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The development of hailstorms along the south coast of England on 5 June 1983

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Summary

Hailstorms developed rapidly along the south coast of England during the late morning of 5 June 1983. They occurred on the cold side of a narrow baroclinic zone and just ahead of a rather shallow middle-level trough. Although these synoptic features were moving eastwards, satellite and radar evidence indicates that all the storms originated close to the south coast of Devon over a period of three hours, suggesting that some form of localized forcing was occurring in this region.

1. Introduction

During the night and early morning of 5 June 1983, large areas of medium-level cloud covered most of southern England and northern France. Within this cloudy area there existed several bands of thundery rain. At 0600 GMT the main areas of thunder were over the extreme south-east of England and north-east France. By 1200 GMT, however, reports of large hailstones were being received from places close to the Dorset and Hampshire coasts. The radar data from Camborne and Clee Hill show that several distinct thunderstorms with intense cores were moving east-north-eastwards along the south coast of England, with less heavy rain extending for nearly 100 km north-westwards from each of these centres (Fig. 1). The reader may wish to compare this figure with the NOAA-7 satellite image shown in a brief article on these storms by Wells (1983), which shows the same five storms just over two hours later.

This paper first describes the upper-air conditions at the time when the storms developed. Then the positions at which the storms were first observed are related to the cloud structure observed by satellite. Maps show the location of the growing cells and the tracks of the storms while they were within radar coverage. The formation of rainbands to the north-west of each storm is illustrated in section 7, followed by an account of the wind and pressure fluctuations associated with the passage of each storm across a station close to the centres. After showing the total rainfall attributable to the storms, possible reasons for the rapid development are discussed.

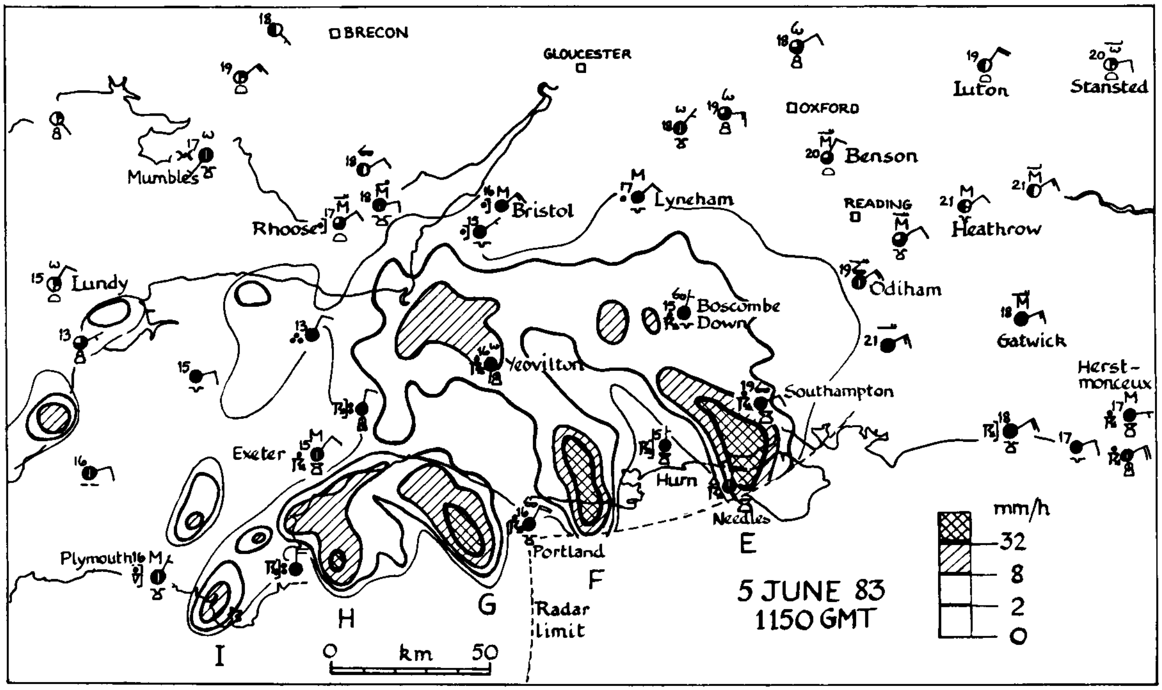

Figure 1. Location of the five main storms over southern England at 1150 GMT on 5 June 1983. Rainfall rates are derived from radar measurements.

2. Surface and upper-air patterns on 5 June 1983

(a) *Surface and 500 mb analyses*

During the night of 4/5 June, a broad band of thundery rain extended across north-west Europe from west of Portugal to north Germany. These thundery areas were not related closely to any surface pressure features; indeed the surface analysis at 1200 GMT on the 4th (Fig. 2) shows high pressure from southern England to central Europe. An anticyclone to the west of the British Isles built across Scotland during the night as a depression over the North Sea moved eastwards, while pressure remained relatively low over Spain and western France. These pressure changes caused the surface wind over southern England and the English Channel to freshen from the east early on the 5th. Surface temperatures over most of continental Europe had been much higher than those over the British Isles on the 4th (mostly 28 °C to 32 °C over France and eastern Spain at 1500 GMT but only 15 °C to 20 °C over Britain) and this contrast was repeated on the 5th. Although the north coast of Spain was cool also, the Corunna ascent showed warm air above 950 mb with wet-bulb potential temperature of about 18 °C. HERMES temperature data (a satellite-sounding technique described by Eyre and Jerrett (1982)) confirm that the warm air over France extended westwards across Biscay. The warm front shown in Fig. 2 corresponds approximately to the northern boundary of this warm air and to the southern boundary of the thundery rain.

The rain was caused by ascent in a baroclinic zone at middle and upper levels. This zone, comprising a broad band of strong south-westerly winds, lay to the south-east of an upper trough which was moving slowly south-eastwards across the British Isles. Both features are evident in Fig. 3 which shows the

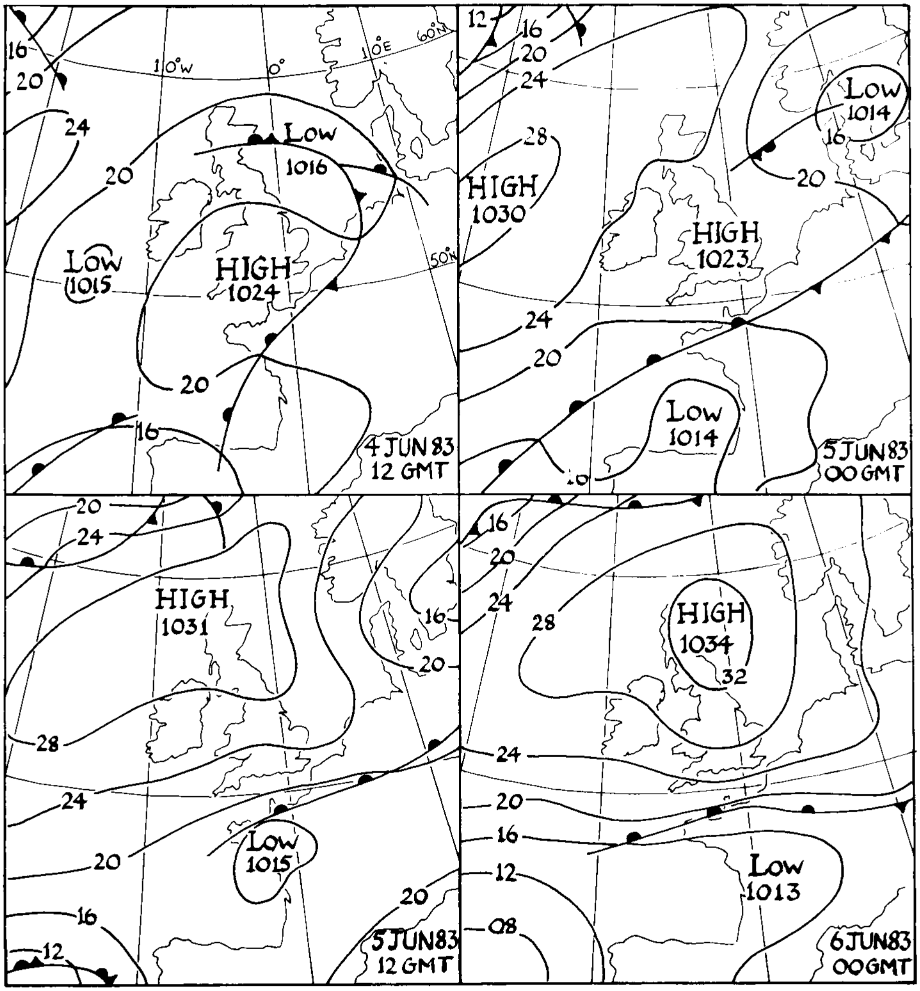

Figure 2. Surface analyses at 12-hour intervals from 1200 GMT on 4 June to 0000 GMT on 6 June 1983.

500 mb contours and 1000–500 mb thickness analyses at 12-hour intervals from 1200 GMT on the 4th to 0000 GMT on the 6th. On the 4th, the trough extended from the Norwegian Sea, where it was broad and fairly fast-moving, to the west of Ireland, where it was sharper and moving only slowly. The analyses show that the southern end of the trough became detached as it crossed Ireland. This portion of the trough can be regarded as a separate feature after 0000 GMT on the 5th; it was also rather shallow, being most evident between 600 and 400 mb. The sequence of analyses shows also that the previously broad and extensive baroclinic zone weakened from the south-west during the night and morning of the 5th as warming occurred to the north-east of a depression over sea area Finisterre; it also veered slightly as a result of cold advection to the east of the British Isles. By the morning of the 5th, the entrance to the baroclinic zone was just west of the English Channel.

There is a difference between the 1000–500 mb thickness analysis for 0000 GMT on the 5th shown in Fig. 3 and the analysis issued by the Central Forecasting Office at Bracknell a few hours later. The

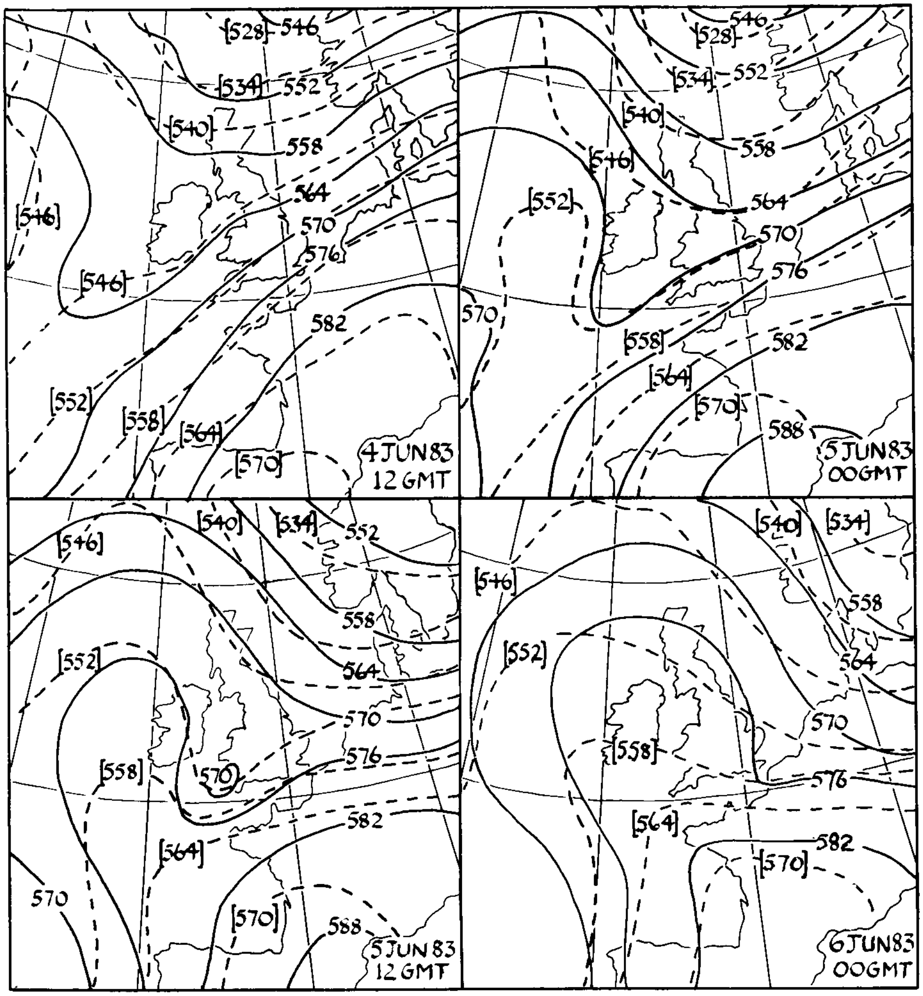

Figure 3. 500 mb contours (continuous curves) and 1000–500 mb thickness (broken curves) at 12-hour intervals from 1200 GMT on 4 June to 0000 GMT on 6 June 1983.

operational analysis does not fit the strong northerly thermal wind implied by the upper winds at Valentia. By accepting these winds as correct, we obtain a sharper trough to the south of Ireland and a thermal ridge to the west, both of which are more consistent with the analysis of the data at 1200 GMT on the 5th.

