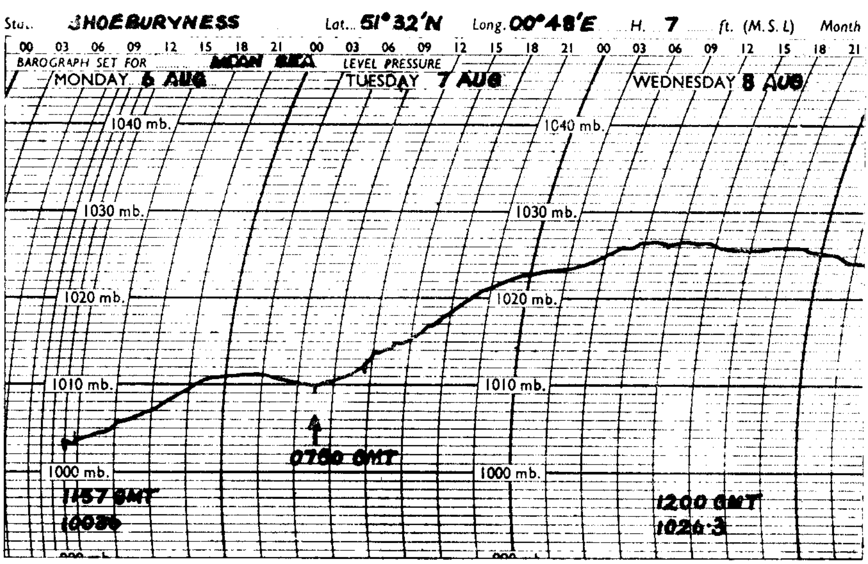

FIGURE 3—DIAGRAMMATIC REPRESENTATION OF SHOEBURYNESS BAROGRAM FOR 7 AUGUST 1973

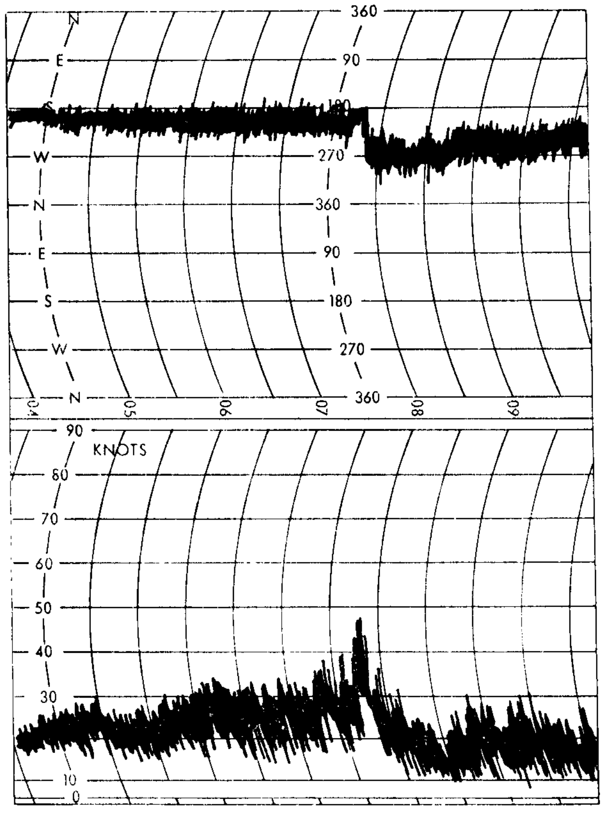

FIGURE 4—DIAGRAMMATIC REPRESENTATION OF SHOEBURYNESS ANEMOGRAM FOR 7 AUGUST 1973

Chart time is GMT.

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551.586:595

A METEOROLOGICAL/ENTOMOLOGICAL STUDY

By R. J. ADAMS

Summary. An account is given of an experiment designed to obtain temperatures at 10 cm below, near, and at 25 cm above the surface at different locations around a deciduous tree, for comparison with meteorological records from a nearby standard site. Such non-standard data are frequently needed, for example in assessing the ability of an imported pest species to survive in a climate beyond its normal geographical range.

Introduction. 'Readings of temperature and rainfall depend, to some extent, on the exposure of instruments, and if observations made at different stations are to be comparable, it is necessary to ensure that instruments are set up under as near uniform conditions as possible.' This perfectly valid statement, from the Meteorological Office pamphlet *Making weather observations* should not be interpreted as meaning that such observations are the only ones worth making.

