THE METEOROLOGICAL MAGAZINE

HER MAJESTY'S STATIONERY OFFICE

February 1987

Met.O.978 No. 1375 Vol. 116

METEOROLOGICAL OFFICE Met.O.978

THE METEOROLOGICAL MAGAZINE

No. 1375, February 1987, Vol. 116

551.509.58:629.7:662.75

Impact of weather forecasts on aviation fuel consumption*

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Summary

The Meteorological Office has developed a computer-based weather forecasting system for civil aviation that permits the provision of weather forecasts for aircraft anywhere in the world. Information provided by airlines indicates that they are saving an additional £50 million per year through reduced aviation fuel consumption directly related to the improved forecasts.

Civil aviation requires a wide range of weather forecasts from meteorological services. The main types of forecasts are as follows:

(a) Forecasts of route winds, temperatures and weather for flight planning.

(b) Warnings of adverse weather for in-flight operations (e.g. moderate to severe turbulence, icing, thunderstorms, low-level wind shears and cloud covering hill tops) and the handling of aircraft and passengers on the ground (e.g. strong cross-winds, heavy rain and standing water, fog and snow).

(c) Landing forecasts of the weather expected at the destination and at suitable diversions to ensure that sufficient fuel is loaded.

(d) Weather forecasts issued to air traffic control authorities so that they can ensure that a safe distance between aircraft is maintained.

The provision of these services by the Meteorological Office relies upon the forecasts produced by their global, numerical forecasting system. In some cases the computer forecasts are used direct (e.g. for route forecasts) whilst for other services the forecasters have to interpret the computer products before issuing forecasts.

During the last decade there has been a clear and continuous reduction in the error of the forecasts to the extent that, in terms of the correlation of actual and predicted atmospheric changes, forecasts for 3 days ahead are now as accurate as 1-day forecasts were only a decade ago. A particularly marked improvement occurred in 1982 when the present global 15-level forecasting model came into operation; the root-mean-square forecast errors fell by 15% for winds and by about 30% for temperatures. These improvements have had a beneficial effect on the services provided to civil aviation. In particular they have allowed airlines to make considerable savings on aviation fuel consumption.

* Taken from a lecture following the presentation of the Royal Society ESSO Award for 1986 to a team from the Meteorological Office.

Aircraft fuel savings can be achieved in a number of ways. The most obvious of these is to use the forecast winds and temperatures for planning the most economical route between the departure and destination airfields, taking advantage of favourable winds and avoiding unfavourable ones. The freedom to choose such tracks only exists over oceanic sectors of the flights; over land the density of air traffic necessitates strict air traffic control and the confinement of air movement to predefined air lanes. Accurate forecast information can, nevertheless, allow airlines to calculate their expected fuel burn over the land flight sectors. By taking on board an appropriate fuel load the aircraft can avoid transporting excessive quantities of fuel, or alternatively avoid making intermediate unscheduled refuelling stops because of unexpected wind conditions.

The principal difficulty in carrying out a survey of fuel savings achieved by airlines is the lack of firm figures that can be used in the calculation. Despite this problem, independent calculations based on the experience of two airlines have been made.

The extent of airline operations can be measured by the amount of revenue tonne kilometres (RTK), defined by the product of the weight conveyed and distance flown on revenue earning flights summed over a year. For the 23 major airlines using forecast data supplied by the Meteorological Office for their flight planning procedures, the total RTK is 80 996 million. Scandinavian Airline Systems (SAS) have a RTK of 1473 million and have reported a fuel saving (directly attributable to the improved forecasts) of 35 kg per hour of flight as an average over all their operations; over a year this saving amounts to £2 million. Assuming that all airlines have the same pattern of operations as SAS, this would imply a total saving by the 23 airlines of £110 million. However a conservative and more realistic estimate of annual saving would probably be about half this figure, say £50 million per year.

British Caledonian Airways estimate that savings on their transatlantic flights have amounted to 2% of fuel used. Since the total annual cost of fuel consumed by airlines for operations over the ocean is about £2000 million, the saving, if extrapolated to apply to all transatlantic flights, is equivalent to £40 million. If savings achieved elsewhere are added to this, a saving of around £50 million per year is obtained once again. The consistency of the two calculations gives some confidence to the estimates.

Fuel savings that may arise from accurate weather forecasts are appreciably smaller than the potential savings from improved aircraft and engine technology (figures as high as 10–20% have been quoted). However, against this must be set the cost of achieving these savings. The 23 airlines mentioned above possess over 2500 aircraft. The cost of replacing these with new technology aircraft would be at least three orders of magnitude greater than a 10-year research programme at the Meteorological Office devoted to improving aviation forecasting. These figures indicate that for civil aviation the meteorological services provide excellent value for money.

