

The Meteorological Magazine

November 1989

Heavy rainfall at Khartoum
Meteorological support during pollution incidents
Ceilometer comparison



DUPLICATE JOURNALS

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Met.O.986 Vol. 118 No. 1408



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November 1989
Vol. 118 No. 1408

551.577.37(626)

Heavy rainfall at Khartoum on 4–5 August 1988: A case-study

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Summary

Surface and upper-air observations, and satellite imagery have been used to study the development of a rare event of large rainfall over parts of the Sudan on 4–5 August 1988.

1. Introduction

The intertropical convergence zone (ITCZ) is a narrow region where northerly and southerly tropospheric winds meet. It shows a discontinuity of moisture which in the Sudan (Fig. 1) is usually indicated at the surface by the location of the 15 °C dew-point isopleth.

The moist southerly to south-westerly air to the south of the ITCZ which affects the Sudan has two sources:

- (a) an air mass which passes over equatorial Africa from the Atlantic and is moist and unstable to a great depth (the main source), and
- (b) an air mass which comes from the Indian Ocean meeting the one in (a) over the Congo.

In addition to a seasonal movement of the ITCZ, which in eastern Africa follows closely the solar latitude, there are periodical movements lasting several days consisting of a southward displacement followed by a northward one. These periodical movements are associated with the oscillation of subtropical anticyclones and their interactions with mid-latitude troughs, cyclones and fronts. In addition to the convective precipitation caused by convergence at the ITCZ, steady widespread rain, not thundery in character, occurs during mornings

and evenings in the moist southerly air masses.

Daily rainfall totals of a few (or a few tens of) millimetres are common in this area as in Fig. 2(a) which shows the totals for 3 August (i.e. for 0600 UTC on 3 August to 0600 UTC on 4 August). On this day the rainfall was confined to an area across central Sudan. On 4 August, rainfalls in the range 0–20 mm were recorded across central Sudan but in addition heavy rainfall was registered to the north at Atbara (64 mm) and especially Khartoum (210 mm) (Fig. 2(b)). The rainfall had a well defined southern edge with no rain being recorded at Edduim and Wadi Medani about 160 km to the south of Khartoum. At Khartoum the rain fell in two storms, one lasting from about 1800 UTC to 2000 UTC on 4 August and the second from 2200 UTC on 4 August to 0800 UTC on 5 August.

This is clearly a rare event and the aim of this case-study is to demonstrate the meteorological factors involved in this rain storm using all surface and upper-air data available. The result can be regarded as a contribution to the development of forecasting techniques for such events when similar pre-conditions are observed.

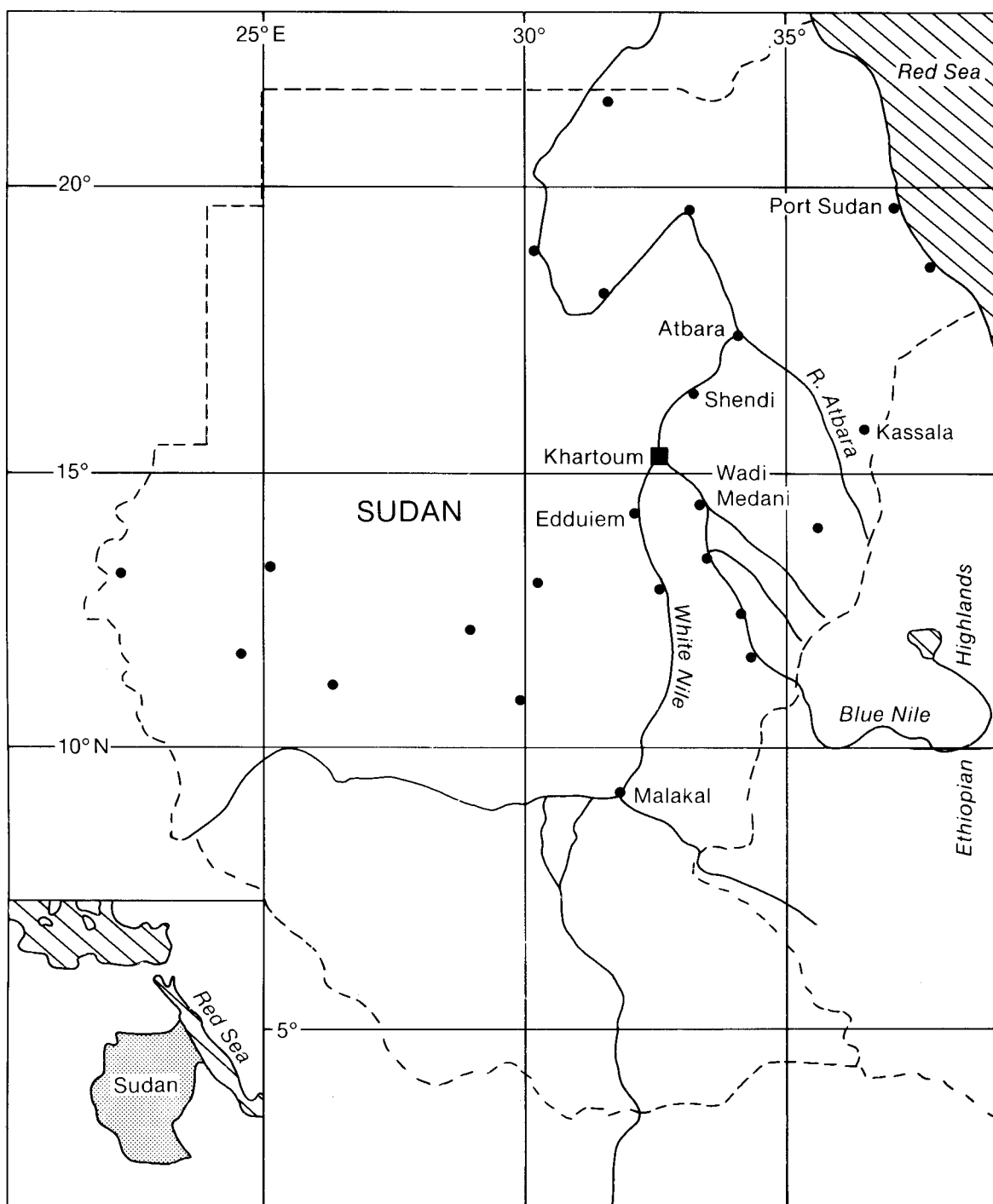


Figure 1. The Sudan, showing the location of places mentioned in the text. In this, and other figures, the location of Khartoum is denoted by a black square, and the black dots are stations in the observing network.

2. The synoptic situation

2.1 General

The surface pressure chart for 1200 UTC on 3 August (Fig. 3(a)) shows a low pressure area over the Arabian Gulf from which a trough extended westward to link with the low centred over the north of the Sudan. An anticyclone over the Sahara desert extends northward over eastern Europe.

By 1200 UTC on 4 August (Fig. 3(b)) the anticyclone over the Sahara desert has collapsed allowing the low pressure area to extend south-westwards. A ridge of high pressure over north-east Sudan with its axis approximately along the line of the Atbara river led to a wave development at the eastern end of the ITCZ.

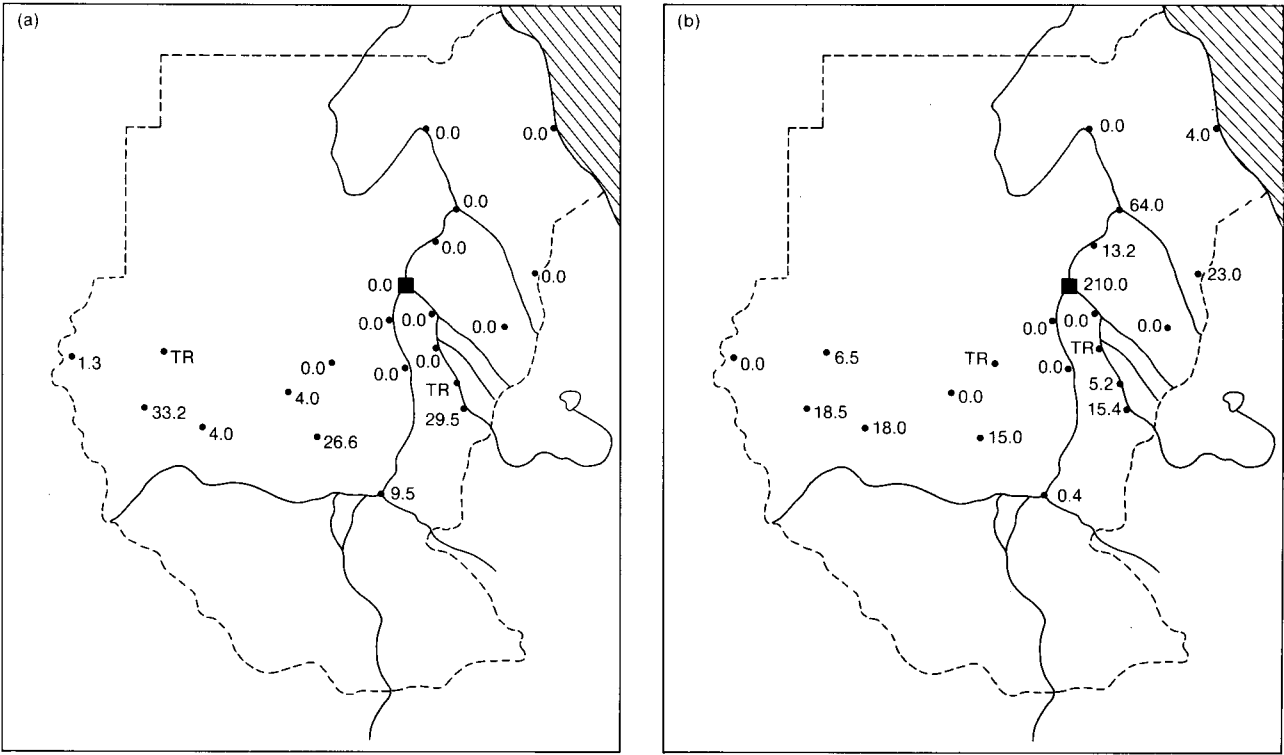


Figure 2. (a) Daily rainfall totals (mm) for the period from 0600 UTC on 3 August to 0600 UTC on 4 August. (b) As in (a) but for 0600 UTC on 4 August to 0600 UTC on 5 August.

