

Instant occlusions  
Management of meteorological data  
Winter of 1987/88  
A forecaster's storm



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## The development of instant occlusions in the North Atlantic

**J.B. McGinnigle**

Meteorological Office, Royal Air Force, High Wycombe\*

**M.V. Young and M.J. Bader**

Meteorological Office, Bracknell

### Summary

The evolution of the traditionally interpreted 'instant occlusion' is explained using satellite and radar imagery, synoptic observations and numerical-model diagnostics. An alternative analysis scheme is proposed for the cases studied in this paper. The main physical processes are described in the form of simple airflow models. Finally, forecasting guidelines are presented.

### 1. Introduction

In the North Atlantic, it is often necessary to predict the synoptic evolution and resulting weather distribution during interaction between a front and an approaching cold-air vortex or polar trough. The two features, both of which are readily identified on infra-red satellite imagery, may remain separate or merge. Where merging occurs it is conventional (Anderson *et al.* 1969) to place an 'instant occlusion' along the cloud band originally associated with the polar vortex since the cloud pattern resembles a classical occlusion, although its evolution and structure differ (see Fig. 1).

Locatelli *et al.* (1982) studied a number of cold-air vortices interacting with a polar front and proposed the analysis scheme reproduced in Fig. 2. Upon merging, the low-pressure centre and the main transition to cold air were associated with a cold-air vortex rather than the polar front.

For the cases presented in this paper, an analysis scheme adopting the same principle as Locatelli *et al.* (1982) is proposed, with the cold-air vortex being treated as a separate baroclinic disturbance which interacts with the polar front. The revised analysis is shown to be consistent with the thermal gradients which develop around the cold-air system and describes the synoptic evolution and associated weather more realistically than the traditional 'instant occlusion'. Browning and Hill (1985) studied a similar type of system and derived the simple conceptual model shown in Fig. 3(a), relating the principal cloud-features to ascending airflows or conveyor belts. In the cases studied in this paper, the cloud band of the cold-air vortex corresponds to a warm conveyor belt (labelled W in Fig. 3(b)) derived from a

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\* Now at Meteorological Office, Bracknell.

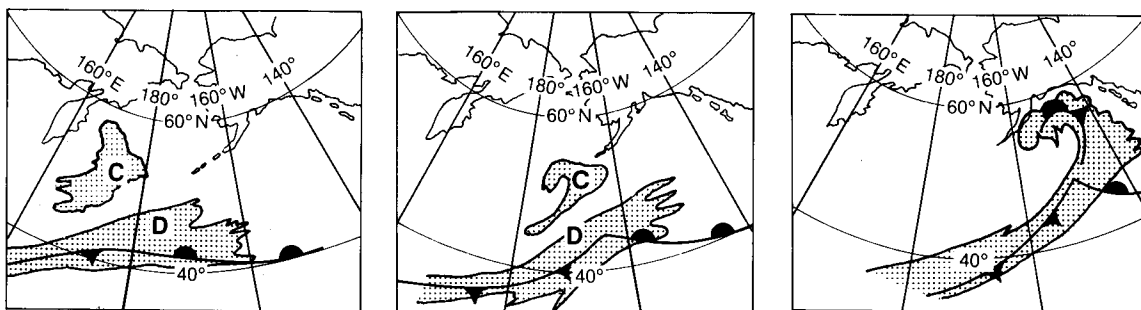


Figure 1. Evolution of cloud features resembling the instant occlusion as portrayed by Anderson *et al.* (1969), stippling representing the main cloud areas. Cloud labelled C is associated with the polar vortex, and D with the polar front.

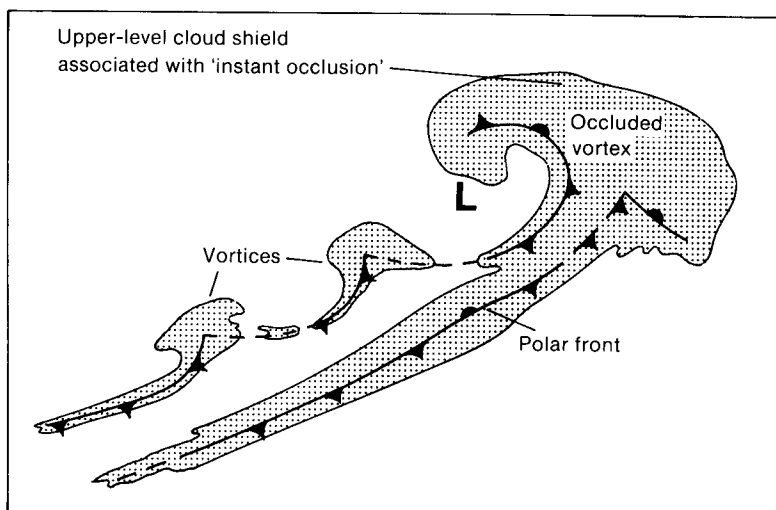


Figure 2. Schematic representation of polar vortex/polar front interaction reproduced from Locatelli *et al.* (1982).

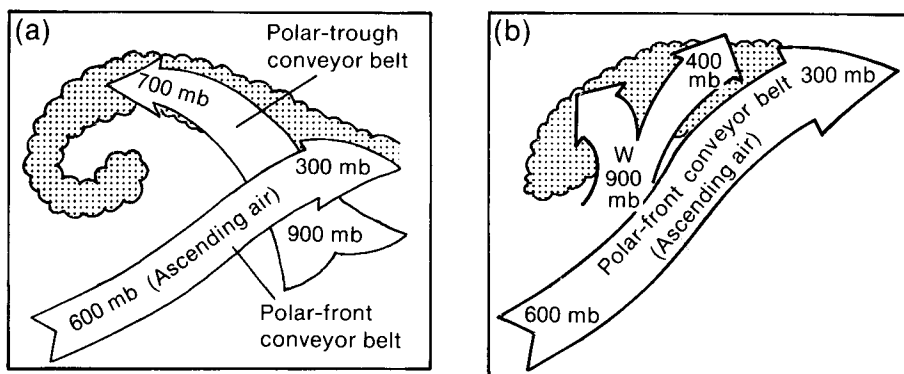


Figure 3. Airflows relative to the motion of the cloud band of the cold-air vortex in the systems described (a) by Browning and Hill (1985), and (b) in this paper. In (b) W is the conveyor belt referred to in the text.

shallow layer of moist air behind the band rather than a flow orientated along its axis as in Fig. 3(a). The difference between the two flow regimes appears related to whether the cold-air feature possessed baroclinicity prior to interaction with the polar front.

The study is based mainly on the case of 7–10 February 1987 and is supported by evidence from two other similar cases. We seek to

- (a) describe the synoptic-scale evolution by relating the features on the imagery to the surface and upper-air analyses and the main dynamical processes,
- (b) describe the sequence of surface weather,
- (c) suggest a simple model of the principal airflows during the interaction and merging of the two cloud features, and
- (d) provide guidelines for the prediction of the development sequence.

## 2. The sequence from satellite imagery and surface analysis

Fig. 4 shows the sequence of events between 7 and 10 February 1987 as seen from NOAA satellite imagery. On the 7th (Fig. 4(a)) the significant features prior to interaction were

- (a) cold front F which is referred to in this paper as the forward cold front, and
- (b) two areas of enhanced convection A and C in the polar air which were accompanied by surface troughs (Fig. 5(a)).

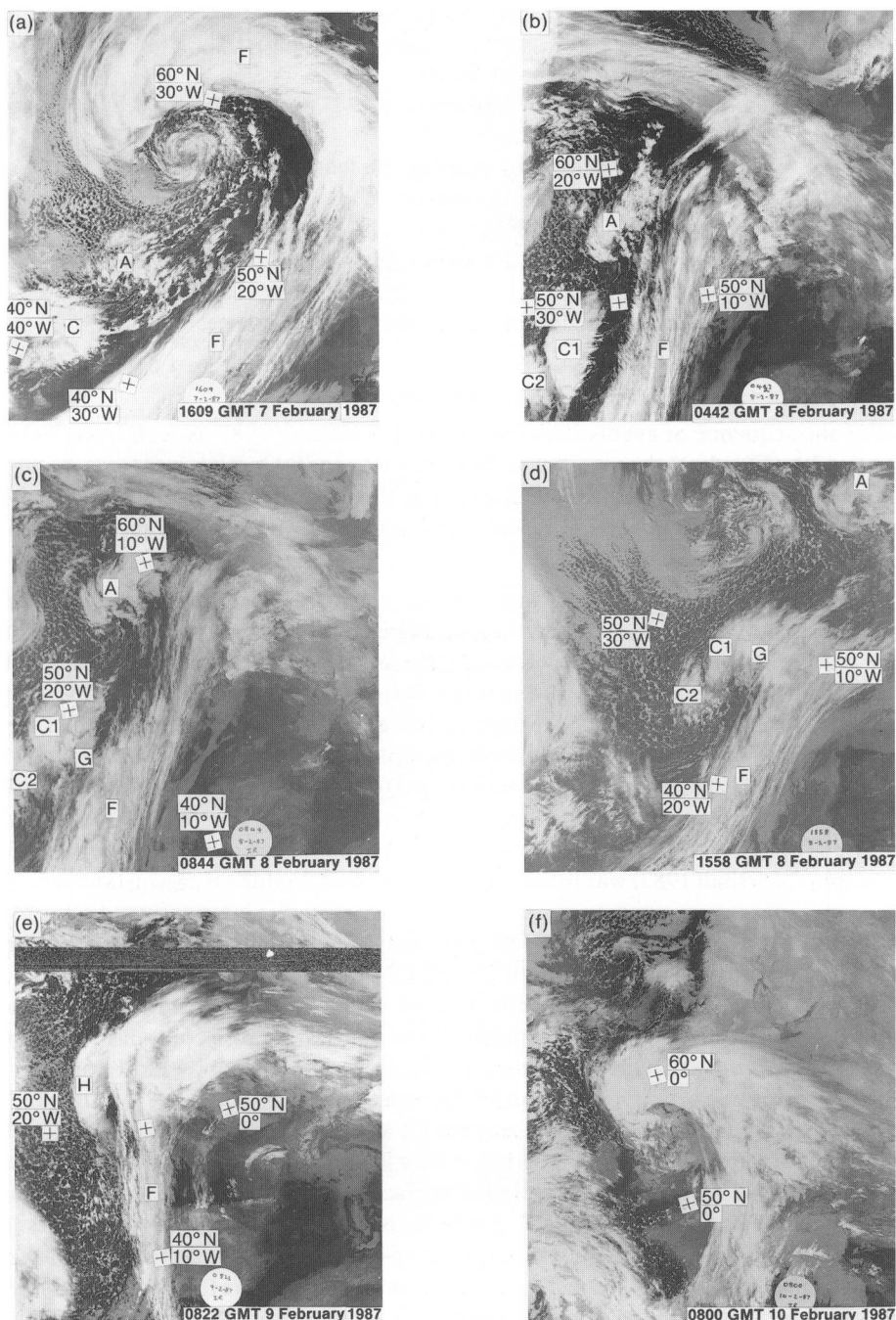
Examination of earlier satellite imagery and synoptic charts revealed that C originated from a front which had moved east over Canada. It then became engaged into a western Atlantic upper trough as a weak surface feature retaining some baroclinicity. Thus C inherited a gradient of wet-bulb potential temperature (WBPT) as shown in Fig. 5(a) and is therefore analysed as a cold front; this is referred to as the rearward cold front in this paper. In contrast, A had much less baroclinicity. A and C resemble the vortices shown in Fig. 2 which are detached from the polar front.

Area A moved quickly north-east (Figs 4(a) to 4(d)) accompanied by its surface trough which eventually came to lie close to the occluded front north of the British Isles where it lost its identity as a separate feature. The criterion that the polar vortex should approach the front to within 350 n mile to initiate interaction (Marshall 1982) was found not to be satisfied. In this case an instant occlusion did not form.

By the early morning of the 8th, C had moved north-east, approximately parallel to the north-western edge of F, and evolved into two distinct clumps C1 and C2 (Fig. 4(b)). The leading clump, C1, contained much layered cloud (with embedded convection) whilst C2 had more broken cloud. An indication of baroclinicity can be inferred from satellite imagery if the cold-air feature contains dense layered cloud which can sometimes be leaf-shaped (Weldon 1979), instead of being a small convective comma, characteristic of a positive vorticity advection (PVA) maximum.

During the morning, new cloud G formed between C1 and F (Fig. 4(c)). By 1200 GMT, a minor wave had formed on the forward cold front (Fig. 5(b)). A new low of 1011 mb had developed at the northern end of the rearward cold front. (A more detailed surface analysis is presented by McGinnigle *et al.* (1988).) Tightening of the 850 mb WBPT gradient north of this new low suggests that warm frontogenesis was taking place. By the afternoon, the tops of G had grown to form a nearly continuous cloud mass between C1 and F (Fig. 4(d)). The upper cloud appeared to rotate cyclonically to form hook H (Fig. 4(e)) which advanced ahead of the rearward cold front. Meanwhile the originally well defined southern tail of C1 became increasingly fragmented (Fig. 4(c)) and difficult to identify. G and H together gave the appearance of an 'instant occlusion' linked to a wave (see Fig. 1).

