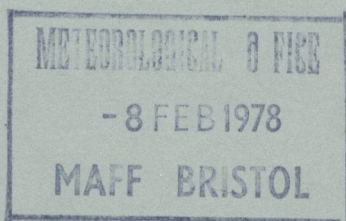


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## THE ONSET AND THE NORTHERN LIMIT OF THE SOUTH-WEST MONSOON OVER INDIA

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### SUMMARY

The weather changes associated with the onset of the monsoon at about 70 stations in India have been studied with a view to developing a specific definition for the onset of the monsoon suitable for application in fixing the northern limit of the monsoon at the time of routine analysis. It is shown that the rainfall and its nature alone should be considered for such a definition. The authors have suggested that the day when the first rainfall associated with the first north-westward progressing rainstorm is received at any place should be considered as the onset day at that place. The northern limit of the monsoon is defined as the line joining all the places of latest onset of the monsoon. The advance of the monsoon is analysed by using this definition for five seasons and the charts are compared with those of the India Meteorological Department. The differences are explained and are attributed to lack of specific definition of the onset of the monsoon for its determination in routine practice.

### INTRODUCTION

The onset of the south-west monsoon over India has been considered as a special meteorological phenomenon and its study will be one of the important aspects of the MONEX-79 program. The normal date of onset at any station was determined from the characteristic rise in the cumulative mean rainfall curve at that station by the India Meteorological Department. A chart of normal onset-dates for India and neighbourhood was published by the India Meteorological Department in 1943 (see Figure 1). According to this chart the monsoon sets in over the south Andaman Sea and lower Burma by about 20 May and advances north-westwards, reaching the Indian mainland by 1 June. It reaches the northernmost limit in the extreme north-west by 1 July.

Investigations have been made in order to study the onset in relation to the changes in winds and circulations in the middle and upper troposphere over India as well as over Eurasia and the Pacific by Maung Tun Yin (1949), Koteswaram (1958), Subbaramayya (1961), Lockwood (1963), Wright (1967), and de la Mothe and Wright (1969). An attempt was made by Ramadas *et alii* (1954) to forecast the date of onset of the monsoon on the west coast of India. These investigations require precise and accurate information regarding the time of onset.

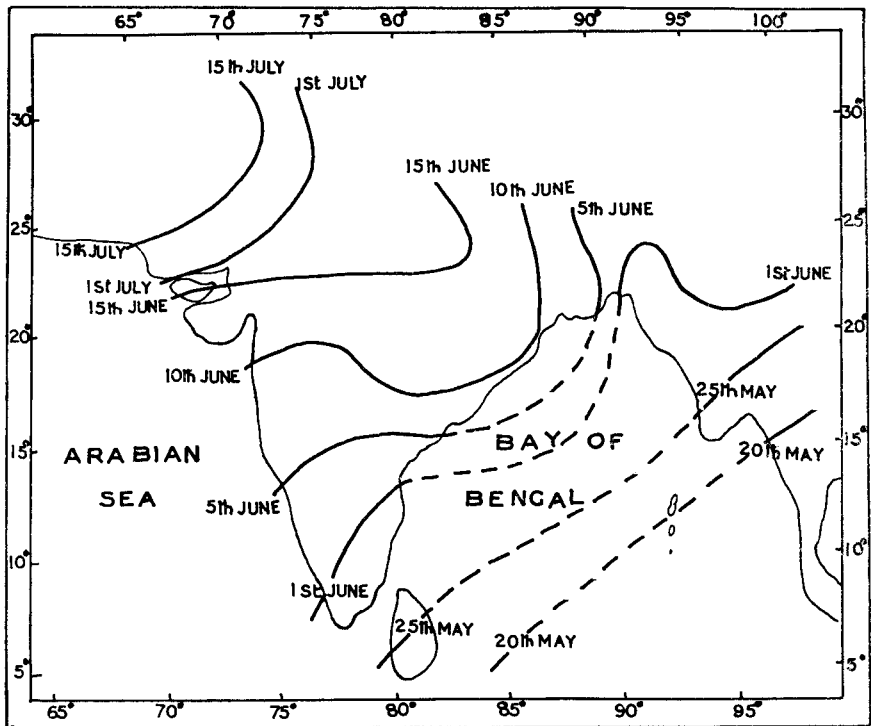


FIGURE 1—NORMAL DATES OF ONSET OF THE SOUTH-WEST MONSOON  
(After India Meteorological Department (1943))

The determination of the normal date of onset of the monsoon from the cumulative mean rainfall curves is not unambiguous. This is particularly true in the areas where the pre-monsoon thunderstorm rains merge with the monsoon rainfall and in those areas where the rainfall in the monsoon season is poor. This point was brought out by Ananthakrishnan and Rajagopalachari (1964). The determination of the time of onset in individual years, which is also necessary for demarcating the northern limit of the monsoon (NLM) at the operational level, is much more ambiguous and difficult because it is not possible to have cumulative rainfall curves to the required extent for the characteristic rise to be properly noted. It became a custom to consider the changes in the other weather parameters to define the onset of the monsoon. But this was not done systematically and the precise method varied from person to person. It is necessary to have a specific definition for the onset of the monsoon so that its northern limit can be determined objectively. The need for a specific definition has also been stressed by Ananthakrishnan *et alii* (1967) who gave a criterion for defining the onset of the south-west monsoon over Kerala only, according to which 'beginning from 10 May if at least five out of the seven stations report 24-hourly rainfall 1 mm or more for two consecutive days the forecaster should declare on the second day that the monsoon has advanced over Kerala'.



## WEATHER CONDITIONS IN MAY AND JULY

Since the onset of the monsoon is being considered as an event when the pre-monsoon summer conditions abruptly change to the cool, humid and rainy monsoon weather, the difference in the mean weather conditions between May and July should be due to the characteristic change in weather associated with the onset of the monsoon at any place. On this assumption, to formulate a criterion for the identification of the onset, the authors have prepared and studied the charts of 'changes' in different weather elements, where these changes are expressed as differences or ratios. Some of these charts are presented in Figures 2-6 and the salient features are discussed. For the preparation of the charts the mean values for a period of 30 years at about 70 stations published by the India Meteorological Department (1963) have been used.

The average ratios of rainfall on a 'rainy' day\* in July to that on a rainy day in May (Figure 2) show that the rainfall on a rainy day increases over a major part of the country by a factor of from 1 to 2. However, in the neighbourhood of Delhi the factor is 3. In the extreme south, on the other hand, the rainfall on an average rainy day in July is less than that in May.

The distribution of numbers of rainy days in the month of May and the differences from May to July are presented in Figures 3(a) and 3(b). In the month of May the number of rainy days is less than 3 over much of the country. In a small area on the west coast near about 10°N the number of days is 10. A similar small area is present in north-east India, where the number is 15. These rains are attributed to the pre-monsoon thunderstorms. The increase in the number of rainy days is quite significant on the west coast between 13°N and 20°N. Over much of the country the number increases by more than 10.

The north-westward spread of the monsoon rains is accompanied by a fall in day maximum temperatures. In May the average maximum temperatures are a little above 40 °C except in coastal regions and in some parts of peninsular India. Figure 4 shows the extent to which the monsoon depresses average maximum temperatures. The quantity shown is average July maximum minus average May maximum. The decrease is as much as 10 °C over central India. The mean diurnal range of temperature in July as compared with May is reduced by 4-8 °C over a major part of the country. It is to be noted that these changes are not as large as those of maximum temperature; this indicates that there is a slight increase in minimum temperatures. This increase should be due to the general cloudiness of the monsoon current.

The changes in mean low-cloud amount and total cloud amount from May to July (Figures 6(a) and 6(b)) show a general increase by 2-4 oktas and 3-5 oktas respectively over the whole region except for the extreme south and north-west regions where the monsoon rains are meagre and the north-east regions where the pre-monsoon rains are frequent.

Keeping the above-described changes in view it may be assumed that the onset of the monsoon would be associated with an increase in rainfall on a rainy day by a factor of as much as 3, an increase in the frequency of rains from 1 day in 10 to 1 day in 2, a decrease in maximum temperature by 4-10 °C, a decrease in diurnal range of temperature by 3-8 °C, an increase in total

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\* 'rainy' days are defined as having falls of at least 2.5 mm.

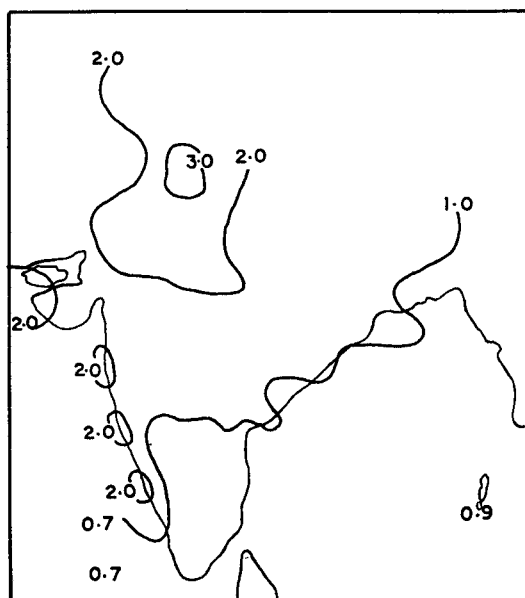


FIGURE 2—RATIO OF RAINFALL ON A RAINY DAY IN JULY TO THAT ON A RAINY DAY IN MAY

cloud amount by 3–5 oktas and in low-cloud amount by 2–4 oktas. It should also be borne in mind that there would be regional differences from these general values.

#### WEATHER CHANGES AND THE ONSET OF THE MONSOON IN 1975

The changes in the values of the different weather elements associated with the onset of the monsoon in 1975 have been studied in order to understand how far the May to July weather changes occur at the time of the onset of the monsoon. For this purpose the weather data published in the Indian *Daily Weather Reports* at 70 stations for a period of 15 days, one week on either side of the officially declared onset day at each station, have been critically examined.