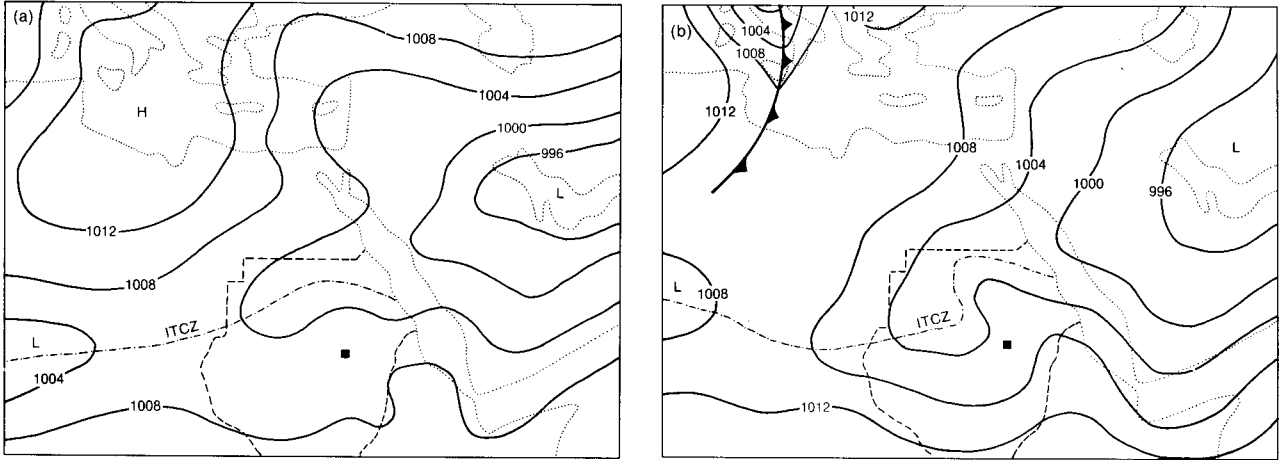


Figure 3. (a) Surface pressure (hPa) over the Sudan and neighbouring areas at 1200 UTC on 3 August. (b) As in (a) but for 1200 UTC on 4 August.

2.2 The Sudan area

At 1200 UTC on 3 August (Fig. 4(a)) a small area of low pressure lay to the south of Port Sudan. Most of the area south of the ITCZ was under the influence of moist southerly winds with dew-point temperatures in the range 16–24 °C; only one station, to the south of Khartoum, reported cumulonimbus clouds. Twenty-four hours later (Fig. 4(b)) there was a low pressure centre to the west of Khartoum, the dew-points were not changed significantly but now cumulonimbus cloud was being reported in the elongated area from Malakal to Atbara and lightning further north-westwards at Port Sudan. Six hours later (Fig. 4(c)), again the low pressure was centred nearly over Khartoum and now the cumulonimbus clouds and lightning were observed there and to the north and east. The dew-points remained high.

2.3 Upper-air analyses

The 850 hPa height for 1200 UTC on 4 August (Fig. 5(a)) shows a trough aligned north-east to south-west, approximately coincident with the main trough in the surface pressure. This trough extends up to the 500 hPa level (Fig. 5(c)); at 700 hPa (Fig. 5(b)) the trough axis passes over Khartoum.

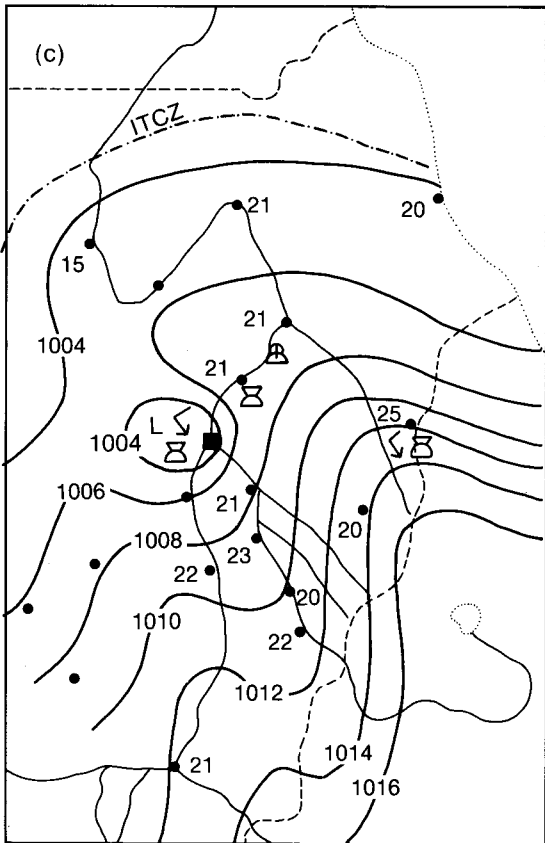
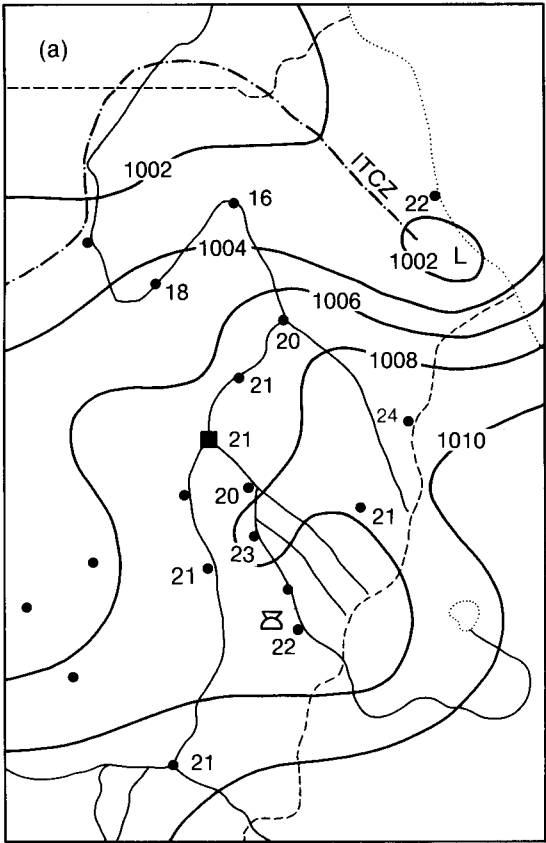
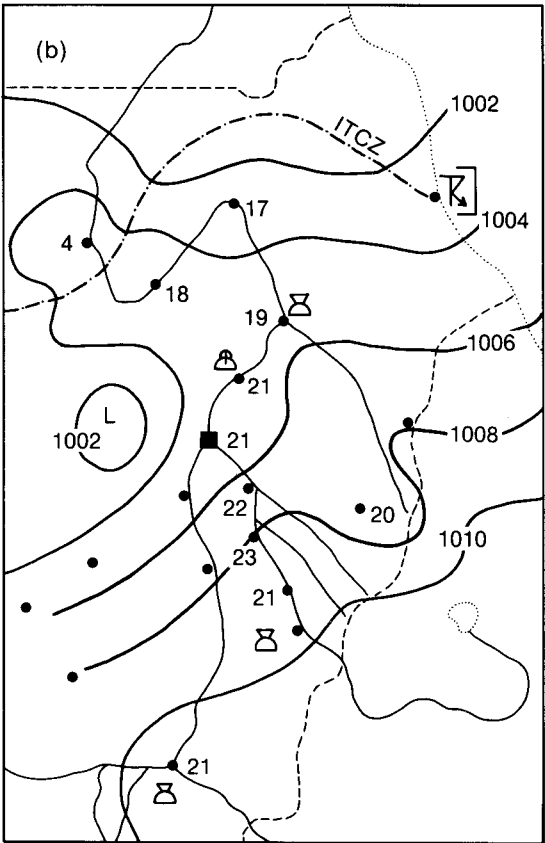


Figure 4. (a) Surface pressure (hPa) at 1200 UTC on 3 August. Also shown are station values of dew-point temperature (°C). Cumulonimbus clouds and lightning are denoted by conventional symbols. (b) and (c) As in (a) but for 1200 UTC on 4 August and 1800 UTC on 4 August respectively.

2.4 Additional information

The percentage changes in the surface relative humidity in the 24-hour period from 1500 UTC on 3 August to 1500 UTC on 4 August for the Khartoum area are shown in Fig. 6. The changes in daytime maximum temperature from 3 to 4 August are shown in Fig. 7.

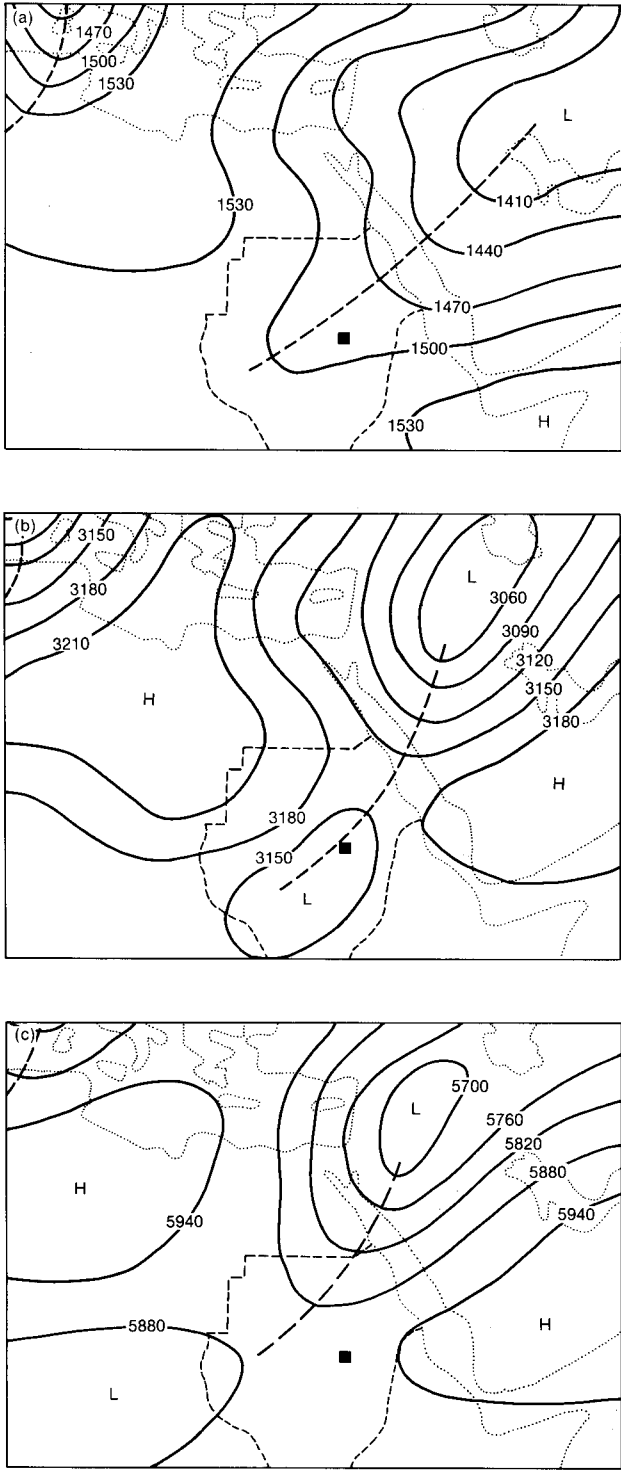


Figure 5. (a) 850 hPa level height (gpm) over the Sudan and surrounding areas at 1200 UTC on 4 August. (b) and (c) As in (a) but for 700 and 500 hPa levels.