On the 9th (Fig. 4(e)), the wave and hook remained identifiable but the frontal cloud to the south narrowed and became more fragmented. By 1200 GMT on the 9th, the frontal wave had moved quickly



**Figure 4.** NOAA infra-red imagery for 7–10 February 1987. (a) 1609 GMT on the 7th, (b) 0442 GMT on the 8th, (c) 0844 GMT on the 8th, (d) 1558 GMT on the 8th, (e) 0822 GMT on the 9th, and (f) 0800 GMT on the 10th. All times are equator crossing times. Cloud areas A, C, C1, C2, F, G and H are referred to in the text. Selected latitude/longitude intersections are shown by a cross. (Photographs by courtesy of University of Dundee.)

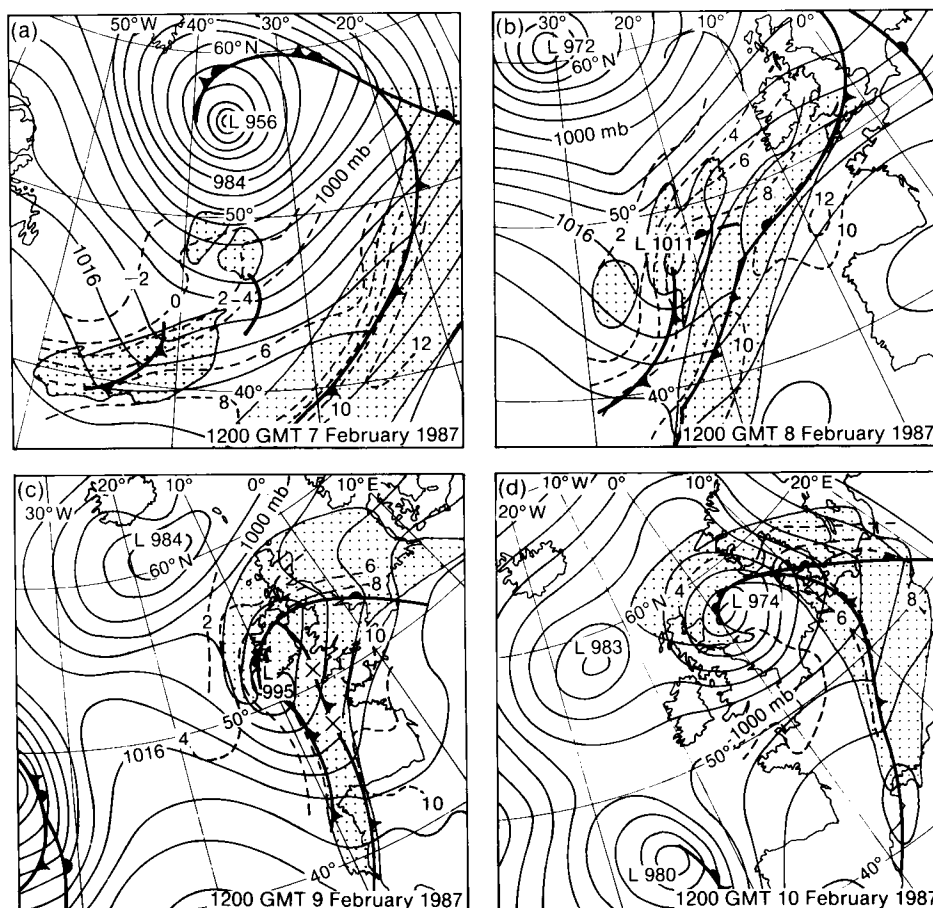


Figure 5. Analyses of sea-level pressure and frontal positions, model-analysed 850 mb WBPT ( $^{\circ}\text{C}$ ) (dashed lines), and upper-cloud areas (stippled) derived from available NOAA and Meteosat imagery for 1200 GMT on (a) 7, (b) 8, (c) 9, and (d) 10 February 1987. The bold line on (a) at approximately  $45^{\circ}\text{N}$ ,  $34^{\circ}\text{W}$  is a surface trough.

north-east to Northern Ireland (Fig. 5(c)) deepening to 996 mb while the cold-air low had deepened to 995 mb. This low became co-located with the cloud-free slot near south-west Ireland (Fig. 4(e)) whilst the forward cold front progressively lost its identity. As the complex low-pressure area over the British Isles transferred eastwards it steadily deepened, consolidating into one centre forward of the cold-air low which soon lost its identity.

### 3. Upper-air and dynamical considerations

The 300 mb winds and contours for 1200 GMT on 7, 8 and 9 February 1987 are presented in Figs 6(a), 6(c) and 6(e) respectively. Areas of ascent, descent and thermal advection analysed by the Meteorological Office fine-mesh model (Gadd 1985) are shown in Figs 6(b), 6(d) and 6(f) for the same times. The main cloud areas derived from satellite imagery are superimposed on all the fields. The model can be used to explain the dynamics because its cloud and humidity fields were consistent with the satellite imagery over the area of interest even though analysis of the cloud-free slot and hook at 1200 GMT on 9 February was a little too far east.

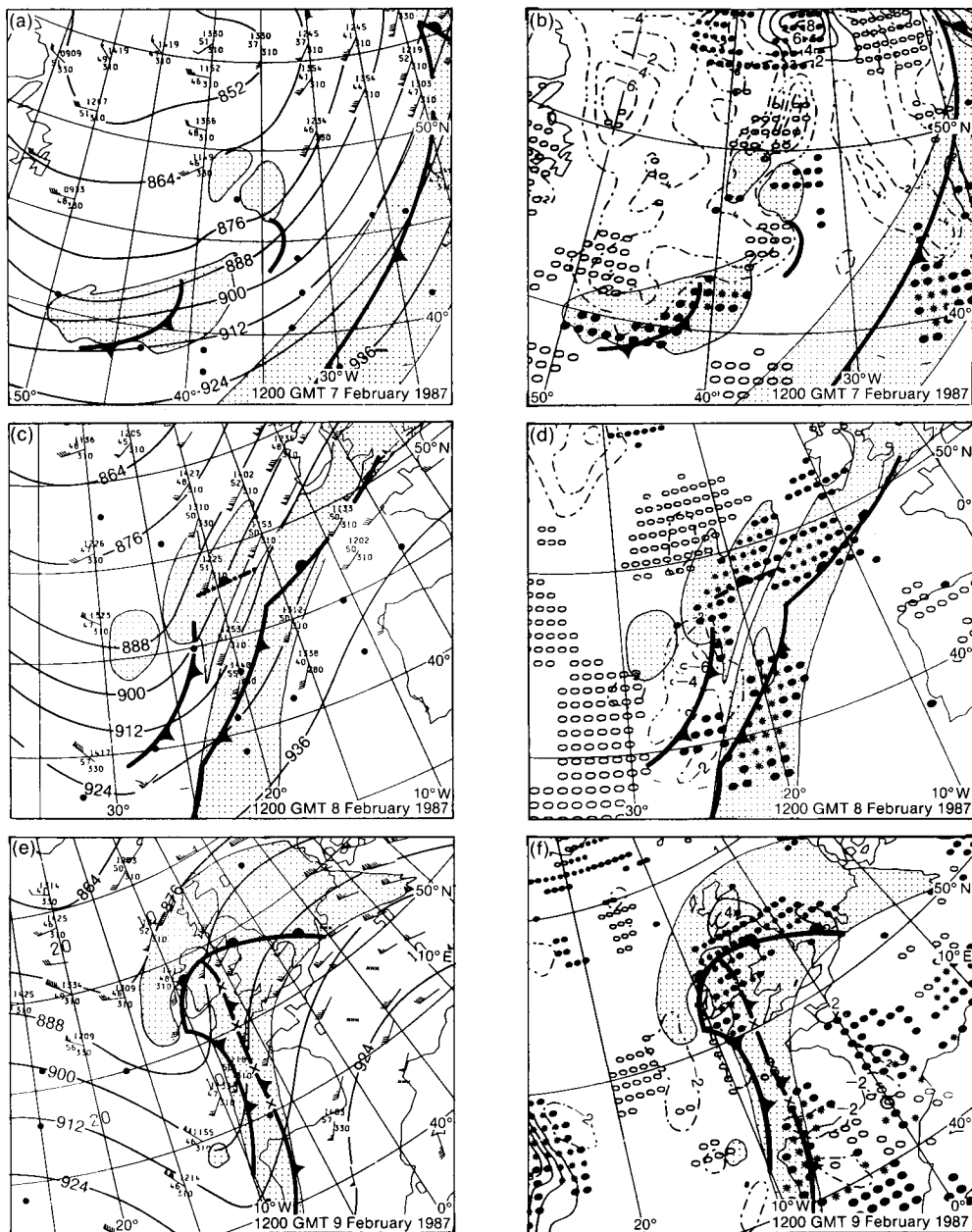


Figure 6. Upper-air pattern, model diagnostics and upper-cloud areas for 7-9 February 1987. (a) and (b) 1200 GMT on the 7th, (c) and (d) 1200 GMT on the 8th and (e) and (f) 1200 GMT on the 9th. Surface fronts are shown conventionally and troughs are shown as bold lines. In (a), (c) and (e) upper-cloud areas (stippled) are deduced from Meteosat imagery. Wind reports at 300 mb and from aircraft near that level are shown. Contours are in decametres for the 300 mb level. Other observation locations are marked by a dot. (b), (d) and (f) show upper-level cloud areas (stippled) and fronts superimposed on fine-mesh model analyses of vertical velocity ( $\circ$  6.2  $\text{mb h}^{-1}$  or more descending,  $\bullet$  6.2-12.5  $\text{mb h}^{-1}$  ascending and  $*$  12.5  $\text{mb h}^{-1}$  or more ascending), and thermal advection ( $^{\circ}\text{C}/6\text{h}$ ) averaged over the 850-500 mb layer (solid contours indicate warming, dash-dot contours cooling).



At 1200 GMT on the 7th, cloud areas A and C were situated on the forward side of broad upper troughing covering the western half of the North Atlantic and were co-located with ascent in the lower and middle troposphere (Fig. 6(b)). This ascent resulted from PVA induced by short-wave troughs within the flow. Area A did not develop because it did not lie in a favourable part of the upper-air pattern.

By 1200 GMT on the 8th, the main troughing had moved east (Fig. 6(c)), and C1 remained within a PVA maximum ahead of the trough. C2, near the base of the trough, moved quickly towards Iberia and the cloud became broken (see Fig. 4(d)). Meanwhile ascent was co-located with C1; this expanded, intensified and extended towards the forward frontal cloud to the east. The region of ascending motion between the two cloud areas corresponded to the right entrance region of the jet, inferred from the upper-level wind observations on Fig. 6(c). Very little WBPT contrast now remained on the forward cold front due to advection of high WBPT between C and F. (On the forward side of the extending upper trough, another wave was carried eastwards towards Iberia, embedded in the large area of ascent (Fig. 6(d)), along with the remnants of C2.)

Following merging of C and F after 1200 GMT on 8 February, the upper trough continued eastwards (Fig. 6(e)) and a large area of warm advection giving ascent resulted in the cloud over the north of the British Isles (Fig. 6(f)). Within the frontal cloud to the south and near the hook, there was slight descent (Figs 4(d) and 4(e)) giving thinning and warming of the cloud tops.

This case is one of several in which the relationship between the imagery, upper-air pattern, and surface analyses were similar. For instance, Fig. 7 shows analyses of 500 mb height and 1000–500 mb thickness with added major cloud areas derived from imagery for the present case, 10–11 November 1986 and 7–8 December 1986. In each case, the cloud system in the polar air was embedded in a strong upper flow that carried it towards the forward front. Any earlier cyclogenesis in the cold air upstream which distorts the flow would prevent interaction between the two systems. Later in this paper, the implications of the similarities are exploited to produce general forecasting guidelines.

#### 4. Mesoscale weather distribution

The features on the imagery can be related in more detail to the frontal analysis as they crossed the British Isles on 9 February, soon after the NOAA image in Fig. 4(e). More frequent imagery from Meteosat and the UK weather radar network is presented in false colour in Figs 8(a) to 8(f).

The main features in the Meteosat infra-red image for 1100 GMT (Fig. 8(a)) have already been identified in section 2 except for some convective cloud, labelled T, over the south-west tip of Ireland in the originally cloud-free slot between the decaying forward cold front and the hook. This convection developed rapidly under a tongue of dry air aloft, clearly shown on the water vapour imagery (Fig. 8(b)) which depicts the distribution of moisture at about 400 mb (Eyre 1981). The dry air was observed above 470 mb in the radiosonde sounding from Valentia in south-west Ireland; the air was also unstable and, according to the numerical-model diagnostics (Fig. 6(f)), was rising ahead of the surface low near south-west Ireland (allowing for the slight longitudinal phase error in the model's analysis). Fig. 8(e) shows convection having closed the gap between the hook and forward cold front.

Other features of interest from the satellite and radar imagery are as follows:

- (a) There was a narrow band of rain to the west of England and Wales, associated with the forward cold front (Fig. 8(c)). This corresponded with the band of thicker cloud in the visible image (Fig. 8(d)). The rain gradually decayed as it moved east, especially over the southern half of the United Kingdom (Figs 8(c) and 8(f)). The band of heavy rain over the Irish Sea and North Wales is thought to have resulted from mid-level convection which had developed earlier behind the forward cold front.

(b) The thicker cloud on the eastern side of the hook shown in the visible image (Fig. 8(d)) corresponded to warmer tops in the infra-red image. Rainfall here was probably heavier and more widespread than further west where the cloud was thinner. Cloud warmed and decayed in the southern tip of the hook (Figs 8(a) and 8(e)).

(c) The area of rain over northern England was associated with ascent due mainly to warm-air advection (Fig. 6(f)) north of the warm front.