The Camborne ascent for 1200 GMT on the 5th (Fig. 4) shows that the trough was crossing Cornwall at this time: the wind was still over 50 kn but had veered to 280°. During this ascent, however, the dry-bulb appears to have responded as a wet-bulb element at 730 mb. By comparing HERMES data with radiosonde ascents, it seems likely that the temperature at 700 mb near Camborne should have been at least 0 °C instead of −5 °C. Assuming that the actual temperature profile was similar to the revised curve

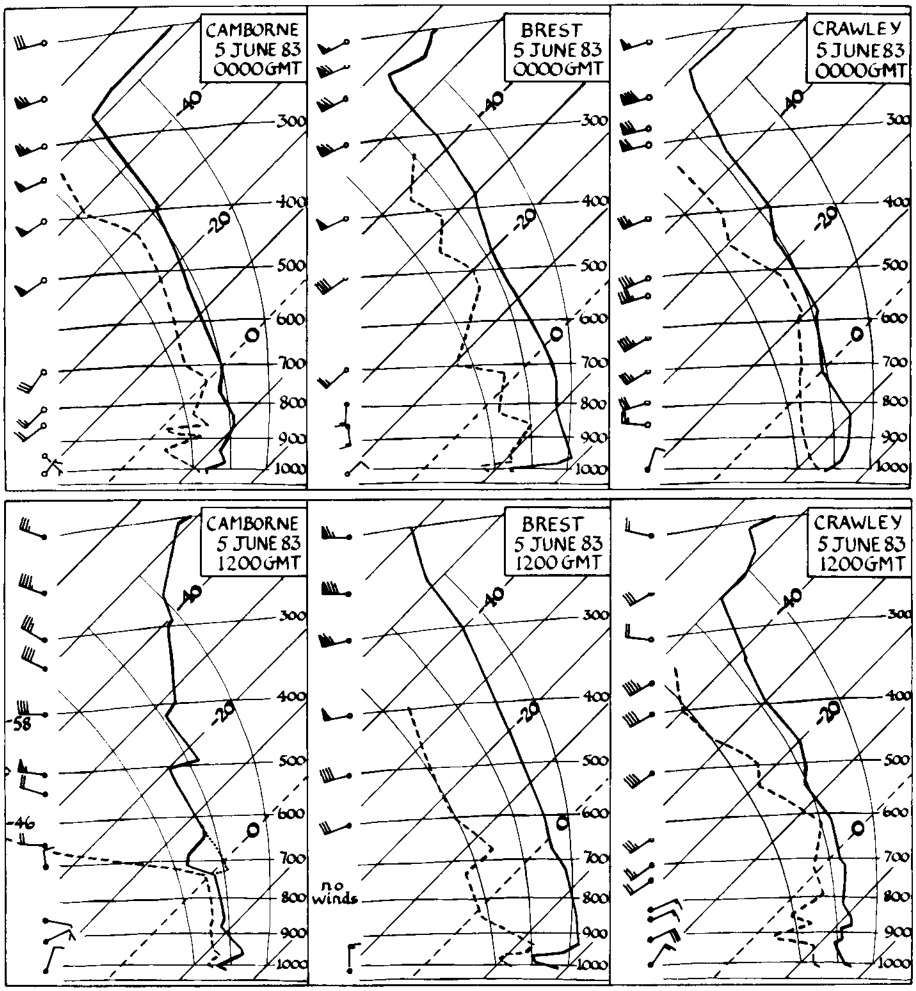

Figure 4. Temperature, dew-point and winds for Camborne, Brest and Crawley at 0000 GMT and 1200 GMT on 5 June 1983. The three saturated adiabats are for wet-bulb potential temperatures of 10, 15 and 20 °C. Dots on the Camborne ascent near 700 mb are an estimate of the environment curve assuming that the temperature element on the radiosonde responded as a wet-bulb between 730 and 710 mb.

shown in Fig. 4, then the heights of the 700 and 500 mb levels should have been respectively 10 and 17 m higher than were reported. This adjustment reduces the area enclosed within the 5700 m contour from that shown in Fig. 3 of Wells (1983) which was identical to the Bracknell operational analysis.

Comparing the 0000 GMT and 1200 GMT ascents at Crawley (Fig. 4), the wet-bulb potential temperature at 400 mb (θ_{w400}) had fallen from 15.2 °C to 14.8 °C whereas $\theta_{w/00}$ had risen from 13.7 °C to 14.6 °C. Hence θ_{w400} minus θ_{w700} had fallen from 1.5 °C to 0.2 °C which indicates that the middle tropopause was approaching a state of potential instability over a deep layer, well in advance of the upper trough. Cooling of only 1 °C to 2 °C around 600 mb and lifting by about 40 mb would have made the whole layer from 800 mb to 400 mb absolutely unstable with respect to saturated ascent.

(b) *Isentropic analyses*

Because this event occurred on a Sunday, there were no ascents from Larkhill (near Boscombe Down). Additionally, some ascents from Brest had incomplete wind data. These deficiencies have impeded the task of obtaining a detailed analysis of the upper air just forward of the trough.

Although air does not necessarily move along dry isentropic surfaces, such analyses are useful indicators of where broad-scale ascent is likely to be occurring provided that the relative motion of adjacent systems is taken into account. The analyses shown in Fig. 5 are for the 25 °C, 30 °C and 37 °C surfaces at 1200 GMT on 5 June. Over the English Channel, the 25 °C surface lay just above the cool and moist low-level layer; the adjustment made to the Camborne ascent changes the level of this surface from 680 to 730 mb, which accounts for the difference in the height of this surface from that quoted in Wells (1983).

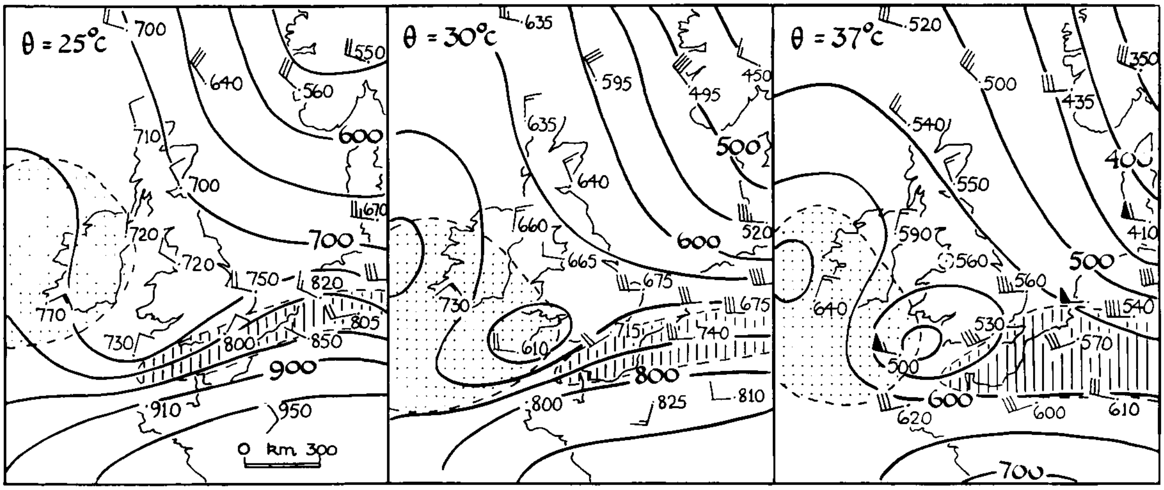

Figure 5. Isentropic analyses of the 25, 30 and 37 °C surfaces at 1200 GMT on 5 June 1983. Figures show heights in millibars. Vertical hatching shows moist air (dew-point depression ⩽ 6 °C); stippling shows dry air (dew-point depression ⩾ 20 °C). Based on the surface isobars, the wind at 910 mb over Brest was probably east-north-easterly at about 15 knots. From the 0000 GMT ascent (Fig. 4) the wind at 800 mb was probably south-south-westerly at 15 knots.

From the top of the friction layer to the base of the warm air, the north-easterly winds over southern England backed to northerly before becoming westerly, whereas those over northern France veered. In view of the steepness of the 25 °C isentropic surface over the English Channel, this relative motion suggests that convergence may have been occurring at the base of the warm air. The region most favourable for ascent in this surface at 1200 GMT was over the English Channel, with the warm air originating between Brittany and Paris.

In the 30 °C and 37 °C surfaces the upper trough produced a marked pressure minimum over south-west England and a steep gradient over the western half of the English Channel. The winds over northern France were south-south-westerly at 800 mb, so there would have been ascent in the 30 °C surface relative to the eastward-moving trough. In view of the potential instability which must have existed just ahead of the trough at middle levels, fairly widespread convection is indicated here. At these levels, the warm air had probably arrived over the English Channel via Biscay and the Brest Peninsula. Note the sharp humidity gradient over sea area Plymouth caused by the advection of cooler and drier air from the west.

3. Broad-scale distribution of cloud on 5 June

This section is illustrated by Fig. 6 which shows the main areas of cloud at six-hour intervals on 5 June as observed by Meteosat.

It would be wrong to assume that thundery rain had been occurring near the upper trough on the 4th. In fact there was mainly cumulus and stratocumulus, and a few showers near the trough while it crossed Ireland that afternoon. The broad band of medium-level cloud which can be seen over most of England and South Wales at 0000 GMT on the 5th was moving slowly east-south-eastwards and contained a narrow band of thundery rain which was approaching Cornwall and the Bristol Channel. The Meteosat water vapour channel indicated a band of dry air at upper levels close to the axis of the trough at this time (dotted line in Fig. 6). The thundery rain was about 200 km east of the trough axis.

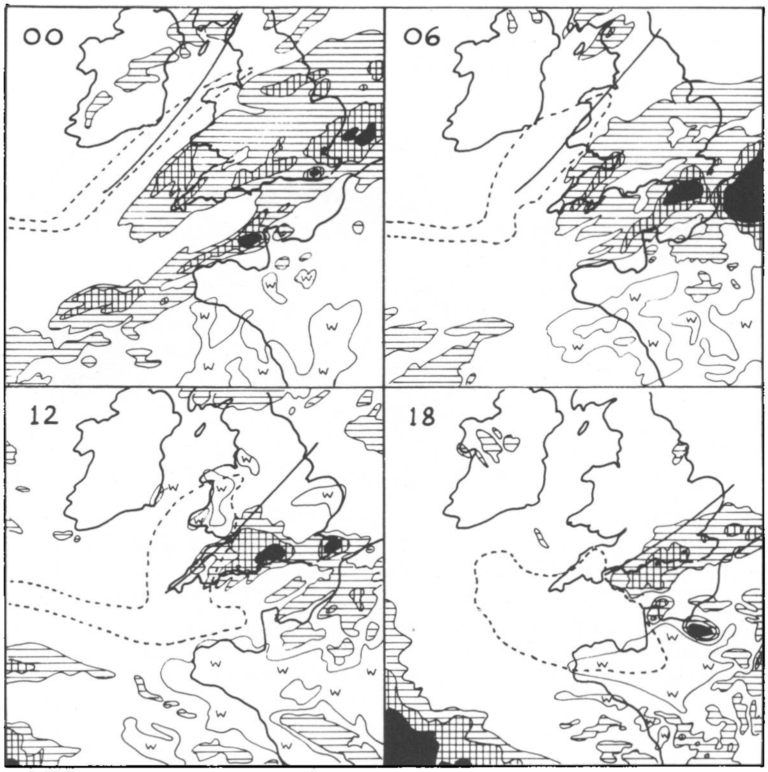

Figure 6. Main cloud distribution at 0000, 0600, 1200 and 1800 GMT on 5 June 1983 as shown by Meteosat infra-red images processed at the Meteorological Office Radar Research Laboratory, Malvern. Horizontal hatching shows cloud tops colder than 0 °C; cross-hatching, −20 °C; solid, −40 °C. Areas marked W were warmer than 20 °C near the surface. The line orientated from north-east to south-west over the British Isles shows the axis of a 500 mb trough. The broken line near the trough shows a region of dry air at upper levels (above about 600 mb) as indicated by the water vapour channel on Meteosat.