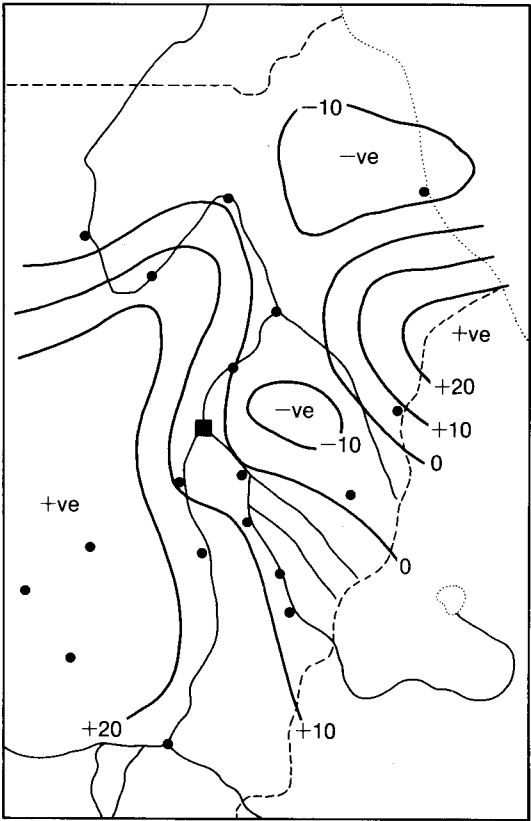


Figure 6. Percentage changes in relative humidity in the 24-hour period from 1500 UTC on 3 August to 1500 UTC on 4 August.

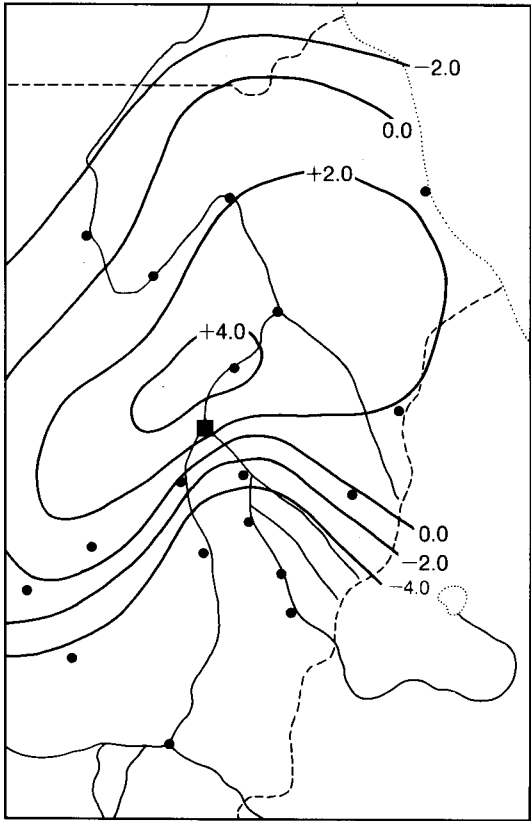


Figure 7. Changes in daytime maximum temperatures (°C) from 3 to 4 August.

The divergence/convergence was calculated using streamline and isotach analysis for the area bounded by latitudes 10–22° N and 30–40° E for a time of 1200 UTC on 4 August. The wind data were interpolated on a mesh of size $2^\circ \times 2^\circ$. The divergence/convergence at 850, 700 and 500 hPa are shown in Figs 8(a), 8(b) and 8(c) respectively and the 850 hPa streamlines and isotachs for 1200 UTC on 4 August are shown in Fig. 9.

Meteosat infra-red images are available during the event. Figs 10(a), 10(b) and 10(c) are sketches of images for 1450 UTC on 4 August — about 4 hours before the first storm over Khartoum, 1818 UTC on 4 August — at its commencement, and at 2218 UTC on 4 August — at the start of the second and longer storm.

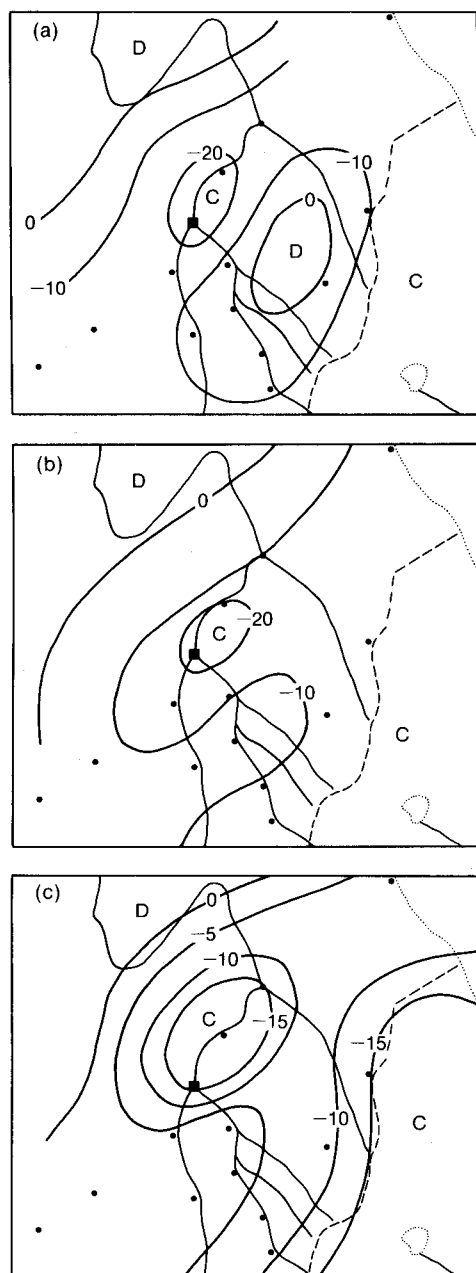


Figure 8. (a) Divergence (D)/convergence (C) at the 850 hPa level at 1200 UTC on 4 August. Numbers are in units of 10^{-6} s^{-1} . (b) and (c) As in (a) but for 700 and 500 hPa levels.

3. Discussion

The surface and upper-air charts as described in section 2 show that on the day of the event the area was under the influence of a very deep layer of unstable moist monsoon air. The presence of a trough line, at least up to the 500 hPa level (Figs 3(a), 3(b), 5(a), 5(b) and 5(c)) triggered the mechanism of development. The relative humidity anomaly charts in Fig. 6 and the isotachs in Fig. 9 show that moisture was injected into the Khartoum area by two mechanisms:

- the north-easterly surface flow from the south-west of Khartoum where widespread rainfall took place on 3 August (Fig. 2(a)), and
- the westerly flow from an area north-east of Kassala, and at the northern end of the Ethiopian Highlands. This flow is revealed by a line squall which can be seen as an extensive band of clouds with cloud-top temperatures of lower than -70°C on the extreme right-hand side of Fig. 10(a). This band of cloud moved steadily westward on successive Meteosat images as in Fig. 10(b). The formation and movement of line squalls in this part of the world have been described by Ali (1986).

In Fig. 7 it can be seen that in the Khartoum–Shendi area there was a increase of about 4°C in surface temperature from 3 to 4 August, but in the same period the temperature to the south of Khartoum decreased by the same amount. This steepening of temperature gradient made a thermal contribution to reinforce the dynamical instability which caused the storms.

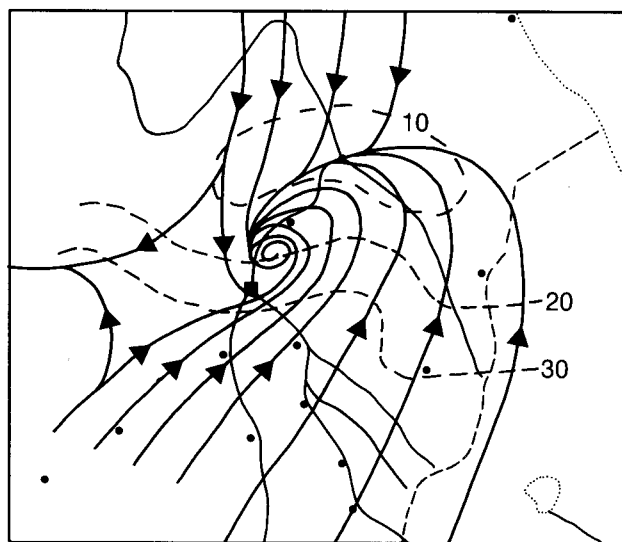


Figure 9. Streamlines (solid lines) and isotachs (dashed lines) at the 850 hPa level at 1200 UTC on 4 August. Units of wind speed are knots.

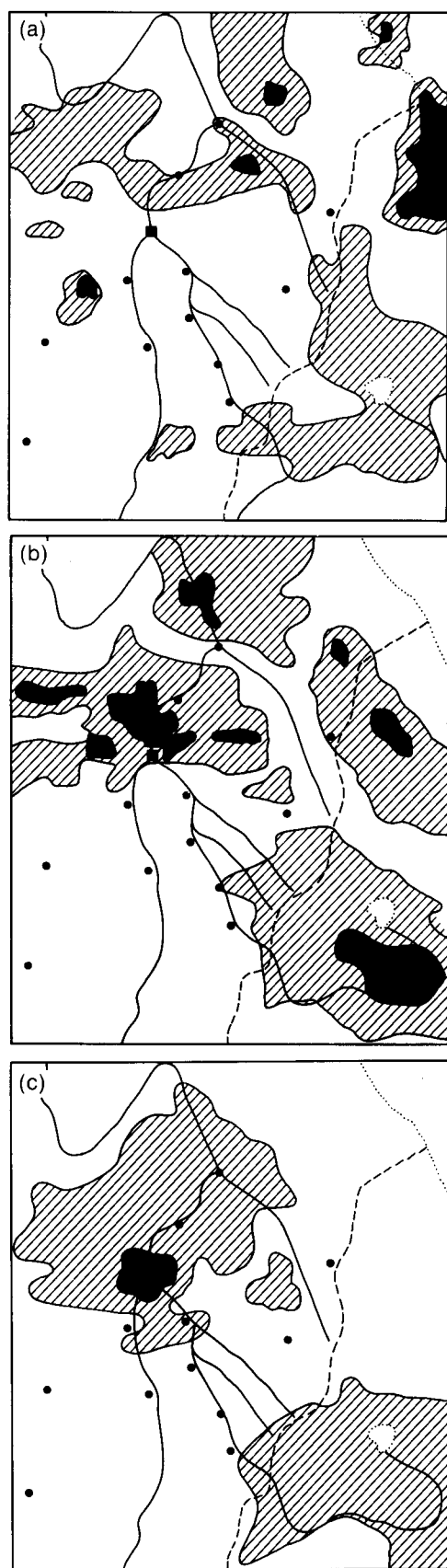


Figure 10. (a) Sketch of Meteosat infra-red channel image for 1450 UTC on 4 August. The shading denotes cloud-top temperatures in the range -40 to -69 °C and the black areas temperatures less than -70 °C. (b) and (c) As (a) but for 1818 UTC and 2218 UTC on 4 August.

The convergence/divergence fields at 850, 700 and 500 hPa at 1200 UTC on 4 August (Fig. 8) all show a centre of convergence situated over the Khartoum–Shendi area. The large vertical extent of convergence right up to the usual level of non-divergence — about 500 hPa — concentrated over a small ground area promoted vigorous uplift. The streamlines and isotachs (Fig. 9) confirm that a vortex formed just to the north of Khartoum which was on the cyclonic-shear side of the low-level winds. The region of confluence is between the drier air advected from the Sahara and the more humid air from the south-west.