(d) The rearward cold front was difficult to identify from the visible and infra-red imagery.

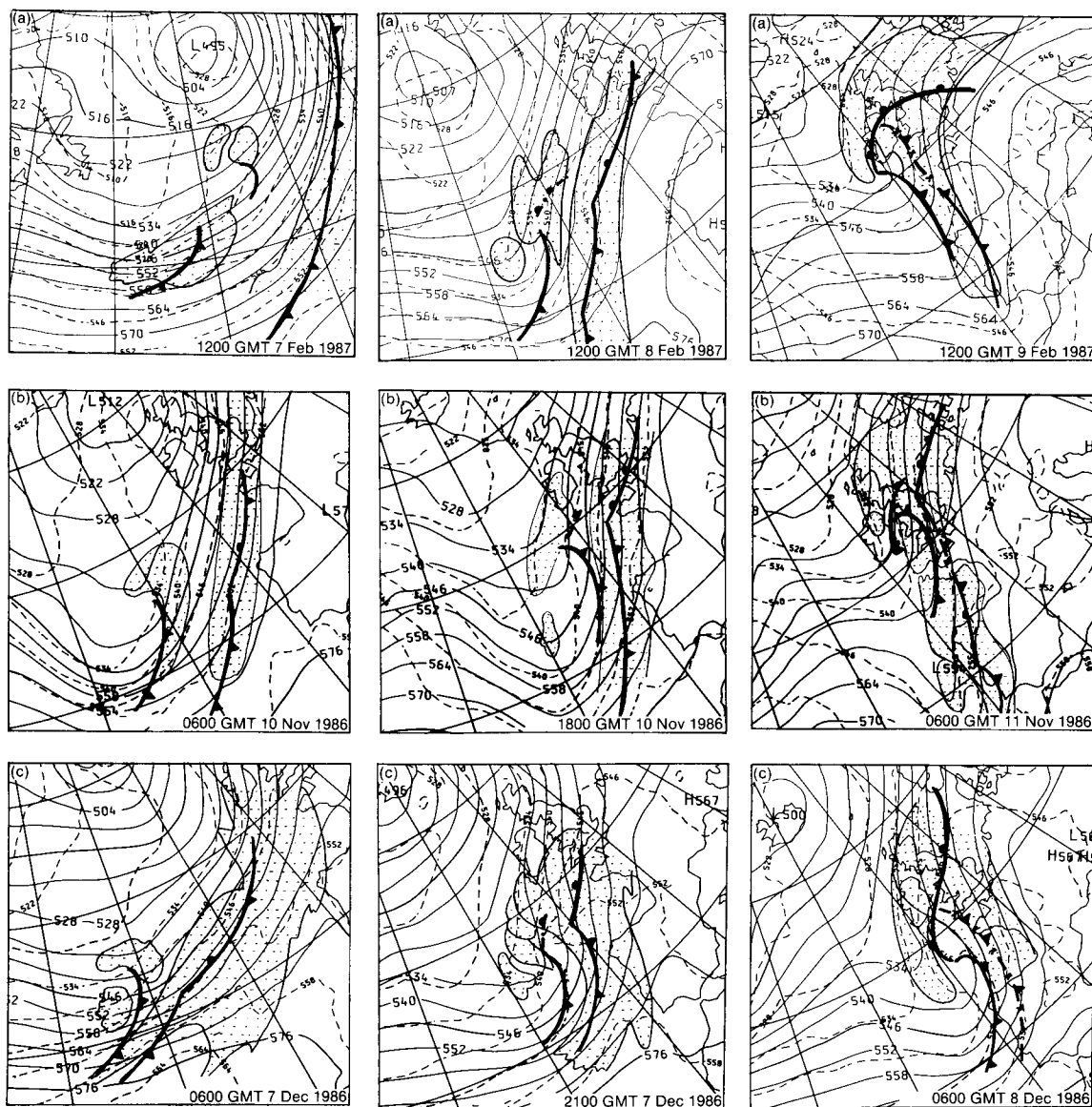


Figure 7. Sequences of upper-air analyses derived from the fine-mesh model for (a) 7-9 February 1987, (b) 10-11 November 1986, and (c) 7-8 December 1986. Continuous lines are 500 mb heights and dashed lines are 1000-500 mb thicknesses both in decametres. Upper-cloud areas are stippled.

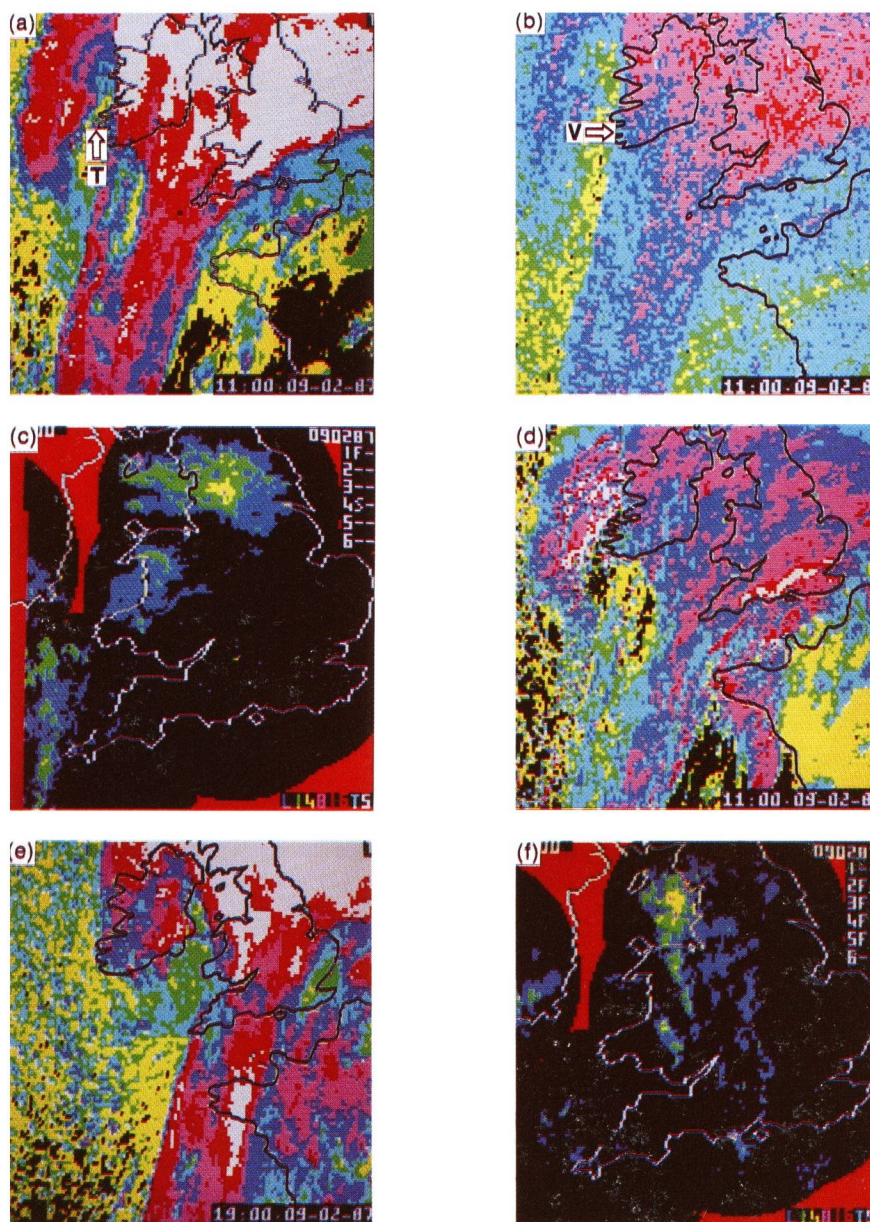


Figure 8. False-colour Meteosat and radar imagery for 9 February 1987. (a) Infra-red image for 1100 GMT. The colour scheme represents temperature slicing as follows: white, colder than  $-40^{\circ}\text{C}$ , red  $-40$  to  $-30^{\circ}\text{C}$ , mauve  $-30$  to  $-20^{\circ}\text{C}$ , dark blue  $-20$  to  $-10^{\circ}\text{C}$ , light blue  $-10$  to  $0^{\circ}\text{C}$ , green  $0$  to  $5^{\circ}\text{C}$ , yellow  $5$  to  $10^{\circ}\text{C}$ , and black warmer than  $10^{\circ}\text{C}$ . T is an area of growing convection referred to in the text. (b) Water vapour image for 1100 GMT. This shows the amount of moisture in the mid and upper troposphere, centred around 400 mb (Eyre 1981). The colour sequence is as in (a) and represents increasing dryness of the air, red being moistest, yellow being driest. V marks the location of Valentia. (c) Radar network imagery for 1100 GMT. Blue represents rainfall rate of  $< 1 \text{ mm h}^{-1}$ , green  $1\text{--}4 \text{ mm h}^{-1}$ , and yellow  $> 4 \text{ mm h}^{-1}$ . The apparent gap over south-west Wales is due to the radars not seeing rainfall at long range. (d) Visible image for 1100 GMT. The colour sequence is as in (a) representing decreasing reflectivity, white being the densest, most reflective cloud. Yellow and black are predominantly cloud-free areas. (e) Infra-red image for 1900 GMT. Colour slicing as in (a). (f) Radar network imagery for 1900 GMT. Colour slicing as in (c).

The surface analysis corresponding to the time of the imagery in Figs 8(e) and 8(f) is shown in Fig. 9. The forward cold front has been drawn through the line of patchy rain which could be followed on radar imagery, but there was little change of wind or dew-point across it. The thunderstorm reported over Ireland was within the region of convective activity identified in Fig. 8(e). The main air-mass change was at the rearward cold front where the dew-point fell significantly and the cloud base lifted but only patchy rain occurred. Fig. 10 is a time sequence of hourly observations from two stations in southern England, one coastal (Culdrose) and one inland (Gatwick), showing that the basic characteristics of the two fronts were preserved whilst crossing southern England. The warm front in Fig. 9 has been analysed along the warm side of the surface wet-bulb temperature gradient.

This case is one of several in which the evolution was similar. For example on 8 December 1986 (Fig. 11), as on 9 February 1987, there was deep convection immediately north of the cold-air vortex and lower dew-points followed the rearward cold front. The forward cold front was marked by a progressively weakening rain band. A schematic diagram showing cloud outlines, frontal analysis and weather is presented in Fig. 12, which will be used in section 6 for forecasting guidelines. The area bounded by the forward and rearward cold fronts and the hook is characterized by moist air near the surface and extensive low cloud, giving showery outbreaks of rain, and drizzle. Within the colder, drier air west of the rearward cold front, cloud becomes more broken and convective. Deep convection may develop between the hook and the forward frontal band.

The subsequent behaviour of the system following the stage depicted in Fig. 12 is governed by the large-scale upper-flow pattern. The cold-air surface vortex will, in most cases, be situated so near the upper-trough axis (Fig. 7) that it will undergo little further development and will soon begin to fill. The most favourable development area is found several degrees forward of the upper trough (i.e. well ahead of the original cold-air vortex) and this is where any further cyclogenesis would occur.

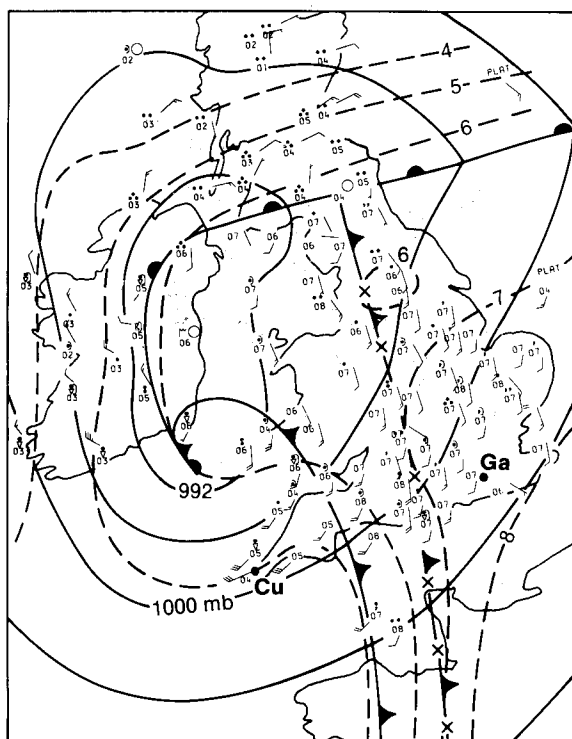


Figure 9. Surface synoptic analysis for 1900 GMT on 9 February 1987. Plotted observations show present weather, wind, and dew-point ( $^{\circ}\text{C}$ ). The locations of Gatwick and Culdrose are shown as Ga and Cu respectively. 850 mb WBPT isopleths ( $^{\circ}\text{C}$ ) derived from a model analysis at 1800 GMT are shown as dashed lines.