The main areas of thundery activity at 0000 GMT on the 5th were embedded in a band of medium- and high-level cloud which extended from sea area Finisterre to the North Sea. This band appears to have been close to the axis of the strongest winds along the baroclinic zone. Some heavy storms moved across the Channel Islands and the coast of north-east France between 0000 and 0600 GMT and a less vigorous storm crossed the English Channel to affect Kent. After 0600 GMT, however, the intensification of the thermal ridge between sea areas Biscay and Shannon eroded the south-westerly flow aloft and cut off the influx of thundery rain. As these storms moved away from south-east England and north-east France, storms developed just ahead of the upper trough and close to the jet entrance. Meanwhile, the narrow band of dry air aloft broadened and moved around the southern end of the trough (Fig. 6, 1200 GMT).

Fig. 6 also shows the areas of warm and mainly cloud-free air as revealed by Meteosat. The radiance values shown here were equivalent to surface temperatures of at least 20 °C. The small areas over the British Isles at 1200 GMT only just reached this threshold, whereas the north-west of France had a sunny and very warm day away from the north coast. Central France was also very warm but there was an extensive cover of cirrus. During the afternoon, cumulonimbus began to build up over north-east France and this became the main area of thunderstorms during the evening as those over southern England decayed.

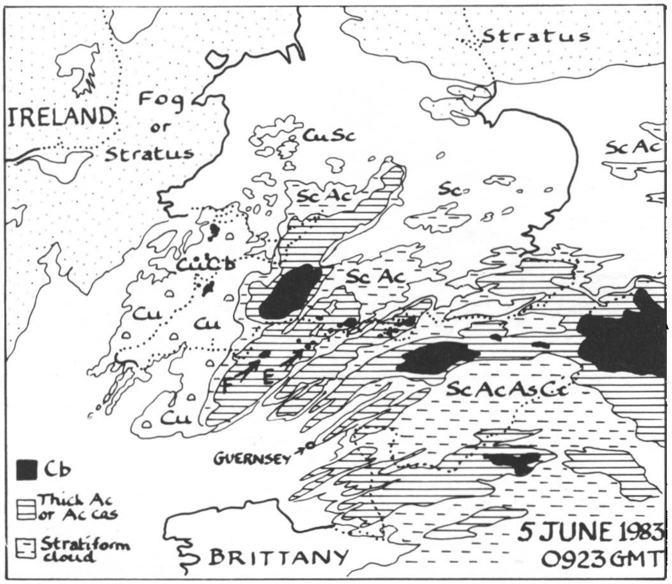

Figure 7. Cloud distribution at 0923 GMT on 5 June 1983, drawn from NOAA-8 visible and infra-red images. Original photographs were processed by the Electronics Laboratory, University of Dundee. The coastline is shown by dots where it was obscured by cloud. Arrows labelled E and F identify the first two of the main storms.

4. Cloud patterns observed at the time of storm development

Fig. 7 shows the cloud over southern England and northern France at 0923 GMT on 5 June. This figure has been drawn from the visible and infra-red images obtained from the NOAA-8 polar-orbiting satellite. At this time, the storms which eventually crossed southern England were beginning to form just to the south-east of Devon.

A broad band of stratus covered northern England and the North Sea. Although the Midlands and East Anglia were mostly clear of cloud at this time, the stratus spread well inland during the day. Over southern England and south-east Wales there was a large cover of medium-level cloud containing several convective areas. From east Devon to northern France the cloud was banded, these narrow bands being orientated from south-west to north-east over central southern England but from west-south-west to east-north-east over south-east England and northern France. Observations from southern England and the Channel Islands show that these were bands of altocumulus which thickened into castellanus along their length. From Meteosat infra-red data it was seen that the tops of the bands were mainly between 500 and 400 mb, but the cumulonimbus tops over north-east France and near the coast of south-east England exceeded 300 mb.

At the time of this satellite image, the axis of the upper trough was probably no more than 50 km to the north-west of Cornwall. Beneath the (probable) closed circulation there were numerous coastal showers, but these lacked clear organization and few of the tops extended higher than 700 mb. The medium-level bands were all located to the south-east of the trough, the approach of which appears to have caused the bands to back into a south-south-west to north-north-east orientation. The broader band across the coast of south Devon may have been formed by the merging of two or three narrow bands. Two of the convective elements in this band are arrowed in Fig. 7. These developed over the next hour to form the leading storms shown in Fig. 1, where they are labelled E and F. Storm E appears to have been an intensification of a cell embedded in the altocumulus castellanus, but it is not clear whether F also formed at castellanus levels or originated at lower levels and grew through the medium-level cloud.

5. Initial formation of the storms as seen by radar

In order to track the storms shown in Fig. 1 back to their earliest point of observation, radar data recorded at 5-minute intervals at Camborne and Clee Hill were analysed (the Upavon radar was not operating on this day). All cells which formed after 0600 GMT were labelled, using C suffixes for cells near the coast of Cornwall and D suffixes for cells over mid-Devon. The most eastward of the five major storms was labelled E and suffixes were used to identify distinct cells contained within each storm complex. This accounts for the labels given to some of the cells shown in Fig. 8, which illustrates this section. (Because the radar measurements are displayed as mean intensities over a 5 × 5 km grid, the term 'cell' implies a convective area of appreciable size which must be several kilometres from an existing storm to be identifiable.)

From 0600 to 0900 GMT, the thundery rain over south-west England was confined chiefly to a narrow band over Devon (Fig 8, 0843 GMT). This band was moving slowly eastwards, although individual cells were running north-north-eastwards along it. To the west of this band there were isolated showers and a cluster of more widespread showers adjacent to the coast of north Devon. To the east, both the Camborne and Clee Hill radars showed thin bands, less than 10 km wide, lying parallel to the main band over Devon. They were moving slowly eastwards across Lyme Bay but new bands were forming near the Devon coast. From surface observations and satellite images, it is evident that these were bands of medium-level cloud which were just beginning to precipitate.

During the next 30 minutes, small cells began to appear on the Camborne display, embedded in one of these previously weak bands (Fig. 8, 0913 GMT). Cell F_1 intensified and moved over Lyme Bay while weaker cells F_2 to F_4 remained close to the Devon coast (Fig. 8, 0943 GMT). It appears that storm F was basically F_1 but it was enhanced by the growth of cell F_5 just to the south of it (Fig. 8, 1013 GMT). Meanwhile several cells had begun to appear over Lyme Bay; E_1 moved north-eastwards as it intensified and was joined by the developing cell E_2 just before reaching Weymouth (Fig. 8. 0943 GMT). Hence the first two of the five storms appear to have formed almost simultaneously.

Storms G, H and I formed over the sea just south-east of Devon between 1000 and 1100 GMT. G appeared at 1004 GMT as a small cell located 20 km south-east of Start Point. H became visible just to the south of Start Point at 1034 GMT and cell I formed to the south-west at 1058 GMT. All these storms can be seen in Fig. 8 at 1113 GMT. In view of the brief interval between their times of formation, it may seem odd that G, H and I were each separated by at least one hour when they crossed the Dorset

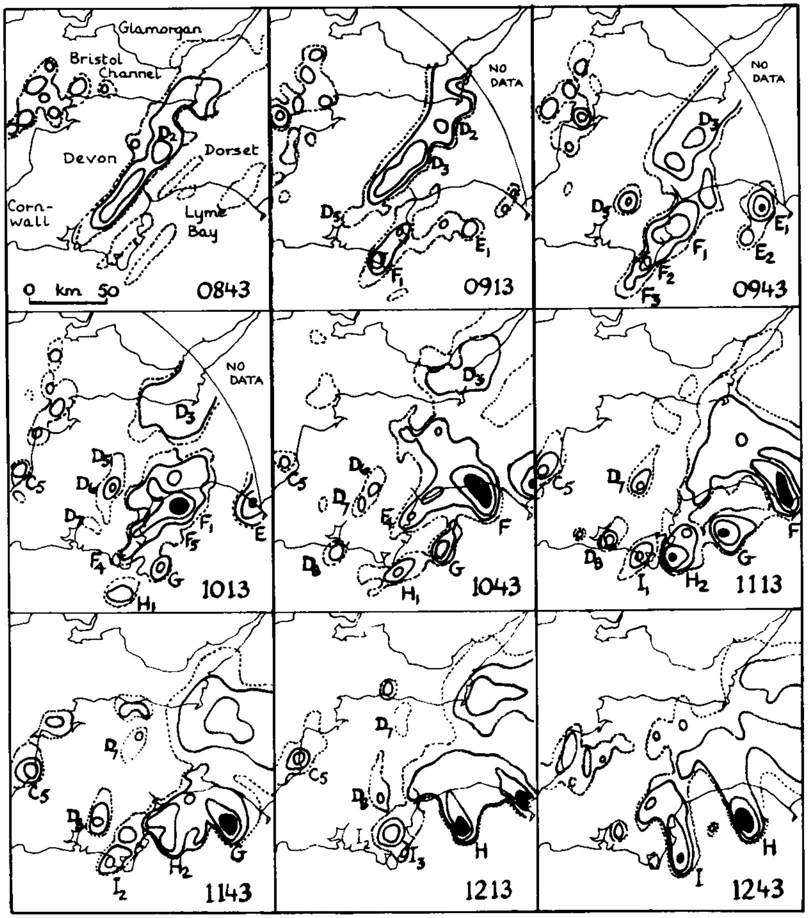

Figure 8. Formation of storms near Devon during the morning of 5 June 1983, as observed by radars at Camborne and Clee Hill. Analyses are shown at 30-minute intervals. Contours show nominal rainfall rates, derived from $Z = 200R^{1.6}$ (where Z is the radar reflectivity factor (mm^6 m^{-3}) and R is the rainfall rate (mm h^{-1})), of 0 (broken lines), 2, 8 and 32 (solid areas) mm h^{-1}. Suffixes are used to identify individual cells contained within each storm complex.

coast. In fact G made a fairly brisk advance across Lyme Bay whereas the cells from which storms H and I eventually grew were initially rather slow moving owing to multi-cell development over the coast of south Devon. Storm H was an intensification of cell H_2, caused perhaps by growth of a new cell very close to it which could not be resolved. Storm I developed from cell I_3 (Fig. 8, 1213 GMT).

A sixth storm (J) began to form about 25 km to the south-east of Start Point at 1330 GMT. After some initial movement north-north-eastwards, the main centre turned east-south-eastwards after 1430 GMT and continued along this track to the limit of radar coverage This storm can be seen in Fig. 6 close to the Cherbourg Peninsula at 1800 GMT. It appears to have crossed the French coast near Dieppe about four hours later.

6. Tracks of the storm centres

The purpose of this section is to record the movement of the areas of heaviest precipitation associated with the storms while they were within range of either the Camborne or Clee Hill radars. If the time at which hail was observed at any site is known, this will enable the storm responsible for its occurrence to be determined. For example, the hailstone of 30 mm diameter which fell at about 1250 GMT at Kimmeridge Bay (10 km south-west of Poole) and is illustrated in Wells (1983), clearly originated from storm G.

Fig. 9 shows for each storm the area bounded by a radar-derived precipitation intensity of 32 mm h^{-1}. These boundaries are shown at 30-minute intervals. Because the most active parts of the storms were characterized by sharp intensity gradients, these contours adequately define the storm boundaries. The actual rainfall rate was not necessarily as high as 32 mm h^{-1} (large hail produces a higher radar reflectivity than rain of normal drop-size distribution); it is likely, nevertheless, that the incidence of heavy rain and hail would have been concentrated within these boundaries.

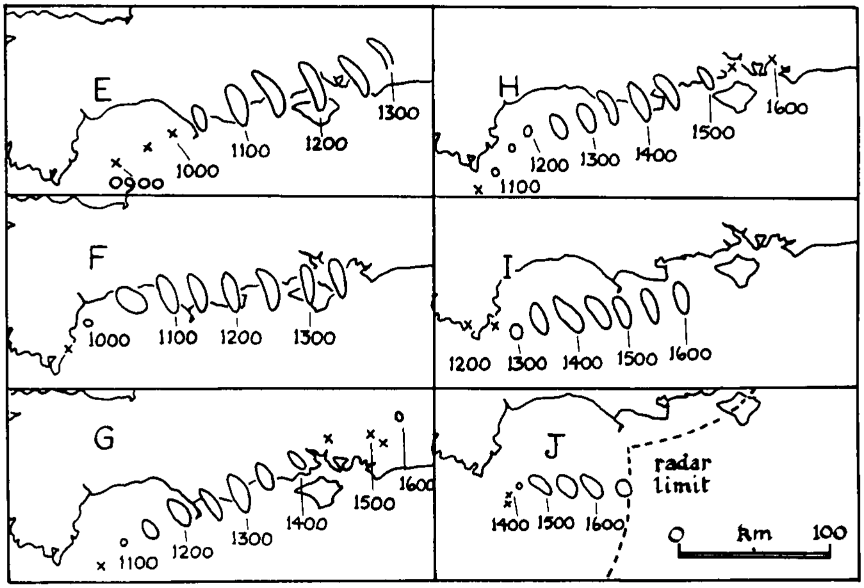

Figure 9. Location of storm centres at 30-minute intervals, shown while they were within range of the Camborne and Clee Hill radars. Elliptical contours show rainfall rates of 32 mm h^{-1} (derived from $Z = 200R^{1.6}$). Crosses show centres which were below this threshold.