There were rain-spells (rainfall on two or more consecutive days) at 60 stations during the periods under study. At 19 stations the declared onset day (hereinafter called 'onset day') coincided with the starting day of the rain-spell. At the rest of the stations the onset was declared 2 or 3 days after the starting of the spell. The rainfall on the onset day was 10 mm or more at 30 stations, less than 10 mm at 14 stations and nil at 14 other stations. At the rest of the stations the rainfall reports were missing on the onset day. The maximum 24 hour rainfall in the spells was 10 mm or more in 53 out of the 60 cases. The onset day coincided with the maximum-rainfall day in 14 of the 53 and 4 of the remaining 7 cases. These observations show that the declared onset day coincided neither with the first day of the spell nor with the day of maximum rainfall in most of the cases. It has been found that the average rainfall on the declared onset day was practically equal to the average rainfall on the starting day of the spells and considerably lower than the average maximum rainfall in the spells.

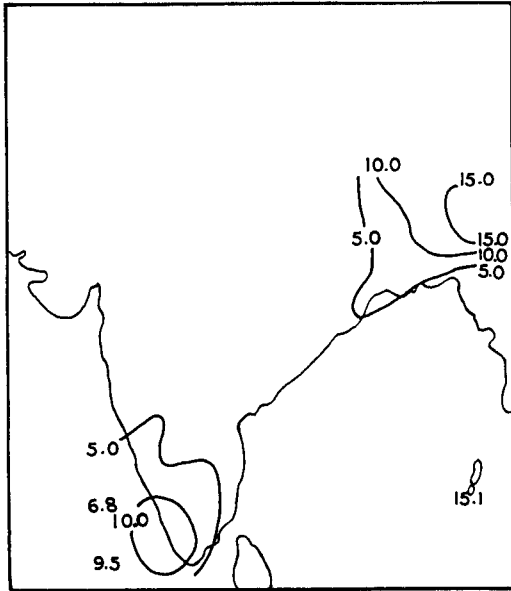


FIGURE 3(a)—NUMBER OF RAINY DAYS IN MAY

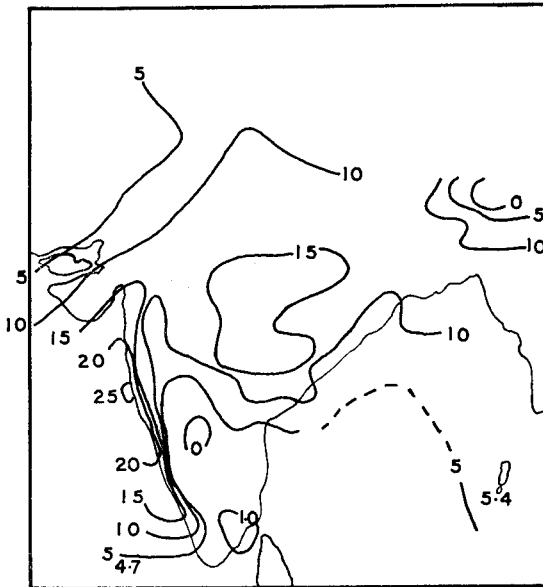


FIGURE 3(b)—CHANGE IN NUMBER OF RAINY DAYS (JULY MINUS MAY)

A drop in the maximum temperature by at least  $4^{\circ}\text{C}$  in 24 hours during the two-week periods of study occurred at 46 stations. In 18 of these cases the change occurred on the onset day, whereas it was later in 13 and earlier in 15 cases. In general the drop in temperature followed a heavy rainfall. A

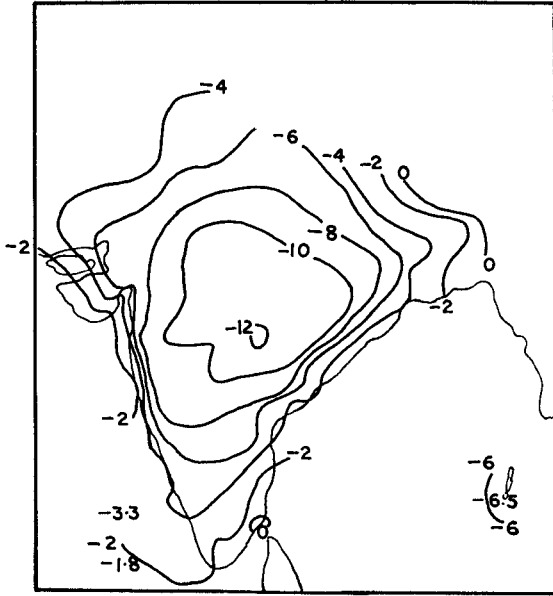


FIGURE 4—CHANGE IN MAXIMUM TEMPERATURE IN DEGREES CELSIUS (JULY MINUS MAY)

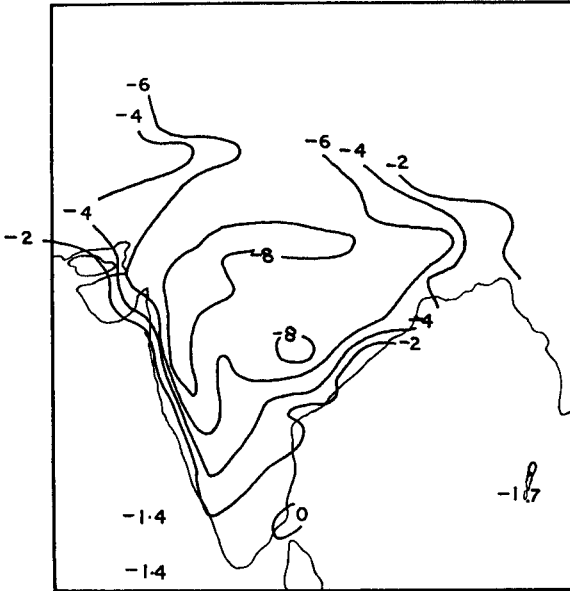


FIGURE 5—CHANGE IN DIURNAL RANGE OF TEMPERATURE IN DEGREES CELSIUS (JULY MINUS MAY)



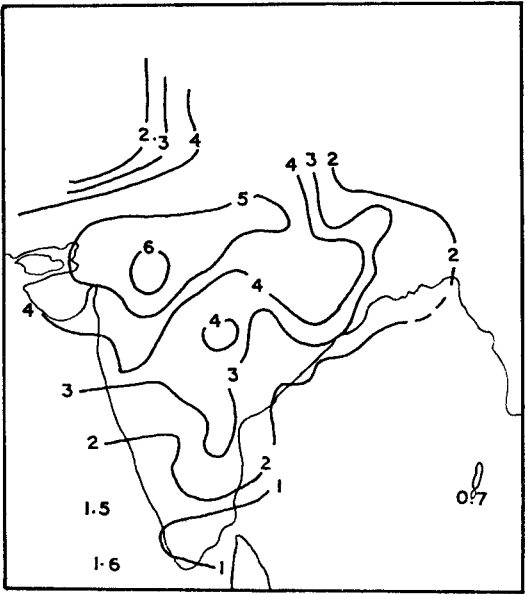


FIGURE 6(a)—CHANGE IN TOTAL CLOUD AMOUNT IN OKTAS (JULY MINUS MAY)

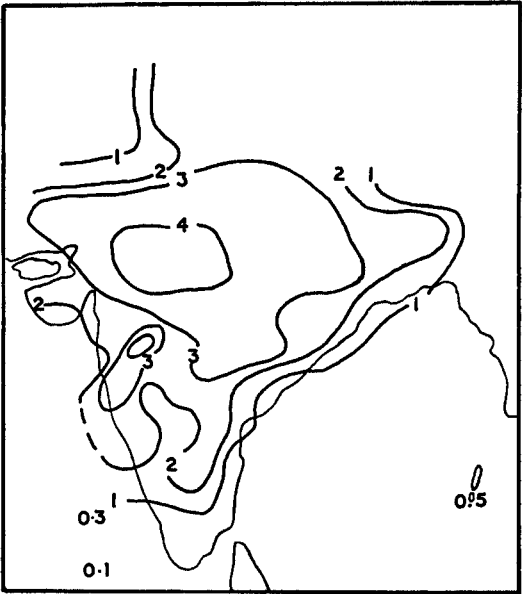


FIGURE 6(b)—CHANGE IN LOW-CLOUD AMOUNT IN OKTAS (JULY MINUS MAY)

discontinuous change ( $4^{\circ}\text{C}$  drop or more in 24 hours) in the diurnal range of temperature occurred in 38 cases of which 11 were on the onset day, 8 earlier and 19 later.

An increase by at least 3 oktas in the total cloud amount and low-cloud amount occurred at 47 and 40 stations respectively. Of the former 47 cases only 5 coincided with the onset day, while 38 occurred earlier by from 2 to 4 days. Changes in low-cloud amount occurred in 12 cases on the onset day while in 20 cases the change was earlier. Thus in the majority of the cases changes in cloud amounts occurred before the onset day. Furthermore, the changes in medium- and high-cloud amounts have occurred a day earlier than changes in low-cloud amount.

The foregoing observations indicate that substantial changes in different weather parameters do occur around the time of onset, but not simultaneously. The changes are spread over 4 or 5 days in general and usually occur in the following order: (1) medium- and high-cloud amount; (2) low-cloud amount; (3) rainfall; (4) maximum temperature and diurnal range of temperature. Differences in the order do occur as well as in the time taken for the changes to take place at some stations. There were also cases where the changes took place only gradually. Hence it may not be possible to have a simple criterion involving several weather parameters and yet maintain objectivity. It is proposed, therefore, that the starting day of the first monsoon rain-spell be considered the prime factor for the determination of the onset day.

#### DETERMINATION OF THE ONSET AND THE NORTHERN LIMIT OF THE MONSOON

A careful study of the rains associated with the onset in several years showed that the monsoon rain-spells at individual stations were due to synoptic and subsynoptic systems which cause widespread rains. This is in contrast to some of the scattered pre-monsoon thunderstorm rains. Widespread rains due to synoptic systems do, of course, occur in the pre-monsoon season also. But the essential difference is that the synoptic systems and associated rainstorms in the pre-monsoon season move eastwards while those in the monsoon period move westwards. The onset of the monsoon at any place may therefore be associated with the first westward-moving rainstorm.