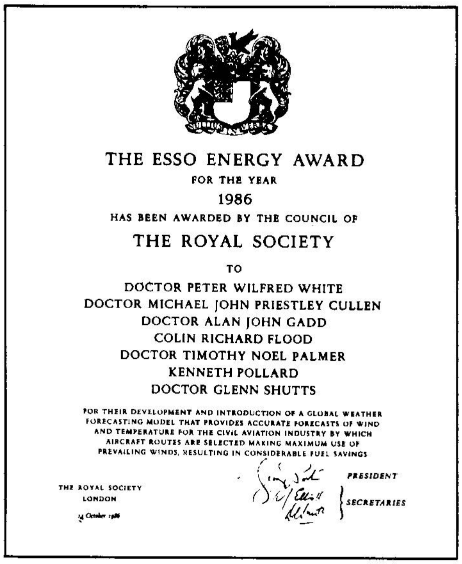
The Royal Society Esso Energy Award

The Royal Society Energy Award for 1986 was presented on Monday 13 October 1986 to a team from the Meteorological Office for their development of a world-wide forecasting model providing accurate information on winds and temperatures to the civil aviation industry, so that flight paths and patterns can be selected to use the minimum amount of fuel. It has been estimated that the extra fuel saved as a result of the improved forecasts is worth at least £50 million per annum.

Dr P.W. White, Dr M.J.P. Cullen, Dr A.J. Gadd, Mr C.R. Flood, Dr T.N.Palmer, Mr K.Pollard and Dr G.Shutts received the Award comprising a gold medal and prize of £2000 from Sir George Porter, President of the Royal Society. Photographs of the award winners, the gold medal and the citation are shown opposite.

The Royal Society Esso Energy Award winners with Sir George Porter (President of the Royal Society) and Mr A.W. Forster (Chairman and Chief Executive of ESSO UK plc), left to right: Dr A.J. Gadd, Mr A.W. Forster, Mr C.R. Flood, Dr M.J.P. Cullen, Sir George Porter, Dr P.W. White, Dr T.N. Palmer, Mr K. Pollard and Dr G. Shutts.

Gold medal presented to the winners of the Award.



THE ESSO ENERGY AWARD
FOR THE YEAR
1986
HAS BEEN AWARDED BY THE COUNCIL OF
THE ROYAL SOCIETY
TO
DOCTOR PETER WILFRED WHITE
DOCTOR MICHAEL JOHN PRIESTLEY CULLEN
DOCTOR ALAN JOHN GADD
COLIN RICHARD FLOOD
DOCTOR TIMOTHY NOEL PALMER
KENNETH POLLARD
DOCTOR GLENN SHUTTS

FOR THEIR DEVELOPMENT AND INTRODUCTION OF A GLOBAL WEATHER FORECASTING MODEL THAT PROVIDES ACCURATE FORECASTS OF WIND AND TEMPERATURE FOR THE CIVIL AVIATION INDUSTRY BY WHICH AIRCRAFT ROUTES ARE SELECTED MAKING MAXIMUM USE OF PREVAILING WINDS, RESULTING IN CONSIDERABLE FUEL SAVINGS

THE ROYAL SOCIETY
LONDON

PRESIDENT
SECRETARIES

The citation presented to the winners of the Award.

551.515.81

The mesoscale frontal dynamics project*

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Summary

Cold fronts are among the most important weather features affecting western Europe. In the last 2 years a number of research groups, particularly in the United Kingdom and France, have set up an intensive programme of theoretical and experimental study of the processes occurring in frontal systems. This article describes the scope of this programme, which will culminate in an international field experiment in the autumn of 1987.

1. Introduction

Over the past few years much progress has been made in understanding the physical processes involved in the formation and maintenance of fronts, problems which occupy a major position in mesoscale meteorology and short-term forecasting. The process of frontogenesis occurs as an inevitable consequence of the development of a baroclinic wave and involves a cascade of energy to smaller scales. The primary and secondary processes of baroclinic instability and frontogenesis take place on scales which can loosely be described as synoptic scale and mesoscale. Ageostrophic circulations associated with fronts imply regions of ascent and descent and, in the presence of moisture, the formation of cloud and precipitation follow. The part played by such moist processes is currently a topic of much attention both in numerical weather forecasting and theoretical studies of frontal dynamics. The cloud organization is itself a phenomenon spanning several scales with both mesoscale and small-scale motions being involved, as well as the scales introduced in the microphysics of precipitation growth. Slantwise and upright convection are invoked to distinguish the varying importance of Coriolis and buoyant forces on the mesoscale and smaller scales. The energy cascade progresses to finer scales leading to turbulence and ultimately dissipation, particularly in transition regions like the tropopause, frontal zones and the boundary layer.