A large area of cloud with cloud-top temperature lower than -70 °C formed over and just to the north of Khartoum at about 1800 UTC (Fig. 10(b)) and heavy rain fell for the next 2 hours. Leading up to this time there was considerable cloud development well to the north of Khartoum due to the advanced northerly position reached by the ITCZ; for instance, Port Sudan registered 4.0 mm of rain on 4 August, an unusual amount of rainfall in that area and at that time of year.

At about 2200 UTC on 4 August the second period of heavy rainfall commenced with the formation of another area of cold cloud-top temperature, this time centred right over Khartoum, and this lasted until about 0400 UTC on 5 August. The rain ceased at about 0800 UTC on 5 August.

The joint effect of this line squall and the local development of clouds which acted as a feeding mechanism to the squall, were the main causes of the second storm.

4. Conclusions

The large rainfall (210 mm in 12 hours) at Khartoum on 4 and 5 August was caused by the following factors:

- (a) The ITCZ had moved to an advanced northerly position on 4 August.
- (b) A deep vortex developed just to the north of Khartoum as a result of intense surface heating coupled with an approaching trough at upper levels.
- (c) There was a deep layer of vertical motion over the Khartoum area leading to the formation of massive cumulonimbus clouds.
- (d) Moisture injection into the area which came from:
 - (i) Widespread rainfall to the south and south-west on 3 August combined with a deep layer of strong south-westerly winds which continued until 4 August.
 - (ii) The arrival of a line squall from the east into the area 2 hours before 0000 UTC on 5 August.

References

- Ali, A.M.A., 1986: Forecasting of dust-generating convective systems in the Sudan with the aid of satellite pictures. (Unpublished copy available in the Sudan Meteorological Department.)

Meteorological aspects of nuclear and chemical incidents

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Summary

This paper summarizes the meteorological support available to the emergency services in the event of nuclear and chemical accidents.

1. Introduction

As soon as either radioactive materials or toxic chemicals have been released into the atmosphere, the area in which the population, livestock and crops are at risk is strongly influenced by the prevailing weather conditions. For those managing the response to incidents of this kind, meteorological advice is probably of most value:

- (a) at a very early stage, when it is important to know where the plume is liable to spread, so that the emergency services can deploy their resources in the safest and most effective manner, and
- (b) after the emergency is under control, when the scientific advisors are trying to ascertain where significant amounts of material may have been deposited on the ground.

This paper outlines what advice the Meteorological Office can offer and how quickly that advice can be made available for scenarios ranging from short duration local chemical accidents to major nuclear accidents such as Chernobyl. The arrangements for the provision of this advice is the responsibility of the Defence Services Branch of the Office (Turton and Caughey 1989).

2. Background

Following the release of a toxic substance into the atmosphere the subsequent path of the material is mainly determined by the prevailing wind. In a 'steady' wind the material would move downwind in a straight line, slowly spreading out as it went through the effects of turbulent diffusion. However the wind is rarely 'steady' and there are nearly always changes in both speed and direction over short periods of time (of the order of 5–10 minutes). The plume of material therefore meanders as it drifts, as shown in Fig. 1. The track of the meandering plume continually changes so that sometimes a given point on the ground is affected by the pollution and at other times it is in clear air. What is required for emergency planning is an indication of the total area which could be affected by the plume at some time during the course of an incident. This area is called the 'Area at Risk'. Its size varies as meteorological

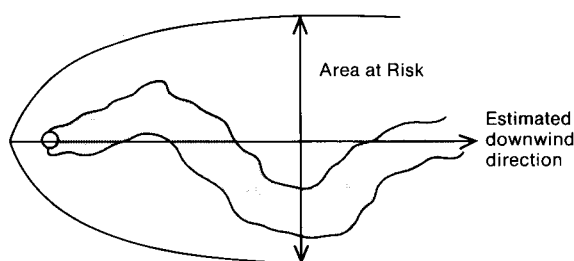


Figure 1. The Area at Risk after the release of a toxic substance.

conditions change, but, with a knowledge of the local conditions near the accident site, it can be calculated to a useful degree of accuracy in any particular instance.

A second aspect, which is particularly relevant to the longer range transport of pollutants, is the effect of rain. For example, as rain falls through a cloud of nuclear material, it collects the particles and deposits them on the ground. This process is referred to as 'wet deposition', or more colloquially 'wash-out', and was largely responsible for the high radioactive levels in the Lake District and surrounding areas following the Chernobyl accident (Smith 1988).

Meteorological advice must be made available to the emergency services both quickly and in a form that they can readily assimilate. The remainder of the paper discusses how that is achieved. Important aspects for consideration are:

- (a) the nature of nuclear and chemical accidents and how that affects the requirements for an emergency response,
- (b) the organization of the authority responsible for leading the emergency response and the communications lines to that authority,
- (c) Meteorological Office procedures for internal (i.e. at sites within the United Kingdom) nuclear and chemical incidents, and
- (d) international aspects and how meteorological advice is made available to deal with overseas accidents which may affect the United Kingdom.

3. Nature of an emergency

From a meteorological point of view there are differences between chemical and nuclear accidents. With chemical accidents there is, broadly speaking, an instantaneous release, followed by a gradual reduction in the amount of material released as the accident is brought under control. Typically this occurs over a period of hours. The amount of released material is usually relatively small and in consequence the area in which there is a requirement for special precautions is typically a few kilometres long by 1 or 2 kilometres wide.

While the above scenario is also applicable to many nuclear accidents, it is possible for nuclear accidents to continue to release significant quantities of material for several days, as was the case at Chernobyl. This, combined with the fact that radioactive material can be measured in very low concentrations, means that the released material can be detected over very large areas; less than 3% of the core of Chernobyl was released to the atmosphere and that accident caused concern over a region many thousands of square kilometres in extent.

Thus, in meteorological terms, most chemical and many nuclear accidents require a good knowledge of the local conditions and are therefore best dealt with by regional Meteorological Offices. However, for large nuclear accidents, in which the radioactive material travels for several thousands of kilometres, global-scale numerical forecast models are required to predict the movement of the plume, and meteorological advice can best be provided by the Central Forecasting Office (CFO) at Bracknell.

Because of this, and because there are different authorities responsible for handling chemical and nuclear accidents within the United Kingdom, it is necessary to have different procedures for supplying meteorological advice for the different types of incident. These are:

CHEMET — CHEMical METeorology — for UK-based chemical accidents.

PACRAM — Procedures And Communications in the event of an accidental release of RadioActive Material — for UK nuclear sites.

INTERNATIONAL PROCEDURES — for overseas nuclear accidents and chemical incidents which may affect the United Kingdom.

4. CHEMET

Under the Control of Industrial Major Accident Hazard (CIMAH) regulations, a firm is required to register any site at which large amounts of hazardous chemicals are stored. However, the large number of such sites precludes the Meteorological Office making special arrangements with each, and it is more practical to make meteorological advice available to the Police and Fire Brigades, who will always be at the scene of any major incident.

The initial response to any request from the Police or Fire Brigade for meteorological advice must be handled

quickly, and, within 2–3 minutes of notification, the appropriate meteorological office will provide:

- (a) Surface wind speed and direction.
- (b) An indication of the plume behaviour — whether it will disperse quickly or remain trapped near the incident site.

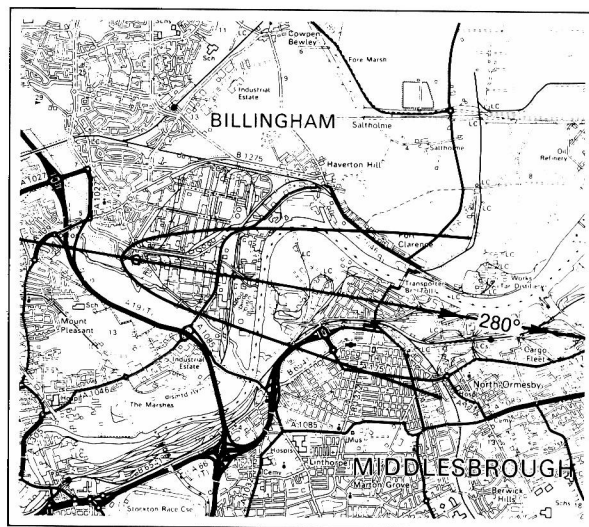
Such information allows those in charge of the response to the incident to deploy their resources both safely and in the most efficient manner.

Following the initial contact, the Meteorological Office will then prepare more detailed information which includes:

- (a) Definition of the Area at Risk.
- (b) Information on any likely significant changes in wind direction.
- (c) Details of any rain, snow, etc.
- (d) Special parameters for scientific advisors.

This will be available some 20–30 minutes later and will be sent automatically to both the Police and Fire Brigade Incident rooms. An example of an Area at Risk diagram is shown in Fig. 2. There are some 15 different templates (outlines of the areas) which can be used depending on the prevailing weather conditions.

Other organizations who are likely to become involved are expected to be informed of the incident by the Police, or come to the Police for initial briefing. Consequently, in the first instance, they will be able to obtain meteorological information from the Police. At a later stage, when more detailed information is required, or there is a need to clarify any information that has already been provided by the Meteorological Office, organizations such as Emergency Planning Authorities, Ministry of Agriculture Fisheries and Food (MAFF), etc. may contact the appropriate Meteorological Office directly.



Reproduced from the Ordnance Survey 1:50 000 Landranger Map with the permission of the Controller of Her Majesty's Stationery Office.

Figure 2. An illustration of the Area at Risk map that is sent to the Police and Fire Brigades as part of a CHEMET response. In this example the prevailing surface wind direction is from 280°.

operator. There are only a small number of these and therefore meteorological advice can be provided to them in a mutually agreed format, and transmitted to the site and/or OSC via nominated telephone lines. The procedures are practised regularly by the operators and the Meteorological Office is involved in many of the exercises.

In the event that a nuclear incident becomes too large to be handled at local level, dedicated incident control rooms are available in London, and in the regions (Scotland, Wales and Northern Ireland), to co-ordinate the national response. The Department of Energy have the main responsibility for responding to accidents at civil nuclear sites and, if necessary, they will open their Nuclear Emergency Briefing Room. There is a similar room in the MOD for military accidents. When either room is opened, the Meteorological Office provides an advisor who liaises between the incident controller and CFO. The role of these government department co-ordination rooms is discussed further in the next section.

6. International nuclear accidents

Following Chernobyl, the Government appointed the Department of the Environment (DOE) as the lead department to co-ordinate the national response in the event of an overseas accident in which released radioactive material might affect the United Kingdom. One of their first actions was to set up a gamma-radiation monitoring network (RIMNET) at 46 Meteorological Office sites throughout the United Kingdom (Fig. 5) — including the Isle of Man and Jersey. The instruments are read once per hour, 24 hours per day, and the information passed via the Meteorological Office Telecommunications Centre at Bracknell to the Central Data Facility at DOE Headquarters in London and Lancaster.

However, from a meteorological point of view, RIMNET only provides confirmation that the cloud has arrived; it gives no indication of the spread and concentrations within an approaching cloud, and this information is vital if the Meteorological Office is to provide forecasts of the cloud movement. Consequently, through international agreements, radiological and special meteorological data will be passed via the Global Telecommunication System (GTS) in the event of major international incidents.