It was also found that the NLM is not a material (i.e. continuous) curve; neither is it a line of discontinuity in the pressure field or in the wind field. The NLM is a curve, south of which the monsoon has already set in. This does not mean that rains occur constantly at all places every day south of that line. The NLM can hence be obtained by joining all the places of latest onset of the monsoon or, in other words, all places which have just received for the first time rain due to the first monsoon rainstorm.

The authors have determined the NLM on every day during the period of the establishment of the monsoon over India in the years 1971–75 according to the above-stated definitions of the onset of the monsoon and NLM and have compared them with those given by the India Meteorological Department. As an example the charts for the year 1973 are presented in Figures 7(a) and 7(b). The advance of the NLM line was never uniform all along its length. The advance was confined to limited lengths on any day, depending on the size of the synoptic systems that advanced north-westwards across the NLM giving the first monsoon rains in areas where the monsoon had not previously set in.

The first official announcement of the NLM was given on 26 May (Figure 7(b)). It touches the southern tip of peninsular India and runs across the Andaman Sea and central Burma. There was a slow northward advance till 5 June. But thereafter it quickly advanced and established itself over most of the country by 14 June. Further advance took place only from 1 July and the remaining part of the country was covered by 5 July.

Figure 7(a), however, shows that, according to the present writers, the monsoon had set in over the Andaman Islands as early as 17 May. The monsoon quickly covered Burma and touched the southern tip of peninsular India by 20 May. Towards the end of the month there was a slight advance over the west coast, the north Bay of Bengal and parts of Assam. Then there was a rapid advance from 3 to 13 June while a major part of the country was covered by the monsoon. The rest of the country was covered by 5 July; this date agrees with the official date. It is to be noted that there are differences in the earlier part of the progress of the monsoon.

The delay in the official declaration of the monsoon in the Bay Islands, south peninsular India, upper Burma and north-east India was due to the rains of the first westward-moving systems having been overlooked. It is also to be noted that the official onset was, in general, some 2–3 days late according to the present writers. Similar differences were observed in the other years also. There were cases when the official dates were earlier than the dates fixed by the authors. In those cases the rains due to eastward-moving systems, or due to lows after recurvature, were considered to be monsoon rains.

In the above study the north-westward progression of the synoptic system or rain area was inferred from synoptic charts drawn at intervals of 12 or 24 hours. It should be stated here that determining the direction of propagation is sometimes quite complicated because the synoptic systems responsible for the onset and advance of the monsoon are formed, or at least affected, by troughs in the subtropical westerlies. These troughs also give rise to widespread rain areas which are sometimes contiguous with those of the eastern disturbances. One should be able to differentiate between the two rain areas. The radar and satellite surveillance of rain and cloud areas would be quite helpful in understanding the progression of the systems and hence in determining the NLM.

### CONCLUSIONS

- (1) Lack of specific definition of the onset of the monsoon over the Indian subcontinent, suitable for application in the routine of daily analysis, results in inaccuracy and subjectivity in the determination of the onset and positioning of the NLM.
- (2) Changes in weather parameters other than rainfall, e.g. temperature and cloud amounts etc. may occur around the time of onset of the monsoon but rainfall only should be considered for the purpose of determining the onset.
- (3) The onset of the monsoon may be declared on the day when the first rain of the first westward-moving synoptic system or rainstorm is received at any place.
- (4) The NLM can be drawn by joining all the places of latest onset of the monsoon.

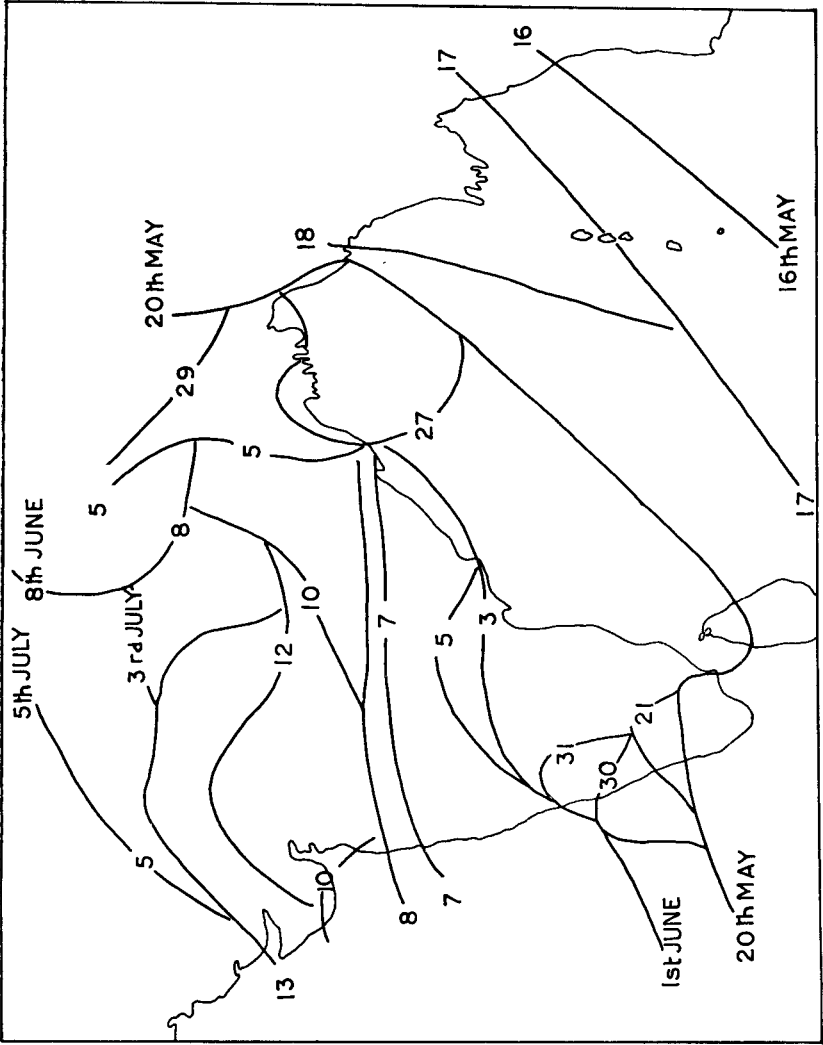


FIGURE 7(a)—PROGRESS OF THE MONSOON IN 1973 (ACCORDING TO THE AUTHORS)

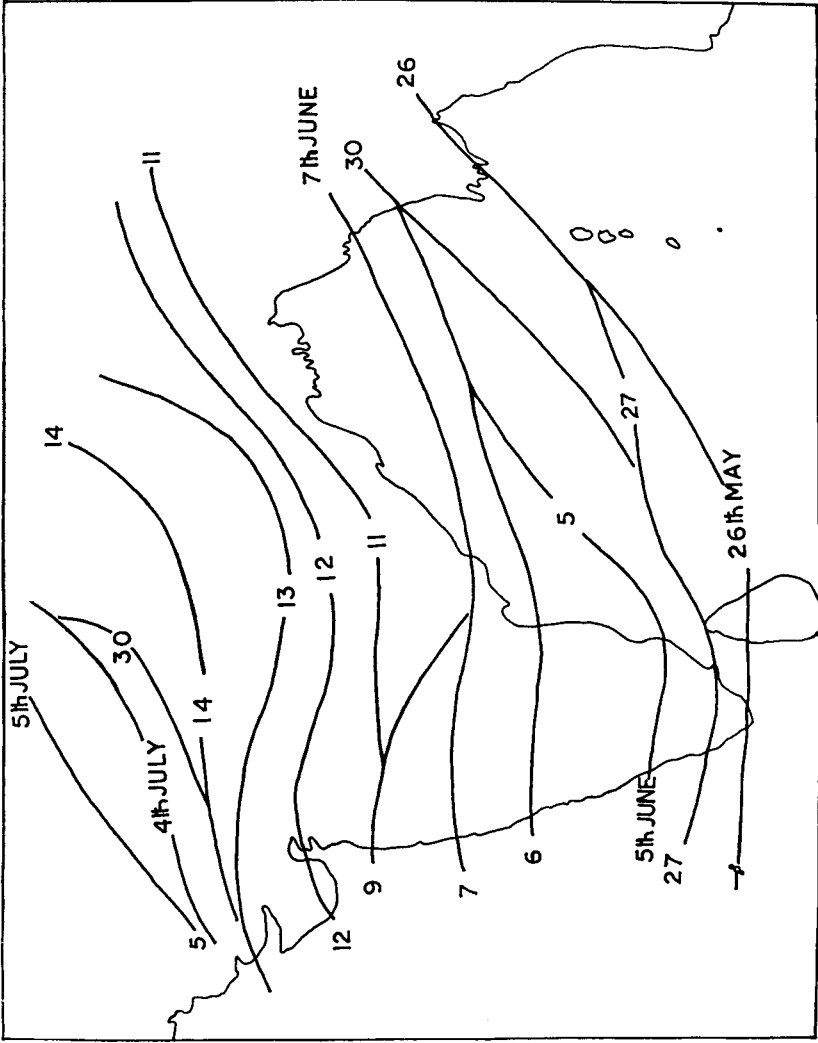


FIGURE 7(b)—PROGRESS OF THE MONSOON IN 1973 (ACCORDING TO THE INDIA METEOROLOGICAL DEPARTMENT)

- (5) The NLM is neither a material (i.e. continuous) curve, nor a line of discontinuity in the pressure field or in the wind field; it does not advance uniformly all along its length, its advance normally depending on the synoptic system that is responsible for the spreading of the rain-area.
- (6) Satellites and radars can play useful roles in fixing the NLM, particularly when the western and eastern disturbances are interlinked.
- (7) Finally the authors wish to state that the dates of onset at a number of stations should be determined in as many individual years as possible and thence the normal dates of onset should be charted and variability figures evaluated for climatological purposes.