Three developments have brought the mesoscale to the forefront of meteorology in recent years. Firstly, advances in computer technology have allowed ever-increasing resolution in numerical prediction models to a point where, even in synoptic-scale forecast models, accurate representation of mesoscale features such as fronts becomes necessary. Secondly, observational techniques, such as dual Doppler radar, VHF radar wind profilers and dropsondes, have been developed to provide a capability for detailed kinematic and thermodynamic measurements on the mesoscale, while routine coverage by weather radar networks and satellites is also improving. Thirdly, advances in the theory of frontogenesis and mesoscale instabilities are showing that the hitherto vague notion of the mesoscale can be better defined from a dynamical viewpoint, so that a proper understanding of these phenomena is beginning to emerge.

Mesoscale meteorology is receiving increased attention world-wide. Notable projects outside Europe include the CYCLonic Extratropical Storms (CYCLES) Project for the study of fronts in the USA, the Cold Fronts Research Programme in Australia, and also the planned Genesis of Atlantic Lows Experiment (GALE) and National STORM Programme in the USA where mesoscale meteorology is being given high priority following a recommendation of the National Academy of Sciences and a series

* This article is a synthesis of reports by the British and French Steering Groups.

of workshops that began in 1977. A sizeable research effort is dedicated to mesoscale problems in Europe also, and it is now timely to bring together this effort in coherently related studies concentrating specifically on cold fronts, particularly active ones. Study of these systems lends itself to such an international collaboration because of the geographical scale necessary to define the synoptic environment and the range of expertise and facilities necessary to understand the complex interplay of processes occurring near cold fronts.

The area centred on the Channel between England and France offers a natural setting for such an experiment, being quite well served by the combination of British and French routine observing networks. As well as the leading contributions to the project from many British and French scientists, it is expected that groups from other western European countries will participate in the project, and such collaboration is welcomed. Groups from the Federal Republic of Germany and Switzerland, for example, have been involved in discussions, and German aircraft, radiosonde and other facilities will be contributing to the field experiment. The British effort, the Mesoscale Frontal Dynamics Project (MFDP), is co-ordinated by a steering group made up of Dr K.A. Browning (Chairman) and Dr P.R. Jonas of the Meteorological Office, and Prof. B.J. Hoskins and Dr A.J. Thorpe of the University of Reading, while Dr J. Testud leads the French team in the parallel FRONT 87 programme.

Active cold fronts like the one illustrated in Fig. 1 are important from several viewpoints. They are ubiquitous features of the weather in north-western Europe, giving a substantial fraction of the precipitation in this area during autumn and winter, and often giving rise to other significant weather such as abrupt changes in wind, temperature, cloud base and visibility. Over the October–December period about two active systems would be expected in a month. The need for monitoring and very-short-range forecasting of systems such as these are two of the reasons for setting up networks of European radars, the integration of which is being considered as part of the COST-72 (European Co-operation in Science and Technology) project.

The specific scientific objectives of the present project are:

(a) To obtain an improved dynamical understanding of synoptic, mesoscale and smaller-scale interactions within systems containing cold fronts, especially active ones.

(b) To acquire mesoscale data sets and use them for the further development of numerical models and the parametrizations in them.

(c) To describe the structure and evolution of mesoscale features in cold fronts, within the full synoptic context, and to derive conceptual models of value in very-short-range forecasting (00–12 h).

It is envisaged that, in the course of the experiment, substantial practical benefit will be derived from the progress made in developing and evaluating new techniques of observation and forecasting. Other scientific objectives will be pursued as far as can be accommodated practicably, e.g. chemical, microphysical or radiative measurements.

On the basis primarily of British and French proposals a composite plan has been developed, detailing the main dedicated resources and their likely deployment. A contribution from the Federal Republic of Germany has also been incorporated into this plan. The project timetable allows a period of 2 years for the necessary logistical development to the experimental phase; during this time the theoretical programme described in Section 2 will be in progress to assess existing theories and models, and provide testable hypotheses for the observational stage described in Section 3.