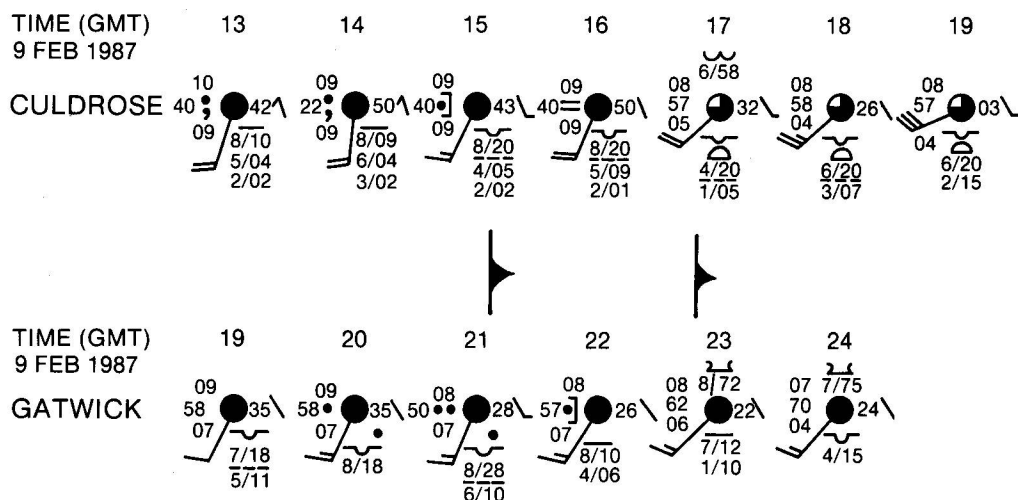


Figure 10. Sequence of hourly surface observations from Culdrose and Gatwick (labelled Cu and Ga respectively in Fig. 9) between 1300 and 2400 GMT on 9 February 1987. The cold front symbols are marked adjacent to the time of passage across both stations.

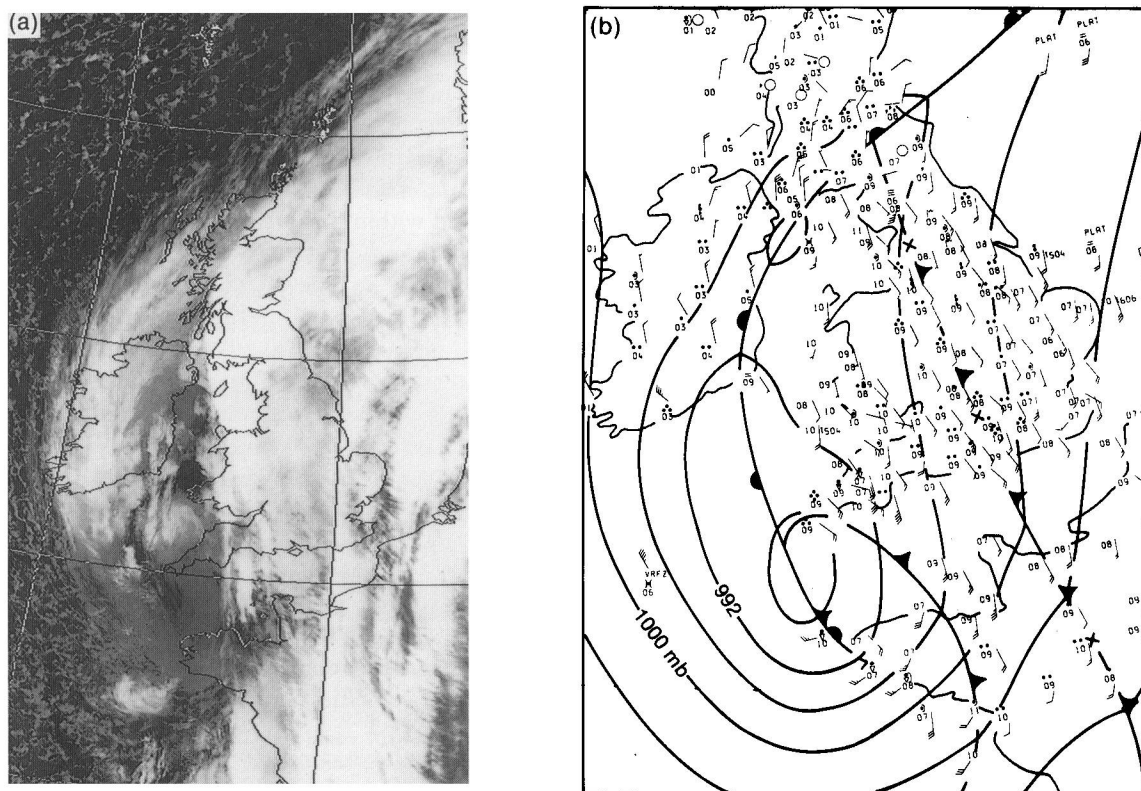


Figure 11. (a) NOAA-9 infra-red imagery and (b) surface analysis for 1500 GMT on 8 December 1986. The symbols on the surface analysis are as in Fig. 9. (Photograph by courtesy of University of Dundee.)



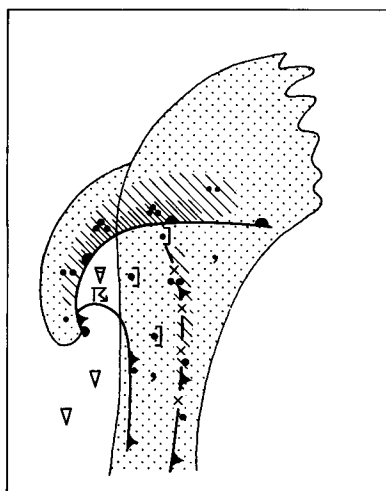


Figure 12. Schematic representation of upper-level cloud, and rainfall in the mature system as it crossed the British Isles. Current-weather symbols are used to depict observations characteristic of various parts of the system. Stippling represents upper-cloud areas, light hatching areas of light rain and dense hatching areas of moderate or heavy rain.

## 5. Conceptual model

Of the three cases already presented, that of 10–11 November 1986 provides the best opportunity of detailed understanding of the merging process since this took place in a data-rich area over the British Isles. Fig. 13 shows the merging of the two systems using a sequence of 3-hourly Meteosat infra-red and water vapour images. The cooling of the cloud tops can be seen in the former gap between the cold-air vortex and the forward frontal band with rapid moistening at upper levels. The pockets of locally heavy rain over the Irish Sea, labelled R in the radar image, occurred within this area of cloud growth, and amalgamated into an area of heavy rain over northern England shortly afterwards.

The hook consisted of three separate mesoscale convective elements labelled X, Y and Z. Region X expanded as it moved north-east whilst Y and Z dissipated and warmed. The differential motion of X, Y and Z produced the apparent rotation of the cloud envelope associated with the cold-air vortex.

Vertical velocities derived from fine-mesh analyses are also shown in Figs 13(a) and 13(c). Prior to merging, a band of upward motion extended across from the cold-air vortex to the forward frontal cloud with a separate maximum on each, then consolidated into a single region of ascent by 0000 GMT on 11 November. Following examination of the fine-mesh model analysis, it was found that the air immediately upwind of the region of rapid cloud growth was potentially unstable (McGinnigle *et al.* 1988). Therefore, merging appears to have been a response to large-scale forcing within a potentially unstable environment.

The airflow model presented in Fig. 14 proposes to account for merging of the cold-air vortex and frontal cloud band, formation and maintenance of WBPT gradients and the precipitation distribution. The model has been derived using rapid movie-loop sequences of half-hourly Meteosat images, along with fine-mesh model diagnostics (isentropic analysis, vertical velocities and 850 mb WBPT). The evolution is described in three separate stages.

### Stage 1 (Pre-merging stage)

The cold-air feature C, coincident with a PVA maximum, approaches a cold frontal zone F. At this stage C is composed of a series of convective cells generated at its rear edge, with anvils combining to

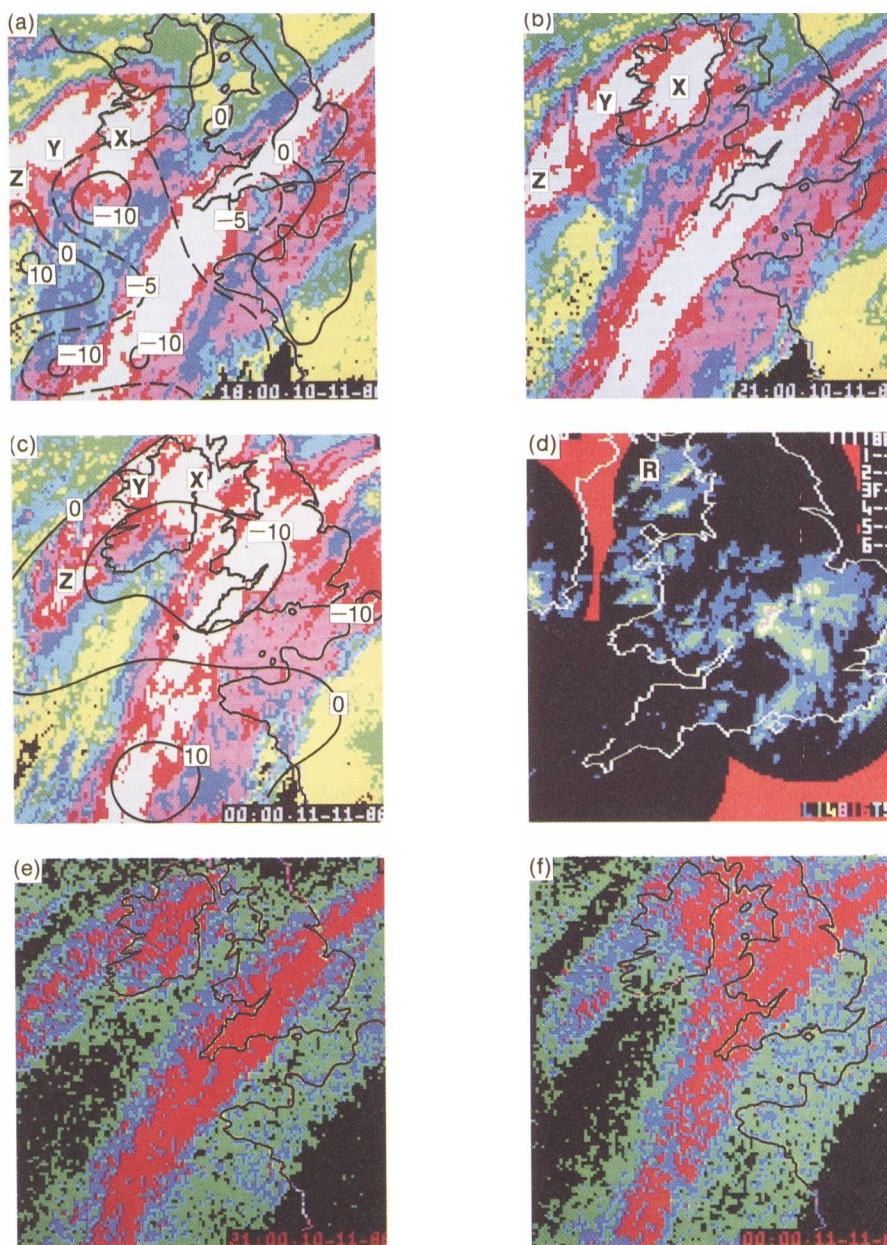


Figure 13. Sequence of Meteosat and radar images for 10–11 November 1986 showing merging of a cold-air vortex and frontal cloud band over the British Isles. Infra-red images are shown for (a) 1800 GMT and (b) 2100 GMT on 10 November, and (c) 0000 GMT on 11 November, the colour scheme being white, colder than  $-40^{\circ}\text{C}$ , red  $-40$  to  $-30^{\circ}\text{C}$ , mauve  $-30$  to  $-20^{\circ}\text{C}$ , dark blue  $-20$  to  $-10^{\circ}\text{C}$ , light blue  $-10$  to  $0^{\circ}\text{C}$ , green  $0$  to  $10^{\circ}\text{C}$ , yellow  $10$  to  $15^{\circ}\text{C}$  and black warmer than  $15^{\circ}\text{C}$ . Isopleths of vertical velocity ( $\text{mb h}^{-1}$ ) at 600 mb derived from model analyses are superimposed on (a) and (c), negative values representing upward motion. The letters X, Y and Z mark the convective elements referred to in the text. (d) Radar-network image for 0000 GMT on 11 November, the colours as in Fig. 8(c). R is the rainfall area referred to in the text. (e) and (f) are water vapour images for 2100 GMT on 10 November and 0000 GMT on 11 November respectively, black representing driest upper-tropospheric air, and green, blue and red successively moister air.