With the exception of storm E, all storms began to produce heavy precipitation while they were over Lyme Bay. The intensity of some of the radar echoes at the centres of these storms, which appeared to reach over 100 mm h^{-1} while they were still 30 km or more from the Dorset coast, suggests that hail was already present at this stage although it may not have fallen into the Bay immediately. Storm E had only just reached the 32 mm h^{-1} threshold when it crossed the Dorset coast near Weymouth. Surface reports indicate that all of the storms gave some hail, although very large hail (over 20 mm in diameter) was associated mainly with storms E and G.

One interesting feature of the tracks of the storm centres, compared in Fig. 10, is that four of them (E, F, G and H) intersect over Poole Harbour. These storms were overhead at approximately 1100, 1205, 1305 and 1420 GMT. They appear to have reached their maximum intensity while they were between Weymouth and Bournemouth.

Most of the storms were still intense when they passed out of range of the radars. It will be seen later from the rainfall totals, however, that the heaviest falls had occurred while the storms were just within radar coverage.

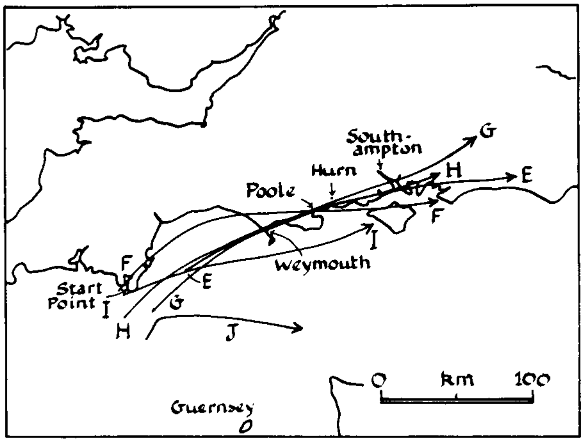

Figure 10. Tracks of the centres of the main storms on 5 June 1983, shown while they were within range of the Camborne and Clee Hill radars.

7. Storm orientation and the development of rainbands

As was illustrated in Fig. 8, most of the storms developed from more than a single convective cell. Usually two or three cells were observed, aligned from south-south-west to north-north-east along the altocumulus bands, with new cells forming to the south of older cells. The intensification of each storm was accompanied by a merging of cells in the south and a change in orientation of the principal axis to south-south-east to north-north-west. This rapid transformation can be seen in Fig. 8 during the passage of storm F across Lyme Bay and is illustrated in Fig. 11 for storm H. From this stage onwards it became more difficult to see new cells forming, although it does appear from the radar intensities that most of the storms underwent intermittent reinvigoration on their southern flank from new cells which were sometimes too close to the main storm to be resolved. The cells which had formed earliest could still be identified for an hour or so because they were moving on a north-north-easterly track, whereas the main centre usually moved east-north-eastwards as a result of cell propagation on its southern flank.

Within one to two hours following the main development of each storm, a band of thundery rain extended north-north-westwards, obscuring the older cells. The bands extended for a maximum distance of 100 km from the storm centres, being longest close to the trough axis. At 1250 GMT, Odiham, Boscombe Down and Yeovilton (see Fig. 1 for location) reported rain and thunder; each station was being affected by different bands which were associated with storms E, F and G respectively, the centre of each storm being 60 km to the south-east of each station. It would be wrong, however, to infer that these bands were solely the product of the coastal storms. The middle levels over central southern England were already cloudy (see Fig. 7) and the decaying cumulonimbus merged with these areas of unstable medium-level cloud. The greater eastward velocity of the coastal storms relative to the decaying cells caused the orientation of the bands to become south-east to north-west as they extended over land.

Fig. 12 is based on the visible and infra-red images of the NOAA-7 satellite taken at 1426 GMT, i.e. at the time of maximum storm activity (for more detail in the cloud structure, see the visible image shown in Wells (1983)). The older storms were beginning to merge, however, presumably because there was less vigorous ascent at middle levels well forward of the trough. Cloud-top radiance levels indicate that the tops of the five main storms reached the tropopause, near 250 mb; the other cumulonimbus tops over

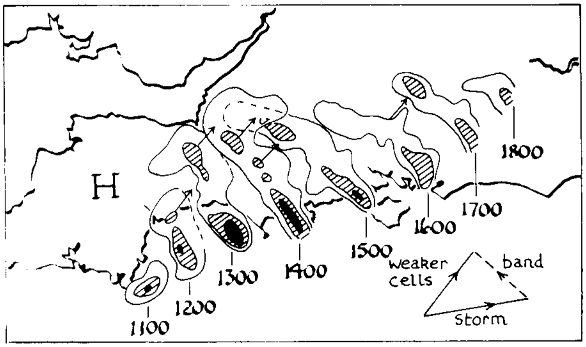

Figure 11. Hourly positions of storm H and its associated cloud band. Contours show nominal rainfall rates of 2, 8 (hatched) and 32 (solid) mm h^{-1}

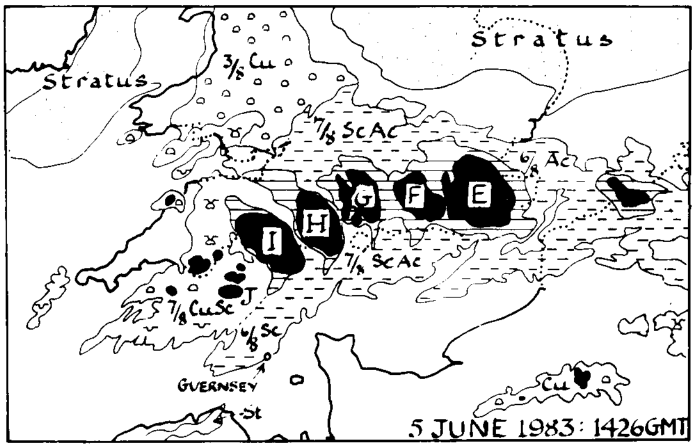

Figure 12. Cloud distribution at 1426 GMT on 5 June 1983, drawn from NOAA-7 visible and infra-red images. Original photographs were processed by the Electronics Laboratory, University of Dundee. The coastline is shown by dots where it was obscured by cloud.

south-west England, including storm J, were nearer 400 mb. Note that the cirrus anvils were not sheared forward of the storms; this implies that, forward of the trough, the winds between 400 and 250 mb decreased to a value equal to the mean storm velocity, which was about 260°, 25 kn. This characteristic is evident only in the Crawley winds at 1200 GMT (Fig. 4).

8. Surface wind and pressure perturbations

Fig. 13 shows the pressure, wind direction and speed, 10-minute rainfall amounts, temperature and dew-point recorded at Hurn (6 km north of Bournemouth) during the passage of the storms. The station was close to the cores of storms E, G and H (see Fig. 10). An enlargement factor of ten was necessary to convert the barograph trace to the same time-scale (one inch per hour) as that used for anemograph charts. Allowance has been made for timing errors; these were indicated by the time marks, which are

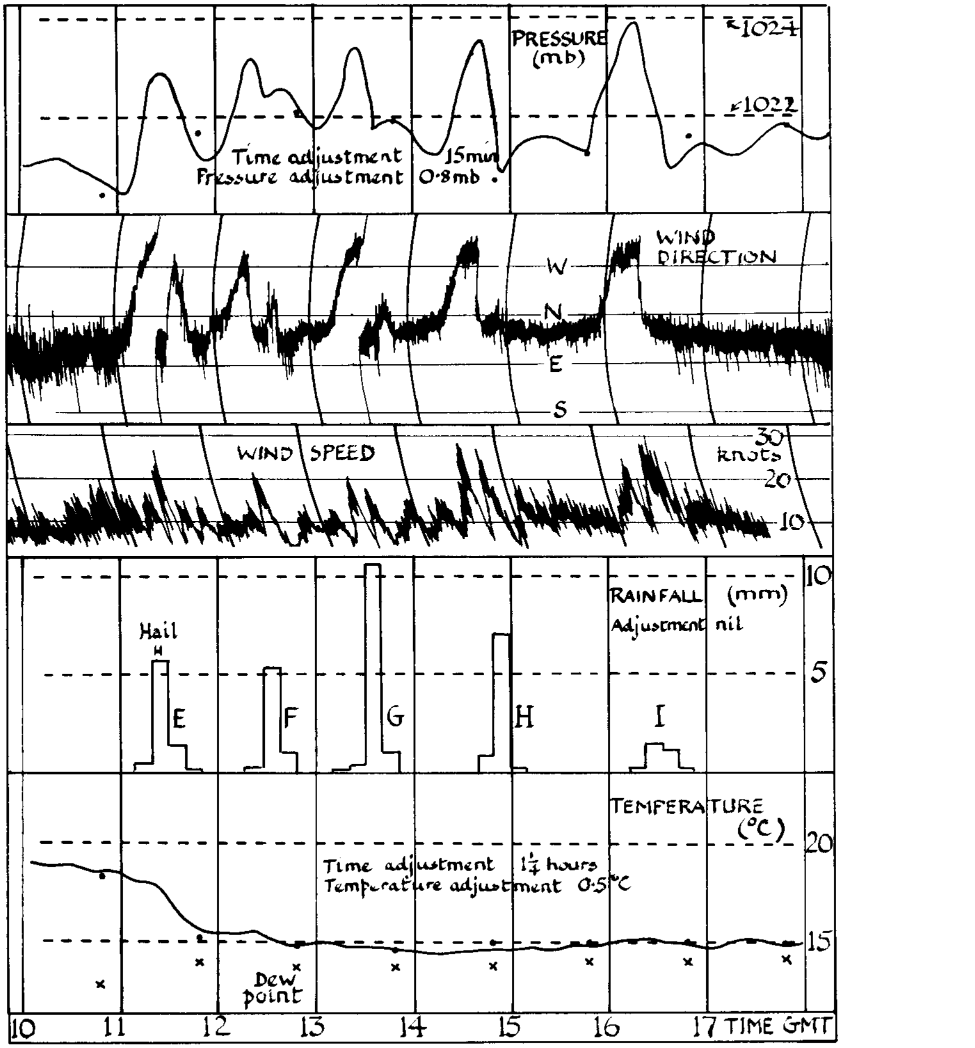

Figure 13. Pressure and wind fluctuations recorded at Bournemouth (Hurn) Airport between 1000 GMT and 1800 GMT on 5 June 1983. Autographic records on which this figure is based were supplied by the Metorological Officer, Hurn. The histogram shows rainfall totals at 10-minute intervals. Dots show hourly (*H*–10) measurements of mean sea level pressure and screen temperature. Crosses show hourly dew-point values.

made once or twice a day. The pressure and temperature reported in the *H*-10 observations were compared with the autographic records: these sometimes indicated a small instrumental error. All adjustments made are noted in the figure.

The 10-minute rainfall totals are plotted with respect to each storm; the wettest 10-minute period of each storm was identified first and then other 10-minute periods were marked off on either side. This procedure avoided the division of wet bursts and hence gives a better indication of the maximum rainfall intensity. Only storm E gave hail at Hurn, some of the stones being 20 mm in diameter. This would have caused the time of clearance of the precipitation as indicated by the rain-gauge to be delayed by several minutes.