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## ON FORECASTING DRY THERMALS FOR GLIDING

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## SUMMARY

Data derived from glider flights over Salisbury Plain indicate that a minimum depth of neutral stability is required before thermals can develop. Simple discriminant analyses of small samples representing days of strong thermals and days of weak thermals show that temperatures at 1000 metres above ground level are particularly important when considering upper-air temperatures in relation to surface temperatures for discriminant purposes. If the difference between the potential temperature at 1000 metres above ground level and the maximum surface potential temperature is  $\geq 3$  K, thermals are unlikely to be weak.

## INTRODUCTION

To remain airborne, the glider is dependent on rising currents of air which develop from time to time in the free atmosphere. These may be divided into two main categories—lee waves and thermals. Although hills are normally a necessity for the formation of lee waves, thermals develop over almost any terrain subject to insolation and it is on these thermals that the pilot normally depends when making cross-country flights. When considering the possibility of a prolonged soaring flight a pilot will ask the forecaster four basic questions about the thermal prospects for the day:

- (a) When will thermals start?
- (b) How long will they last?
- (c) How strong will they be?
- (d) How high will any convection extend?

The problem of the depth of penetration has already been adequately described by Browne *et alii* (1955) and Reid and Wu (1965), but considering that soaring flights have been made in the United Kingdom since 1933 it is surprising that there is little published work to assist the forecaster in answering the remaining questions, and this despite the wealth of descriptive literature, for example Wallington (1961), that has been written.

In an attempt to shed further light on the problem a study has been made of thermals found over Salisbury Plain at various times between 1969 and 1975. A thermal for the purpose of this paper is defined as a rising current of air strong enough to enable a glider to remain airborne. At the thermal's highest point of penetration it may, or may not, be capped by cumulus, but throughout this paper 'thermal' refers to the ascending current or bubble of air beneath cumulus or blue sky. (Thermals uncapped by cumulus are called blue thermals.) Differential surface heating is probably by far the most common method of development of thermals but they can form in other ways. Close to the ground the excess temperature of warm bubbles over that of the environment is about 1 K (Murgatroyd, 1954), but at heights of above 300 m above ground level (agl) this difference is very much smaller, being about 0.2 K according to Goldney (1970) and James (1954).

Thermals are usually only strong and persistent enough from April to September to enable a glider to make a prolonged soaring flight (Wickham, 1966), so this study is restricted to data which have been gathered in these months. Although on occasion the strength of thermals in other months did reach 2 m/s, they tended in general to be weak, with vertical velocities around 1.0 to 1.5 m/s or less.

## DATA

Reports of vertical velocities,  $W$ , found in thermals over Salisbury Plain were obtained from gliders launched by aero-tow at about 600 m above airfield level. Values of  $W$  are measured by the pilot's noting the rate of climb indicated on the glider's variometer. (A variometer in this context is an instrument indicating the rate of climb or descent of a glider.) Although many variometers are limited to a range of reading of  $\pm 5$  m/s (10 kn), recent modifications allow measurements of rates considerably in excess of this. In practice



the simpler type of variometer is adequate for most dry thermals since it is rare for thermals to reach 5 m/s in this country.

All thermals were contacted at heights of 300 m or more agl, not because thermals have to rise to this height before developing enough to enable a glider to remain airborne, but because most of the observations were made from a Blanik two-seater trainer, and at this height the pilot would be concentrating more on landing procedures rather than on searching for thermals. All values of  $W$  referred to throughout this paper are those indicated by the variometer; no correction has been made for the rate of sink, or descent, of the glider. The rates of sink for the gliders themselves vary with the ways in which the gliders are being flown and with the types of glider. For the contemporary gliders used in this investigation the rates of sink would vary a little between 0.5 and 1.0 m/s because of differences in glider performance and by similar amounts because of the ways in which they were being flown, e.g. radius of turn, angle of bank etc. These variations are likely to have had a secondary effect on the recorded values of maximum vertical velocity ( $W_{\max}$ ) on different days (so far as differences in  $W_{\max}$  for weak and for strong thermals are concerned) except for the addition of an approximate constant of about 1 m/s to all the values recorded.

Initially the flights were made from Compton Abbas in Dorset, 245 m above sea level (asl), but in 1973 the club concerned moved to Inkpen, 240 m asl, some 60 km to the north-east. Routine surface observations made at Upavon, 176 m asl and 20 km south-east of Inkpen, were taken to be representative of the area, whilst upper-air observations were usually obtained from Larkhill, 132 m asl (Figure 1). The Larkhill upper-air temperatures were all measured between 05 and 09 GMT but sometimes, because Larkhill soundings were not made, or because appreciable changes were taking place in the upper-air temperatures, reference was made to soundings elsewhere in England in order to estimate upper-air temperatures representative of conditions for the area (before modification by solar heating occurred).

#### METHOD OF ANALYSIS AND DISCUSSION

A thermal has its origins in the surface layers and may be considered as a bubble of air which breaks away from these layers under the action of various forces (Scorer, 1954; Grant, 1965). Since it is warmer than the environment at this stage of its development, and hence less dense, it will continue to rise until it reaches a zone where the density of the environment is less than that of the bubble.

In practice thermals appear to vary considerably in structure and frequency on any one day, so much so that it is not unknown for pilots based at the same airfield to encounter completely different conditions on the same day. This could be due to a number of reasons, not the least being the skill and experience of the individual pilot. In general, pilots are reasonably consistent in their condemnation of a poor day; it is on the better days that their views tend to diverge. For example, on one afternoon five consecutive flights recorded thermal strengths of 1.5, 2.0, 0.0, 2.0 and 1.5 m/s. Most pilots are satisfied if values of  $W$  consistently reach 2–3 m/s and will quite happily report that the day has been a good one for soaring. But some days are even better, with  $W$  reaching maxima of 4–5 m/s.

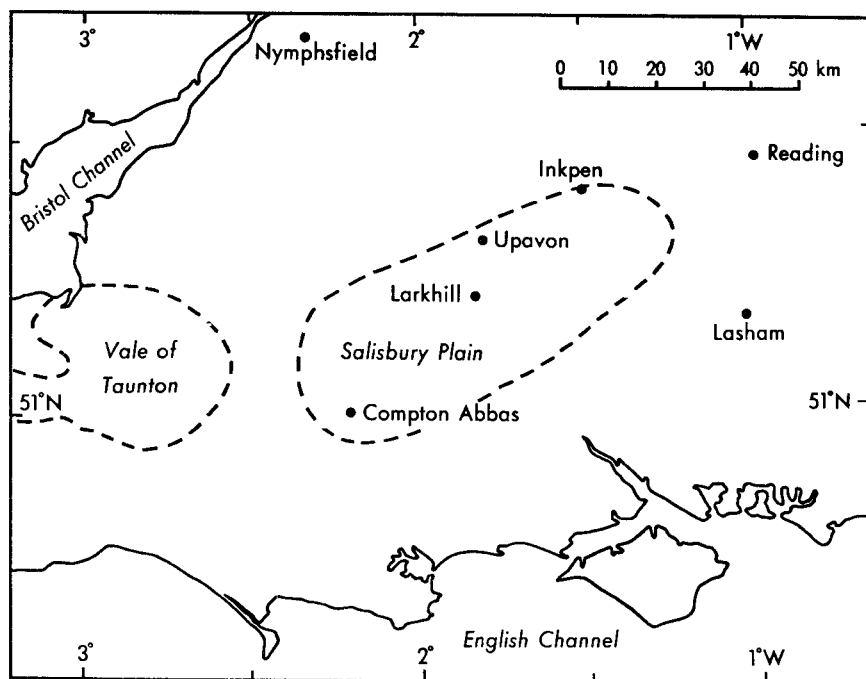


FIGURE 1—LOCATION OF PLACES REFERRED TO IN THE TEXT

Considering all the problems inherent in this type of exercise it was felt that the best approach would be to analyse those days which gave weak thermals, and those which gave strong thermals. Days of weak thermals were defined as those on which all the reported values of  $W$  were  $<1.5$  m/s and launches were made to coincide with the time of maximum temperature; days of strong thermals were days for which one or more of the reported values of  $W$  exceeded 3 m/s\*.

Data on thermal conditions were available for 50 days, 13 being classified as good, 11 as poor and 14 as moderate days. Thermal activity was inhibited on the remaining days by layer cloud. The weather on the majority of days was broadly similar, with early mist or stratus quickly clearing to give clear skies or small amounts of shallow cumulus. Thickening cirrus probably brought thermal activity to a premature halt on three good days. Mean surface winds were never greater than 7 m/s.

One drawback in relying on a limited number of gliders in this type of investigation is that the area to be explored is necessarily limited. Since thermals can be notoriously inconsistent even on good days, it is possible that on some occasions thermal conditions have been underestimated.

\* On one of the days when the maximum reported value of  $W$  ( $W_{\max}$ ) was 3 m/s, evidence became available of stronger thermals at Nymphsfield and Lasham, to the north-west and south-east respectively of Inkpen. Exceptionally therefore this day was also classified as a good day. It may be that other days when  $W_{\max}$  was reported as 3 m/s could also have been associated with larger values elsewhere, but in the absence of positive evidence they were not included in the sample of good days.

# RELATIONSHIP BETWEEN ENVIRONMENTAL TEMPERATURE CURVE AND THERMAL STRENGTHS

On considering the problem from several different angles it became apparent that the basic shape of the temperature profile at dawn between the ground and about 2000 m had a major influence on the eventual value of  $W_{\max}$ .