The way in which comparable conditions for the measurement of temperature are achieved includes the exposure of instruments in a standard screen, which is itself sited in a standard enclosure in surroundings not unduly influenced by local features. For synoptic and climatological purposes a network of such sites is precisely what is required, but the information so obtained is frequently inadequate for other purposes. Expressed more simply, most processes influenced by weather in everyday life occur in places other than little white boxes 4 feet above the ground. Meteorologists are frequently called upon to comment upon such processes but find themselves with only partially relevant data. Typical of such an inquiry is a recent request from the Plant Pathology Laboratory, Harpenden, Herts., for information to help them assess the ability of insects to survive in regions outside their normal geographical range.

Entomological factors. One of the responsibilities of entomologists at Harpenden is to devise regulations to control the import of agricultural products which may carry with them potentially harmful pests. If a species cannot survive and reproduce under its new biological and climatic conditions there is no need to prohibit its entry. As has been pointed out by Baker,[1] biological factors affecting the survival of species include the availability of suitable food, the interaction between pest, predator and prey, and the structure of the plants and soil in which the species live and move. The net result of the complex interaction of these factors cannot be determined by entomologists with sufficient accuracy, so any assessment of the potential pest status of an exotic species by a method which attempts to predict the results of such interaction can be little more than a guess. The process of releasing a colony of pests into a suitable field to see how they behave is impracticable, not only because of the risks involved, but also, in the event of a negative result, because of the difficulty in identifying those particular factors which caused the failure of the species to establish itself. If these factors cannot be defined, there can be no confidence in declaring the results applicable elsewhere.

Within a limited range the rate of growth of insects increases with temperature, so laboratory experiments under controlled conditions can approximately establish the effect of such parameters as day-length, mean temperature, and diurnal temperature range on the life cycle of a pest. Baker[1] has demonstrated that for some species this can be done in sufficient detail to enable the results to be used to explain, and even to predict, the timing of events in the life cycle of an insect in an outdoor environment. This is the first step in any assessment of the potential of a species in a new environment, because in order that a species shall survive, its life cycle must be adequately synchronized with the seasons so that, for example, insects are in a suitable development stage at the onset of winter. Clearly, associations derived from laboratory studies and attempts to explain meteorologically the timing of events are only of value if related to conditions occurring in possible sites for insect habitation. Although some specialist studies have been undertaken (e.g. Lewis,[2] in which insect emergence was related to tree-bark temperature), using the relevant physical conditions, the standard meteorological data do not provide this information.

Site, instrumentation, and purposes of experiment. In order to measure directly some suitable temperatures, a pilot experiment has been set up in the grounds of the Meteorological Office College, Shinfield Park, near Reading, at a site selected in co-operation with the Plant Pathology Laboratory. The site, comprising the area close to and immediately under the canopy of a mature pear tree (see Plate I) is of interest to entomologists, since several species of insects and larvae spend the summer months in the leaves of deciduous trees, and subsequently fall to the ground to continue their life cycle in the upper few millimetres of the soil.

Platinum-resistance thermometers with continuous remote recording have been placed at the four cardinal points, 1·5 m from the bole of the tree, and at a distance of 12 m to the west, at depths of 10 cm (for comparison with a standard soil thermometer), 25 cm above the surface, and, of most significance, in the region of roots and decayed vegetation about 0·5 cm below the surface. Initially only the northerly point has temperature probes at each of the three depths indicated. Eight probes have been deployed between the five points, and a further four probes are available to be sited following examination of the records for the first few months. It is conceivable, for example, that such examination will indicate that variation of temperature as a function of distance from the tree is of more significance than its directional dependence. Continuously recorded temperature, radiation and other data from the Meteorological Office College site about 100 m distant are available, and also daily readings of all standard climatological data from the University of Reading agrometeorological station (Shinfield) about 0·5 km to the south-east. It is hoped that in the forthcoming year or two sufficient data will have been gathered to satisfy the following aims :

(a) To obtain quantitative measurements of localized temperature variations in a field situation of biological interest.

(b) By examining these results in conjunction with other meteorological data, to assess the feasibility of either making appropriate adjustments to the standard-screen and grass-minimum temperatures, or estimating the magnitude of errors introduced by assuming these temperatures to be indicative of a nearby, but dissimilar, environment.

(c) By conducting such an experiment at first hand to place the Agricultural Section of the Meteorological Office in a better position to advise other research organizations wishing to set up their own investigation into an environment in which they have particular interest.

Studies of the inter-relation between entomology and meteorology have of course already taken place (e.g. Hurst[3]). It is hoped that this venture will extend such interdisciplinary co-operation further.