A similar analysis was made of the autographic records at Southampton Weather Centre. Provided that the possibility of errors caused by the need to magnify some of the time-bases is borne in mind, these analyses indicate that:

(i) with the approach of each storm, the prevailing north-easterly wind fell light for a minute or two before backing to west-south-westerly and freshening;

(ii) each period of west-south-westerly winds lasted about 10 minutes and was accompanied by a pressure surge of between 1.5 and 3.0 mb;

(iii) the duration of the pressure surge was identical to the duration of the west-south-westerly wind;

(iv) there was usually a lull in the west-south-westerly wind, lasting from 2 to 5 minutes, before the wind returned to east-north-east; at Southampton, which was north of all the storm centres (see Fig. 10), the wind always veered from west-south-west to east-north-east, but there was more fluctuation in the wind direction at Hurn during the passage of storms E and G;

(v) precipitation began to fall while the wind was west-south-westerly but was heaviest during the lulls and for a few minutes after the wind had returned to the north-east;

(vi) the magnitude of the pressure jumps was not directly related to the intensity of the precipitation;

(vii) just to the rear of each storm, there was a minor pressure jump of less than 1.0 mb, sometimes accompanied by a brief fluctuation in the wind direction (this feature was less evident at Hurn than at Southampton);

(viii) very little change in temperature occurred during the passage of the storms, except that the arrival of the first storm (E) caused a general cooling of 3 °C over Dorset and Hampshire and 3 °C to 5 °C further east.

The west-south-westerly winds indicate that a wind reversal of about 40 knots occurred in advance of the storms above the friction layer. Some of the gusts from this direction were as strong as those from the east-north-east; consequently there was sometimes a pronounced double maximum in the wind speed. This feature is evident at Hurn in storms G, H and I (Fig. 13) and also occurred at Southampton in storms E and H.

In spite of the strength of the outflow from the storms, little cooling reached the ground. The temperature fall associated with storm E was too gradual to have been caused solely by the downdraught and was probably due in part to the change from a bright morning to a cloudy one as the altocumulus thickened overhead. Application of the method suggested by Fawbush and Miller (1954) for calculating the surface temperature in downdraughts from cumulonimbus confirms that little fall of temperature was likely. The method is based on the assumption that evaporation of heavy precipitation will cause the downdraught air to be chilled to near saturation, in which case its temperature during most of its descent will follow the saturated adiabat from the wet-bulb temperature at the melting level. Judged from the Camborne and Crawley ascents, the 0 °C level must have been close to 700 mb and the wet-bulb at this level must have been near −2 °C. The saturated adiabat from the wet-bulb to the ground gives 15 °C as the estimated surface temperature in the downdraughts. This was, however, only about 1 °C less than the temperature in the east-north-easterly winds between the storms.

Over south-east England, fluctuations in the pressure and wind were recorded by many stations. Because of the diversity of the storm tracks in the east, however, not all the storms had a major impact at each station. For example, there is little sign of storm G in the wind and pressure records at Gatwick and Herstmonceux although some precipitation occurred there. This storm passed to the north of these stations; hence it is likely that the pressure surge associated with each storm did not extend far to the south of the storm centres.

Fig. 14 is an estimate of the sea-level pressure pattern at 1250 GMT based on surface observations but using the known pressure fluctuations to improve the analysis near the storms. Note that the observations alone indicate the existence of only five 1023 mb isobars, one running from east to west

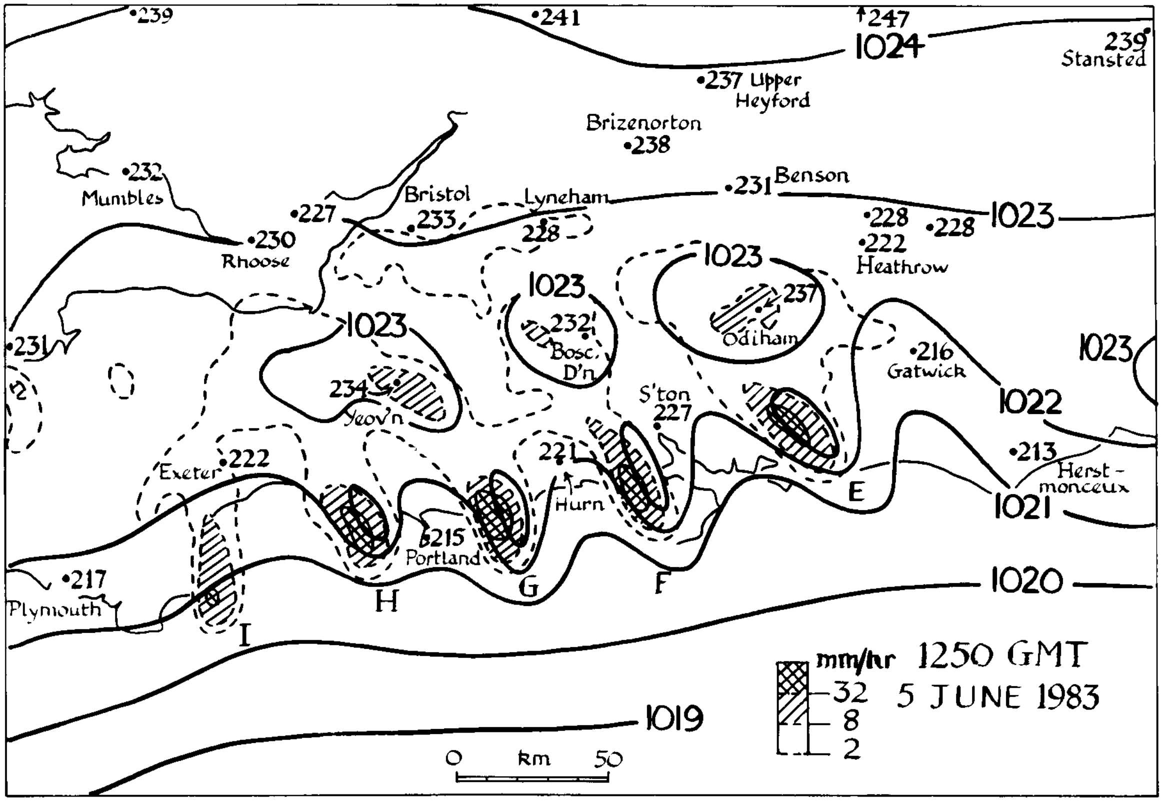

Figure 14. Surface pressure analysis for 1250 GMT on 5 June 1983, with nominal rainfall rates (derived from $Z = 200R^{1.6}$)

across the south Midlands, the others embracing the decaying areas of thundery rain. A further three or four 1023 mb isobars must have existed beneath the mature coastal storms but probably not beneath storm I which was just beginning to intensify.

9. The precipitation totals

Fig. 15 shows the total rainfall caused by these storms. It has been obtained by combining the daily rainfall as measured by rain-gauges over the 24 hours commencing at 0900 GMT on 5 June 1983 with the rainfall derived from radar measurements over the period 0900 to 2100 GMT. The only rain to fall during these periods other than from the storms described here occurred over Sussex and Kent between 0900 and 1400 GMT but amounts were mostly small.

The radar-derived totals were generally larger than the rain-gauge measurements and have been reduced by 30% over Lyme Bay so as to fit the gauge readings over the coast of Devon and Dorset. The radar integration is helpful in showing the growth of heavy precipitation across Lyme Bay and the isolated storm (J) over the English Channel, while the gauges indicate the gradual decrease in rainfall as the storms moved across south-east England. Both the radar and gauge totals showed that the heaviest falls occurred between Weymouth and Bournemouth.

Also shown in Fig. 15 are the distributions of hail, based mainly on the records of official observers. These indicate that large hailstones fell chiefly along a band from near Weymouth to beyond

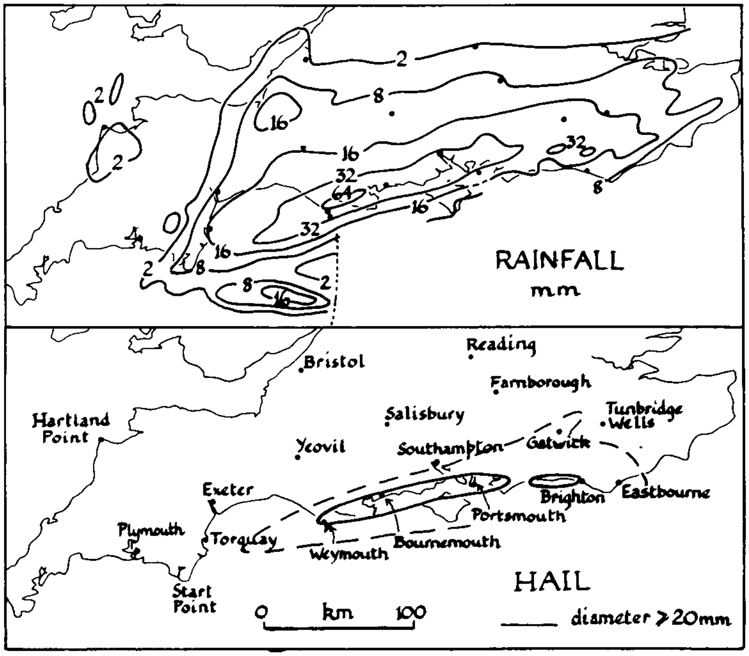

Figure 15. Rainfall totals and distribution of hail associated with the storms of 5 June 1983. Rainfall over land is based on 24-hour totals (commencing 0900 GMT), which were supplied by the Agriculture and Hydrometeorology Branch of the Meteorological Office. Rainfall totals over the sea were derived from radar measurements and adjusted to fit gauge totals over the coast. The distribution of hail is a simplified version of an analysis by E. McCallum, based partly on data supplied by the Climatological Services Branch of the Meteorological Office.

Portsmouth, some of the stones exceeding 50 mm in diameter. This band lies close to, but a little south of, the axis of the highest rainfall totals, suggesting that the larger hail fell in the southern portion of the storms.

Five rain-gauge sites between Weymouth and Poole Harbour recorded total falls of over 60 mm, the highest individual measurement being 74 mm at Winfrith. Bearing in mind that some losses could have occurred through hail bouncing out of the funnels of the gauges and (to a lesser extent) through evaporation of the stones as they lay melting in the funnels, it is probable that the maximum 'rainfall' was about 80 mm.

10. Possible influence of low-level winds and topography on the area of storm development

This section is largely conjectural but is intended to provoke further study into the mechanisms responsible for this type of development.

Arguments in favour of the view that some localized forcing might have influenced development of the storms are that (a) if it is correct that the trough was moving eastwards, then it is surprising that all the storms intensified within such a small area, and (b) once the trough had moved beyond Devon the succession of storms died away. Forced ascent over the hilly land mass of Devon does not seem to have triggered the storms directly. Only cells which formed offshore intensified; hence we require a coastally induced mechanism.

During the night of 4/5 June an east-north-easterly gradient had become established over southern England and the English Channel. By 0900 GMT the geostrophic wind over Lyme Bay was 070°, 30 kn and it probably exceeded 40 kn between Start Point and Guernsey. The flow was stronger over this region of the English Channel than further west because of the movement of a heat low across Brittany (Fig. 2). These east-north-easterly winds were capped by a temperature inversion at about 900 mb, the magnitude of which is hard to judge from the ascents at Brest, Camborne and Crawley (Fig. 4) but may have been only 2 °C near the coast of south Devon. This hilly coast protrudes over 40 km further southwards than the remainder of the English coastline to the east and hence presents a block to the low-level east-north-easterly flow as it crosses Lyme Bay. It is possible that this blocking caused an increase in the depth of the cool air to the east of Devon. Since the warm air over the English Channel above the inversion was probably moving from the south-east quadrant between 900 and 850 mb, its rate of ascent may have increased sufficiently to trigger deep convection before the warm air reached the mainland. The major storms developed from those cells that formed within the bands of altocumulus castellanus, which were regions of maximum instability and moisture. These storms removed the supply of warm air from the broad band over Devon which had been producing thundery rain earlier in the morning, causing this band to decay from the south (Fig. 8).

Recent reports by Rogers and Meaden (1984) of coke being found embedded in hailstones near Bournemouth suggest that the weakly stable surface layer near the coast was readily disrupted by the strong vertical motion associated with the developing cumulonimbus. Pockets of moist air, travelling with a velocity of about 50 kn relative to the cumulonimbus, could have been fed into the base of the storms, accelerating the production of hail.

With regard to the regular 50 km spacing of the mature storms, we have seen that the first two storms (E and F) formed along separate castellanus bands which were moving slowly eastwards (Fig. 8, 0843 GMT). However, the orientation of cells F, G and H at 1043 GMT suggests that several cumulonimbus clouds formed along only one band. Hence the regular spacing of the storms was probably not the result of the eastward movement of equally spaced bands of enhanced medium-level ascent. A more likely explanation is that descending air to the rear of an intensifying storm suppressed convection in its immediate vicinity so that each new development was delayed until the preceding storm had been carried across Lyme Bay away from the generating region.