Strong inversions, subsidence or nocturnal, which affected levels up to about 700 m agl and limited the upward penetration of dry adiabatic lapse rates from surface temperatures during the morning, were characteristic of the representative temperature profile on 10 of the 11 poor days. Subsidence and nocturnal inversions were also present on some of the good days but none of the bases of these subsidence inversions was below 1300 m agl. An attempt to quantify the effects of these inversions on the types of thermal day was made by carrying out a simple discriminant analysis on a parameter  $\delta N_H$  defined as the difference between the potential temperature of the surface night minimum and the potential temperature at a height of  $H$  m agl on the representative sounding. This was done for a selection of values of  $H$ . (In practice this is equivalent to adding  $H/100$  K to the temperature at height  $H$  m agl before subtracting the minimum surface temperature to obtain  $\delta N_H$ .) A measure of the discriminant properties of  $\delta N_H$  for each  $H$  is given by the ratio of the difference in mean values of  $\delta N_H$  for the sample of good days ( $M_{HG}$ ) and for the sample of poor days ( $M_{HP}$ ) divided by the average of the standard deviations ( $\sigma_{HG}$  and  $\sigma_{HP}$ ) of the values of  $\delta N_H$  on the good and the poor days respectively, i.e. by

$$2(M_{HG} - M_{HP})/(\sigma_{HG} + \sigma_{HP}).$$

Results are summarized in Table I, which shows an orderly change of the discriminant ratio with  $H$  and an extreme value for the ratio of 2.3 at  $H = 1000$  m. When used as a discriminant,  $\delta N_{1000}$  allocates days with values above 9.9 K to poor, and those with values below 9.9 K to good, thermal days. On this non-independent sample  $\delta N_{1000}$  incorrectly allocates only one of the 24 days.

TABLE I—DISCRIMINANT MEASURES OF  $\delta N_H$  FOR FIVE VALUES OF  $H$

		$\delta N_{300}$	$\delta N_{750}$	$\delta N_{1000}$	$\delta N_{1500}$	$\delta N_{2000}$	No. of days
Good days							
Mean	(a)	4.81	6.08	6.92	8.92	12.38	13
Standard deviation	(b)	2.31	2.51	2.59	3.33	2.44	13
Poor days							
Mean	(c)	6.27	9.88	11.14	12.91	15.00	11
Standard deviation	(d)	2.94	1.64	1.12	1.95	2.61	11
(a) - (c)		-1.46	-3.80	-4.22	-3.99	-2.62	
(b) + (d)		5.25	4.15	3.71	5.28	5.05	
Ratio $\frac{2\{(a) - (c)\}}{(b) + (d)}$		-0.56	-1.83	-2.27	-1.51	-1.04	

Where

$\delta N_{300} = \theta_{300} - \theta_{\min}$  at 300 m agl etc.

$\theta_{300}$  = the potential temperature on the representative dry-bulb environment curve at 300 m agl.

$\theta_{\min}$  = the potential temperature of the minimum surface temperature.

All values other than ratios and numbers of days are expressed in kelvins.

Although  $\delta N_{1000}$  so far appears to be a promising discriminant, inclusion of data from the 14 moderate days in the analysis showed that this parameter had little power to discriminate between poor and moderate or moderate and good days.

On the available evidence it is difficult to decide at what height an inversion ceases to have any great inhibiting effect on thermal formation. Inversions up to 700 m agl restrict thermal activity to the weak category, whilst an inversion above 1300 m has little restrictive effect on thermals. Limited experience suggests that moderate thermals (1.5–3.0 m/s) can develop even if there is an inversion with a base as low as about 1000–1100 m agl. When the bases of inversions are below this level thermals are usually weak.

Another attempt to quantify the effects of these inversions and temperature profiles was made by carrying out a similar form of discriminant analysis to that described above for  $\delta N_H$  on a parameter  $\delta D_H$ —defined as the difference between the potential temperature of the surface at the time of day-time maximum temperature (actual maxima were used, not forecast maxima) and the potential temperature at height  $H$  m agl on the representative sounding. Results are summarized in Table II.

TABLE II—DISCRIMINANT MEASURES OF  $\delta D_H$  FOR SIX VALUES OF  $H$

	MAX— MIN	$\delta D_{300}$	$\delta D_{750}$	$\delta D_{1000}$	$\delta D_{1500}$	$\delta D_{2000}$	No. of days
Good days							
Mean (a)	11.54	6.73	5.46	4.62	2.54	—0.85	13
Standard deviation (b)	2.39	1.03	0.72	0.68	1.35	1.61	13
Poor days							
Mean (c)	12.36	5.91	2.14	1.23	—0.50	—2.64	11
Standard deviation (d)	1.23	2.52	1.43	0.61	1.60	2.36	11
Ratio $\frac{2\{(a) - (c)\}}{(b) + (d)}$	—0.45	0.46	3.09	5.26	2.06	0.90	

Where

$\delta D_{300} = \theta_{\max} - \theta_{300}$  at 300 m agl etc.

$\theta_{\max}$  = the potential temperature of the maximum surface temperature.

$\theta_{300}$  = the potential temperature on the representative dry-bulb environment curve at 300 m agl.

All values other than ratios and numbers of days are expressed in kelvins.

This also shows an orderly change in the discriminant measuring ratio with  $H$  and a maximum value of 5.3 for the ratio at  $H = 1000$  m agl. This value of 5.3 is quite high, implying that the central values of  $\delta D_{1000}$  for good and for poor days are separated by some 5.3 of their own standard deviation units (i.e. by 2.6 of each of the two individual standard deviation units measuring the scatter of each sample). This shows that the discriminant power of  $\delta D_{1000}$  is substantially better than that of  $\delta N_{1000}$ .  $\delta D_{1000}$  used as a discriminant, between good and poor days only, allocates values above 2.8 K to good days, and values below 2.8 K to poor days. Assuming normal distributions of  $\delta D_{1000}$  for good and for poor days (plots on probability paper confirmed that both sets were well represented by normal distributions) and that the samples are representative, this value of 5.3 for the ratio implies that  $\delta D_{1000}$  would misclassify only about 0.5 per cent of these two populations. On this non-independent sample it achieves complete success in classifying the 24 days.

On the 13 days associated with strong thermals  $\delta D_{1000}$  was at least 3 K whilst on the 11 poor days it was not more than 2 K. However, again only good and poor thermal days have been considered and in practice the performance of  $\delta D_{1000}$  as a discriminant will be degraded because forecast values of the maximum surface temperature will have to be used rather than the actual values used in this investigation.

Indeed the degradation of performance will be quite sensitive to forecast errors of surface maximum temperature because the small values of the standard deviations of  $\delta D_{1000}$  on the two kinds of day contribute materially to the large discriminant ratio.  $\delta D_{1000}$  although apparently far superior in discriminant performance to  $\delta N_{1000}$  is considerably less robust. For example, errors of forecasting maximum temperatures with no bias but a standard deviation of 1 K would increase the standard deviations of  $\delta D_{1000}$  for both good and poor days to 0.2 K (assuming no correlation between the forecast errors and the scatters of  $\delta D_{1000}$ ) and reduce the discriminating ratio to 2.8, implying a misclassification of some 8 per cent of the populations.

Inclusion of  $\delta D_{\pi}$  data for the moderate days at this stage of the analysis showed that  $\delta D_{1000}$  could be used to discriminate between poor and moderate, and moderate and good days, allocating values of  $\delta D_{1000}$  of less than 1.6 K to poor days and greater than 3.7 K to good days. On the non-independent sample  $\delta D_{1000}$  used within these limits gave the results shown in Table III.

TABLE III—RESULTS FOR  $\delta D_{1000}$  USED AS DISCRIMINANT ON THE NON-INDEPENDENT SAMPLE OF 38 DAYS

Observed	Good	Forecast Moderate	Poor	Total	Percentage correct	Percentage correct overall
Good	12	1	0	13	92	} 82
Moderate	1	10	3	14	71	
Poor	0	2	9	11	82	
Total	13	13	12	38		

Any factor reducing  $\delta D_{1000}$  will have an adverse effect on thermal formation. Experience has shown that areas of stratocumulus, medium-level cloud and even thick cirrus can inhibit thermals completely, although these do develop should breaks occur in any of the cloud sheets.

Even vigorous development of cumulus can itself inhibit the formation of thermals, especially when 'overconvection' occurs. ('Overconvection' is a term used in the gliding world to describe the spreading out of cumulus on reaching an inversion layer.) Conversely the lack of cumulus does not necessarily mean an absence of thermals, but merely that the thermal has not reached the condensation level.

Having established that for discriminating between good and poor thermal days 1000 m agl is the best level to use for both  $\delta D_{1000}$  and  $\delta N_{1000}$  and that  $\delta D_{1000}$  is a better discriminant than  $\delta N_{1000}$  it is tempting to produce a linear regression equation which could be used to forecast  $W_{\max}$  from  $\delta D_{1000}$ . For this purpose variations between  $W_{\max}$  on different days are somewhat reduced in value by the uncertainties associated with their determination, that is to say by the effects of variations in the rates of sink of the gliders, by differences in the numbers of observations of  $W$  available on different days from which

to assess  $W_{\max}$ , and by the style of some of the individual reports which were abbreviated to  $W_{\max}$  in excess of some specified integral value of metres per second. Nevertheless values of  $W_{\max}$  were assessed for each day of the sample of 38 days which have been categorized and a linear regression analysis carried out. This gave:

$$W_{\max} = 0.85 \delta D_{1000} + 0.5 \quad \dots \quad (1)$$

This equation had a standard error of estimate of  $W_{\max}$  of 0.8 m/s on the sample whose values range from 0 to 5 m/s for  $W_{\max}$  and 0 to 5.5 K for  $\delta D_{1000}$ . On independent data this performance is likely to be degraded and the performance in practice will also be degraded by the necessity of using forecast values of maximum temperature to obtain  $\delta D_{1000}$ . Assuming root-mean-square errors of 1 K for such forecasts and a degradation of about 25 per cent (of the 0.8) for independent data, a standard error of about 1.3 m/s is indicated for the likely performance of equation (1) in practice.

Independent data for the early part of summer 1975 were subsequently made available by a gliding club based at Upavon. Forecast values of the maximum vertical velocity ( $\hat{W}_{\max}$ ) were obtained by using equation (1) and  $\delta D_{1000}$  for the day in question, and these were compared with reported values of  $W_{\max}$ . This gave root-mean-square errors of 0.8 m/s consisting of a mean error of 0.2 m/s ( $W_{\max} > \hat{W}_{\max}$ ) with a standard deviation of 0.8 m/s.

#### THE EFFECT OF ADVECTION

When assessing the likelihood of thermals an important point to be considered is how warm or cold advection will affect the existing air mass. Thus warm advection or subsidence will tend to inhibit thermals as the potential temperature at 1000 m agl increases, whilst cold advection enhances conditions. (German forecasters stress this aspect of thermal formation — T.A.M. Bradbury in a private communication.)