2. The theoretical programme

The main emphasis of the theoretical programme will be on the general theory of baroclinic instability and frontogenesis from the synoptic scale to the scales of cloud and turbulence, and the influence of

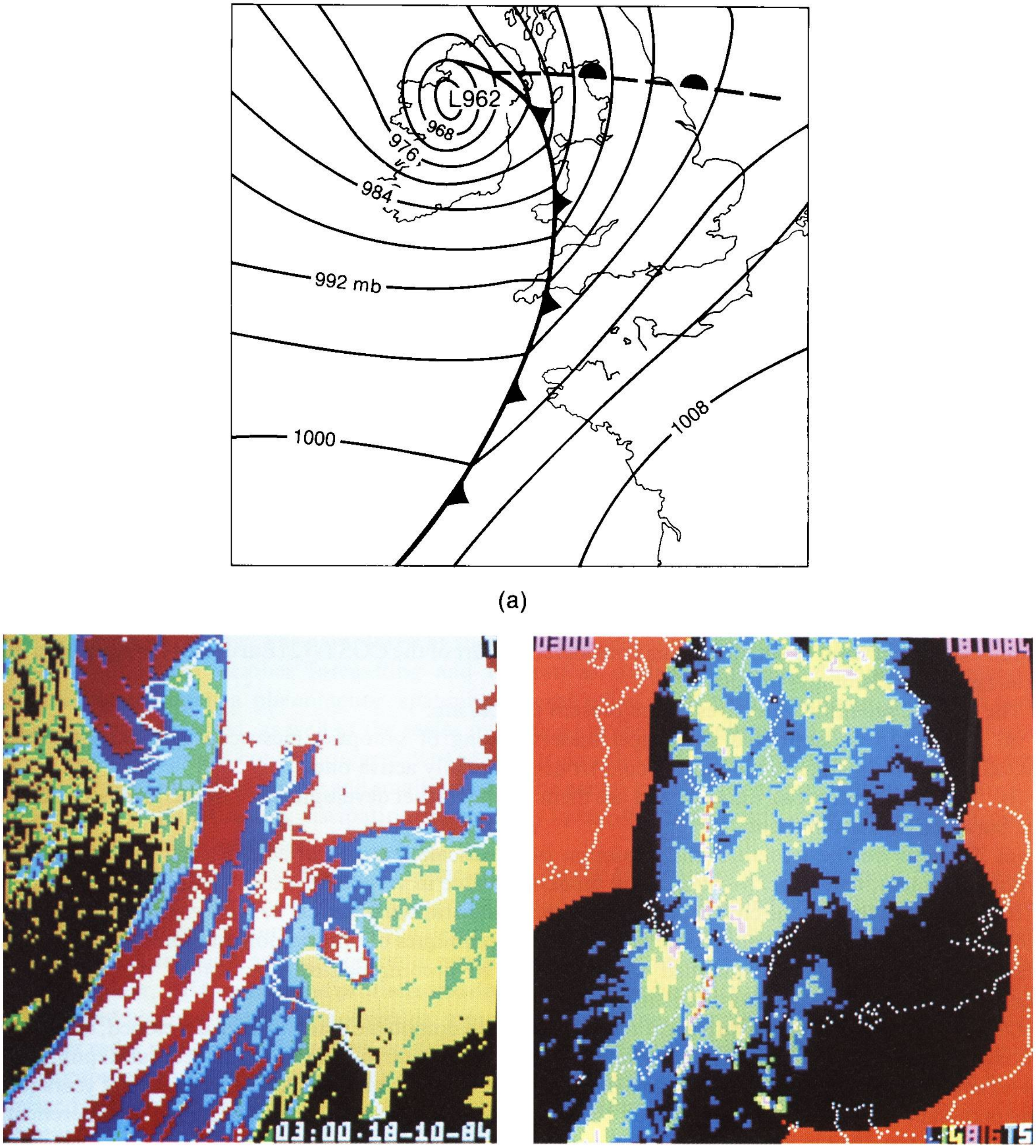

Figure 1. A case of line convection at an active surface cold front on 18 October 1984: (a) surface pressure pattern at 03 GMT, (b) Meteosat infra-red image at 03 GMT: white and red denote high cloud; dark and light blue, medium cloud; green and yellow, low cloud or cold land; black, sea or warm land and (c) radar network observations at 03 GMT: within the network area pink, red and light blue denote heavy rain; yellow and green, moderate rain; dark blue, light rain. The heaviest precipitation occurs at the position of the analysed cold front, while the satellite image shows much of the upper cloud shield behind the surface front.

latent heating and convective structure. Of central importance is the interaction between processes with different scales:

(a) Motion on the synoptic scale can be described by the quasi-geostrophic approximation, which leads to a length scale

$$L \approx NH/f$$

where L and H are the horizontal and vertical length scales, N the Brunt–Väisälä frequency and f the Coriolis parameter. For circulations with scale H corresponding to the depth of the troposphere, $L \approx 1000$ km. Such scales require, for a complete definition, observations at a spacing of less than 300 km.