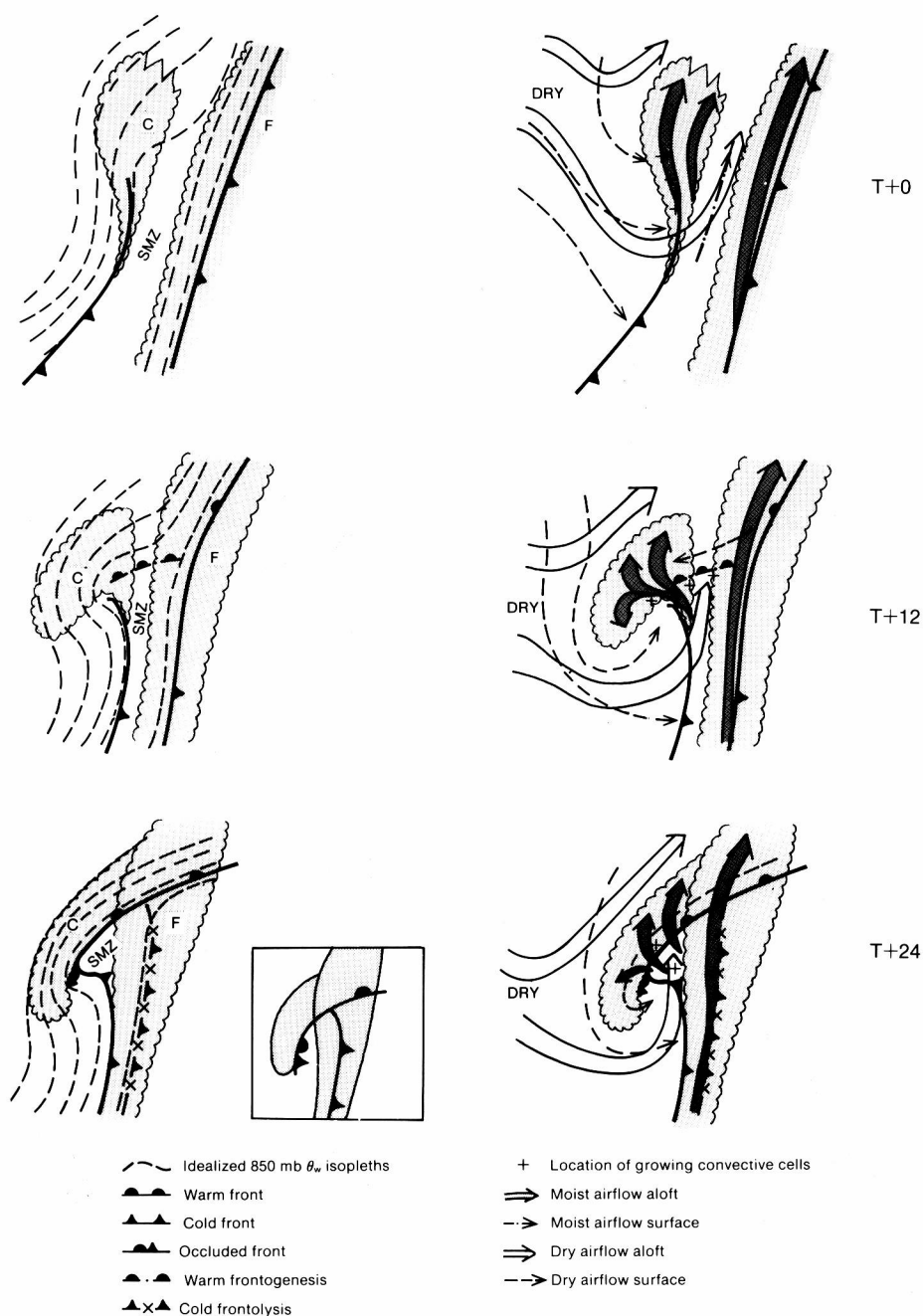


Figure 14. Life-cycle model showing the interaction between a polar air cloud feature, C, and polar frontal cloud, F, at approximately 12-hourly intervals. Such an interaction is conventionally interpreted as an 'instant occlusion' but a revised frontal analysis is presented here. Stippling denotes upper cloud. The figures in the left-hand column show idealized thermal structure superimposed on schematic upper-cloud outlines. In the right-hand column airflows relative to the system's movement are superimposed, broadening and narrowing arrows showing ascending and descending air respectively. SMZ denotes shallow moist zone. Inset shows the conventional analysis corresponding to stage 3.



produce the upper-cloud shield. At low levels, air of low WBPT follows the cold front at the rear of C. At middle and upper levels, dry air moves around the base of the trough within the strong upper flow, overrunning the tail of C, then travelling parallel to the sharp edge of F. At low levels, warm, moist air is advected ahead of C, weakening the thermal contrast associated with F and generating potential instability within a new shallow moist zone (SMZ) between C and F. This contrasts with the case of Browning and Hill (1985) in which the cold-air feature possessed little baroclinicity and so the thermal gradient was retained on the polar front. (In such cases, any new cyclogenesis would occur on the forward front rather than on the rearward frontal zone and the cold-air feature would remain separate from the main frontal cloud canopy, e.g. Browning *et al.* 1987.)

### *Stage 2 (The merging stage)*

C appears to rotate rapidly leaving behind a trailing low-level WBPT boundary. Convective cells continue to be generated at the southern rear edge of C, with a series of anvils carried forward, and dissipating upon encountering the dry air to the rear of F. The potential instability already created between C and F may then be released as ascending motion is imposed upon this region by a combination of warm-air advection and PVA. Rapid cloud growth then proceeds in the gap. Warm advection ahead of C generates a thermal gradient on its northern side and a low-level flow (similar to the cold conveyor belt described by Carlson 1980) is established from F towards C ahead of this nascent frontal zone.

### *Stage 3 (The mature stage)*

C and F have linked, thus completing the instant occlusion process as traditionally interpreted. The new front has been placed along the inside edge of the hook-shaped cloud, C, on the warm side of the 850 mb WBPT gradient. The edge of the cold-frontal cloud band may still be apparent above the hook and normally corresponds to the upper-level jet axis. (Since the temperature gradient along the rearward cold front occupies a shallow layer, the jet axis will normally remain ahead of it, tied to the forward front which, at upper levels, retains some thermal structure.) C becomes aligned with the upper trough (Fig. 6(e)) and, having stopped rotating, may appear unchanged for many hours. Warm, moist boundary-layer air from the SMZ ascends along the new frontal slope, producing a band of rain along the inside of the hook-shaped cloud C. Since this region is overrun by dry, low-WBPT air, some convection cells will also be generated. Continued but less rapid ascent associated with the newly-formed baroclinic zone produces progressively colder cloud tops towards the outside of the hook but with lighter rainfall. Deep convection may occur anywhere within the SMZ, but is most likely to become concentrated just ahead of the cold-air low where strong PVA is acting upon an environment that is destabilizing due to cold advection aloft.

The mature system corresponding to stage 3 differs from Browning and Hill (1985) in that cloud band C is fed by air with high WBPT from an SMZ behind it instead of a flow predominantly along its axis. The presence of this flow originating from a potentially unstable SMZ is crucial in determining whether new cloud growth and possibly heavy rain will occur within the previously cloud-free gap. Conversely, in cases where this flow is absent, (e.g. in Fig. 3(a)), precipitation intensity is suppressed near the intersection of the two cloud bands.

The analysis shown in Fig. 14 reflects the thermal and weather distributions more realistically than the commonly used 'instant occlusion' analysis, which is shown in the inset of the figure for comparison. The overall shape of the system corresponding to stage 3 resembles the 'cloud head' frequently observed prior to explosive cyclogenesis (Böttger *et al.* 1975, Monk and Bader 1988). Indeed, an analysis scheme by Monk (personal communication) similar to that proposed in Fig. 14 probably also applies in such cases.

A vertical section across the two cold fronts in stages 2 and 3 of Fig. 14 is similar to the split-front model (e.g. Browning *et al.* 1987). The weakening forward front acts as the 'upper cold-front' as it still possesses an upper-level moisture boundary despite very little surface temperature contrast. Meanwhile, the rearward front acts as the surface cold front.

## 6. Forecasting guidelines

In this section, forecasting guidelines are presented which are based on the foregoing case-studies.

(a) An 'instant occlusion' of the type described in Fig. 14 may form if all the criteria (i) to (iii) below are satisfied:

(i) A cold-air cloud cluster, which may be leaf-shaped, contains dense layered cloud.

(ii) Surface observations or numerical-model diagnostics (e.g. 850 mb WBPT) show that a thermal gradient is associated with this cloud.

(iii) The cloud is embedded in a strong upper flow that will carry it to within 350 n mile of the polar front (Marshall 1982).

(b) Having satisfied the criteria in (a), and if the cold-air cluster rotates (indicating cyclogenesis), merging of the cold-air cluster and the polar-frontal cloud band normally follows.

(c) During 'merging', cloud develops rapidly ahead of the rearward cold front producing rain which may be heavy. This front trails behind its original upper cloud. The resulting hook-shaped cloud canopy then moves parallel to the orientation of the forward cold front.

(d) After merging (see Fig. 12) the following occurs:

(i) The heaviest rain falls at the inside of the hook.

(ii) The main air-mass boundary is along the rearward cold front, the forward cold front becoming difficult to identify at the surface.

(iii) Convection may develop anywhere between the hook and the forward cold front, but is particularly likely to be deep (perhaps with thunder) immediately ahead of the cold-air surface low.

(iv) As the cold-air surface low occludes and starts to fill, any further cyclogenesis will take place on its forward side.

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## Acquisition, checking and management of meteorological data

F. Cerquetti

Geophysical Experimental Observatory, Macerata, Italy

### Summary

The basic system for acquiring, checking and managing meteorological data used at the Geophysical Experimental Observatory at Macerata, Italy is presented. The system uses a data logger and a personal computer.

### 1. Introduction

During the last ten years the development of technology used in meteorological research has led to the application of systems which acquire and check numerical information about ambient atmospheric parameters. Therefore it is now possible to automate totally the acquisition and processing of data.

In the Geophysical Experimental Observatory at Macerata (approximately 43° 17'N, 13° 25'E and 303 m above sea level) in Italy there is a trend towards the total automation of the system for acquiring meteorological data. The system described here has been used for various applications and it has proved to be particularly versatile and easy to use.

### 2. The meteorological data acquisition system

The basic acquisition system is shown in Fig. 1. An integral part of the system is a planning data logger (Campbell Inc. model CR7) which is capable of carrying out mathematical and statistical operations. The sensors connected to the data logger are listed below.

- (a) Platinum-resistance thermometers with a resolution of 0.2 °C (dry- and wet-bulb).
- (b) Sensor with a chemical element for measuring relative humidity with a resolution of 1%.
- (c) Heated rain-gauge with a resolution of 0.2 mm.
- (d) Impulse sunshine recorder with a minimum threshold of 0.147 cal cm<sup>-2</sup> min<sup>-1</sup>.
- (e) Tachometric anemometer with a minimum threshold of 0.25 m s<sup>-1</sup>.
- (f) Potentiometric sensor for the wind direction with a resolution of 1°.
- (g) Potentiometric barometer with a resolution of 0.5 mb.
- (h) Nine Moll thermopiles — one for global solar radiation (direct plus diffuse radiation), one for diffuse solar radiation (including the Schuepp band), and others with optical filters for specific spectral bands of the global solar radiation (the total spectrum covers 300 to 2800 nm).

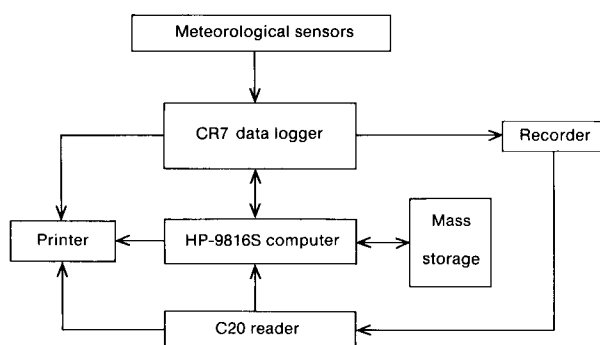


Figure 1. Data acquisition system.

Platinum-resistance thermometers to measure soil temperature and an instrument to measure evaporation are planned to be installed in the near future.

For each meteorological parameter there is a specific sampling and data-processing program which allows various mathematical manipulations to be carried out — these include addition, multiplication by a constant, varying offset, fitting of polynomials of up to degree five and the computation of trigonometric expressions. The operator of the system sets the sampling time and derives the meteorological parameters from the information collected by the sensors using two principal programs, both of which provide hourly values of various parameters.

The first program uses data collected every 3 seconds to provide the following hourly information.

- (a) Total global radiation and total diffuse radiation.
- (b) Total sunshine.
- (c) Total rainfall.
- (d) Mean wind speed and direction, mean vector wind, standard deviation of wind speed and direction, and maximum wind speed and the hour in which it occurred.

Additionally, every 24 hours, information about global solar radiation in various spectral bands is available.

The second program allows the processing of temperature (wet- and dry-bulb), relative humidity and pressure using a scanning period of 30 seconds. Each hour the following information is available.

- (a) Instantaneous temperature (dry-bulb), mean and standard deviation of the temperature, and the maximum and minimum hourly temperature and the hours in which they occurred.
- (b) Instantaneous relative humidity, and the mean and standard deviations of the relative humidity.
- (c) Instantaneous pressure.

There is no processing of the wet-bulb temperature, but this temperature is used to check the relative humidity sensor and, indirectly, the air-temperature sensor.

The data logger stores the hourly data in ASCII code, and after about nine days (the period depending on the rate at which data is stored in the CR7) an overwrite process is started. Periodically all the data are stored on tape using a recorder (each tape holds about 180 000 pieces of data). At any time it is possible to act manually on the CR7 system to obtain tabulations and to monitor the quantities being displayed; this can be done without altering the execution of the program. When there are incorrect readings because of interference, special codes are displayed. However, the system is completely protected from variations in the power supply system and also from electromagnetic interference on the external sensors. A buffer battery system allows the system to continue working when the mains electricity supply fails.

The data stored on the tapes are periodically tabulated using a C20 reader connected to a printer. This reader is also connected to a Hewlett Packard HP-9816S series 200 computer by means of an RS232 serial interface. The transmission of data processed by the CR7 system to the computer takes place by means of definite hardware protocol and by software which has about ten instructions. The meteorological parameters are passed in a sequence fixed by the program. This ensures a homogeneous sampling of the sensors.

### 3. Checking the meteorological data

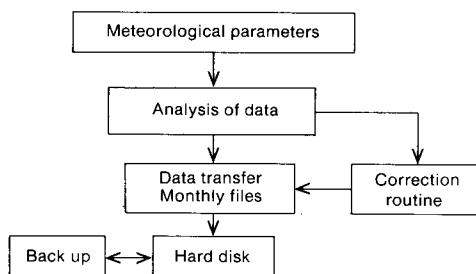


Figure 2. Checking procedure for meteorological data.