As examples, 14 and 15 August 1973 were two of the hottest days of the year with maximum surface temperatures around 29 °C. Despite this, thermals on both days were reported as weak; in fact the Inkpen-based gliders found no thermals at all on the 15th. The synoptic situation was typical of the type which produces high surface temperatures in summer with an east-south-easterly surface flow being maintained by a thundery low over France. The 09 GMT Larkhill ascent on the 15th (Figure 2) is representative of both days.  $\delta D_{1000}$  values were 1.5 K for the 14th and 2 K for the 15th, whilst  $\delta N_{1000}$  values were 11 K and 12 K respectively. On both days the development of the dry adiabatic to any great height was limited until after midday at which time the inversion near 700 m agl was broken. These are rather surprising results. Consideration of the environment curves in relation to dry adiabatics from surface temperatures would lead many forecasters to expect quite good thermals to develop in the afternoons after the inversions were broken. However, on both days gliding attempts were continued well into the afternoon without any good thermals being found. These were not circumstances when poor gliding conditions in the morning resulted in the cessation of observations by midday.

By way of contrast thermal conditions on 1 June 1973 were good, with many strong thermals. A cold front had crossed the country the previous night and the following ridge maintained north-north-westerly surface winds

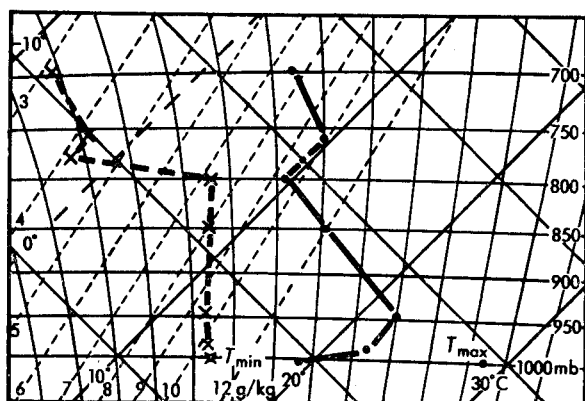


FIGURE 2—LARKHILL RADIOSONDE ASCENT FOR 09 GMT, 15 AUGUST 1973

· — · dry-bulb temperature X — — X dew-point temperature

of 5 m/s. The air was unstable to about 1500 m and dry, so only small amounts of cumulus developed. Because the cold front crossed the country late in the night the nocturnal surface inversion was very small, and easily destroyed as the temperature rose during the morning (Figure 3). At the same time cold air was flooding across the country, as the change in the Larkhill ascent shows (Figure 3). Here was a classic situation for strong thermals with dry air, rather limited instability, increasing surface temperature and cold advection aloft.  $\delta D_{1000}$  and  $\delta N_{1000}$  were both assessed as 5 K.

As a further step in the investigation, the heights to which dry adiabatics from the maximum surface temperatures could reach before intersecting the environment curves were also subjected to discriminant analysis. Results are shown in Table IV.

TABLE IV—DISCRIMINANT PROPERTIES OF  $h$  (HEIGHT IN METRES TO WHICH A DRY ADIABATIC LAPSE RATE FROM THE SURFACE MAXIMUM TEMPERATURE COULD RISE BEFORE INTERSECTING THE ENVIRONMENT CURVE)

	Mean	Standard deviation	No. of days
Good days	1840	270	13
Moderate days	1590	350	14
Poor days	1330	400	11
Discriminant ratios: Poor-Good		1.5	
Poor-Moderate		0.7	
Moderate-Good		0.8	

Considering just the poor and good days the value of 1.5 for the discriminant ratio is ill-established, quite poor, and implies (assuming normal distribution etc.) that some 23 per cent of the populations would be misclassified. In fact 3 of the 13 good days and 2 of the 11 poor days of this non-independent sample are incorrectly placed by  $h$  in the other category.

Sutton (1948) has shown that the greater the height to which a thermal can penetrate the stronger is  $W$ . More recently Lindsay (1970), in a study of glider flights made in the United States of America, found a convenient



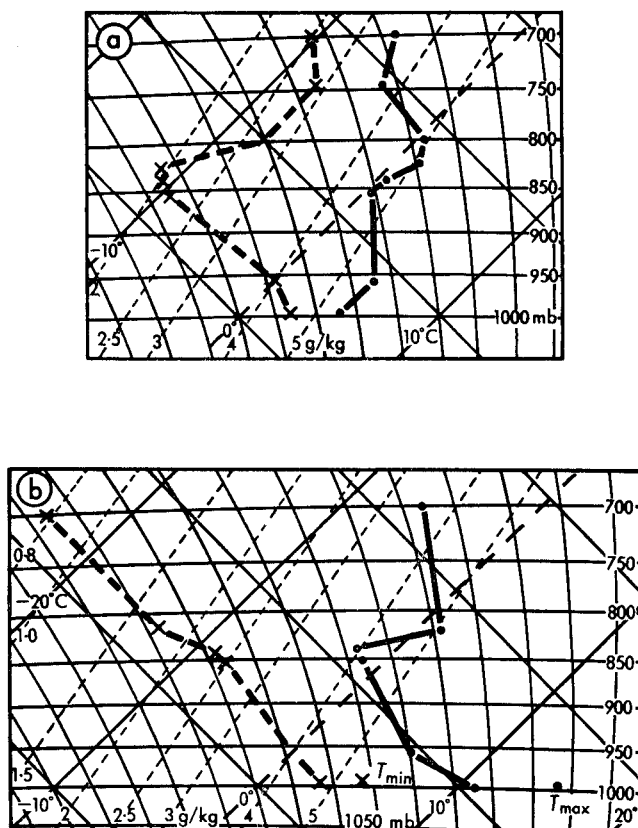


FIGURE 3—LARKHILL RADIOSONDE ASCENTS ON 1 JUNE 1973

(a) 05 GMT before cold advection

(b) 09 GMT after cold advection

· — · — · dry-bulb temperature X — — X dew-point temperature

relationship to exist between  $W_{max}$  and the vertical extent of dry adiabatic (or neutral) conditions, but his findings are not entirely consistent with observations of thermals over southern England, the greatest difference being that the maximum vertical velocities found in this country appear to be much stronger than those discussed by Lindsay. Why this is so is hard to explain, but possibly the poor performance of the American glider has some bearing on the difference. For example according to Lindsay's data extension of neutral conditions up to 2000 m would be associated with thermals of 2 m/s, whereas over southern England this kind of situation produced thermals of 4–5 m/s.

Lindsay's data, which appear on his published graph relating to  $W_{max}$  and the height to which dry adiabatic conditions extend, were also subjected to discriminant analysis for subsamples of good and poor days (Lindsay's  $W_{max}$  of  $\geq 2.5$  m/s and  $\leq 1.5$  m/s were used to define subsamples of 10 good and 8 poor events respectively). This gave a discriminant ratio of 1.9, rather better



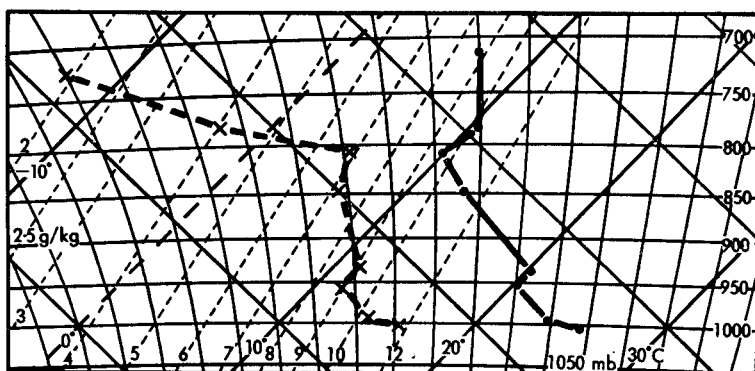


FIGURE 5—CRAWLEY RADIOSONDE ASCENT FOR 12 GMT, 15 AUGUST 1973

· — · dry-bulb temperature X — — X dew-point temperature

agl before modification by solar heating have a special significance from the point of view of the formation of thermals. Perhaps this is associated with some characteristic depth of the atmosphere necessary for strong thermals to be able to form. It may be relevant that Pearson and McGregor (1976) by use of a numerical model have shown that for convection in a neutral environment a lid to the top of the boundary layer will influence the upward velocity of a temperature perturbation well before it reaches the level of the lid. It may also be relevant that in Johnston's (1958) method for forecasting temperature rise, the thickness of a layer which is changed from an isothermal to a dry adiabatic state by maximum insolation over southern England is about 1000 m from April to September.

#### COMMENCEMENT AND CESSATION OF THERMAL ACTIVITY

As would be expected from previous discussion thermal activity started earliest on unstable days at various times between 0900 and 1030 GMT, with one exception, and persisted until between 16 and 18 GMT. On poor days thermals started after 12 GMT and, again with one exception, ceased by 1630 GMT. Since gliders were not usually airborne until mid-morning it is possible that thermal activity could have started earlier than the times reported. On the basis of the information available, thermals only became strong and frequent enough to enable a glider to remain airborne on an unstable day if dry adiabatic conditions extended up to at least 800 m. That thermals do develop with a shallower adiabatic layer is evidenced by the weakness of the thermals that develop on stable days. Even so the dry adiabatic had to penetrate to at least 500 m, and on most occasions 600 m, and be associated with the breakdown of the inversion before sufficiently strong thermals developed to permit gliding. Once thermals had formed they were usable at heights below 800 m agl; in fact experienced glider pilots claim to have contacted thermals as low as 100–150 m agl although at this level they are very weak.

The early cessation of thermals on stable days was not entirely unexpected. On average the diurnal air temperature change is at a maximum at the surface and decreases with altitude (Johnson, 1929). There is also a small lag effect so maximum air temperatures tend to occur slightly later as higher and higher

levels are considered. This effectively creates the beginnings of a nocturnal inversion and is the mechanism whereby thermals begin to become less frequent. The weaker the thermals are at the time of their maximum development the earlier they cease.