11. Conclusions

The explosive development of hailstorms over the south coast of England on 5 June 1983 occurred in potentially unstable air on the cold side of a baroclinic zone and just ahead of an upper trough. The trough was rather shallow, being most evident between 600 and 400 mb, and the thickness values along it were rising; nevertheless, it was still fairly sharp and may have contained a small centre as it approached south-west England. Large-scale developments had caused the disruption of the previously broad baroclinic zone from Finisterre to north-west Europe and had displaced the main region of middle-level ascent closer towards the trough. The south-westerly upper winds had remained strong to the south-east of the trough because of the rising thickness values over France and Biscay. Because of the shear across the baroclinic zone, the ascending warm air over the English Channel had become organized into narrow bands of altocumulus castellanus which were producing thundery rain. Drier air, with a relatively low wet-bulb temperature, was moving around the southern flank of the trough as it crossed south-west England; the enhanced convective instability along the forward edge of the cool air led to the formation of cumulonimbus along the medium-level bands. The approach of the trough coincided with the strengthening of a cool and rather moist east-north-easterly flow below 850 mb over the English Channel; this flow was strongest between Devon and the Channel Islands because of the movement of a shallow heat low across Brittany. It is possible that blocking of the cool low-level air by the south coast of Devon may have increased the depth of the cool layer, causing an increased rate of ascent at the base of the warm air as it approached the coast from the south. The production of cumulonimbus was most rapid along the castellanus bands as they moved slowly eastwards across the region. The growing cumulonimbus clouds moved initially north-eastwards along the bands but, as they engaged the stronger west-south-westerly winds around 500 mb, they began to accelerate and veer; cell propagation just to the south of the storms caused the resulting tracks of the storm cores to be east-north-eastwards, which took the storms close to the south coast of England. Vigorous ascent and descent near the cumulonimbus intermittently disrupted the surface inversion, causing pockets of moist low-level air to be fed into the storm. Large hail fell close to the vigorous cores but thundery rain extended north-westwards from each storm as the decaying cells moved more slowly north-eastwards. Each storm developed a well-marked pressure surge and caused sharp wind reversals at sites close to the heaviest precipitation. The succession of storms was ended by a veering and decrease of the upper winds with the passage of the trough, which brought much drier air above 700 mb across southern England during the late afternoon and evening.

Acknowledgements

The author is grateful to Dr J. R. Eyre and D. Jerrett of the Satellite Meteorology Branch of the Meteorological Office for processing the HERMES data. The provision of other data from various sources, referred to in Figs 7, 12, 13 and 15, is also appreciated. Some helpful comments on a preliminary version of this paper were received from Dr K. A. Browning, S. D. Burt and E. McCallum of the Meteorological Office.

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Forecasting road surface minimum temperatures

By J. Roodenburg

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Summary

Nocturnal road surface temperatures were obtained from a recently installed automated network in the central Netherlands. With the use of standard observed weather variables as predictors, regression equations could be derived that calculated the lowest road surface temperature in the network up to 6–12 hours ahead. A test on independent material proved the equations to perform satisfactorily.

1. Introduction

Forecasting road surface conditions for traffic safety purposes has been a notoriously difficult task for as long as the demand for such forecasts has existed. Obviously the ability to forecast road surface minimum temperatures within reasonable margins for up to 6–12 hours ahead would be a step forward.

Literature on this particular subject is scanty. In Britain several experiments have been carried out in attempts to gain a better understanding of surface temperature behaviour. From measurements on motorways near Newport Pagnell and near Bray Wick, Hay (1969) concluded that the best forecast would probably be obtained by simply equating the road surface minimum temperature forecast to the air minimum temperature forecast, for which objective methods are available. Parrey (1969), using readings from a standard grass-minimum thermometer attached to a road surface at Watnall, found a correlation between the date and the difference, minimum air temperature minus minimum road temperature, with a large scatter around individual values. Ritchie (1969) applied Fourier analysis to monthly mean values of minimum air temperature minus minimum road temperature from measurements at Wyton. This resulted in an expression which relates these values to the day of the year. He claimed an accuracy of better than 2 °C throughout the winter season and better than 1 °C on most occasions.

More recently, several physical models have been proposed (Thornes 1972, Rosema and Welleman 1977, Nysten 1980). Although the final word undoubtedly will come from the modellers, as yet their results seem only marginally useful. This is not surprising: the models need input of such variables as net radiation, rates of condensation and evaporation, water vapour pressures, conductivities of road materials — from totally dry to totally wet — cloud amounts, etc. Some of these variables are not accurately known and most of them vary rapidly in space and time.

In this paper a statistical method for forecasting minimum road surface temperatures is presented. The basic material is obtained from a fully automated measuring network in the central part of the Netherlands.

2. The measuring network

By the end of the 1970s a fully automated network, measuring amongst other quantities road surface temperatures, had been installed by the Road Research Laboratories in the province of Utrecht. The network encompasses an area of approximately 1000 km^2; the Royal Netherlands Meteorological Institute at De Bilt (52°06′N, 5°11′E) is conveniently located near its centre. The network consisted of six sites on various four-lane motorways (Fig. 1). At each site thermistors are implanted in the road body at 2 mm below the surface. There is one thermistor for each lane and hard shoulder. A microprocessor at each location provides for assimilation and storage of the data. A central computer at the road authority's main office reproduces, when activated, the road surface temperatures that have been recorded at five-minute intervals over the past hour. The observation sites differ in orientation of the roads (insolation), in number and size of surrounding obstacles, in elevation and in traffic density. Moreover, the roads differ in construction and materials used. In general, however, they consist of a sand bed, a layer of 15–20 cm of gravel asphaltic concrete, a layer of 4 cm of open-textured asphaltic concrete topped by 4 cm of coarse dense asphaltic concrete. The sites were chosen as a result of previous infra-red measurements by the Road Research Laboratories which indicated these locations as 'cold spots'.

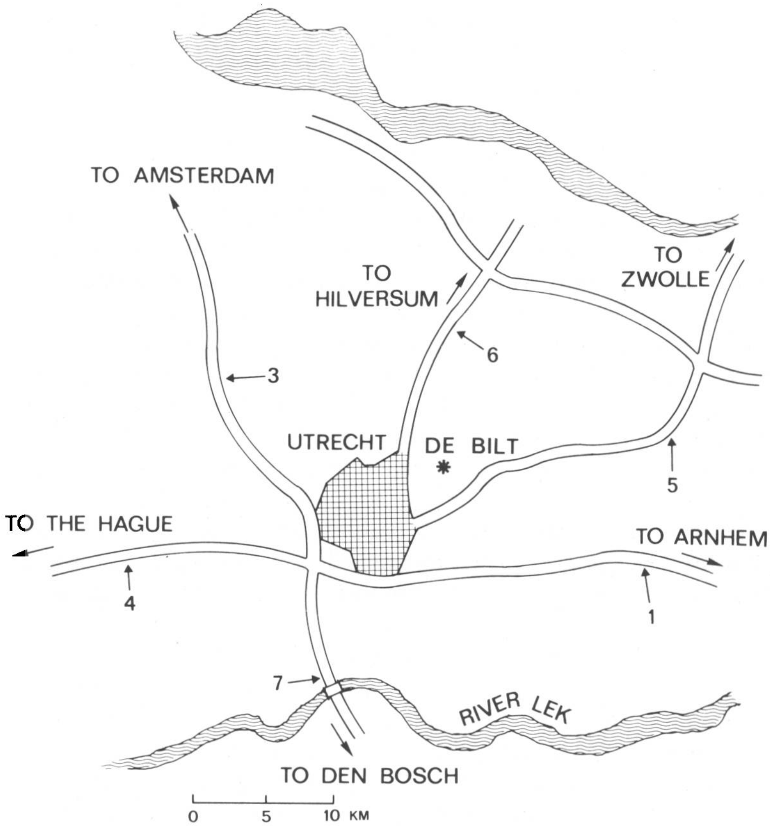

Figure 1. Location of sites used in this study.

3. The data

Every night during the period from 1 November 1981 to 31 March 1982 road surface temperatures were collected directly from the road authority's central computer via a telephone link. To prevent interference with the road maintenance crews, data could be collected only at 0000, 0300 and 0600 GMT. On 10 nights the data were incomplete or missing altogether. From the remaining 141 nights every fifth was set apart to form an independent data set, leaving 113 nights for study. The main computer was instructed to output the lower temperature of any two corresponding (e.g. inner) lanes at all times and at all sites. This seemed sensible from a safety point of view. Frequent calibration of all sensors ensured an accuracy of ±0.2 °C. All other observational material was taken from the records of De Bilt.

Some observations

As little appears to be known about road surface temperatures, it seemed worth while to inspect a few samples in some detail before proceeding to statistical analysis. Three nine-day periods grouped around 15 November, 15 January and 15 March were chosen. Site 3, on the motorway between the cities of Utrecht and Amsterdam, was selected as it is practically free of obstacles. Moreover, the road at that location is oriented north-south, thus giving equal amounts of insolation to all lanes during the, say, six hours around noon. In Figs 2(a)–(c) are plotted the maximum screen temperature and the subsequent 0300 GMT temperature at De Bilt, the lowest road surface temperature recorded between 0200 and 0300

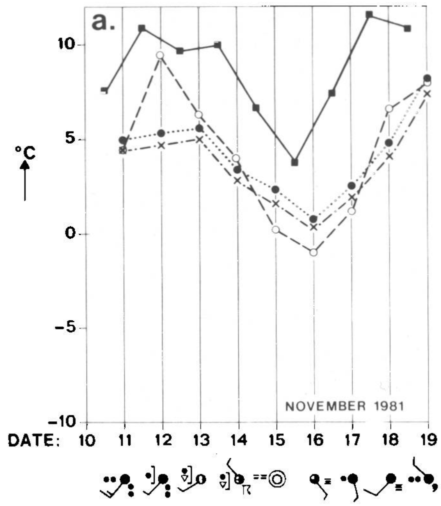

Figure 2(a). Comparison of various temperatures recorded during November 1981. ■ maximum temperature on previous day
○ temperature at 0300 GMT × inner lane ● outer lane

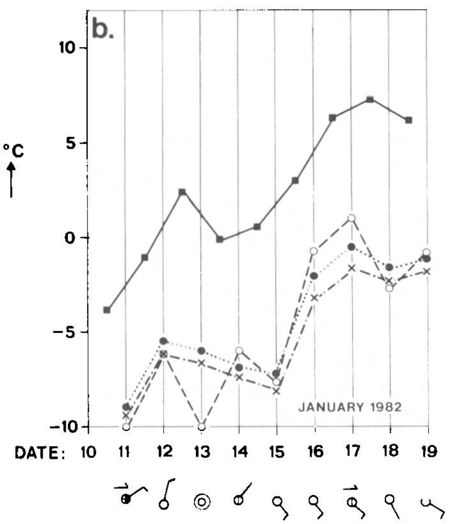

Figure 2(b). As Fig. 2(a) but for January 1982.

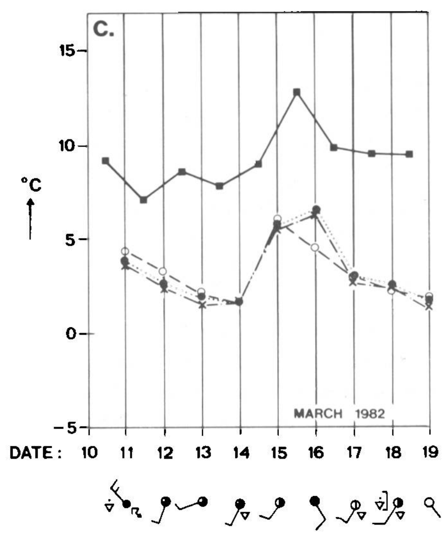

Figure 2(c). As Fig. 2(a) but for March 1982.

GMT on the inner and outer lanes and the relevant part of the 0000 GMT synoptic observation from De Bilt in WMO-standard symbols.

Several interesting features can be inferred from the figures. The large-scale temperature tendencies as depicted by the 0300 GMT temperature curves are reasonably well followed by the road surface temperatures, but the amplitude of the latter is considerably smaller. The screen temperature at De Bilt responds much more quickly to a changing temperature regime than do the road surface temperatures. The day-to-day changes may even differ in sign as on the nights of 12–13 November, 13–14 January and 15–16 March.

The magnitude of this time-lag is thought to depend upon the recent weather history. After a wet spell the thermal conductivity of the road body is at a maximum; even a considerable warming of the air will cause only a moderate temperature rise at the road surface as the absorbed heat is easily transported towards deeper layers. The opposite would occur after a dry spell: the top layers of the road would be thermally isolated from the lower layers and thus be able to follow any air temperature changes fairly rapidly.