Fig. 2 illustrates the checking procedure used for the data. All the meteorological parameters are analysed using suitable software — there is no manual quality control. The checking is carried out by means of various calculations which should identify unreliable data; this is done before parameters are stored as monthly files. The most important of these checks are listed below.

- (a) Global radiation ( $G$ ) and diffuse radiation ( $D$ ) must be positive and satisfy  $0.25 \leq D/G \leq 1.0$  and  $0 \leq G/G_0 \leq 0.7$  where  $G_0$  is the amount of radiation from the sun on a horizontal surface at the top of the atmosphere (depends upon time of day, time of year and latitude as well as other astronomical parameters; see Appendix).
- (b) Sunshine given by the sensor ( $E_E$ ) and that from the Campbell–Stokes recorder ( $E_C$ ) which is keyed into the system must satisfy  $(E_E - E_C) \leq 0.15$  hours and  $E_E < E_0$  where  $E_0$  is the theoretical amount of sunshine (see Appendix).
- (c) Precipitation must be less than  $50 \text{ mm h}^{-1}$  (Allen 1972, Shearman 1975).
- (d) Maximum gust speeds must be less than  $50 \text{ m s}^{-1}$  and more than the mean wind speed; the standard deviations of the wind speed and direction must be less than  $10 \text{ m s}^{-1}$  and  $81^\circ$  respectively (Bryant 1979a, 1979b).
- (e) Air temperature, mean temperature, and maximum and minimum temperatures must be within their climatological extremes for the month.
- (f) Relative humidity and mean relative humidity must lie between 0 and 100%, and the standard deviation of the humidity must be less than 12%.
- (g) Atmospheric pressure must lie between 950 and 1000 mb.
- (h) Global radiation in various spectral bands must be less than values based on experiment (Kondratyev 1969).

These checks are based on the meteorological conditions at Macerata so that if the system is used at a location where the conditions are significantly different the numerical limits in the checks would have to be changed (Mammarella 1986, Cerquetti and Cruciani 1987, Ricketts 1980).

With the checking program it is possible to act on 'wrong' data using a correction subroutine. By means of a series of checks made with suitable laboratory instruments, it is possible to test the sensors'

efficiency and also to estimate if an event is exceptional. In the case of wrong data it is possible either to interpolate a value or give it a numerical code which indicates a missing value (Worthing and Geffner 1965). The program stores each parameter in monthly files on logical records with immediate access. The final step of the checking program is to transfer all files to the hard disk and the back-up.

Through a software process of continuous monitoring of all sensors, it has been possible to make further checks of the values. This monitoring program uses a direct link between the computer and the CR7, and allows the CR7 readings to be monitored without altering the continuous data processing. This procedure aims at identifying incorrect readings due to a malfunction of a sensor or incorrect data processing. The checks on the reliability of a value are the same as those for each meteorological parameter. There are also other relationships that, for example, make it possible to check the correct working of the relative humidity sensor and the air thermometer. They make use of the temperature of the wet-bulb thermometer whose value is measured every 30 seconds. By making use of psychrometric formulae (see Appendix) it is possible to calculate the value of the relative humidity and make a comparison with the value given by the sensor. The difference between the two values must be less than 6% to ensure good estimates of dew-point temperature, saturation vapour pressure and absolute humidity. When the difference is greater than 6% it is necessary to check the sensors against suitable calibration instruments.

#### 4. Meteorological data management

Fig. 3 shows the procedure for the standard daily management of all available observations. The data acquired through the sensors are augmented by synoptic information (e.g. clouds and visibility) inserted into the system by the operator via a keyboard. The synoptic observations are processed, in accordance with international regulations, at 08.00, 14.00 and 19.00 hours local time.

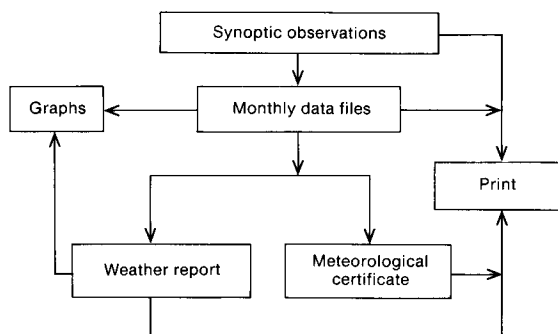


Figure 3. Meteorological data management.

Every month, data files are prepared which contain the data averages and general summaries. This information can be displayed as diagrams or tables (referred to as 'weather report' in Fig. 3). Generally the software allows random access to all data, with the ability to perform mathematical/statistical analysis. Moreover, when meteorological information is requested by public bodies, corporations and industry, the system can provide tabulations of the required data (referred to as 'meteorological certificate' in Fig. 3).

#### 5. Conclusions

The system for acquiring, checking and managing the meteorological information is very effective in providing information for the Meteorology and Climatology Department of the Geophysical

Experimental Observatory (Osservatorio Geofisico Sperimentale 1957–86). The system has considerably reduced the time taken to analyse data and to carry out research — it has also made it easier to check and file data. In spite of this, procedures are still being improved in order to eliminate errors and to increase the versatility of the system.

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## Appendix — Some formulae used in the data-checking program

### Direct solar radiation

Hourly values of the extra-atmospheric radiation on a horizontal surface ( $G_o$ ) are given by integrating the following equation

$$dG_o/dt = KI_o \cos Z$$

with the reduction factor for the earth–sun distance ( $K$ ), the solar constant  $I_o = 1.94 \text{ cal cm}^{-2} \text{ min}^{-1}$ , solar zenith angle ( $Z$ ) and the solar declination ( $\delta$ ) given by

$$K = 1 - 0.034 \sin\{(360/365)(i - 94)\}$$

$$\cos Z = \sin \phi \sin \delta + \cos \phi \cos \delta \cos h$$

$$\sin \delta = 0.4 \sin\{(360/365)(i - 80)\}$$

where  $t$  is the time in minutes,  $\phi$  is the geographical latitude,  $h$  is the hour angle of the sun and  $i = 1, 2, \dots, 365$  is the Julian day (Smithsonian Institution 1958, Coulson 1975).

**Theoretical sunshine**

The theoretical amount of sunshine ( $E_o$ ) is given by

$$E_o = (2/15)\cos^{-1}(-\tan\phi\tan\delta)$$

where  $\phi$  and  $\delta$  are the latitude and the solar declination respectively.

**Psychrometric formulae**

From the dry- and wet-bulb temperatures ( $T_A$  and  $T_B$ ) the saturation vapour pressures at the dry- and wet-bulb temperatures ( $E_A$  and  $E_B$ ) and the vapour pressure ( $P_v$ ) are computed using

$$E_A = 6.1 \times 10^{\{7.5T_A/(237.3 + T_A)\}}$$

$$E_B = 6.1 \times 10^{\{7.5T_B/(237.3 + T_B)\}}$$

$$P_v = E_B - 0.65(T_A - T_B).$$

From these the relative humidity ( $U$ ), absolute humidity ( $U_A$ ) and dew-point ( $T_R$ ) are derived from

$$U = P_v(100/E_A)$$

$$U_A = (U/100)(0.795066E_A)/(1 + 0.00366T_A)$$

$$7.5T_R/(237.3 + T_R) = \log_{10}(P_v/6.1).$$

**Wind**

The hourly values of the scalar ( $\bar{S}$ ) and vector mean ( $\bar{V}$ ) speeds (Brooks and Carruthers 1953) are given by

$$\bar{S} = \frac{1}{n} \sum_i (N_i + E_i)^{1/2}$$

$$\bar{V} = \frac{1}{n} (\sum_i N_i^2 + \sum_i E_i^2)^{1/2}$$

where  $N_i = V_i \cos\alpha_i$  and  $E_i = V_i \sin\alpha_i$  are the north-south and east-west components of the wind (where  $\alpha_i$  is the wind direction and  $V_i$  is the magnitude of the vector wind), and  $n$  is the number of samples.

The standard deviation of the wind direction is

$$SD(\alpha) = 81(1 - \bar{V}/\bar{S})^{1/2}.$$



## The winter of 1987/88 in the United Kingdom

G.P. Northcott

Meteorological Office, Bracknell

### Summary

The winter was very mild, especially in eastern and central areas of England and Wales, and generally wet. After a dull December most places in England and Wales had above-average sunshine, February being particularly sunny; Scotland, however, had a generally dull winter.

### 1. The winter as a whole

Mean temperatures over the winter (December 1987–February 1988) were above normal nearly everywhere, apart from some places in western Scotland, and ranged from about normal in western Scotland to nearly 2 °C above normal on the east coast of England. Ashover, Derbyshire reported that only the winter of 1974/75 was warmer at the station since records began there in 1967. It was wet in most places. Rainfall amounts ranged from 85% of normal in Northamptonshire and Grampian Region to 157% of normal in parts of the Lake District. Sunshine amounts were above normal in all parts of England and Wales, but below normal in Scotland, and ranged from 47% in north-west Scotland to 166% in the north Midlands.

Information about the temperature, rainfall and sunshine during the period from December 1987 to February 1988 is given in Fig. 1 and Table I.

### 2. The individual months

*December.* Mean monthly temperatures were above normal nearly everywhere in the United Kingdom, ranging from about normal in the south-west to more than 2 °C above normal in north-east England. Monthly rainfall amounts were below normal in all areas except southern Scotland, ranging from less than half the normal in south-east England and part of eastern Scotland to just above normal in southern Scotland and South Wales. Monthly sunshine amounts were generally below average except in north-west Scotland and Northern Ireland, ranging from 53% of average at Wattisham, Suffolk to 169% at Stornoway, Western Isles. It was the dullest December at Sheffield, Weston Park, South Yorkshire since 1958 and at Coventry (Bablake), Warwickshire since 1964.

*January.* Mean monthly temperatures were above normal nearly everywhere but near normal in north-west Scotland, ranging from 0.1 °C below the average at Tiree, Strathclyde to 2.4 °C above average at Gatwick, West Sussex. Mean monthly rainfall amounts were above normal everywhere except Shetland and the far north of Scotland, ranging from about 80% of average in Shetland to over 250% in parts of East Anglia. It was a very wet month with record amounts of rainfall in parts of southern England and the east coast of Scotland; it was the wettest January in England and Wales since 1948, the wettest at Hampstead, Greater London since records began there in 1909 and one of the wettest months on record with more than 100 mm falling in central London, the most since the London Weather Centre started records in 1940, according to provisional figures. Sunshine amounts were average or above average everywhere except parts of southern Scotland and some eastern areas of England, ranging from 55% of the average at Eskdalemuir, Dumfries and Galloway to 143% in north-east Scotland.

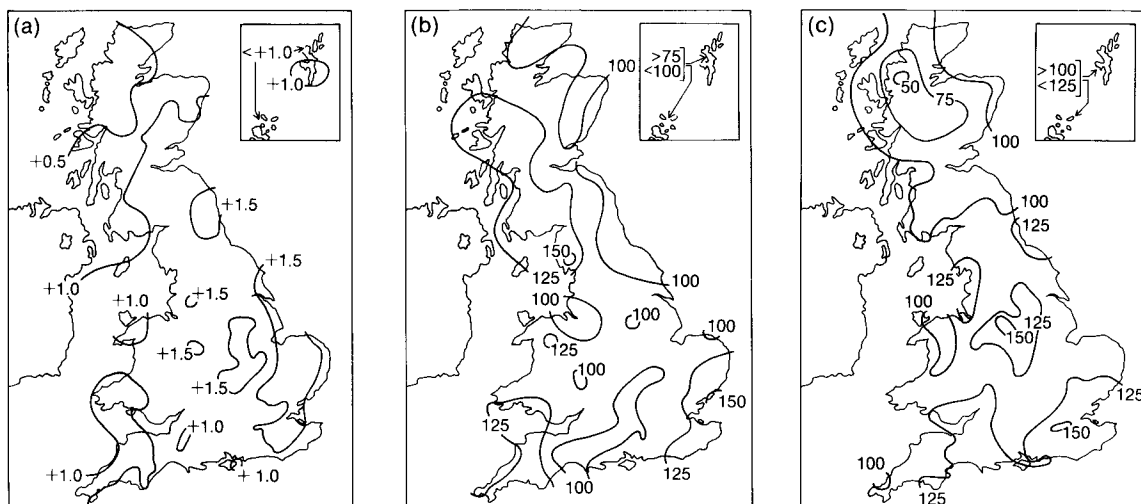


Figure 1. Values of (a) mean temperature difference, (b) rainfall percentage and (c) sunshine percentage for winter 1987/88 (Dec-Feb), relative to 1951-80 averages.

**Table 1.** District values for the winter months, December 1987-February 1988, relative to 1951-80 averages

| District                                | Mean<br>temperature (°C) | Rain-days             | Rainfall | Sunshine |
|---|--------------------------|-----------------------|----------|----------|
|   | Difference from average  | Percentage of average |          |          |
| Northern Scotland                       | +0.6                     | +5                    | 119      | 103      |
| Eastern Scotland                        | +1.0                     | +4                    | 113      | 95       |
| Eastern and north-east England          | +1.5                     | +4                    | 107      | 108      |
| East Anglia                             | +1.5                     | +3                    | 117      | 113      |
| Midland counties                        | +1.5                     | +1                    | 107      | 117      |
| South-east and central southern England | +1.3                     | -5                    | 118      | 123      |
| Western Scotland                        | +0.9                     | +5                    | 130      | 100      |
| North-west England and North Wales      | +1.1                     | +3                    | 124      | 108      |
| South-west England and South Wales      | +0.9                     | +7                    | 118      | 116      |
| Northern Ireland                        | +0.7                     | +6                    | 124      | 104      |
| Scotland                                | +0.8                     | +5                    | 121      | 99       |
| England and Wales                       | +1.3                     | +2                    | 115      | 114      |

Highest maximum: 15.2 °C in the Midlands in December.