Once there is a report of an international accident, the Meteorological Office has two numerical models available to predict both where the plume will go, and where it has come from. The first is a fairly basic model which can backtrack the plume for about 2 days and forecast its approximate movement for up to 5 days ahead. The output from this model is available within about 30 minutes of notification, and an illustration of the output is shown in Fig. 6. In November 1988 there was a report that radiation had been detected in the air at a village in Poland — this was later found to be a false

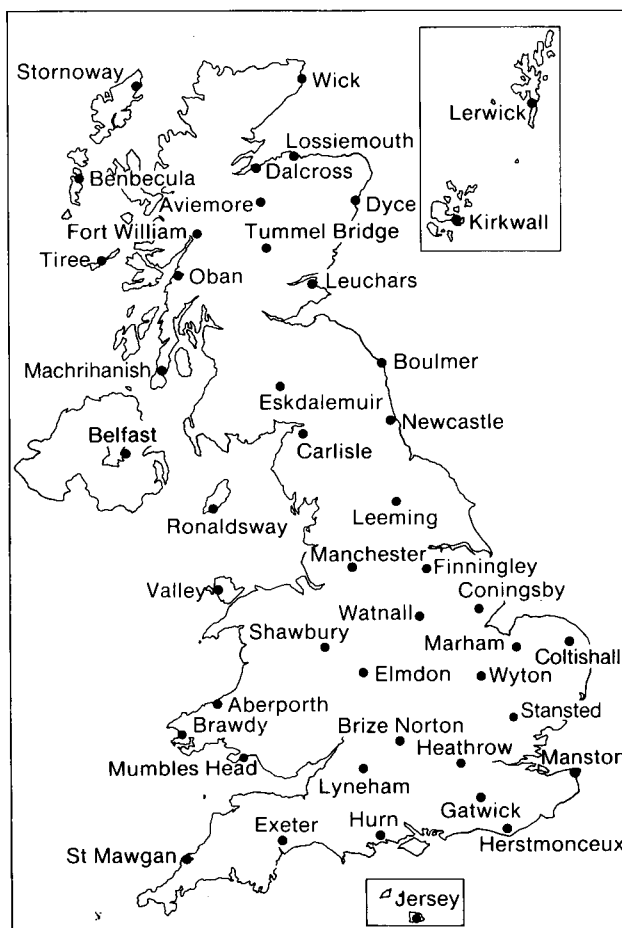


Figure 5. Radioactive Incident Monitoring Network (RIMNET) Phase 1.

alarm. However, in Fig. 6 it is well demonstrated that in this incident there would have been no serious threat to the United Kingdom; the forecast section of the trajectory showed that the plume would have been advected over the USSR while the hindcast section suggested that its origin was over Northern Poland, Scandinavia or the Norwegian Sea.

If this incident had developed into a serious threat then the more sophisticated trajectory model, developed by the Boundary Layer and Atmospheric Chemistry Branch of the Meteorological Office (Met O 14), would have been run to determine accurately the path of the material, and the likely level of air concentrations and surface deposition (Maryon 1989). This model simulates the spread of material due to wind shears and atmospheric turbulence. In addition to air concentrations it computes the radioactive decay and deposition to the surface of radio-nuclides, including material washed out of the air by rain — a process of critical importance. An illustration of this is shown in Fig. 7 which depicts a fictitious incident at 50° N, 00° W. If it had been a real incident then, as data from RIMNET and other countries' equivalent monitoring networks became available, the forecasts would have been continuously updated and refined. The different levels of shading

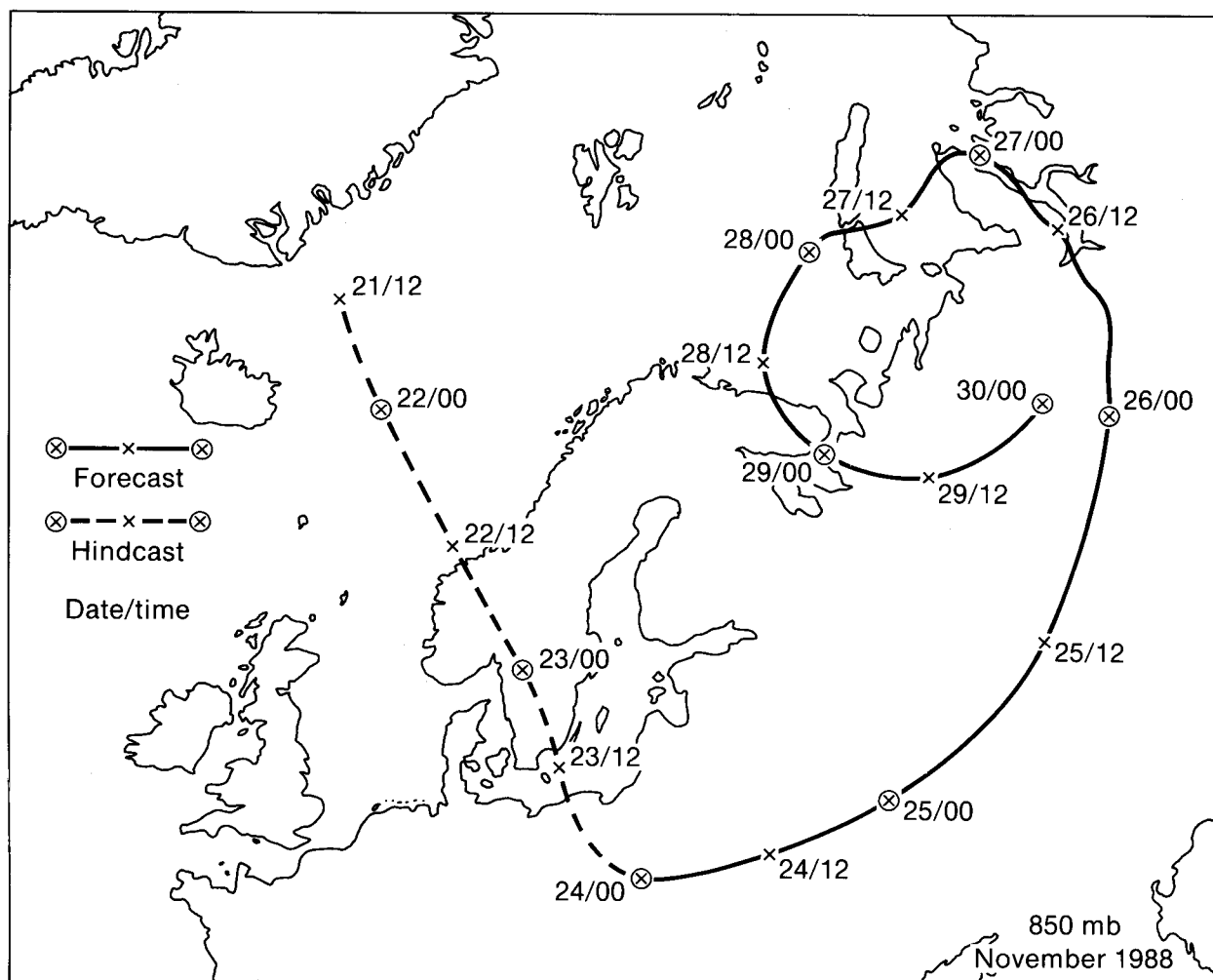


Figure 6. An example of hindcast and forecast trajectories.

indicate different levels of air concentration and shows how material can be dispersed at different rates and in various directions by the differential motion within weather systems. Air concentrations need not decrease uniformly with distance from source.

In the event of an incident, data from both models is made available to the DOE. If there is a threat to the United Kingdom then the Technical Co-ordination Centre (TCC) is opened and from there the DOE co-ordinate the national response. (The TCC has a similar function to the Department of Energy and MOD co-ordination rooms discussed in the previous section. It differs in that those rooms are concerned with accidents at sites within the United Kingdom while the TCC is for accidents abroad.) Many Government Departments are represented at the TCC and meteorological advice is made available from CFO via the Meteorological Office representative.

7. International chemical incidents

For completeness there is one further type of accident that must be considered — the chemical accident which occurs abroad but where the plume of material is blown

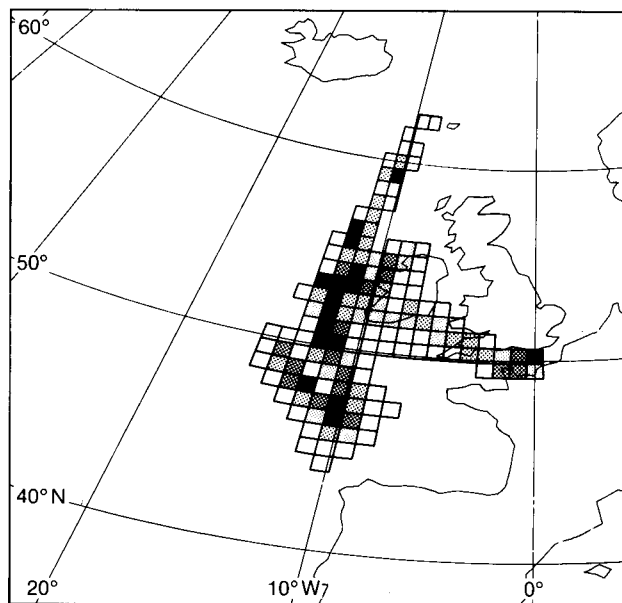


Figure 7. An example of trajectory information available from the Met O 14 model. Illustrated is the air concentration (larger shown by heavier shading) expected 3 days after a fictitious radioactive release accident at 50°N, 00°W. Note how material can be dispersed at different rates and in various directions by the differential motion within weather systems.

towards the United Kingdom. Essentially this reduces to the possibility of a very large amount of material being accidentally released in a nearby European factory (e.g. at a fertilizer factory). It requires a considerable amount of material, released reasonably near to the United Kingdom, for the toxic fumes to cross the English Channel and arrive in sufficient concentration to pose a threat to the population. Consequently the risk of this type of incident is considered to be very low.

In 1988 a possible example of such an incident did occur at a large factory in Nantes in north-west France. The prevailing southerly winds advected the plume towards the United Kingdom and there was initially some concern in the south-west peninsula. In the event the plume was not detected, having dispersed sufficiently during the intervening 200 miles for the air concentration to be very low, by the time it reached the United Kingdom.

Fortunately the long-range trajectory models developed by Met O 14 (Maryon 1989) in response to the Chernobyl incident, are a good basis for tracking plumes of toxic chemicals, and therefore appropriate advice is available to whichever Government Department takes the lead in the UK emergency response to such international chemical accidents.

8. Future developments

There is still considerable national and international activity in this area. The World Meteorological Organization (WMO) and the International Atomic Energy Authority are currently developing codes for the exchange of both radiological and special meteorological data via the GTS in the event of future international nuclear accidents. Such codes are particularly important; the amount of available radiological data is increasing rapidly in the wake of Chernobyl, as nations install and expand their radiological networks.

In the United Kingdom, RIMNET Phase 1 (Fig. 5) is complete and work has now begun on expanding the network to some 80 stations, at the same time automating the data collection procedures from both the new and existing sites.

There are also initiatives within WMO to formalize the exchange of information in the event of large chemical accidents in which there is a possibility that the toxic plume may cross national boundaries. As discussed above, the risk to the United Kingdom is not particularly great, but other countries are not as geographically isolated, and there is growing concern on the continent.