Acknowledgements. The author wishes to thank Mr D. H. Johnson and his staff at the Meteorological Office College for their willing co-operation, and Mr C. R. B. Baker of the Plant Pathology Laboratory, Harpenden, with whom this joint meteorological/entomological study is being conducted.

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AWARDS

L. G. Groves Memorial Prizes and Awards

The annual award of prizes took place on Friday, 23 November 1973 at the Ministry of Defence, Whitehall. The Vice Chief of the Air Staff, Air Marshal R. L. Wade, C.B., D.F.C., presided and the Prizes and Awards were presented by the generous donor Major K. G. Groves, who was accompanied by Mrs Groves. The ceremony was attended by the Director-General of the Meteorological Office, Dr B. J. Mason, C.B., F.R.S., and by the Director of Services, Mr J. K. Bannon, I.S.O. (see Plates II–IV).

The 1973 Aircraft Safety Prize was awarded to Master Air Loadmaster M. W. Bailey of Royal Air Force Akrotiri, with the following citation :

'At RAF Akrotiri, Master Air Loadmaster M. W. Bailey is a member of No. 70 (Hercules) Squadron whose role includes a Search and Rescue (SAR) commitment.

The existing SAR role equipment on the squadron is basically that previously used in Argosy aircraft but, although operationally effective, it has been found to have shortcomings when used in the Hercules. In seeking a remedy, Mr Bailey has devised a series of modifications embracing the pyrotechnic container, the layout and accessibility of equipment inside the aircraft, and improved dispatch to survivors.

The modifications, tested and found workable, include locating the SAR role equipment in the aircraft on five pallets mounted on a roller conveyor, an arrangement which permits an aircraft role change in some 30 minutes instead of the present 5 to 6 hours. Furthermore, since the pallets are made from standard Army one-ton baseboards, the configuration could be considered for Argosy and Andover aircraft if required.

In applying himself to this worthwhile project, Master Air Loadmaster Bailey has made a valuable contribution to the RAF Safety Services and he is a worthy winner of the Aircraft Safety Prize.'

The 1973 Meteorology Prize was awarded to Mr P. Goldsmith, Senior Principal Scientific Officer, Meteorological Office, with the following citation :

'As leader of a scientific team responsible for the study of cloud physics and dynamics, Mr Goldsmith has been the inspiration and driving force behind a major series of expeditions which have exploited radar, aircraft and other sophisticated new methods in the study of the structure of rain-producing weather systems. Conducted from the Isles of Scilly these experiments have convincingly demonstrated that the rainfall pattern at fronts can be linked with the air motions on a scale of tens of kilometres. By developing new techniques of employing aircraft, dropsondes, radiosondes and radar Mr Goldsmith has forged a new tool for the investigation of the causes of the observed patterns of rainfall.

Mr Goldsmith has also played an important role in devising programmes to examine the possible impact of supersonic aircraft on the constitution of the stratosphere and has demonstrated in particular that there is no reason to expect effects upon atmospheric ozone greater than those produced by atomic bomb tests — effects which, if they exist, are too small to be detected.'

Mr Goldsmith was unable to attend, as he was a delegate at the World Meteorological Organization Commission for Atmospheric Sciences meeting in Versailles. The Prize was accepted on his behalf by Dr W. T. Roach, the recipient of the Meteorology Prize awarded in 1967.

The Meteorological Observer's Award for 1973 was awarded to Squadron Leader N. Lamb, Meteorological Research Flight, with the following citation :

'Squadron Leader N. Lamb has been Officer Commanding the Meteorological Research Flight at Farnborough since 1970. Throughout this period he has contributed greatly to the observational programme by his ability to recognize fully the scientific requirements and suggest appropriate in-flight variations of plan to meet the meteorological circumstances. During the first three months of 1973 the Canberra aircraft was detached to Boulder, Colorado to participate in a multi-aircraft project to investigate airflow disturbances over the Rocky Mountains. During the detachment a total of 37 sorties was carried out, the serviceability of the aircraft being far greater than that of any other aircraft involved. The leadership of Squadron Leader Lamb was largely responsible for the successful fulfilment of the mission.'

The Second Memorial Award for 1973 was awarded to Flight Lieutenant P. Wallis, formerly of Royal Air Force Tern Hill, with the following citation :

'One of the problems confronting a survivor in a single-seat liferaft is the removal of sea water from within the dinghy. Existing bailing arrangements require the canopy to be at least partly open and, in rough weather, more water may enter than is being removed.