Another remarkable effect is the constant positive temperature difference between the outer and inner lanes at site 3; it was the only site that showed this phenomenon consistently. Site 1 (Fig. 1) demonstrated opposite behaviour just as consistently. This could be explained easily as the road's orientation at that location is west–east with extensive sheltering to the south. Therefore the eastbound outer lane (on the Continent one keeps to the right!) will be in shadow most of the time during the low-sun season (remember that the lower temperature of corresponding lanes is registered). At site 6 (Fig. 1) which is also relatively clear of obstacles, and where the road's orientation is south-south-west to north-north-east, no significant differences could be found. According to information from the Department of Traffic Technology the nocturnal traffic density at site 3 is about three times as high as at any other site; this would make the consistent temperature difference between the outer and inner lanes at site 3 plausible.

Screen temperatures usually reach their minimum value near dawn. Road surface temperatures — at least on the roads under discussion — do not. The lowest temperatures are recorded in the middle of the night, after which a general increase can be noted. This is also likely to be ascribed to enhanced traffic density towards morning.

4. Regression equations

During the night, gains and losses of heat by the road surface are governed by various processes. These are listed in Table I, together with those routinely observed and thus easily available weather variables that are assumed to be influential. Moreover, in view of the experiments by Parrey and Ritchie (Parrey 1969, Ritchie 1969) the length of the night was included in the data set.

Table I. *Processes causing changes in road surface temperatures and influential variables.**

Process	Variables
Radiative exchange	Sunshine of previous day, cloud amount during the night, length of night
Advection of sensible heat	Wind speed during the night, maximum temperature of previous day, 0000 GMT screen temperature, presence of snow cover
Advection of latent heat	Ignored in present work
Conductivity of road body	Occurrence of rain
Heat storage in road body	Soil temperatures at various depths, length of night

*All weather variables as observed at De Bilt

Altogether 19 variables were submitted twice to a stepwise forward multiple regression scheme to yield calculated lowest road surface temperatures for the periods 0200–0300 and 0500–0600 GMT. Some of the variables were transformed into binary ones first by splitting them up into classes and assigning a value of 1 to the observed classes and a value of 0 to the remaining classes.

Table II gives a summary of the variables used in order of cumulatively explained variance (period 0200–0300 GMT).

Table II. *Variables used and cumulatively explained variance (per cent).*

1.	Screen temperature at 0000 GMT	85.07
2.	Soil temperature at 5 cm at about 2300 GMT	89.41
3.	Cloud cover at 0300 GMT ⩾7/8	91.72
4.	Maximum temperature on the previous day	93.39
5.	Cloud cover at 0000 GMT ⩾ 7/8	94.47
6.	Snow cover ⩾50%	94.90
7.	Sunshine, percentage of possible hours	95.15
8.	Precipitation ⩾0.3 mm between 0000 and 0600 GMT	95.25
9.	Cloud cover at 0000 GMT ⩽ 2/8	95.34
10.	Wind speed at 0000 GMT ⩽3 kn	95.45
11.	Soil temperature at 10 cm at about 2300 GMT	95.47
12.	Soil temperature at 20 cm at about 2300 GMT	95.57
13.	Length of night	95.59
14.	Precipitation ⩾0.3 mm between 1200 and 1800 GMT	95.60
15.	Precipitation ⩾0.3 mm between 1800 and 0000 GMT	95.62
16.	Cloud cover at 0300 GMT⩽ 2/8	95.62
17.	Wind speed at 0300 GMT ⩽ 3 kn	95.62
18.	Wind speed at 0300 GMT ⩾ 8 kn	95.62
19.	Wind speed at 0000 GMT ⩾ 8 kn	95.62

From Table II it is clear that after the seventh variable the increase of variance explained proceeds so slowly as to be virtually negligible. For the period 0500–0600 GMT the same seven variables were picked out by the regression scheme (in a slightly different order) with 94.18% of variance explained. Therefore these variables were again regressed against the lowest road surface temperatures for the periods 0200–0300 and 0500–0600 GMT. This resulted in the following regression equations:

$$T_{R3} = -3.73 + 0.37T_0 + 0.34T_{s5} + 1.30N_3 + 0.22T_x + 1.11N_0 - 1.12s - 1.28S. \qquad (1a)$$

$$T_{R6} = -3.00 + 0.39T_0 + 0.34T_{s5} + 1.17N_3 + 0.19T_x + 0.72N_0 - 14.3s - 2.18S. \qquad (1b)$$

The correlation coefficients were 0.98 and 0.97 respectively.

The symbols have the following meaning:

T_{R3}, T_{R6} : the lowest road surface temperature at any site for the periods 0200–0300 and 0500–0600 GMT, respectively (°C);

T_0 : screen temperature at 0000 GMT (°C);

T_{s5} : soil temperature at a depth of 5 cm (°C);

N_3 : this variable becomes 1 if at 0300 GMT cloud cover is 7/8 or more ('sky indiscernible' included), otherwise it becomes 0;

T_x : maximum screen temperature of the previous day (°C);

N_0 : this variable becomes 1 if at 0000 GMT cloud cover is 7/8 or more ('sky indiscernible' included), otherwise it becomes 0;

s : this variable becomes 1 if at least half of the surrounding area is covered by snow, otherwise it becomes 0;
S : percentage of sunshine possible of previous day divided by 100.

In order to test the merits of the equations, they were applied to the data set that was kept apart (28 days). The results are summarized in Table III; calculated and observed values are plotted in Fig. 3.

Table III. *Performance of equations on independent data*

	T_{R3}	T_{R6}
Correlation coefficient	0.97	0.96
Root-mean-square error (°C)	0.98	1.19
Mean absolute error (°C)	0.71	0.90

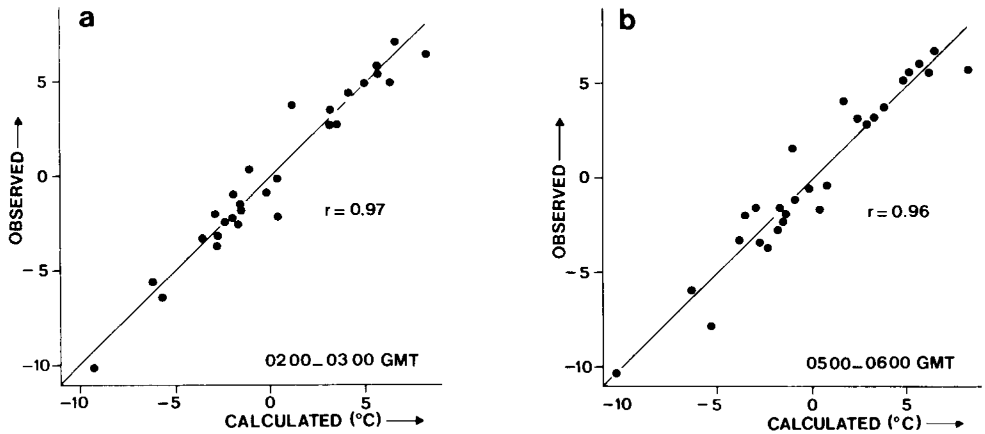

Figure 3. Calculated versus observed temperatures for (a) 0200–0300 GMT and (b) 0500–0600 GMT.

5. Discussion

With one exception, the variables that appear in the equations contribute to the minimum road temperature in the way to be expected on physical grounds. Sunshine, however, seems to lower road surface temperatures. This is undoubtedly due to the net radiation balance being negative in temperate latitudes during winter. Probably persistence is also partly responsible.

Advection of latent heat had to be ignored in the present work as no data were available.

Wind speed does not enter into the equations. This is supposedly due to the differing orientations of the roads, which would average out any effects. There was, however, a weak positive correlation between the class with wind speeds > 8 kn and road surface temperatures, confirming the well-known fact that stronger winds inhibit cooling. Thermal conductivity of the road body was represented by the occurrence or non-occurrence of precipitation. Here there was little or no correlation with road surface temperatures.

It should be noted that the results shown in Table III are optimistic, as the 0000 GMT screen temperatures as well as the cloud conditions during the night were taken from observations, whereas in operational practice these will have to be estimated by the forecaster. From previous experience (Roodenburg 1983) it is assumed that this will not lead to a serious deterioration of the results.

The equations have been programmed for interactive use on a computer. Quantities that have already been measured are fed in automatically. The system works satisfactorily.

6. Conclusions

Despite the limited data set and the rather crude way in which some of the physical processes involved have been represented, it is believed that the present method will be useful in providing the forecaster with guidance as to the lowest road surface temperature to be expected during the coming night.

Acknowledgements

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Closure of the meteorological office at Paphos

By. W. G. Durbin

(Meteorological Office, Akrotiri)

The closure of the meteorological office at Paphos in the south-west of Cyprus on 30 June 1984 marked the end of an unbroken period of hourly weather observations which, from the final site, began in May 1947. They were not, however, the first to be made from the Paphos area, there having been three earlier sites.

The first of these, established in January 1881 in the grounds of the town hospital, was known as Papho (not Paphos). Under the auspices of the local medical authorities, climatological observations were made twice daily at 9 a.m. and 9 p.m. by staff named Thomson, Olive and Young. The elements observed included air temperature (wet- and dry-bulb, maximum and minimum), rainfall (with estimated duration), cloud amount and type, atmospheric pressure and wind (direction in compass points and speed in Beaufort force). There was also what was called solar radiation but as it is unlikely that a Campbell–Stokes sunshine recorder would then have been available, even Kew Observatory having been equipped with one only the previous year in 1880, it was probably 'black-bulb' temperature rather than sunshine duration. Until June 1882 the returns were completed in an exemplary manner, beautifully written and with few errors, by the District Medical Officer Amin Moghabghab who, under an arrangement notified by a 'Fred W Barry Sc' who also countersigned the returns, had been given charge of the instruments from the end of February 1881. The heights of the barometer and rain-gauge were both originally given as 250 ft but in August 1881 the former was changed to 265 ft, possibly as a result of reassessment. In December 1881 they changed to 230 and 204 ft respectively which suggests a minor move to a nearby location. There were no returns for July 1882 but from August of that year they were signed by the new District Medical Officer Elia Malliotis who remained in post until December 1900. In 1901 a Mr Entwistle took over the station and the height of the barometer cistern changed to 243 ft. Thereafter the returns bore various signatures including, from 1908 to 1910, a Mr Ierotheos V. Zachariades who signed himself 'Government Compounder'. In the early days the name of the town was Ktima and it was in favour of this that in 1900 the name Papho was dropped but in December 1911 there was another change with the returns being headed 'Paphos Hospital'.

Observations from the second site, the latitude and longitude of which were given as 34°46′20″N, 32°25′40″E, began in January 1917. At that position, which is half a mile or so south of the first site, the height of the ground above mean sea level is about 160 ft so either that position or the 100 ft given for the height of the rain-gauge is in error. Returns continued from this location until June 1936 when apparently the station closed. From 1922, however, the returns were sent to the Physical Department in Cairo, regrettably without a copy being kept in Cyprus, and it has not been possible to trace them.

For a short period from 5 November 1940 observations recommenced on an hourly basis from the coastguard station which, as the third meteorological site, was at Paphos castle, but in 1941 they became three-hourly, possibly for reasons of staff shortage. The move to the final location, some 400 metres to the north-north-west on what was then open ground, took place at the end of 1944. The heights above mean sea level of the barometer cistern and rain-gauge became and remained at 28 and 33 ft respectively, notwithstanding a further move of 100 metres or so on 21 January 1947.

The Paphos office was the last of three initially set up in co-location with coastguard stations for observational purposes in support of operational flying by the RAF. The others which opened in 1941 were at Cape Andreas and Kyrenia castle. The former provided 3-hourly observations until, owing to problems concerned with the provision of drinking water, it moved in 1954 to Ayios Nikolaos. It was eventually to close in 1977 as a consequence of the opening of the nearby meteorological station at Larnaca airport. The station at Kyrenia moved to Morphou where it closed in 1963. These stations provided advance notification of weather approaching from different directions which would affect RAF airfields of which, after 1974, only Akrotiri remained. The importance of Paphos in this context can be judged from the fact that the next nearest observations to the west are from Crete, about 400 miles away. Paphos is only some 35 miles from Akrotiri but, when the weather is approaching from that direction, its hourly weather observations and four-times daily pilot balloon ascents have enabled changes likely to affect landing conditions at Akrotiri to be forecast more precisely, a matter of greater importance when aircraft having limited fuel reserves are being dealt with.

The Paphos office closed because Cyprus's second civil airport which has been built a few miles away requires its own meteorological station and there is no necessity for two to continue to exist so close to each other. The new airport opened, for day flights only, on 1 November 1983 with observations for 12 hours a day but from late March 1984 they were extended to 18 or 24 hours depending on the use being made of the airport. With the continuous RAF requirement for Paphos observations to be available throughout the 24 hours a period of overlap was necessary but, from 1 July 1984, only the airport meteorological office, administered by the Cyprus Meteorological Service, remained.