In favourable conditions in high summer isolated thermals have been found over southern England as late as 19 GMT, but in most cases the main period of activity can be considered to have ceased by 18 GMT.

A mechanism which destroys thermals is the influx of sea air behind the sea-breeze front. In the sea-breeze circulation  $\delta D_{1000}$  is reduced as relatively cold sea-air can eventually reach a depth of some 700–800 m near the coast; a similar depth to that of the inhibiting subsidence inversion (McCaffery, 1966). Following the onset of the sea-breeze the air near the coast is constantly replenished by the cool sea-air, thus restricting any further temperature rise (Watts, 1955). This cooling effect of the sea-air diminishes inland, but even so aircraft observations across a sea-breeze front between Lasham and Reading have shown a potential temperature difference of 1.5 K across the front (Simpson—private communication). Because the sea-air arrives at inland areas near maximum temperature it accelerates the process which reduces thermal activity. It is believed that thermals useful for gliding do not usually develop in the sea-breeze air.

#### STUBBLE FIRES

During the latter part of summer stubble fires are a source of strong thermals, even when thermals formed naturally are very weak. Vertical velocities in these thermals can be very high and have been known to exceed 10 m/s (Lever—private communication).

#### ADDITIONAL COMMENT

The flights discussed in this paper were made over some excellent soaring country. Owing to the nature of the terrain other areas are notoriously poor for thermals, for example the poorly drained rather flat Vale of Taunton, and even on the best days activity over such terrain will be relatively weak.

#### CONCLUSION

It could be argued that the sample used in this investigation is too small to be used to formulate any hard and fast rules for forecasting thermals. Nevertheless the results are consistent in themselves and agree with the general impression gained from descriptive literature. The performance of equation (1) on the independent data is especially encouraging. Thus, broadly speaking, thermals will start as the adiabat approaches 800 m agl, but if this depth of penetration is limited until midday or later thermals will be weak. If  $\delta D_{1000}$  exceeds 3 K then it is unlikely to be a poor day for gliding. Obviously each case should be given careful consideration and special thought given to the effects of advection and any element which inhibits any temperature rise.

In practice pilots are usually content with a statement that thermals will be weak ( $>0$ ,  $<1.5$  m/s), moderate ( $\geq 1.5$ ,  $\leq 3$  m/s) or strong ( $>3$  m/s). Sensible use of  $\delta D_{1000}$ ,  $h$  and Figure 4 aided by equation (1) should enable such forecasts to be made on a sound basis.

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I would like to thank my colleagues at Upavon for the helpful suggestions they have made during discussion on this subject, and Mr C. L. Hawson of Meteorological Office Headquarters, Bracknell for his guidance, particularly with the statistics. Especially I would like to thank Mr P. Cottrell and his associates at Inkpen for their infinite patience, and all those who have been good enough to write to me privately.

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**REPORT ON THE SUMMER SCHOOL IN SATELLITE  
METEOROLOGY HELD IN ALPBACH, AUSTRIA  
FROM 3 TO 12 AUGUST 1977**

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**1. INTRODUCTION**

The summer school was initiated and co-ordinated by the Austrian Solar and Space Agency (ASSA) and other bodies involved in its organization and sponsorship were CNES\* (France), DFVLR (Germany), ESA, NTNF (Norway), SBSA (Sweden) and SNG (Switzerland). The summer school was one of a series on various aspects of space science—in 1978, for example, there is to be one on Spacelab. This probably explains why the sponsoring bodies were all space research organizations rather than meteorological services or research organizations. However, both the lecturers and the students came from a wide variety of institutions and represented a broad spectrum of interests—there were two oceanographers, for example. Nationally, German-speaking (i.e. including Austrian) numbers exceeded the rest, and although I was the only representative of a British organization others whose native tongue was English were a Canadian working for a NATO oceanographic research establishment in Italy, a representative of the UK branch of the office of US Naval Research, and John Morgan of the European Space Agency who until recently was a member of the Meteorological Office.

The subjects lectured on and studied in workshops (perhaps 'practicals' would be a better word to use) could be broadly split up into four categories: the present observational system, the usefulness of satellite observations and the First GARP Global Experiment (FGGE); software and hardware necessary for processing satellite data; interpretation of satellite imagery; and remote sounding of the atmosphere. These are the subjects of the four following sections; a fifth is given over to impressions.

One lecture which did not fall into any of the above categories was given by D. Nikoden (ECON, New Jersey, USA) on the economic benefit of improved meteorological forecasts to the Florida citrus industry. Attempts to estimate economic benefits of weather forecasts are numerous but I have not heard of other assessments of the effects of improved forecasts. The experiment is in progress, the 'control' trials utilizing the relatively poor forecast having taken place in the winter of 1976/77 and the trials utilizing what it is hoped will be improved forecasts being intended to take place in the following two winters. (The improvements will be partly due to the employment of satellite data, apparently by using window-channel infra-red data to estimate land-surface temperatures.) There are all sorts of problems with this kind of study—for example, if it is announced that there has been a widespread severe frost the market price of citrus fruit increases and if the frost is not as severe as had been announced then clearly the growers have benefited although it is not clear whether there has been an overall economic benefit. It appeared

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\* See the Appendix for an explanation of these and subsequent sets of initials.

that the improved forecast would be accompanied by improved publicity—for example, satellite-derived actual surface temperatures would be shown on television weather forecasts—and it would be difficult to decide whether the economic benefits were due to the improved forecast rather than to the improved publicity. Nevertheless it was interesting and encouraging that such a study was being attempted, even if the only outcome was the knowledge necessary to carry out an improved study in the future.

## 2. THE USEFULNESS OF SATELLITE DATA IN THE PRESENT OBSERVING SYSTEM

B. Bolin (University of Stockholm) gave two lectures which discussed the data requirements of numerical general-circulation and climatic models. Ideas such as predictability, and experiments to simulate observing systems were described and emphasis was placed on measurements which were not needed for operational forecasts but which were needed for climatic studies such as cloudiness, radiation balance, and amounts of trace gases.

A. Piaget (Swiss Meteorological Institute, Zurich) gave a talk on the data requirements for synoptic and numerical forecasting in which it was stressed that appropriate interpretative techniques should be devised to make the best use of satellite data.

P. Morel (CNES, France) talked about the use of satellites for tracking drifting sensors in the atmosphere and ocean, and the use to which the data from such experiments have been put.

I. Haupt (Free University of Berlin) reviewed the operational satellites flown in polar orbits, with emphasis on the present NOAA series, and also discussed the instruments to be flown on the TIROS-N series.

D. Lennertz (ESA, Toulouse) introduced METEOSAT and explained its history and T. Mohr (Deutscher Wetterdienst) explained the role of geostationary satellites in FGGE, giving a brief survey of the evolution of the latter.

## 3. DESCRIPTION OF HARDWARE AND AUTOMATIC DATA PROCESSING

C. Honvault and J. Antikidis (both from ESA, Toulouse) described in some detail the METEOSAT system and the processing of image data once they had reached the ground.

P. Bernadet and M. Taillade (CNES, France) described the ARGOS system, which will be on board the TIROS-N series of satellites, for locating and collecting observations from drifting sensors (buoys and balloons).

K. Zimmermann (Central Office for Meteorology and Geodynamics, Vienna) spoke on the subject of reception and storage of image data, his talk being a fairly general one, with reference to particular satellites only by way of illustration.

J. Gredel and W. Ratten (DFVLR) described the system being developed at Oberpfaffenhofen to process geostationary satellite imagery interactively—to give the user the option of examining any subset of a sequence of images on a user-specified scale, both spatial and temporal. (The system would operate using archive tapes for the case being studied, these tapes having been obtained by the user from ESA.)

K. Richter (Technical University of Graz) spoke on the subject of satellite instrumentation, giving a historical review before talking in some detail about the instruments to be flown on NIMBUS G.



P. Louis (ESA, Toulouse) gave a review of ESA studies for future meteorological satellites. A few eyebrows were raised at the estimated cost of such systems, even though the cost was less than that of METEOSAT.

#### 4. IMAGE INTERPRETATION

M. Debois (Dynamical Meteorology Laboratory, Palaiseau) spoke in general terms about methods of extracting winds from satellite images, describing in more detail the optical methods used at his establishment.

F. Cayla and L. Fusco (ESA, Darmstadt) described the method to be used by MIEC for METEOSAT data, including the preliminary fully automatic processing of arrays of pixels\* to determine the general properties of the cloud field in view. Workshop 5 was devoted to an attempt to extract winds manually from a sequence of cloud images, and a discussion of the problems involved, for example the representativeness of cloud motions of the wind field.

I. Haupt (Free University of Berlin) talked on her group's work which uses images in the visible spectrum to map the changes in sea-ice distribution in the North Atlantic and in neighbouring sea areas. Her attempts to correlate sea-ice distribution with synoptic features were regarded somewhat sceptically but undoubtedly the analysis of sea-ice distribution had been very thorough.

H. Rott (University of Innsbruck) spoke on the use of LANDSAT and VHR data for determining snow cover in the Alpine regions. This is a subject of great importance for the Austrians and there was a reasonable correlation between snow cover, as determined from cloud photographs, and spring-time melt runoff. Workshop 3 was given over to this subject—techniques for assessing snow-lines are fairly subjective so this was a useful introduction to the problem. In the Alps it is necessary to know the height of the ground above sea level before one can relate images with large zenith angles to their true position on the earth's surface—this was not a problem that I had encountered before!

V. Meise (Central Office for Meteorology and Geodynamics, Vienna) gave a most illuminating lecture on the application of satellite images to synoptic weather forecasting. Several cases were presented comparing, for example, cloud photographs with charts of 1000–500 mb thermal vorticity, there being marked correlation for this particular case. This theme was the subject of Workshop 2 in which the relationship between cloud photographs and synoptic features was stressed.

G. Warnecke (Free University of Berlin) demonstrated motion pictures made from satellite images. These illustrated the point that there is a danger of trying to use too much data—the most informative movie-loops comprised a sequence of perhaps three or four images each of which was a relatively small segment from the full earth disc. Some cases were shown in which the time sequence was run backwards so that, for example, a readily identifiable fully developed mid-latitude depression could be traced back to a stage where it was less easy to recognize but important to pick out for forecasting purposes.