Flight Lieutenant P. Wallis has proposed modifications, utilizing the existing bailer attached to a pipe through the side of the closed canopy, which permits the evacuation of sea water by gravity. The limited tests so far conducted suggest that the concept is sound and that the idea could lead to much improved comfort and safety for the occupants of single-seat liferafts. For his resourcefulness in tackling this problem, Flight Lieutenant Wallis well merits the Second Memorial Award.'

REVIEWS

Radar observation of the atmosphere, by Louis J. Battan. 230 mm × 155 mm, pp. xvi + 197, *illus.*, The University of Chicago Press, 126 Buckingham Palace Road, London SW1, 1973. Price: £7·15.

This book is a new version of the author's *Radar meteorology* which was published in 1959. This earlier book has been the only general account of the subject available in the English language but during the 14 years which have elapsed since its appearance there have been many significant developments, so it has become increasingly out of date. In fact the new book contains sufficient new material to justify the change of title. Professor Battan states in his preface that the book is intended primarily for use by meteorologists, atmospheric scientists, and students who have had little training in electronics, but that it should also be informative to a much broader spectrum of scientists and engineers. The book succeeds in providing an adequate summary of the principles involved in using radar in meteorological applications, and presents a wide selection of observations. The author does not go into any substantial detail in the topics discussed, so a reader particularly interested in a specific item may not find enough information to satisfy his interest, but the list of over 600 references will enable him to proceed further into the literature; his task might however have been simpler if articles published in readily accessible journals had been cited when possible, rather than contract reports or conference proceedings.

The first six chapters, constituting about a quarter of the total text, summarizes theoretical aspects of the meteorological uses of radar. The summary begins with a simple account of the principles of radar, and then discusses the properties and propagation of electromagnetic waves. This is followed by three chapters on the scattering and attenuation produced by precipitation particles, including an entire chapter on the back-scattering by melting spheres and non-spherical particles, one of the fields in which Professor Battan has specialized, but which he has perhaps overemphasized in a book of this type. There is a danger that a reader interested primarily in the meteorological applications of radar will find this first part of the book tedious. It would be a pity if this resulted in his not reading the later chapters, which summarize the wide variety of meteorological uses to which weather radars have been put. There are chapters on the uses of radar for precipitation measurement, Doppler radar, the use of radar in cloud-physics research, radar observations of medium- and large-scale systems and clear-air echo studies. This last field of investigation was in its infancy at the time of the earlier book but with the current availability to meteorologists of very sensitive radars it is now the area of most striking progress in radar meteorology.

Anyone who has found *Radar meteorology* of value will find this version more so, and anybody new to the subject would be well advised to commence his reading with this book.

T. W. HARROLD

Studies in ice physics and ice engineering, edited by G. N. Yakovlev (translated from the Russian by the Israel Program for Scientific Translations, Jerusalem). 245 mm × 175 mm, pp. v + 192, *illus.*, John Wiley and Sons Ltd, Baffins Lane, Chichester, Sussex, 1973. Price: £7·50.

This book consists of 21 articles on various subjects relevant to ice technology, and is largely the work of the Arctic and Antarctic Institute of the U.S.S.R. It represents work that could only be carried out in Russia, in Canada, or in the Antarctic, and has been done by Russian scientists and engineers in an effort to apply scientific methods to the severe environment of the Arctic and the Antarctic.

The first group of articles deals with methods of estimating the strength (i.e. carrying capacity), and resistance to icebreakers, of a natural ice-cover. Theoretical and laboratory studies and observations in the 'field' are described. Formulae are given for the static pressure exerted at various depths in an ice-cover at its boundaries. The salinity of the ice and the duration and intensity of the frost are controlling factors, but the formulae are subjective and irregular with regard to sign. As one might expect, the history of an ice field greatly affects its strength and resistance to icebreakers. Ice 'covers' have been synthesized in the laboratory, and natural and artificial ice have been subjected to exhaustive electrical and mechanical tests. Ice has been considered as a building material and successfully reinforced with wood, and the performances of towed models in ice-covered tanks have been recorded.

Further articles show that ice may not be treated as a homogeneous continuum; uneven stresses, within the ice, cause cracks which make large pieces more likely to break up than small. The general orientation of the ice-crystal axes, which depends on the thermal history of the original freezing water, decides the strength of a layer of ice. Therefore the strength and character of ice fields and areas of fast ice can be classified according to geographical regions. The elastic qualities of a complete ice-cover, or very large ice floe can best be measured ultrasonically or seismically, i.e. practically instantaneously. Static methods are possible in which the slope of an ice sheet is measured by a tiltmeter in response to a heavy load placed on the ice. However, Young's Modulus measured by the latter method is less than half that measured by 'instantaneous' methods. The elastic qualities of ice depend on the period of time during which any load is applied. Theoretical studies of elastic waves in a large floating ice sheet do not appear to have produced useful practical results. One paper describes the tiltmeter, which is a precise instrument in which a pendulum is used to measure the slope of ice sheets.