Lowest minimum: -9.8 °C in eastern Scotland in December.

**February.** Mean monthly temperatures were above normal everywhere and ranged from 0.1 °C above normal in north-west Scotland to 1.5 °C above normal in parts of eastern Scotland and northern England. Sheffield, Weston Park reported the highest February mean temperature at the station since 1980. Monthly rainfall totals were generally above normal in Scotland and Northern Ireland but below normal in England and Wales, ranging from just over 170% of normal at Tiree, Strathclyde to just over half the normal in central London. Monthly sunshine totals were generally above normal everywhere except north-west Scotland, ranging from 56% at Cape Wrath, Highland Region to about twice the normal in some parts of the Midlands and East Anglia. It was a very sunny month, with many places in

central and southern areas in particular having the highest February sunshine total since records began. Five places measured about 144 hours: Brighton, East Sussex, Bognor Regis, West Sussex, Swanage, Dorset, Teignmouth, Devon and Torbay, Devon. Among others it was the sunniest February on record in Coventry (Bablake), Warwickshire in a record going back to 1895, and Sheffield, Weston Park reported the sunniest February since 1949.

### **3. The weather month by month**

*December.* The month started cold but mainly dry over most parts of the United Kingdom. There was extensive and persistent fog in north-east Scotland for the first few days of the month, where temperatures stayed below freezing all day on the 3rd. Outbreaks of rain reached south-western areas on the 3rd, giving some snow over the moors. This was followed by 10 days of cold settled weather, but with overnight fog forming, mainly over England. Rain came to nearly all parts except the far north and brought milder weather to parts of southern England, Northern Ireland and Wales on the 16th. The weather in the second half of the month remained unsettled with frontal systems moving in from the Atlantic, bringing cloud and rain, but also staying mild or very mild. Although there was frost early on the 25th, it was generally a very mild day with some dense fog at first in southern England. Thunder was heard in Shetland on the 22nd and at several places in northern or western Scotland on the 29th and 30th. Hailstones between 10 mm and 20 mm in diameter were reported at Colonsay, Strathclyde on the 29th. Most of the area south of a line from Torbay, Devon to The Wash was rather dry, with only about half the average rainfall. Brooms Barn, Suffolk reported the driest December since 1963; it was the driest December at Hampstead, Greater London since 1963, at Sheffield, Weston Park, South Yorkshire, since 1971 and over Northern Ireland as a whole since 1975.

*January.* The month started with fronts bringing heavy rain and some exceptionally mild conditions to England, Wales and Northern Ireland. On the 2nd heavy rain caused a landslide on the road between Bideford and Torrington, Devon. By the 4th rain moved north-east across England and Wales, with some fairly heavy snow on the Pennines. On the 4th gusts to 68 kn and 63 kn were measured at Aberporth and Brawdy, Dyfed; a 13 800 tonne tanker was reported to have been blown away from its moorings at Milford Haven by very strong winds. In Cardiff three women were injured when winds sent glass roof panels crashing down on shoppers and stallholders at the Central Market, and a double-decker bus was blown into a wall injuring the driver and two passengers. On the 6th gales caused the closure of the Severn Bridge for the third time in its history when gusts overturned a high-sided lorry. A mean wind of 41 kn and gust of 64 kn was measured at Rhoose, South Glamorgan. In west Oxfordshire a motorcyclist was killed and his pillion passenger badly injured when a gust of wind blew them into a tree. Showers were widespread on the 10th, with sleet and snow over higher ground. On the 14th there was a little sunshine nearly everywhere; many eastern and south-eastern areas stayed dull and cold on the 15th. Heavy rain fell on north-western parts of the United Kingdom on the 17th; there was a return to cold weather on the 18th, and on the 20th and 21st it was very sunny. On the 29th torrential rain fell in southern parts of England and Wales causing flooding as far apart as Gloucestershire and Wiltshire in the west and Essex and Kent in the east. The month ended with further heavy rain. Thunder and hail were reported on 6 days, notably over England and Wales on the 4th and 6th; on the 5th about 20 people escaped injury when lightning demolished the steeple of a Swansea chapel, hurling masonry blocks into nearby houses.

*February.* February was a month of contrasts. The month began generally unsettled, with showers or longer periods of rain. Snow, sleet or hail occurred widely, especially in northern and western areas. It

remained unsettled until the 15th when high pressure brought more settled conditions to southern areas, although showers of rain or hail continued to affect Scotland and Northern Ireland, but with some sunny spells in between. Thunder was widely reported, notably on the 1st, 9th and 13th. Hail was widespread and frequent during the first half of the month. Gales or severe gales were widespread across England and Wales on the 1st: gusts of more than 50 kn were widely reported, and gusts to over 70 kn near exposed western and south-western coasts. Strong winds continued to affect many areas on the 2nd with gales in places; there were several gusts between 60 kn and 75 kn at exposed places in the south and west at about midday. Further gales and storm force winds came to many parts of Great Britain on the 9th. There was a gust of 96 kn during the afternoon at Gwennap Head, Cornwall, a record February gust for England and Wales and in many places, especially in the west, gusts of more than 70 kn were recorded. Plymouth, Devon reported a gust of 72 kn, the highest February value on record there. The wind slowly moderated on the 10th. Strong cross winds in Devon and Cornwall brought down trees and disrupted traffic. North-west England suffered the worst damage, however, with structural damage to buildings, including the roof of the Town Hall at Bury, Greater Manchester and disruption of road and rail traffic.

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## **The great storm of 16 October 1987 — a forecaster's story**

**G.M. Capstick**

**London Weather Centre**

### **Summary**

One wet day this summer whilst reading yet another article about the great storm of October 1987 I realized that perhaps I should tell the story of one forecaster on duty at the time. The following is my personal account of the events that night as seen through the eyes of an offshore forecaster at London Weather Centre.

As the first anniversary of the storm of 16 October 1987 passes, it is interesting to look back on that night. The storm of Friday 16 October 1987 will be remembered by the staff at London Weather Centre for many years to come, and those who were on duty that day will remember it for the rest of their lives. I was on duty that night having started a run of shifts on Monday the 12th prior to going on holiday in Yorkshire. Thus I was able to follow events fairly closely, from being aware on Monday that a major low was likely to be near the United Kingdom towards the end of the week, to being aware on Thursday night that the event was actually happening.

My job was to forecast the winds and waves for the rigs and platforms in the North Sea. With a major new contract starting at midnight on Thursday a decision was made as early as Tuesday between myself and the Commercial Manager that, in view of the situation, it would be advisable to send the new customer an update on the weather situation as soon as possible after midnight on Thursday. The night duty begins at 1900 GMT and my first task was to look at the situation and to consider whether the previous forecast was adequate or whether it needed amending. In order to do this it is normal procedure to analyse the 1800 GMT wind and sea data. After drawing up the relevant charts it became evident that a major weather event could take place overnight and that the forecast winds from the previous issue could be too low, even though gusts over 60 kn were forecast. The main problem was threefold; (a) when would the event take place, (b) how windy would it be, and (c) where would the strongest winds occur?

At this time severe gale force 9 warnings were in force for most of the relevant sea areas. After analysing the charts I rang the Central Forecasting Office (CFO) at Bracknell to tell them that I thought the winds would be stronger than force 9, but I decided that the situation was still uncertain and would wait until the 2100 GMT data had been seen before making any major amendments. At this stage a certain amount of planning was being done for the morning forecasts but time did not allow as much planning as normal.

The 2100 GMT chart was analysed and although pressure falls were increasing in the south-west there was as yet no concrete evidence of what was to come; but things were beginning to happen. The warm front had moved north through London Weather Centre, therefore I thought it unlikely that the low would pass to the south of us as previously envisaged. The midday run of the fine-mesh forecast confirmed this by placing a low near Norfolk at 0600 GMT on the 16th (this was received too late to be used by the day duty). It gave a mean west-south-westerly wind of 35 kn (at 25 m above sea level) over Essex but not too much wind over the North Sea. It was now becoming obvious that amendments would probably have to be made and the sooner the better. Exactly what values to put on the wind speeds in the amendment and the timing of the onset of the storm were still in doubt.

There are normally two forecasters on duty dealing with the North Sea and most of the decisions that night were made after consultations between the two of us. It was decided that the new customer should be warned first as their forecasts were most in error (the previous forecasts issued by a competitor had been made available at London Weather Centre). An amendment was then written indicating that a major storm was expected to hit the English Channel and the North Sea later that night.

At this stage it was considered that there would be only a limited amount of time later in the night, so planning was done for the morning forecasts for the Mediterranean and also for parts of the North Sea which were thought unlikely to be seriously affected by the storm (the Moray Firth area). Between 2300 GMT and midnight a message was sent to all the locations which were under the authority of the new customer.

The 0000 GMT observations were analysed — south-south-westerly winds gusting to over 70 kn in Devon and northerly winds gusting to over 70 kn in Cornwall. Also there were marked pressure falls being reported over south-west England. The situation was deteriorating rapidly, therefore I rang CFO again to tell them that we were going to forecast hurricane force winds for the North Sea. Between 0030 and 0130 GMT messages were sent forecasting means of 60 kn and gusts to 90 kn to most of our customers — including the new one. Planning for the morning issue was renewed and by now the hourly observations were being scrutinized more closely with each hour as the situation deteriorated.

#### PRELIMINARY WARNING

THE DEPRESSION NOW MOVING ACROSS SOUTHERN ENGLAND ON ITS WAY TO THE NORTH SEA IS PROVING EXTREMELY VIGOROUS AND IT SEEMS LIKELY THAT MEAN SPEEDS AT 10 M OF 60 KTS ARE LIKELY IN THE NORTH SEA THIS MORNING AND AFTERNOON WITH GUSTS PERHAPS 80 OR EVEN 90 KTS. THE EXACT TRACK OF THIS LOW IS STILL UNCERTAIN AND CONSEQUENTLY EXACTLY WHERE THE STRONGEST WINDS WILL BE BUT YOUR AREA IS AT RISK. HOPEFULLY A MORE DETAILED ANALYSIS OF THE SITUATION WILL BE AVAILABLE BY THE TIME OF THE MORNING FORECAST SO THAT MORE PRECISE DETAILS CAN BE GIVEN.

The wind at London Weather Centre became a useful distraction — the power had failed, destroying a certain amount of planning, and the computer had failed at Bracknell. This proved to be a serious set-back. Not only would there be no computer guidance in the morning but also automated products

for numerous places in the North Sea would not be available and therefore forecasts for these areas would have to be done by hand from scratch.

The 0000 GMT charts were analysed but our sandwiches remained uneaten. As 0315 GMT approached, with only 3 hours 45 minutes to go before relief arrived, it was decided to begin the morning forecasts. The Mediterranean forecasts were then sent. The 0300 GMT observations were studied and it became evident that the low was heading for the oil rigs. But where, precisely, would it go? The senior forecaster at CFO was consulted and the problem was discussed. For some time it had become evident that there were two main areas of strong winds, one to the east of the centre and the other to the south. The movement of these areas was discussed, decisions were made, and a track taking the low across the north Midlands and turning to go northwards up the North Sea near the Greenwich meridian was decided upon. This proved to be very accurate. The Aberdeen forecaster was briefed while the forecaster at Sullom Voe was told that the storm would miss them.

The 0300 GMT chart was drawn and the forecasts prepared and sent (a task which incidentally took about 3 hours of continuous tapping on the word processor). The London Weather Centre forecaster on the Buchan platform rang and the situation was discussed. Other telephone calls were dealt with and eventually all the forecasts were prepared and despatched.

```
FORECAST 0800 TO 2000 GMT FRIDAY 16/10/87
WIND 10 METRES    NE 30 PROBABLY VERY SOON BECOMING VARIABLE 25 AS
                  THE LOW PASSES OVER YOU THEN VERY SOON BECOMING
                  SSW 45 WITH OCCASIONAL INCREASES 55 TO 60
GUSTS             ABOUT 80
WIND 50 METRES    NE 35 PROBABLY VERY SOON BECOMING VARIABLE 30 AS
                  THE LOW PASSES OVER YOU THEN VERY SOON BECOMING
                  SSW 50 WITH OCCASIONAL INCREASES TO 65
GUSTS             ABOUT 85
SIG WAVE HEIGHT   3.0 BECOMING 8.0
WAVE PERIOD       5 OR 6 BECOMING 9
MAX WAVE HEIGHT   12.0 OR 13.0 LATER WITH EXTREME WAVE NEAR 15.0
```

0700 GMT arrived and the sandwiches were still uneaten. It was time to go home, but nobody had arrived to relieve us. Nobody could get to work, there was no relief and the reality of the situation dawned — we would have to do it all over again. The 0600 GMT charts were drawn — there was still no fine-mesh forecast guidance from CFO but the planning for the afternoon forecasts began. At 1200 GMT my relief arrived and I was able to set off to start my holiday in Yorkshire. However, there were no trains from King's Cross — why weren't we warned?