(b) On the mesoscale, fronts can be described by the semi-geostrophic approximation in which ageostrophic advection is important. Although not directly describable by these equations, moist slantwise convection is believed to occur on a similar scale. Suitable scale analysis suggests that the horizontal scale of mesoscale motion is

$$L \approx U_g/f \approx 100 \text{ km}$$

where U_g is the geostrophic wind. Such scales require observations at a spacing of 20–30 km in the horizontal for their specification. Vertical variations on small scales are often present and observations at 300 m in the vertical may be required to describe slantwise convection adequately.

(c) Smaller-scale processes such as line convection at cold fronts, embedded convective cores within slantwise ascent and gravity waves generated by convection or other processes, generally have $L \approx H \approx 1$ km. Hydrostatic balance is no longer valid for this scale, and observations with horizontal and vertical spacing of not more than a few hundred metres are required to resolve it adequately. On an even smaller scale there are the turbulent processes which provide a cascade of energy that ultimately results in dissipation at the molecular scale.

It is the aim of this project to describe the important interactions between these scales of motion at fronts. For example, phenomena such as rain bands can only occur given an appropriate synoptic environment, while the feedback of such organized convection on the synoptic scale may significantly influence frontal development.

2.1 *Baroclinic instability and frontogenesis*

There have been many studies in two and three dimensions of the life cycle of a baroclinic wave and the consequent frontogenesis but several areas still remain to be clarified, even before moist processes are considered.

Three-dimensional aspects of frontal structure. It is a common occurrence that a quasi two-dimensional cold front approaching north-west Europe will develop a wave on the scale of a few hundred kilometres. This problem was identified by the Bergen school of meteorologists and indeed led to the Norwegian polar front model of cyclogenesis. However, only a limited understanding exists of the dynamics of this process or of the mechanisms leading to differences between fronts distinguished as anafronts or katafronts. It is possible, for example, that wave development is accelerated or indeed is caused by the redistribution of heat and potential vorticity produced by moist and boundary-layer processes. Also it is not clear whether this wave development problem is adequately treated by present operational models. If such a development occurs in the field phase of the project, it would present a valuable opportunity to obtain a three-dimensional observational data base for detailed study.

The interaction of ageostrophic circulations linking upper and lower frontogenesis is also of interest. It is believed that the position of the upper jet core relative to the surface front is of critical importance in providing conditions suitable for the generation and release of convective and potential instability. For example, if the upper jet exit region is to the west of, and aligned along, the surface front it seems possible that upright convection at the surface front may be of limited depth while slantwise convection is enhanced. The mechanism of these processes is an important element in understanding the organization of smaller-scale structures within the synoptic scale.

The concept of geostrophic or other dynamical balance underlies almost all theoretical ideas on synoptic-scale motions, such as Sutcliffe's development theory or the *Q*-vector method. It is of some importance to obtain observational evidence about the extent and nature of departures from the balanced state, particularly in mobile features such as jet streaks. The provision of well-resolved dynamic and thermodynamic fields by the observational programme will be valuable for this purpose.

Role and structure of the boundary layer and frontal discontinuity. In the neighbourhood of an active surface cold front, air parcels undergo large accelerations through flow patterns similar to the schematic of Fig. 2. Frictionally induced ageostrophic flow in the planetary boundary layer is believed to be an important contribution to the gross cross-frontal ageostrophic circulation. In any quantitative account of the frontal dynamics it is thus important to determine the magnitude of the ageostrophic boundary-layer flux and its relation to the boundary-layer structure. The observational programme should provide measurements of the mean boundary-layer flow and turbulent structure. These details will be essential to the diagnosis of numerical models and their boundary-layer schemes.

It is important to describe the role and structure of the boundary layer in the regions where a front is in contact with the surface. Understanding of the disturbed boundary layer, particularly in regions of convection, such as may occur at sharp surface cold fronts, is only at an early stage of development.