On the meteorological aspects of the subject, work continues on the development of the long-range dispersion model (Maryon 1989). However, this model is of use only for major incidents. In the majority of cases the plume poses a threat for at most a few kilometres downwind. Because of the necessity for speed of response, and due to the limitations both of observational data and in our knowledge of the effects of topography on air flow, the current models defining the Area at Risk are relatively crude, and it is left to the subjective assessment of the forecaster to determine the effects of terrain and other local features. This is a topic that requires further research and it is hoped that, in a few years time, it will be possible to give better guidance in this aspect of the problem.

References

- Maryon, R. H., 1989: Trajectory and plume analysis in the Meteorological Office Atmospheric Dispersion Group. *Meteorol Mag*, **118**, 117–127.
- Smith, F. B., 1988: Lessons from the dispersion and deposition of debris from Chernobyl. *Meteorol Mag*, **117**, 310–317.
- Turton, J. D. and Caughey, S. J., 1989: Defence Services Branch 50th Anniversary. Part II: Current commitments and the future. *Meteorol Mag*, **118**, 168–175.

The WMO International Ceilometer Intercomparison, Beaufort Park 1986

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Summary

This paper describes the instruments, data recording, analyses and results for the WMO International Ceilometer Intercomparison hosted by the Meteorological Office in 1986.

1. Introduction

The first WMO International Ceilometer Intercomparison was conducted under the auspices of the Commission for Instruments and Methods of Observation, and held from February to July 1986 at the Meteorological Office experimental site at Beaufort Park, near Bracknell, England.

The objectives of the intercomparison were:

- (a) To record cloud-height data from production ceilometers together with simultaneous measurements and observations of relevant meteorological variables, and when feasible to make independent estimates of cloud base using alternative techniques.
 - (b) To publish analyses of recorded ceilometer data, classified according to related meteorological variables, and comparisons against independent (or reference) measurements.
 - (c) To make recommendations concerning definitions for cloud-base measurement identifying, as appropriate, the needs for further studies and further practical experiments.
 - (d) To assemble information on the operational aspects of the ceilometers used in the intercomparison.
- The present paper is a summary of the conduct and results of the intercomparison, and is therefore concerned mainly with the first two objectives.

2. Description of instruments studied

A total of eleven ceilometers, comprising seven different models, were eventually investigated. A list of their characteristics appears in Table I. Five of the instrument models were laser ceilometers, using the LIDAR technique based on the time for return of a pulse of infra-red laser light. The other two worked on the triangulation principle, measuring the angle of elevation of a patch of cloud illuminated by visible light.

Four of the five laser models were represented by two instruments each, which enabled conclusions to be drawn not only about the consistency of manufacture, but also about the degree to which the ceilometer performance varied according to exposure. The instrument sponsored by The Netherlands was an old design,

producing analogue chart output, which had been modified for the intercomparison to produce, in addition, digital messages via a microcomputer. The remaining systems were all in production or under development at the time of the intercomparison. Several of the instruments were capable of reporting more than one cloud-base height on a given sounding; the maximum number for each is given in Table I under 'Levels per sounding'. The final column of Table I lists the abbreviations used to identify individual instruments in the remainder of the paper.

The intercomparison commenced on 3 February 1986, although the Belfort instruments (B1/B2) were not available until 22 May. The Netherlands instrument (K1) failed for periods in February and April, the Impulsphysik Ceilograph II (I4) was not repaired following a failure early in June, and B1 and B2 both developed hardware faults causing 26% and 17% loss of data, respectively. The remaining seven systems had lost little data when the intercomparison was terminated on 17 July 1986.

3. Ceilometer deployment

The laser instruments were deployed approximately 20 m apart around a circle of about 60 m diameter. The two triangulation devices were about 100 m (I4) and 350 m (K1) from the centre of the circle. No discernible bias was noted as a result of these separations.

4. Measurements and data recording

Data from the ceilometers were logged every minute. Also, measurements of temperature, humidity, horizontal visibility, global irradiance, presence and rate of rainfall, wind speed and direction were made automatically at 1-minute intervals throughout the intercomparison, with daily manual checks. In addition, special hourly observations were made between 0600 and 2100 UTC daily by experienced staff. Alternative estimates of cloud-base height were obtained on an opportunity basis by double-theodolite tracking of pilot balloons. Effort was concentrated on occasions of relatively rare weather phenomena, and was confined to daylight.

Table I. Characteristics of the ceilometers deployed in the intercomparison

Member	Manufacturer	Model	Type	Number entered	Maximum range (m)	Soundings per min.	Levels per sounding	Vertical vis?	Abbrev.
Finland	Vaisala	CT12K	Laser	2	3600	2	2	Yes	V1/V2
Federal Republic of Germany	Impulsphysik	LD-WHX	Laser	2	3600	2	3	No	I1/I2
	Impulsphysik	LD-WHL	Laser	1	1500	4	2	No	I3
	Impulsphysik	Ceilograph II	Triangulation	1	900	2	1	No	I4
Netherlands	Crouse/Hinds	TXJ-2	Triangulation	1	1500	1	1	No	K1
Sweden	ASEA	QL1212	Laser	2	3000	1	2	Yes	A1/A2
USA	Belfort	7013	Laser	2	5000	1	1	Yes	B1/B2

5. Principles and methods of analysis

The principles for analysis of the data were agreed by the International Organizing Committee; the most important of these was that no single instrument would be used or appear to be used as a standard against which others were judged. Thus, in the analysis, the median of the heights from the seven models of ceilometer were selected for each minute as representative values of cloud-base height. Where two instruments of the same type were available, only one of them was used in the calculation; a median was not defined when fewer than five had reported cloud within range. It was also agreed that analyses would be performed at the shortest common time-interval, namely one minute, and on the lowest cloud base reported by a given instrument.

Cloud-base height is very variable in space and time, and often clouds of widely differing height are present simultaneously. Minute-by-minute comparisons of reported heights therefore reveal little useful information, and much more may be obtained from comparisons of height distributions. The main tool chosen for the assessment of reported heights is the Empirical Quantile-Quantile (EQQ) plot (Murphy and Katz 1985) in which two cumulative distributions are compared directly in a compact format. Each point on the plot defines a pair of heights corresponding to a common cumulative frequency of the two height distributions. Interpretation of the resulting plot is not always straightforward, but in general if the curve lies predominantly above the line of equality, then the instrument featured on the ordinate produces heights which are on average greater than those from the instrument on the abscissa, and vice versa. (Interpretation of the EQQ plot has been discussed more fully in Jones *et al.* 1988.)

Each EQQ plot compares data at 1-minute resolution, either from two ceilometers, or from one ceilometer and the median height (MEDIAN). In either case, data were included in the distributions only if the two sources agreed that cloud was present simultaneously within

range of both, thus ensuring that both distributions resulted from the same underlying meteorological conditions. No numerical analysis was performed on reported heights of higher cloud layers, penetration distances or vertical visibilities, although it was noted that vertical visibility reports were frequently misleading.

6. Results of analysis

For those ceilometers where two examples had been submitted, direct comparisons were made between instruments of the same model. The results showed that the distributions of reported heights were identical within the resolutions of the instruments, indicating that the individual modern LIDAR systems are manufactured to a high degree of consistency of performance. This result also confirmed that there was no effect due to the spatial separation of the ceilometers.

Fig. 1 shows data from a representative of each ceilometer model displayed in an EQQ plot. Each plot is derived from all qualifying available data, and compares the individual cumulative distributions with the distribution of the MEDIAN. The curves are plotted at 1% resolution and symbols appear at 5% intervals; the digits 1-9 mark the 10% intervals. Note that the curves for all but I3 are offset for clarity. Fig. 1 illustrates many of the features characteristic of each model. For heights up to about 600 m, the I4 triangulation system produced results very much in agreement with those from the laser types, although it did display a slight tendency to over-read relative to the others at the upper end of its distribution. This problem was even more pronounced in the reports from the other triangulation system (K1) above about 600 m. It is possible that a misalignment of the sensitive triangulation system could have contributed to this effect. B2 and A1 reports agreed closely with the MEDIAN, whereas I1 appeared to be systematically about 25 m lower. V1 reports exhibited an anomalous excess in the height range 500-600 m, indicated by the slight change of slope in the EQQ plot in that region.

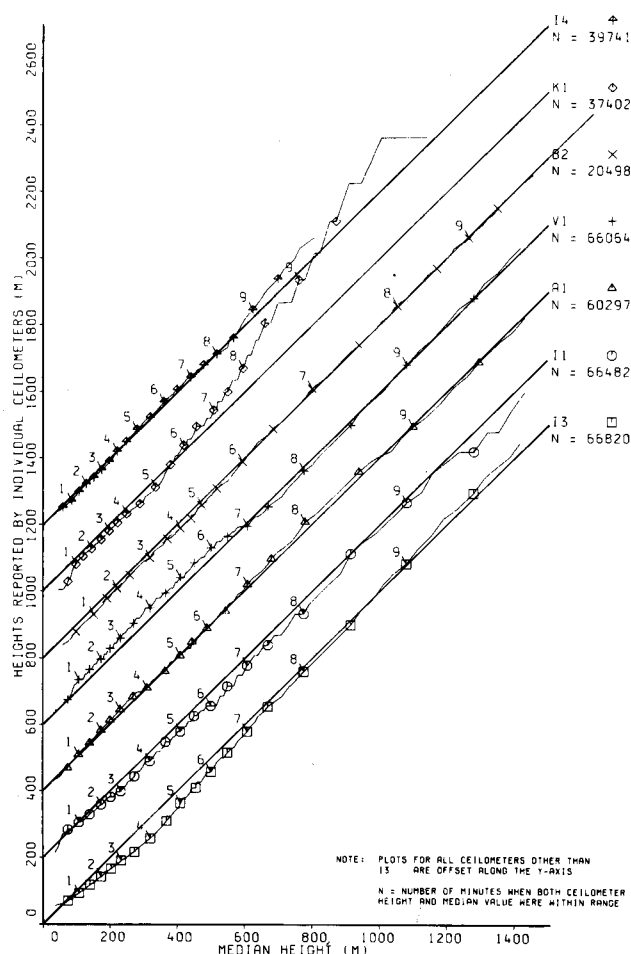


Figure 1. Empirical quantile-quantile plots of heights against median recorded by a representative from each ceilometer model for all available data. See text for further explanation.

The departure from the line of equality shown in Fig. 1 by the I3 reports is due to its response to precipitation, and is one of the more dramatic results of the intercomparison. The effect may be seen more clearly in Fig. 2, which shows only those results obtained during liquid precipitation. The I3 reports form a curve which is quasi-linear up to the 90% point. This implies a systematic difference from the MEDIAN by a factor equal to the slope of the line (i.e. about 0.6). This effect was observed to increase with increasing intensity of precipitation, such that at rainfall rates exceeding 4 mm h^{-1} reported heights were only about 15% of the MEDIAN. The large departures apparent in the tails of many of the other curves in Fig. 2 are not thought to be significant; the EQQ plot is not appropriate for deriving information from the upper limits of the distributions.