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\* The smallest resolvable element of an automatically processed image has come to be known as a 'pixel'.

## 5. INTERPRETATION OF SOUNDING DATA

E. Raschke (University of Cologne) spoke on the subject of the determination of local and global energy budgets from satellite measurements. A major problem was how to get a representative sample, in both space and time, and satellite orbits with fairly low angles of inclination ( $50^\circ$  for example) were suggested for coverage of the tropics.

H. Bolle (University of Innsbruck) spoke about the radiative transfer equation and the determination of atmospheric transmission functions. One aspect covered in some detail was the use of empirical formulae to describe the variation of transmission with pressure, temperature and amount of absorber. Workshop 6, organized by Bolle, looked at the topic of retrieving cloud top and surface temperatures from window-channel infra-red radiance measurements, in which the parametrization of the atmospheric contribution is a major problem.

H. Fischer (University of Munich) spoke on the problems of retrieving temperature profiles and non-uniform absorber amounts from infra-red radiances. This was mostly fairly familiar, although ozone profiles from satellite measurements were relatively new to me. In Workshop 1, organized by Fischer, we used Chahine's relaxation method to retrieve a temperature profile from radiance measurements; this was instructive for me as not only had I never used Chahine's method (it being considered more or less obsolete nowadays) but also I had never done a retrieval by hand, and it was interesting actually to handle the numbers involved.

K. Kuenzi (University of Berne) talked about the problems of sensing atmospheric liquid-water and water-vapour content using passive microwave sensors. Two wavelengths, both responding to both liquid and gaseous water content, but in different proportions, were used. However, the emissivity of the sea surface is variable and it was considered necessary to know either the sea state or the water content of the atmosphere, and to use the microwave measurements to determine the other variable. Note, though, that microwave water-vapour sensors respond to total optical depth of water vapour whereas infra-red channels respond to distribution of water vapour.

P. Kopke (University of Munich) talked on the use of satellite measurements to determine the optical depth of atmospheric aerosols. The solar radiation scattered back to the satellite is a function of many other atmospheric parameters besides the optical depth and the choice of atmospheric conditions optimal for measurements and the best wavelength to use were discussed.

W. Ranger (DFVLR, Oberpfaffenhofen) spoke on the subject of a Spacelab-borne Lidar for atmospheric physics. In a sense all that he said was 'this is a Lidar and this is a Spacelab and we fly one on the other', the advantages and problems of flying instruments on satellites rather than operating them from the ground being fairly obvious. Workshop 4 was on the subject of the use of Lidar and acoustic sounder (Sodar) (ground-based) and was slightly disappointing, partly because the weather situation did not provide any particularly interesting applications for the experiments (for instance there was no inversion which we could try to detect with the Sodar).

## 6. IMPRESSIONS AND COMMENTS

I had expected that a European summer school held in the year of the launch of Europe's first meteorological satellite might have been dominated by

METEOSAT topics, but this was not the case, partly no doubt because Austria is not participating in the ESA METEOSAT program. Nevertheless it was useful to hear from the ESA contingent exactly how they intended to extract from the imagery the various parameters that they intend to transmit to users. Bearing in mind the cost of METEOSAT, and the effort that is being put into the processing of its data, it is to be hoped that potential users show patience and tolerance towards what is basically a new observational device in the hands of relatively inexperienced operators.

Naturally it was disappointing to me that relatively little work is being done by those European institutions represented at Alpbach in the field in which the High Atmosphere Branch of the Meteorological Office is involved, namely the retrieval of atmospheric parameters from infra-red and microwave sounding data. Nevertheless it was interesting to see what information people were managing to extract from satellite images—visible, infra-red and microwave; it is suggestive that this is an area in which the Office lags behind Europe, or at least behind those countries represented at Alpbach.

Although there was relatively little research overlap between myself and the other students on the course it was interesting to discuss with them the set-ups of their own institutions. It was also interesting to see how other institutions engaged both in research and in forecasting (of which there were few) attempted to integrate them; for example, one Swede I spoke to spent three days a week doing research and two days on the bench.

#### APPENDIX

CNES	= Centre National des Études Spatiales = National Centre for Space Studies
DFVLR	= Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt = German Aerospace Research and Testing Institute
ESA	= European Space Agency
GARP	= Global Atmospheric Research Program
METEOSAT	= (European) Meteorological Satellite
NATO	= North Atlantic Treaty Organization
NTNF	= Norges Teknisk-Naturvitenskapelige Forskningsråd = Royal Norwegian Council for Scientific and Industrial Research
SBSA	= Swedish Board for Space Activities
SNG	= Schweizerische Naturforschende Gesellschaft = Swiss Scientific Research Society
VHRR	= Very High Resolution Radiometer

#### REVIEW

*The ocean-atmosphere system*, by A. H. Perry and J. M. Walker, 245 mm × 190 mm, pp. xi + 160, *illus.*, Longman Group, London, 1977. Price £5.50 (paperback).

This is one of the few books to deal with atmospheric and ocean systems together, with the emphasis on their interaction and interdependence. It is intended as a text for second and third year undergraduates in geography, geophysics, and environmental science, for marine biology courses and nautical and maritime studies, as well as being a reference book for research workers in the field.

The introductory chapter on the nature and characteristics of the ocean-atmosphere system includes an interesting historical background. In Chapter 2, called 'Ocean Macro Circulations', the general circulation of the atmosphere is first outlined. The causes of ocean currents are then discussed. The circulation of the Indian Ocean is described in detail, including its response to the reversal of the prevailing surface winds during the Asian Monsoon. Some theoretical aspects of the Gulf Stream are presented. Other topics include the extension of the Gulf Stream and its effect on our climate, the Arctic and Southern Oceans, the formation of bottom water, deep-water circulations and the importance of the thermohaline circulation.

Waves, swell, drift currents and storm surges are among the topics treated under 'The action of wind on sea'. The characteristics of waves are explained using simple formulae, although more complex treatments are referred to. Ekman theory is used to explain the phenomenon of upwelling. Chapter 4 is concerned with ocean-atmosphere heat exchange. The budgets of heat and radiant energy are discussed in detail, with reference to the general circulation. Transfer of heat to the atmospheric boundary layer is examined, then convection on various scales, along with a miscellany of subjects such as sea fog and the formation of sea ice.

In Chapter 5, entitled 'Thermal behaviour of the ocean atmosphere and climatic responses', sea surface temperatures and their variations are discussed. The persistence of sea surface temperature anomalies and their effect on the atmosphere, together with more complex coupled air-sea systems, are reviewed. Finally there is an outline of the possible contribution of ocean-atmosphere interaction to climate changes. The last chapter contains a useful summary of various international research projects and their aims, followed by a very brief section on some advanced numerical climate models.

The book is clearly set out, and follows a logical overall pattern. It is more a review than a textbook, the authors quoting extensively from the literature. The subject matter on the whole is well chosen, comprehensive and up to date. Observational rather than theoretical studies are emphasized. Mathematics, where included, has been reduced to a minimum by quoting the relevant formulae and referring the reader to appropriate sources for the derivation. Almost all the figures are taken or adapted from original papers, greatly enhancing the book's value as a work of reference. However, a few diagrams are not quite in tune with the text, or have inadequate captions.

The book fulfils its aim as a text for undergraduates, being much more than an elementary introduction, yet not requiring an extensive background in mathematics or fluid mechanics. There are more than 500 references, about half of which were published during the last decade, and they include many review papers. Thus the book may also prove useful to research workers, even though there is a very sparse coverage of numerical modelling.

J. F. B. MITCHELL

### THE AKROTIRI TRAGEDY

At 0630 Cyprus time on 7 December 1977 a U2 aircraft of the United States Air Force, monitoring the Arab/Israeli ceasefire in Sinai, crashed on take-off at Akrotiri, destroying the Main Meteorological Office and the RAF operations Centre. The total of five who were killed immediately all died in or near the the meteorological office; they were locally employed meteorological assistants (Mr A. Televantos and Mr C. Hanni), a radio operator (Mr P. Gostinian), the office cleaner (Mr A. Tanayia) and the United States pilot of the aircraft. Mr J. A. Flawn, Senior Scientific Officer, who was the duty forecaster at the time of the accident, was severely burned and died from his injuries thirty-six hours later. Two other radio operators in the Meteorological Communications Centre (Mr M. Michaelides and M. A. Passades) received serious burns and Mr Michaelides has since been transferred to the Princess Mary's Hospital at RAF Halton. The RAF authorities arranged for Mrs Michaelides to stay at Halton with her husband.

A fund was established for the dependants of the locally entered staff involved in the accident and by the end of the year the response from the Office had resulted in the collection of over £1550, illustrating the strength of the special relationship which has been established over the years between United Kingdom and Cypriot staff. The fund is being administered by a small committee in Cyprus. Separate consideration is being given to an appropriate memorial for Mr Flawn. It is thought that the Akrotiri accident is the first to involve loss of life on duty, outside the Second World War, since Mr M. A. Giblett, Superintendent of the Airship Services Division of the Office, was killed in the R101 accident near Beauvais in France on 5 October 1930.

Mr Flawn's funeral, attended by many of his friends and colleagues, was held at New Quay, Dyfed, on 17 December 1977. Mr F. H. Bushby, DD Met O(F) represented the Director-General.

The Commander of the Royal Air Force Element in Cyprus wrote to the Director-General soon after the accident noting the outstanding way in which Mr F. P. Sims, Principal Meteorological Officer at Akrotiri, and his staff had dealt with the many personal and operational problems which were produced.

The Director-General had written immediately following the accident to the families of all the bereaved. The Air Attaché from the United States Embassy in London visited Mrs Flawn in New Quay and Mrs Michaelides at Halton shortly before Christmas to express personally the sympathy of the United States Government.

The site of the Akrotiri office is being completely cleared and a new Main Meteorological Office is to be established nearby as an integral part of the RAF Operations Centre.





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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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