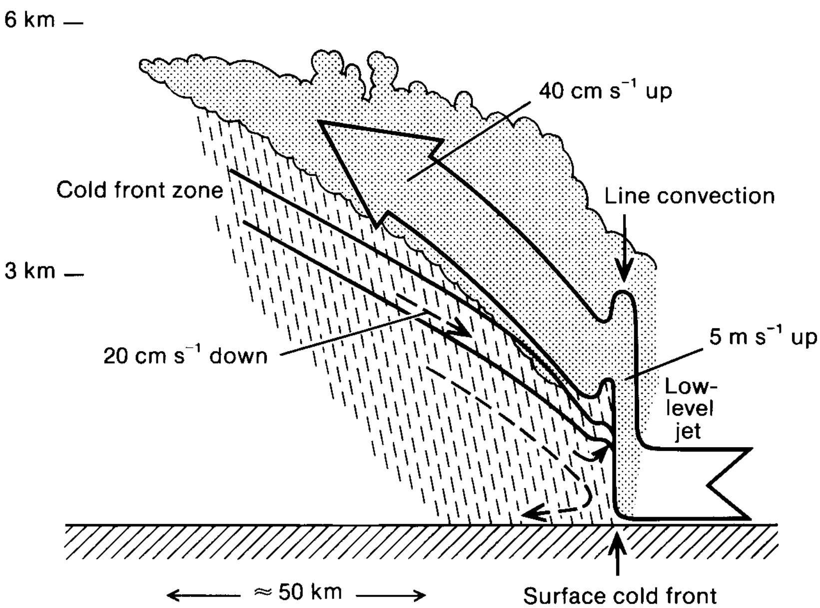

Figure 2. Schematic cross-section of a vigorous cold front (anafront) illustrating the main air flows near the surface front (after Browning 1985).

Further studies using more elaborate boundary-layer theories and models which can be verified against highly resolved wind and temperature data are required.

Frontal theories suggest that a discontinuity will tend to be formed at a boundary, and the modelling of this structure is a challenging problem. As the scale reduces, turbulent stresses and gravity-wave generation become of critical importance and observations may help to decide between differing theories of frontal collapse. Theoretical work is continuing on these problems and it is desirable to observe the process of collapse through *in situ* turbulence measurements in the field programme.

2.2 *Convective structure and the influence of moist processes*

The structure of cloud and precipitation characteristic of active cold frontal zones is indicated in Fig. 3. The role of moist processes is a matter of current research and is a central topic in the project. It is believed that in the frontal zone the synoptic-scale sloped convection of the primary baroclinic wave becomes intensified in moist slantwise convective structures such as rain bands. The scale of such convection is evidently mesoscale (≈ 100 km) and theories and models of moist slantwise convection are producing testable hypotheses for the field experiment.

Upright moist convection (with a scale of about one kilometre) is found embedded within the slantwise convection and at the surface cold front. The pattern of such convection suggests that two-dimensional cloud models with frontal forcing may be able to model these structures, and such research is envisaged. The interaction of slantwise convection, upright convection and synoptic forcing is of major interest, both in the atmosphere and in synoptic or mesoscale model representations.

Several interesting features of the dynamical structure in Fig. 2 are commonly observed: a low-level jet immediately ahead of the front, a nose of cold air resembling a density current and a narrow band (2–5 km) of vigorously precipitating line convection. The dynamics of line convection at active cold fronts is of considerable interest and so theoretical and numerical models of this phenomenon are being developed. A major objective will be to generalize squall-line and line-convection dynamics into a comprehensive theory, consistent with both detailed models and observations.

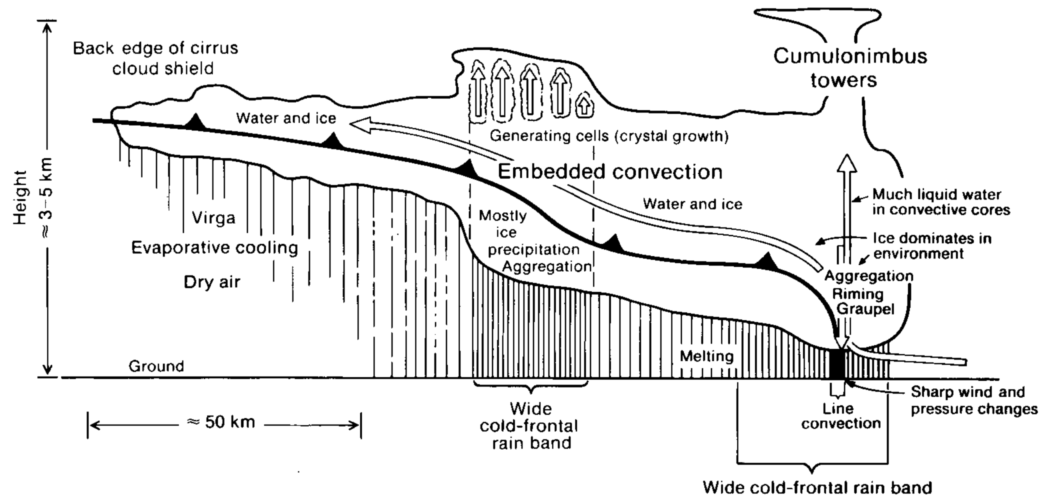

Figure 3. Schematic cross-section of major cloud and precipitation processes in a cold frontal zone (after Matejka *et al.* 1980). The hatched area indicates precipitation, the intensity varying with the density of hatching. Open arrows depict the sense of airflow.