Fig. 3 shows a time-height plot of results from the hour 0800 to 0859 UTC on 21 May 1986. Precipitation was detected at the surface from 0822 onwards and the independent observation at 0845 UTC reported intermittent slight rain with a cloud base (marked 'O') at 420 m. Four pilot balloons ('S') were tracked by theodolites, and were judged to have entered cloud at heights of 400–450 m. Most of the ceilometer reports lay between

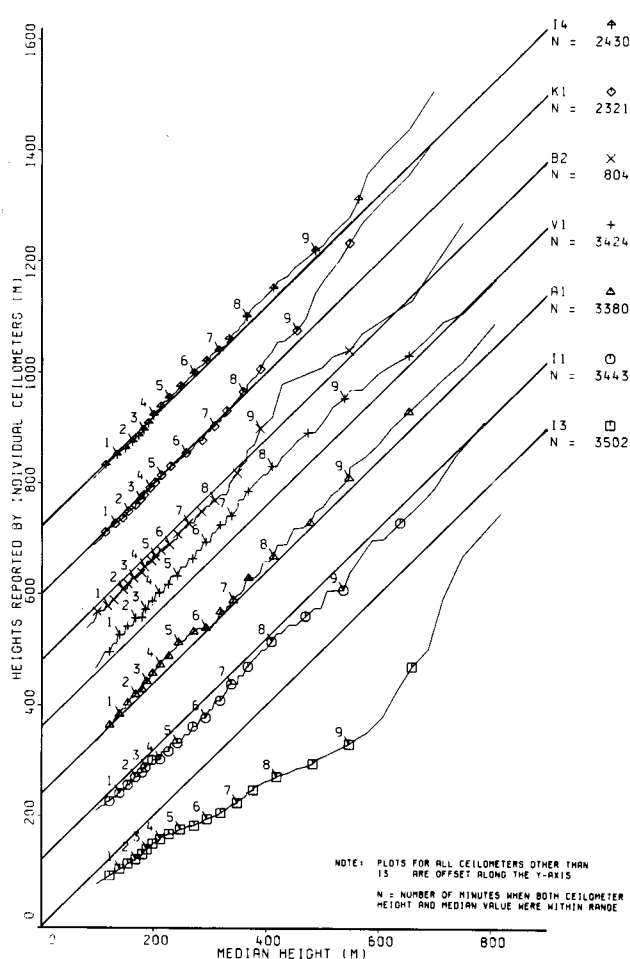


Figure 2. As Fig. 1 but for conditions of any liquid precipitation and visibilities $\geq 1000 \text{ m}$.

400 and 700 m, with large minute-to-minute fluctuations; however, I3 consistently reported cloud around 200 m with only occasional heights agreeing with those from the other instruments.

Results in snow were broadly similar to those in rain, with the exception that both triangulation-based instruments occasionally reported extremely low cloud bases. All ceilometers except K1 consistently responded to fog, although most reported cloud-base heights which were much lower than estimates of vertical visibility made by timing pilot balloons to the point of disappearance.

7. Cloud-strike statistics

The EQQ plot compares distributions of reported cloud-base heights but contains no information on the reliability with which clouds were detected. An assessment of relative reliability may be obtained from Table II, which shows the proportion of minutes in various weather categories for which each ceilometer type reported cloud below 900 m.

It was important to compare instruments under the same set of meteorological conditions, and therefore to select for analysis only those minutes for which correctly formatted data were received from all ceilometers.

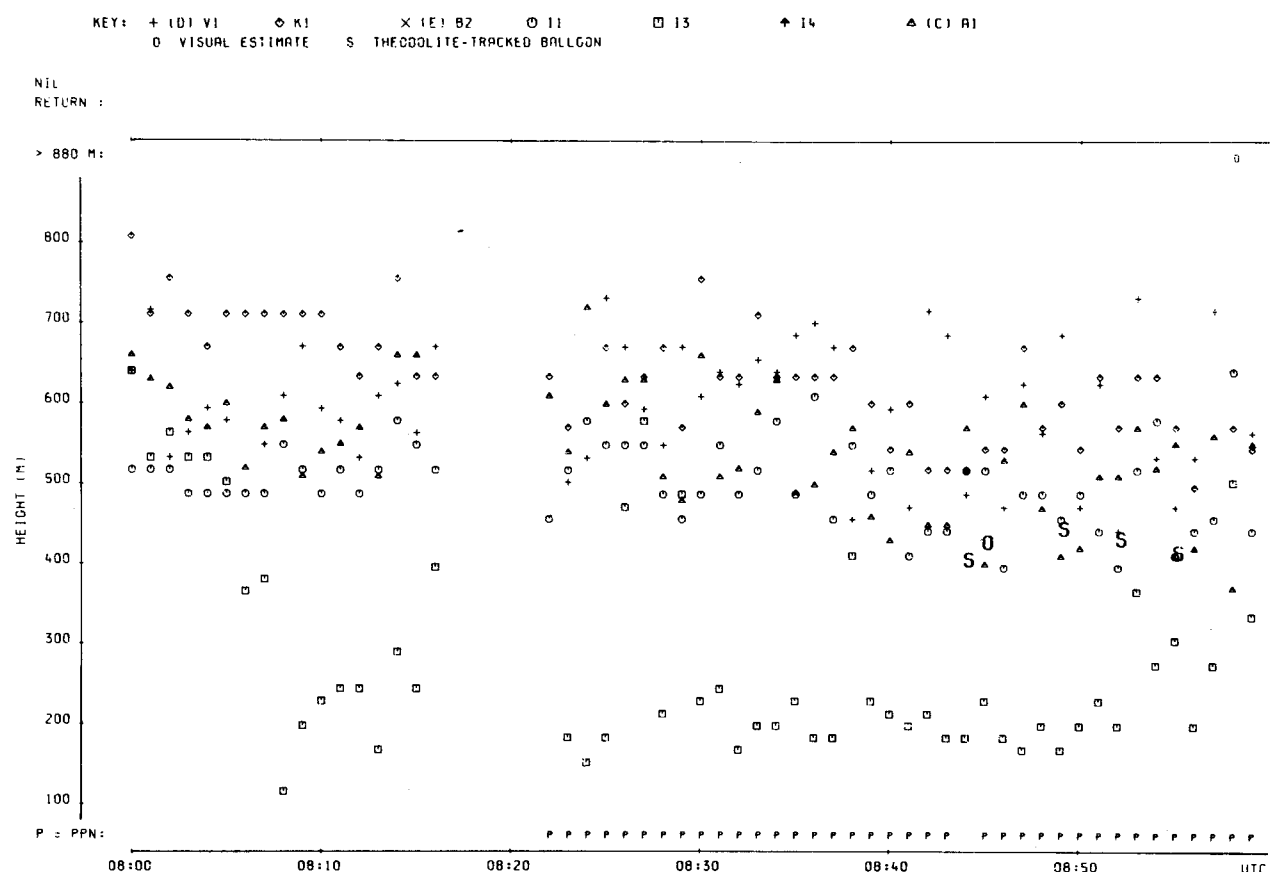


Figure 3. Plot of height against time for the period shown for the ceilometers featured in Fig. 1.

Table II. Percentage of minutes in each weather category for which each ceilometer model reported cloud below 900 m. See Table I for explanation of model.

Model	Vis. ≥ 5000 m No ppn	Slight ppn $\leq 0.5 \text{ mm h}^{-1}$	Mod.-hvy ppn $> 0.5 \text{ mm h}^{-1}$	8/8 cloud $\leq 1700 \text{ ft}$	Snow	Fog
B1/B2	17	61	60	89	—	—
V1/V2	23	83	71	98	65	100
I1/I2	23	83	80	98	61	100
A1/A2	21	80	76	90	24	90
I3	22	90	95	99	71	87
K1	14	64	62	89	41	44
I4	16	66	52	87	27	100

However, owing to the late arrival of B1 and B2, and the almost simultaneous failure of I4, this proved impossible. Entries in Table II were therefore derived from the period up to 1 June only, and the figures for B1 and B2 were estimated from the relationships observed in the

periods when all the laser ceilometers were operational. The percentages in Table II are dependent on meteorological conditions as well as instrument imperfections, and indicate the relative performance of each instrument in the same weather conditions. Note that the consistency

of results from examples of the same instrument model was very high, and therefore they have been combined in Table II.

In general, the two triangulation systems exhibited lower reporting rates than did the laser-based instruments, and in fact behaved similarly to each other in all situations except fog. B1 and B2 consistently reported less cloud than the other laser devices, producing many 'nil returns' instead. The Vaisala and ASEA instruments all tended to report vertical visibility estimates in precipitation; the Vaisalas particularly in heavy rain, and the ASEAs particularly in snow. The values given were usually much too great, and in fact both ASEA ceilometers always produced the value 4200 ft (1280 m) for vertical visibility. Of all the instruments capable of reporting vertical visibility, only the ASEAs did so in fog (on 2–3% of soundings). None of the Impulsphysik instruments had the option to report vertical visibility, and the laser systems, particularly I3, maintained very high cloud-reporting rates in most conditions.

8. Conclusions

(a) V1 and V2 lost a negligible amount of data through faults, and maintained a high cloud-detection rate in all conditions except moderate-to-heavy rain. Cloud heights were greater than the MEDIAN, but corresponded well with estimates using pilot balloons.

(b) I1 and I2 were also very reliable, with a high cloud-detection rate in all conditions. Reported heights were on average slightly lower than the MEDIAN. I3 was very reliable mechanically and

exhibited the highest detection-rate in many situations. However, it consistently reported anomalously low cloud bases in precipitation.

(c) A1 and A2 suffered minor hardware faults resulting in the loss of a few data. Cloud detection was mainly good, except in snow; reported heights were close to the MEDIAN.

(d) B1 and B2 were still under development at the time and suffered from hardware faults which contributed to lower cloud-detection rates. Cloud heights, when reported, were close to the MEDIAN.

(e) The K1 system suffered greatly from hardware faults, and the software written to digitize the output proved inadequate in some situations.

(f) I4 had worked without loss of data until its failure late in the intercomparison. Its height reports compared well with the MEDIAN, but detection rates were modest, particularly in snow.

The intercomparison has shown that modern laser-based ceilometers are technically reliable, and perform significantly better than earlier designs. However, problems remain with the performance of all systems in some situations, particularly in adverse weather conditions which can have a significant impact on aviation.

References

- Murphy, A.H. and Katz, R.W., 1985: Probability, statistics and decision making in the atmospheric sciences. Boulder, Colorado, Westview Press.
- Jones, D.W., Ouldrige, M. and Painting, D.J., 1988: WMO International Ceilometer Intercomparison (United Kingdom, 1986). Instruments and Observing Methods Report No. 32. Geneva, WMO.

Notes and news

European conference on the Landscape Ecological Impact of Climatic Change, Lunteren, The Netherlands, 3–7 December 1989

As a contribution to the UNEP–WMO–ICSU World Climate Assessment Programme and within the framework of the ICSU International Geosphere–Biosphere Programme (IGBP) and the Climatology and Natural Hazards Research Programme (EPOCH) of the European Community, a European conference will be held in Lunteren (near Wageningen), The Netherlands on the Landscape Ecological Impact of Climatic Change (LICC). The scientific preparations for the conference are taking place within six international case-study groups concentrating on: Alpine regions, the Fennoscandian region, the Mediterranean region, fluvial systems, wetlands, and coastal dunes.