## Notes and news

### The Professor Dr Vilho Vaisala Award

This has been awarded jointly to Dr J. Nash (Observational Requirements and Practices Branch of the Meteorological Office) and Mr F.J. Schmidlin (NASA Goddard Space Flight Center, Wallops Flight Facility, USA).

The award was given in recognition of the final report for the WMO International Radiosonde Comparison. The authors of the report, Dr Nash and Mr Schmidlin, were the project leaders of the comparison which took place in two phases, the first in the United Kingdom in 1984 and the second in the USA in 1985.

The comparison provided the most extensive examination of the quality of operational radiosonde measurements (i.e. pressure, temperature, relative humidity, geopotential height, and wind speed and direction) which has been conducted to date. As a result, reliable quantitative measurements of systematic bias between the temperature and geopotential height observations provided by different radiosonde types were made available for the first time. These are being used as the basis of adjustment schemes to improve the compatibility of radiosonde measurements for numerical weather forecasting.

Significant errors were identified in almost all the radiosonde systems which took part in the comparison. In most cases actions have subsequently been taken by the manufacturers or operators to eliminate or compensate for these errors and hence to improve the quality of operational radiosonde measurements. Infra-red cooling errors introduced by the use of white-painted rod thermistor sensors for temperature measurements were quantified. This demonstrated that, for this widely used sensor, the common practice of adjusting daytime temperature measurements to be compatible with those made at night, from the same station, will not produce the best estimate of the 'true' temperature.

## Reviews

*The little ice age*, by J.M. Grove. 192 mm × 254 mm, pp. xxii + 498, *illus.* London, New York, Methuen, 1988. Price £85.00.

This substantial volume is, so far as this reviewer is aware, the first comprehensive collation and assessment of the world-wide evidence for an interval of cooler climate between, approximately, the sixteenth and early nineteenth centuries. As such it will be welcomed by climatologists, because this evidence will, by consolidating our knowledge of the past, help to pave the way for an increased understanding of climate, and of the impact of man-made changes, such as increasing carbon dioxide and other 'greenhouse' gases in the atmosphere.

The author aims not only to describe the 'little ice age' and its consequences, but also to give an account of our current understanding of its causes. In order that the conclusions be seen to be soundly based on facts, high standards for both scientific consistency and historical accuracy are set from the start. The introductory chapter stresses the author's choice of contemporary rather than secondary historical sources, and includes discussions of the uses and pitfalls of techniques such as carbon-14 dating of material in moraines, lichenometry, and dendrochronology. Throughout the book the evidence presented is carefully assessed in terms of the methods involved, and corroboration by independent information is sought if possible. Recorded events are interpreted with due caution; for example, some glaciers are unstable and their frequent surges need not be initiated by a colder or snowier climate.

The concern for accuracy and careful interpretation has not detracted from the anecdotal interest of the descriptive accounts of glacial activity between medieval times and the present, which take up well

over half of the book. The fearsome 'jökulhlaups', which are floods caused by, *inter alia*, subglacial volcanic eruptions in Iceland, are impressed on the reader's memory. So are the exorcisms of Mont Blanc's glaciers by the Bishop of Geneva; each exorcism was followed by a retreat of the glacier. The plentiful illustrations also enhance the descriptive accounts and include useful summaries in diagrammatical form for the various regions discussed.

As the author admits, the descriptive chapters are most complete for Europe, including Iceland, though central Austria (the Gross Glockner) is omitted, and least complete for Siberia and the Far East. If further data were to come to light for these areas, they would be exceedingly valuable. The author deliberately omits Antarctica because of the lack of information and the expected long time-scale of variations in the Antarctic ice sheet.

The discussion of the causes of the 'little ice age' is a well balanced summary and assessment of current understanding. It is put into context by the preceding chapter on the glacial history of the Holocene. Here again the information presented is as global as possible and is carefully, though more briefly, assessed and summarized.

The final chapter, on the physical, biological and human consequences of the 'little ice age' will be of greatest interest to historians and to those concerned with the potential societal and economic impacts of future climatic changes.

There are a few, mainly numerical, printing errors in the book. For example, the height of Pik Karla Marksa is unlikely to be 8726 m (page 203 — K2 is not as high as that); and the height of the Holocene tree-line in Scandinavia has probably only fluctuated by 200 m rather than 2000 m (page 315). On line 3 of page 194, read '1630s' for '1730s'. The autumns of the 1730s, 1740s, 1750s and early nineteenth century were dry in Figure 6.9 not wet as on page 194.

In all the accounts and discussions the author attempts to bring the reader up to date. This is generally done successfully, though one exception is the statement on page 259 that at present it is not known whether the cooling trend since the mid-twentieth century has come to an end or not. Numerous papers published during the 1980s have shown that this trend has ceased and, indeed, reversed.

This book is a valuable and scholarly compilation with an excellent set of illustrations and a substantial bibliography. It is to be regretted that at £85 many interested readers will not be able to afford to buy it.

D.E. Parker

*Meteorology for seafarers*, by R.M. Frampton and P.A. Uttridge. 214 mm × 305 mm, pp. xvii + 137, illus. Glasgow, Brown, Son and Ferguson, 1988. Price £27.50.

Although somewhat larger than most books (A4 format) it would be worth finding space on your bookshelf for this volume. In spite of some disagreements I may have — mainly with some of the contents in the chapters devoted to winds and circulation — this book is physically easy to read, with a particularly clear type-face, simple figures and a selection of colour photographs illustrating cloud types, and some showing the relationship between Beaufort force and the state of the sea.

*Meteorology for seafarers* is one of many nautical books by these publishers, and is a revision of Commander Burgess' classic *Meteorology for seamen* which is now nearing its 40th birthday. Between them, the authors have experience both at a theoretical level and on the sea itself, but they have avoided the pitfall of using jargon, and all acronyms have been spelt out in full at the first time of using.

There are 11 chapters in this book with the two largest devoted to the circulation, both on global and synoptic scales. As well as temperate areas, subtropical and tropical areas are considered, which these



days is becoming increasingly important as yachtsmen charter further and further from their home waters.

The authors begin by discussing the nature of the atmosphere, and then consider how to measure its quantities, taking in turn pressure, temperature and humidity. The radiation budget is balanced, and atmospheric stability then leads into clouds and precipitation. Winds and circulation are covered in sufficient detail to inform, without confusing, less experienced readers.

It is in the chapters on circulation and wind (my two particular 'hobby-horses') that I have mild reservations. Values of cyclostrophic force may be *largely* dependent on the pressure gradient, but the radius of curvature of the isobar also plays its part — adding to the strength of the wind with anticyclonically curved isobars, and diminishing the strength in the presence of cyclonic curvature. For this very reason picking the axis of a ridge to measure the gradient (to demonstrate the use of a geostrophic scale) is not really a very good idea. I appreciate that with a reading of 12 knots on the scale, the gradient wind correction is negligible, but it is a bad practice, and with closer isobars could easily turn an expected Force 8 into an observed Force 10 in temperate latitudes.

There also seems to be a tendency to discuss just one aspect of a topic under a bold heading, and then to present that one aspect as the definition — a dangerous point of view, especially in a reference book which is very likely to be used by readers of mixed ability.

The last two chapters relate to the organization of meteorological services, and how the national meteorological centres fit into the network of satellites and observing sites. Forecasting techniques are briefly looked at with a few examples of prognostic charts together with 'least-time' ship routeing. The final chapter has some thoughts on single observation forecasting, together with sources of additional bulletins — such as the Atlantic, as well as the more normal shipping forecast broadcast on BBC Radio.

I said initially that it would be worth having this on your bookshelf (and I will certainly carry it in my mobile library when instructing) but whether to buy this or for the same money buy two less expensive publications might be a difficult choice.

A.R. Ebling

## Books received

*The listing of books under this heading does not preclude a review in the Meteorological Magazine at a later date.*

*An introduction to boundary layer meteorology*, by R.B. Stull (Dordrecht, Boston, London, Kluwer Academic Publishers, 1988. Dfl.220.00, US\$99.00, £64.00) presents fundamental concepts and mathematics of the subject prior to use, with physical interpretations, sample data, examples and exercises included. It is intended as a combination of textbook, reference and literature review for students with an undergraduate background in meteorology (or similar).

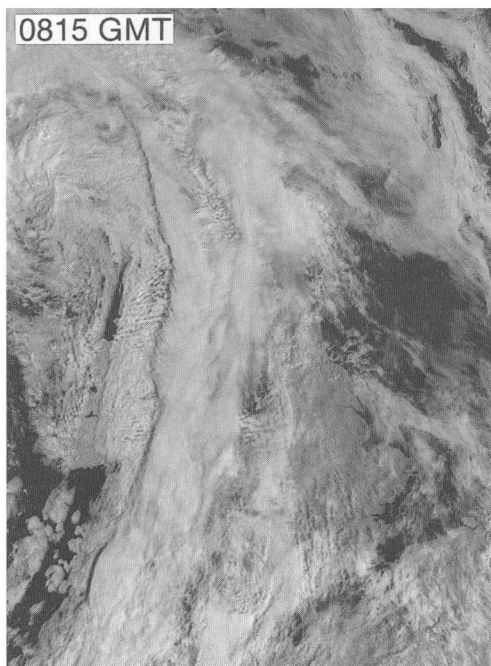
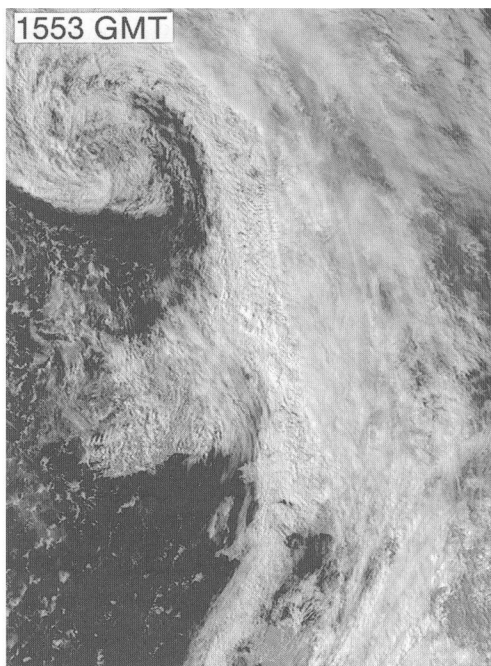
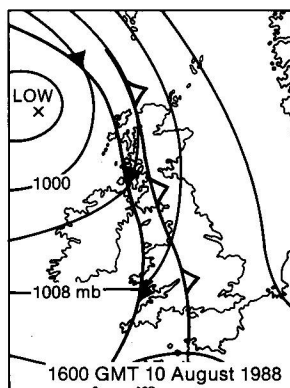
*Sea surface sound*, edited by B.R. Kerman (Dordrecht, Boston, London, Kluwer Academic Publishers, 1988. Dfl.290, US\$149.00, £79.00) contains the proceedings of the NATO Workshop held at Lerici, Italy in June 1987. The central theme of the many and varied papers is 'What are the mechanisms causing ambient noise at the upper surface of the oceans?'

## Satellite photographs — 10 August 1988 at 0815 and 1553 GMT

These NOAA-10 visible images show cloud associated with a split cold front as it moved into the British Isles. At 0815 GMT the rear edge of the upper front is readily identified by its shadow cast upon the lower cloud of the shallow moist zone (SMZ). The surface front lay some 100 km further west. By late afternoon (1553 GMT) the same lateral separation was evident over Scotland and northern England; both fronts had moved east at 15 kn. Further south, however, the upper front had progressed at about 35 kn and the surface front at only 22 kn, with the result that an intervening cloud-free slot was revealed between Brittany and Dorset. Subsequently this zone extended north-east bringing evening sunshine to much of south-east England.

The FRONTIERS display in the Central Forecasting Office at Bracknell showed the cloud top within the SMZ to be near 8000 ft (temperature 2 °C); cloud layers to the east reached to 30 000 ft (−45 °C).

Over southern Britain the heaviest rain fell within the strong, moist south-westerly flow of the SMZ, hourly accumulations reaching about 4 mm where there was orographic enhancement. FRONTIERS radar identified a narrow belt of maximum rainfall rate just to rear of the upper front. Once the fronts 'de-coupled', rainfall largely died out. Precipitation from upper cloud mostly evaporated before reaching the surface and rain in the SMZ became slight and intermittent as this zone moved clear of higher ground. Absence of seeding from above may also have contributed to its rapid demise.



# Meteorological Magazine

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Articles on all aspects of meteorology are welcomed, particularly those which describe the results of research in applied meteorology or the development of practical forecasting techniques.

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Articles, which must be in English, should be typed, double-spaced with wide margins, on one side only of A4-size paper. Tables, references and figure captions should be typed separately.

Spelling should conform to the preferred spelling in the *Concise Oxford Dictionary*.

References should be made using the Harvard system (author, date) and full details should be given at the end of the text. If a document referred to is unpublished, details must be given of the library where it may be seen. Documents which are not available to enquirers must not be referred to.

Tables should be numbered using roman numerals and provided with headings. We consider vertical and horizontal rules to be unnecessary in a well-designed table; spaces should be used instead.

Mathematical notation should be written with extreme care. Particular care should be taken to differentiate between Greek letters and Roman letters for which they could be mistaken. Double subscripts and superscripts should be avoided, as they are difficult to typeset and difficult to read. Keep notation as simple as possible; this makes typesetting quicker and therefore cheaper, and reduces the possibility of error. Further guidance is given in BS1991: Part 1: 1976 and *Quantities, Units and Symbols* published by the Royal Society.

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