The low-level jet is associated with the warmest air in the depression and some aspects of it have been described in dry baroclinic-wave development simulations. It is, however, also associated with a large moisture flux which is likely to be of considerable importance in the development of convective systems. The strong shears below the jet maximum are likely to be due to boundary-layer frictional processes, the role of which needs further quantifying.

To understand the dynamics of all these phenomena, both convective scale and mesoscale data are necessary to describe both the internal structure of the frontal zone and its environment.

2.3 *Model and diagnostic studies*

As well as the idealized theoretical and numerical model studies described above, a major aim of the project is to apply models of varying scale and sophistication to the observations acquired in the field programme. At this stage not only the earlier theoretical predictions but also methods of assimilating or analysing a large and diverse set of mesoscale data will be subject to test.

Numerical models with resolutions from 1 km to 100 km or more will be run as part of the project. At all scales the primary interest will be in validating and tuning model simulations using observations analysed at a resolution appropriate to the model. Following from such work will come diagnostic studies using simulations to help interpret the observations. For models with resolution coarser than a few kilometres, the availability of coincident fine-scale data and validated high-resolution models will provide opportunities for the development of new parametrizations, notably of such features as slantwise and embedded upright convection which are not represented in current models. The other major area of interest will be in data studies and initialization. Very little is known about the response of mesoscale models to high-resolution data, and it is important to determine what mix of variables to specify to achieve the observed evolution.

Dynamical and conceptual models of fronts have been developed in the last decade and they have not yet been adequately compared with either synoptic observations or operational models, such as the Meteorological Office fine-mesh model. Such a comparison will clarify whether these dynamical and conceptual models provide a good synoptic description of frontal dynamics and thus a guide to the design of more accurate integration schemes for use in operational models.

The representation of frontal dynamics and moist convection in mesoscale operational models is also relevant here. This project will provide a good basis for the necessary diagnostic studies, which the operational environment does not readily allow. For example, the comparison of simulations of fronts in operational and other models where moist processes are artifically suppressed may give some good clues as to the role of these processes in the atmosphere and the working of the physical parametrizations used in the models.

The use of cloud models is also seen as a significant component of the programme. They will be used primarily for the study of features requiring explicit convective or microphysical representations, e.g. line convection and precipitation growth, but they will also provide a useful comparison with results of more extensively parametrized models with lower resolution.

3. The field programme

The scientific problems discussed in the previous section concern a wide range of scales from hundreds of kilometres to metres, and observational study of the processes involved will require a network of measuring systems not only capable of measuring fine scales but also extending over a large area. The present proposal has been formulated to meet these requirements, the location being selected to make optimum use of existing observing stations in an area relatively free of topographic forcing.

Fig. 4 shows the experimental area; a threefold nested structure is envisaged, comprising a zone of intensive small-scale measurements, an inner area and an outer observing area. Throughout the outer region (approximately 1200 km × 1200 km) data from the upper-air network will be used to define the largest scales of motion. By enhancing the standard network somewhat, it is hoped to define the synoptic domain over the outer area every 6 hours with about 300 km resolution. Data from satellites and from the various national weather radar networks will be used to assist in the interpolation between soundings, to fill gaps in relatively data-sparse areas over the sea and to provide continuity in time. Radiosonde coverage with finer resolution of about 150 km is needed in the inner region (approximately 500 km × 500 km). Also in this region additional facilities (including dropsondes, instrumented aircraft