Archaeology

As an area of interest in Cyprus, Paphos has a history going back several thousand years and there are many archaeological sites to attract the tourist. One of the most important finds was made in 1962 when about 200 metres north-east of the meteorological office site, diggings brought to light the House of Dionysos, a Roman villa dating from the third century AD. Its rooms, grouped around an open court, are paved with mosaic designs, some of which are geometric while others include subjects taken from Greek mythology and many are in a perfect state of preservation. Two hundred metres or so to the south-south-west another important find, also with well-preserved mosaics dating back to the fourth century, is the Palace of Theseus which probably served as an official residence of the Roman governor of Cyprus. Excavations have continued in the area bringing to light a theatre, the remains of many less important dwelling places and, within the last year or so, yet another important mosaic, this one being at the entrance to the path leading to the meteorological office. It will clearly be a time of great excitement when, with the closure of the station and the handing over of the site of the Cyprus government, excavations can begin to find out what lies underneath.

Staff

Reference has already been made to staff who from 1881 were concerned with the provision of observations from earlier locations of the meteorological station. The last site, occupied since 1944, was of rough grassland and had an abundance of snakes which was a problem to the staff who were required regularly to visit the enclosure, both by day and by night, to read the instruments. In 1963, one of them named Angelos Andreou, having tried other means of keeping them away such as by the planting of

Photograph by courtesy of Mr I. J. W. Pothecary

Staff of the meteorological office at Paphos, May 1984. From left to right: Messrs Pavlos Hajinicola, Pavlos Constantinides, Demetrius Kyriacou, Lewis Deacon and Costas Kyriacou.

garlic, decided to keep a cat. Owing to the apathy of his colleagues, he regularly visited the office during his days off to feed it but with his wife objecting to the extent to which her husband's spare time was being eroded, the problem became more serious when the cat produced four kittens. Andreou decided to refer the matter to the Senior Meteorological Officer at Nicosia and asked for a daily allowance both to buy tinned food for the cats and to oblige his colleagues to feed them. The S Met O consulted the Financial Adviser at HQ NEAF who, to the surprise and amusement of all concerned, authorized the Assistant-in-Charge at Paphos to draw a cat allowance of one shilling and threepence a day to buy tinned food. The cat thus came on to the office strength and the allowance continued until it closed. The last cat, called Tiger, was the third in line, the first having been killed and the second having disappeared — perhaps enticed away to a better-paid job at, for example, one of the nearby fish meze restaurants. The third, which was in post for some five years, was very good, always around the office and on parade at times of inspection, and the snake menace was kept well under control.

At the time of its closure the Paphos office had a staff of five. With its closure two of them, Mr Demetrius Kyriacou and Mr Pavlos Hajinicola have been transferred to Akrotiri but the others, each with 35 years of service, will retire. Mr Lewis Deacon, who was in charge at Ayios Nikolaos when it closed, will retire to Larnaca. Mr Pavlos Constantinides will retire to his village of Aradippou which is near Larnaca, and the brother of Demetrius, Mr Costas Kyriacou, who was in charge, will retire to Nicosia.

All those who have served in Cyprus and who, as visitors to the Paphos office, have enjoyed the warm hospitality of its staff, so much a feature of the Cypriot people, will wish them long and happy retirements.

Notes and news

Retirement of Mr Geoffrey J. Day

When Mr G. J. Day, Assistant Director, International and Planning, retired from the Meteorological Office on 11 September 1984 he completed a career of 34 years in which he had filled at least ten separate posts and had left his own individual mark on all of them.

Geoff Day was educated at Bablake School, Coventry and, following a period of National Service from 1943–46, he went on to gain his B.Sc. (Hons) at St. Andrews University, Fife. After a brief foray into the coal industry, he joined the Office as a Scientific Officer in November 1950. After initial training he was posted to the Meteorological Research Flight where he worked hard and successfully on measurements of the liquid water content of cumuliform clouds and on sampling freezing nuclei using new instruments of his own design.

In autumn 1955, following promotion to Senior Scientific Officer, he moved on to Kew Observatory where he quickly became energetically involved in the problems of measuring solar radiation. It is not surprising that he foresaw the need to implement a nationwide network of radiation instruments, and that he was sorry when the time came for his next move, to Eskdalemuir as the Superintendent in January 1959. At Eskdalemuir, Mr Day was in charge of, as well as routine administration, a wide range of geophysical scientific apparatus covering measurements in geomagnetism, atmospheric chemistry, solar radiation and atmospheric electricity. He suggested and carried out many improvements to the instruments and also made a broader survey, comparing magnetic standards at the Observatories which then existed at Lerwick, Eskdalemuir, Stonyhurst and Hartland.

In 1961, and with some reluctance at first, he moved to a forecasting post at Prestwick Airport. However, he quickly set about learning the new skills required, and his positive approach and alert mind turned out to be well fitted for the shocks and strains of synoptic forecasting. Before the year was out he was promoted to Principal Scientific Officer and had become a Senior Forecaster at Prestwick with all the duties that the post entailed. By August 1963 he was in charge of the Main Meteorological Office at Prestwick, and he was then moved again, this time to take over as the Senior Meteorological Officer at Luqa, Malta. While in Malta he had some of his earliest experiences of negotiating as a UK representative on the AFMED, AFSOUTH Meteorological Committee at meetings in Toulon and Naples, and of the work of WMO as the UK Observer at a meeting of Regional Association I—Africa in Lagos.

In September 1966 Mr Day returned to research and to the post of Superintendent Met R D at Porton Down. There his research effort was directed to the microphysics of the planetary boundary layer, and his negotiating skills were turned to providing co-operative liaison between his Unit, CDE and MRE. He successfully obtained, and ran, the old Mercury computer (ex-Bracknell) while acting as Chairman of a Meteorological Office/CDE/MRE Working Party to specify a suitable ICL 1905 computer system to meet the needs of the whole Porton Down Establishment.

By June 1971 he had spent over four years at Porton, so he was again moved, this time to be Head of the section of the Operational Instrumentation Branch in charge of the development of new operational surface instruments (Met O 16a) and with special responsibilities for automatic weather stations. Once again he took to his new environment with enthusiasm pressing forward in various areas of intrument development and playing an increasing role in international matters, first as Chairman of the COST Project 72 Working Panel on Automatic Weather Stations, then in WMO Commission for Instruments and Methods of Observation affairs, and later in the COST 43 Sub-group on a Faeroes/Shetland data buoy network. His name began to be well known in WMO and IOC (Intergovernmental Oceanic Commission) circles where he created a very favourable impression by his capable and diplomatic manner. He also showed considerable organizational and administrative skills acting as the deputy to the Assistant Director, and few of us were surprised when, in July 1975, he was moved yet again, but this time on promotion to Senior Principal Scientific Officer.

Mr Day was ideally suited to his new post as Assistant Director, Observational Requirements and Practices. His Branch (Met O 1) was concerned with running the network of observing stations and upper-air stations, with trials of new equipment, and with the definition of the requirements of the forecasters for new observations and measurements. The post also gave him an increased involvement in international affairs through participation in the WMO Commission for Basic Systems Working Group on the Global Observing System and as a member of the IOC/WMO Working Group on the Integrated Global Ocean Station System Basic Observing Network.

In December 1977 came his final, and most important move, to the rather special task of Assistant Director, International and Planning. In this post he acted in close proximity to the Director-General as an aide in the preparation of briefs for sessions of WMO and its constituent bodies and as a focal point in the United Kingdom for communications between international bodies, such as WMO and State Meteorological Services, and the Meteorological Office. His skills of diplomacy and tact, his professional knowledge and his shrewd common sense combined to make him a true ambassador for the United Kingdom, and he played an increasingly prominent part in the affairs of WMO and the European Centre for Medium Range Weather Forecasts (ECMWF). As Deputy to the Permanent Representative of the United Kingdom at attendances of WMO Congress and the Executive Committee he earned much respect and goodwill, and as time passed he was to be found as Chairman of the Working Group on Antarctic Meteorology, Chairman of the ECMWF Finance Committee and Chairman of the Programme Board for ASDAR (Aircraft for Satellite Data Relay), all tasks to which he was elected on the basis of the competence and diplomacy that he showed.

Geoff Day had a reputation as a 'bit of a rebel' in his early days, and was given to occasional outbursts of anger. This was no doubt largely due to frustration at the frequency of his moves, which, each time, seemed to occur just as he was beginning to make real progress. He was also often ahead of his time in seeing the need for changes in organization and management, and this too caused his wrath. It is interesting to reflect on the way he has transformed these characteristics, and to note that he will be missed now both in international and national circles for his diplomacy, charm and professional ability. He will be continuing his interests in some WMO activities after his retirement and I hope that he will continue to drop in to see us for many years to come. We wish him and his wife, Barbara, a long and happy retirement.

D. N. Axford

Meteorological observations of the Welsh Plant Breeding Station

In November 1983, Mr 'Wil' Evans of the Welsh Plant Breeding Station (WPBS) Agronomy Department was presented with a barograph to mark 30 years of observations for the Meteorological Office. The presentation was made by Dr J. R. Starr, Regional Agrometeorological Officer for Wales, on behalf of the Director-General and in the presence of the retiring Director of the WPBS, Professor J. P. Cooper, FRS.

WPBS carries out research and development work into the improvement of crops such as grasses, clovers and cereals, which are important in livestock production, particularly in Wales and the west of Britain. Climatological observations have been made at WPBS since soon after its establishment in 1919, initially at Frongoch, a hill site at 138 m above mean sea level (amsl), 2 km east of Aberystwyth.

Investigations into hill land improvement led to the establishment in 1927 of a further climatological site 11 km inland at Llety-Ifan-Hen (290 m amsl). When, in 1953, WPBS moved to Plas Gogerddan, 4

Photograph by courtesy of Cambrian News

Mr 'Wil' Evans (centre) being presented with a barograph by Dr J. R. Starr, in the presence of Professor J. P. Cooper, FRS.

km inland from Aberystwyth, Mr Evans began observations at the new meteorological station (Gogerddan, 31 m amsl).

All three sites became agrometeorological stations. Subsequently, two further stations at Syfydrin, 335 m amsl, 14 km inland, and Pant-y-dwr, 305 m amsl, 40 km inland, were maintained for a time in the 1960s and 1970s. These WPBS sites, situated near a west–east transect running eastward from Aberystwyth along latitude 52°25′N, were considered representative of the main zones of upland grassland production, with the associated climatological, geological and hydrological characteristics.

Frongoch ceased to be an official recording station in 1969; Llety-Ifan-Hen ceased in 1976, having had only two observers in its 50-year history!

The data assembled from these various WPBS sites over the years have emphasized the extent of altitudinal, topographic, seasonal and diurnal restraints on grassland production and have led to breeding and management programs to improve grassland potential.

Meteorological Magazine — increase in price

As from January 1985 the price of an issue of the *Meteorological Magazine* will be £2.30 and the annual subscription will be £27.00 including postage.

Review

Cloud dynamics, by L. T. Matveev. 164 mm × 246 mm, pp. x + 340, *illus.* D. Reidel Publishing Company, Dordrecht, Boston, Lancaster, 1984. Price Dfl 190.00.

This book is primarily a review of the cloud physical research that has been carried out in Russian institutions over the past 10–15 years. It makes fascinating reading, for although all the major subjects are covered, the approach is often totally different from that to which western scientists have become accustomed. As such the book will be of interest mainly to scientists actively engaged in research.

I found the book difficult to read, mainly because many important points were merely hinted at and then followed by a long string of reference numbers, in one case 20; at least if the names had been given, one or two might have been recognizable and the point grasped without constant recourse to the reference section. There was also the difficulty that well over 90% of the papers mentioned were Russian, (and not easily obtainable) and the few foreign papers that were quoted were generally fairly old. It would have been helpful if the references had been equally split between Russian and foreign sources.

The title of the book is also rather misleading. There is little discussion of cloud dynamics as such, the author being more concerned with microphysical processes within real clouds, and how they are influenced by the air motion. This approach is most evident in the mesoscale section where only 6 pages are devoted to the modelling and description of the air motion within convective clouds. Equally disappointing was the section on the prediction of cloudiness and precipitation. This chapter contained a large section on the Meteorological Office 10-level model, and the, now famous, integration of 1 December 1961. There was little description of subsequent results.

The main value of this book is that it is a review of Russian literature and current Russian ideas. As such it provides a useful summary of a vast body of literature that is not easily obtainable in the west. However, it will be of little use to the student trying to understand the subject.

D. A. Bennetts

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