During the first half of the conference, the results of the six case-studies will be discussed in parallel workshop sessions. In the second half, the final findings

of the sessions will be presented and will be set in broader context through plenary presentations on various related topics.

The LICC conference is organized in The Netherlands by the Physical Geography Departments of the Universities of Amsterdam and Utrecht, and the Nature Conservation Department of the Agricultural University of Wageningen. For more information/registration, please contact the LICC conference secretariat:

Rudolf S. De Groot or Matthias M. Boer
Department of Nature Conservation
Agricultural University of Wageningen
Ritzema Bosweg 32a
6703 AZ Wageningen
The Netherlands
Tel: 31-8370-82247, Fax: 31-8370-84731,
Telex: 45015 bluwg.

Also, the Editor, *Meteorological Magazine*, has a copy of the conference programme.

Dr D.N. Axford moves to Geneva

Dr David N. Axford, Director of Services at the Meteorological Office up to September 1989, has left Bracknell to fill the post of Deputy Secretary-General of the World Meteorological Organization (WMO) in Geneva, initially for a period of two years. Before becoming the Director of Services, a post he held for nearly six years, he was Assistant Director in charge of Operational Instrumentation and then Deputy Director in charge of Observational Services.

At WMO Dr Axford will be one of the Directing Team whose duties include liaising and negotiating with other Agencies of the United Nations, such as the United Nations Environment Programme, the United Nations Development Programme, and the World Health Organization. He will take a specific interest in technical aspects of the World Weather Watch, the World Climate Programme and the Technical Co-operation Programme.

Meteorological Office participation in IAMAP 89

As announced, with some details, in Notes and news in the April 1989 issue of the *Meteorological Magazine*, the 5th Scientific Assembly of IAMAP (International Association of Meteorology and Atmospheric Physics) was held at the University of Reading, United Kingdom, from 31 July to 12 August 1989. These assemblies are held at 4-yearly intervals.

The Assembly had four components: invited overview lectures, four major Association symposia, thirteen topical symposia organized by the individual IAMAP Commissions, and two workshops. Altogether 885 papers were scheduled to be presented of which 66 were invited review papers.

The Meteorological Office was well represented, with many of its staff being involved in planning, organization and presenting papers.

Dr K.A. Browning (Director of Research at the Meteorological Office) and Dr R.W. Riddaway (Meteorological Office) were on the Local Organizing Committee. Dr Browning chaired the Scientific Programme Committee and five other senior staff of the Meteorological Office were members and acted as convenors of the symposia. This time as President of the Royal Meteorological Society, Dr Browning also chaired the afternoon session of the opening plenary, introducing his invited lecturers, all well known in their particular subjects: Dr L. Bengtsson (ECMWF) on advances and prospects in numerical weather prediction, Dr F.P. Bretherton (University of Wisconsin, USA) on interactions within the global climate system, Dr V. Suomi (University of Wisconsin) on the global water-cycle observational needs and opportunities.

The morning session of the opening plenary was chaired by Dr G.B. Tucker (President of IAMAP) who presided over the opening address and introduced his

invited lecturer: Dr F.B. Smith (Meteorological Office) on regional pollution — field and theoretical studies.

Meteorological Office staff were authors or co-authors (with workers from other organizations) of 48 papers — about 5% of the total, with strong representation in the symposia on mesoscale phenomena: analysis and forecasting (11 out of 101 papers), boundary-layer parametrization and larger-scale models (4 out of 28) and mesoscale processes in extratropical cyclones (10 out of 81).

Meteorological Office staff also contributed several poster displays — particularly on mesoscale meteorology, satellite sounding and climate-change modelling. The Central Forecasting Office also maintained a sequence of forecast charts up to 5 days ahead (updated daily) and the sequence of UK weather radar pictures of rainfall was also displayed.

On the middle Saturday of the 2-week meeting, the Office played host to about 100 IAMAP delegates, who were given a guided tour of the Office and shown the work of the Operational Instrumentation Branch and the services offered by the Advisory Services, Public Services and Marine Branches.

Books received

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

The human impact of climate uncertainty, by W.J. Maunder (London, New York, Routledge, 1989. £10.95 (paperback), £25.00 (hardback)) provides an overview of the economic dimensions of climate and human activities. It is intended to be of particular interest to decision-makers and students concerned with associated subjects.

Applications of weather radar systems, by C.G. Collier (New York, Chichester, Brisbane, Toronto, John Wiley and Sons, 1989. £44.50) records and elucidates the contribution made by weather radar data to a variety of sciences. The main emphasis is on operationally based systems, with examples drawn from a world-wide range of sources.

Spacious skies, by R. Scorer and A. Verkaik (Newton Abbot, London, David and Charles, 1989. £20.00) contains many photographs and satellite pictures of the sky from all parts of the world. The many facets of the subject are grouped into separate sections, with theoretical discussion and explanation as to why a particular picture looks the way it does.

Correction

Meteorological Magazine, August 1989, p. 164, Fig. 4. Mr S.P. Peters and others have pointed out additions and errors to the names of the people present; the photograph in the pamphlet lodged in the National Meteorological Library, Bracknell will be amended.

Satellite photograph — 21 September 1989 at 0930 GMT

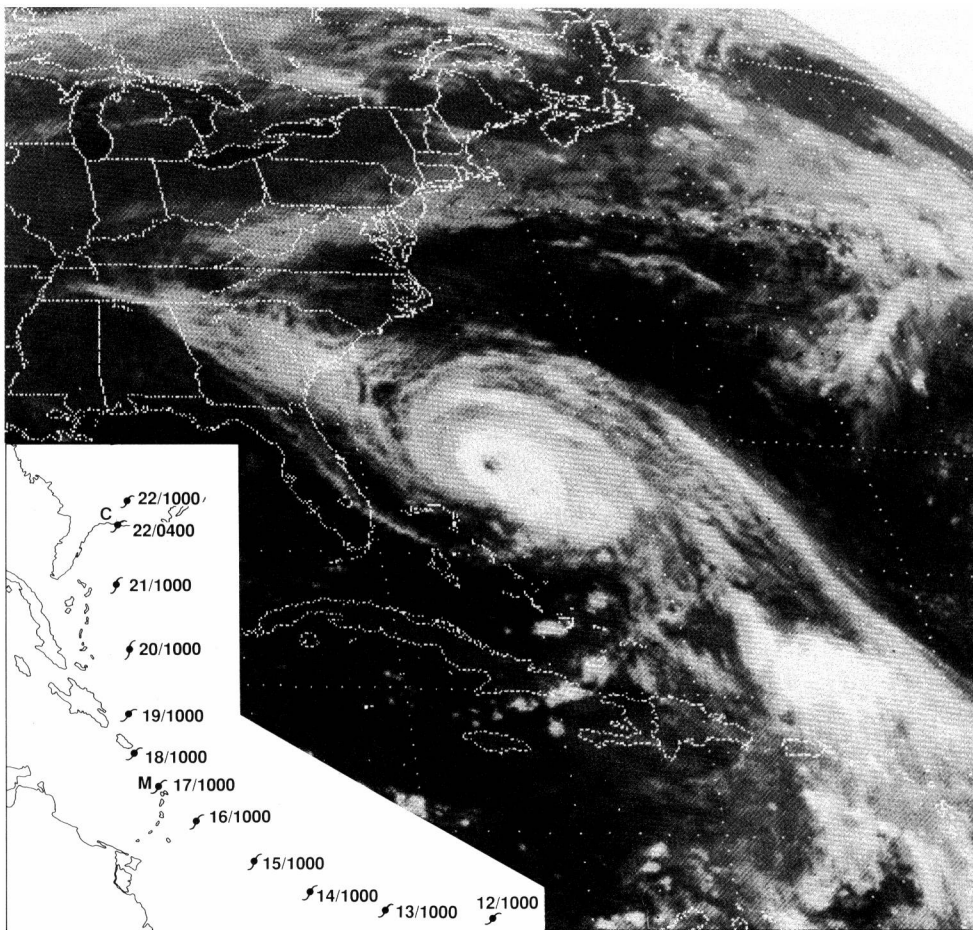


Figure 1. Hurricane Hugo as it approached the USA. The inset shows the track of the hurricane from 12 to 22 September.

This GOES infra-red image (Fig. 1), processed by the Meteorological Office's HERMES system, shows hurricane Hugo as it approached the USA, where it made landfall at Charleston (labelled C in inset), South Carolina. The picture shows a clearly defined cloud-free 'eye' near the centre of an upper-cloud shield some 600 n mile across. Within the shield, cloud tops are progressively colder toward the eye. An aircraft reconnaissance flight that traversed the storm at the time of the picture measured the eye to be 50 n mile across — the largest during the storm's life cycle.

Hugo evolved from a tropical cumulonimbus cluster that developed off the coast of west Africa, south of the Cape Verde Islands early on 11 September. Satellite imagery gave clear indication of Hugo's track (inset). Hugo was upgraded to a hurricane on the evening of 13 September. The eye was observed from early on the 15th until soon after landfall on the 22nd.

Although wind strengths were not as extreme as those associated with hurricane Gilbert in September 1988, at its peak maximum sustained winds (measured by aircraft reconnaissance) did reach 130 kn with gusts to 150 kn. The storm was almost at full strength as it crossed Montserrat (labelled M) causing extensive damage to almost all property) and Puerto Rico. Hugo temporarily weakened as it turned north-west, but reintensified as it approached the South Carolina coast. Severe wind damage was apparently restricted to coastal areas. After landfall, observations showed rapid weakening of surface winds to below hurricane force, and by late on the 22nd Hugo had been downgraded to an 'ex-tropical depression'. This moved quickly and recurved north-eastwards; its remnants becoming involved in an intense cyclogenesis on the 25th south of Greenland, with the central pressure down to 950 mb.

G.A. Monk and A.J. Waters

GUIDE TO AUTHORS

Content

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

Preparation and submission of articles

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* (latest edition). Articles prepared on floppy disk (Compucorp or IBM-compatible) can be labour-saving, but only a print-out should be submitted in the first instance.

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 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, except by 'personal communication'.

Tables should be numbered consecutively using roman numerals and provided with headings.

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 read. Notation should be kept as simple as possible. Guidance is given in BS 1991: Part 1: 1976, and *Quantities, Units and Symbols* published by the Royal Society. SI units, or units approved by the World Meteorological Organization, should be used.

Articles for publication and all other communications for the Editor should be addressed to: The Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ and marked 'For Meteorological Magazine'.

Illustrations

Diagrams must be drawn clearly, preferably in ink, and should not contain any unnecessary or irrelevant details. Explanatory text should not appear on the diagram itself but in the caption. Captions should be typed on a separate sheet of paper and should, as far as possible, explain the meanings of the diagrams without the reader having to refer to the text. The sequential numbering should correspond with the sequential referrals in the text.

Sharp monochrome photographs on glossy paper are preferred; colour prints are acceptable but the use of colour is at the Editor's discretion.

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November 1989

Editor: B.R. May
Editorial Board: R.J. Allam, R. Kershaw, W.H. Moores, P.R.S. Salter

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ISBN 0 11 728484 X ISSN 0026–1149

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