There are interesting studies of the differential melting of hummocks, their static stability and underwater topography. The support and persistence of these massive pieces of ice within an ice sheet are of significant importance in ice navigation.

There are notes concerning the ice-cover in the Antarctic, particularly at the Russian Station at Mirny. Notes are given concerning the structure in depth of the ice-cover in the Antarctic, and these notes are consistent with earlier observations made elsewhere. The clear days are accompanied by intense solar radiation which penetrates the ice and is very effective in breaking it up. Successful experiments in blasting Antarctic ice are described. In another paper an efficient method of directional blasting is described.

Experiments are described in which sea water has been greatly supercooled. In nature, supercooling is very effective in the rapid formation of an ice-cover but it is shown that the degree of supercooling is relatively slight.

There are articles on the cutting of ice with hot torches and with jets of water. The torches require very careful handling as they can burn up; the jets are quite efficient and can be used from icebreakers.

The Russians have dealt adequately with the Arctic for centuries, and must have many sound, purely practical methods of dealing with ice, snow and extreme cold. This book seems to me to be a beginning and does not show that scientific methods have yet advanced sufficiently to overtake practical techniques based on long experience.

The book is well produced and the translation very clear and readable. It is unique to British readers in that it demonstrates the application of science to an environment quite different from their own. It should therefore be of great interest to all those whose work requires a knowledge of ice phenomena.

G. A. TUNNELL

LETTER TO THE EDITOR

551.509.324.2:551.578.45

Wet-bulb freezing level as a snow predictor

Mr B. J. Booth has drawn attention to the wet-bulb freezing level as a snow predictor in his recent paper.[1] Figure 2 of the paper shows that to a good approximation there is a linear relation between the snow index I_s and the height of the wet-bulb freezing level.

Bader[2] has also recently given an excellent example of the effect of the dryness of the air on the form of precipitation.

As long ago as 1950, Douglas[3] stressed the importance of the wet-bulb freezing level as a snow predictor, and it is unfortunate that it was omitted from the list of predictors given by Boyden,[4] especially since it is by far the most useful one on those memorable occasions when snow descends well below the initial dry-bulb freezing level.

Mr Bader and Mr Booth are therefore to be congratulated on having again demonstrated the importance of the wet-bulb freezing level as a snow predictor.

Regional Meteorological Training Centre,
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OBITUARY

It is with regret that we have to record the death of Mr J. A. Miller, Higher Scientific Officer stationed at Episkopi, Cyprus, on 22 October 1973.

NOTES AND NEWS

OFFSHORE TELEMETERING BUOYS

Construction of an operational version of OBOE I, the offshore telemetering buoy, has been approved for eventual deployment in the Thames Estuary. It is hoped to include measurements of wind direction (for the first time) and possibly of visibility. Two small buoys were equipped with anemometers and magnetic-tape event recorders for use by the Fisheries Laboratory, Lowestoft during the international oceanographic exercise 'JONSDAP 1973' in the southern North Sea, which started in September 1973.

FORECASTING FOR THE TRAWLER FLEET OFF ICELAND

Responsibility for forecasting for the trawler fleet off Iceland was taken over by a meteorologist on board the Trawler Support Vessel *Miranda* on 21 September 1973. This service is expected to continue in operation until the end of April 1974.

FORECASTS FOR THE BRITISH GAS CORPORATION

At the request of the British Gas Corporation, arrangements were made for the provision of a MET GAS forecast service to the Northern Gas Board from 1 July 1973 and to the North Eastern Gas Board from 12 September 1973. Ten of the 12 Area Gas Boards now take this comprehensive service.

MAXIMUM PERMISSIBLE LOAD CURRENTS IN AN OVERHEAD TRANSMISSION LINE

At the request of the Central Electricity Generating Board an analysis has been begun of meteorological data leading to computed maximum permissible load currents in a typical overhead transmission line. The limiting factor is the conductor temperature, which is dependent on ambient air temperature, wind speed, solar radiation and electrical heating.

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General Meteorological Office, London Road, Bracknell, Berkshire, RG12 2SZ, and marked "for Meteorological Magazine."

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