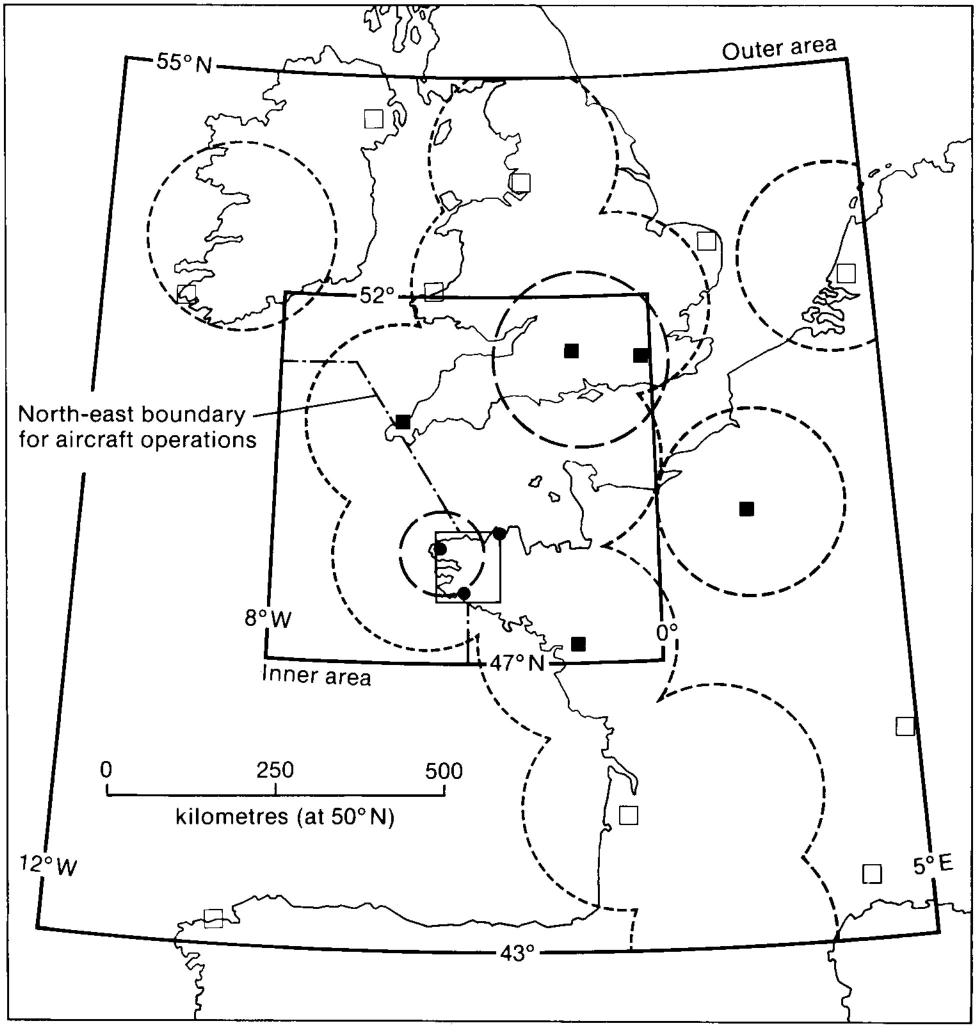

Figure 4. The overall experimental area indicating the main measurement sites and coverage, showing the boundary of the weather radar network coverage (- - - -), boundary of special radar coverage (— —), boxed zone of intensive surface instrumentation in north-west France (——), radiosonde stations reporting at 6-h intervals (□), radiosonde stations reporting at 3-h intervals (■) and mobile radiosonde stations reporting at 1½-h intervals (•).

and ground-based Doppler radar) will also be used to define structure on scales less than 150 km, especially within the intensive instrumentation zone of about 100 km × 100 km based around a dual Doppler radar system.

3.1 *Logistics of the field experiment*

The field phase is planned for autumn 1987, since the period from late September to mid-December appears to offer favourable active frontal cases without some of the adverse operating conditions that might occur in winter. Although individual frontal passages across the outer area are of 1 day's duration it is necessary to have a sufficiently long experimental period to ensure that several active fronts pass through the experimental area during the period.

It is proposed that about six cases of active fronts should be investigated during the 3-month experimental period. A study of frontal systems in the area over recent years has been carried out, and suggests that this number is exceeded in most years. To reduce topographic effects only fronts with a roughly south-west to north-east orientation approaching from the western quadrant will be studied (this is not a severe restriction since most active fronts approach from this direction). At an average frontal speed of 50 km h^{-1} ($\approx$ 15 m s^{-1}) the fronts will cross the outer region in about 24 h. It will therefore be necessary to maintain observations in the outer area for selected periods of about 36 h on each occasion.

Intensive observational periods will be identified at the experimental planning centres (Bracknell in the United Kingdom and Paris in France) 36–48 h in advance, on the basis of numerical forecasts and satellite cloud photographs following consultations with participating groups. The main requirements will be for indications of active fronts with broadly suitable movement and orientation. Based on the expected movement of a front, the period for which additional measurements are required in the outer area will be identified and a first estimate made of the timing of the passage of the front through the inner area. This notification will provide preliminary warning of the need to prepare the intensive observing facilities, to obtain aviation clearances and deploy participating aircraft to suitable bases, and to ensure that essential facilities are fully operational.

At the assumed speed of 50 km h^{-1} the fronts will cross the inner area in about 12 h. Thus it will be possible to provide 12 h notice of the period for which the various national facilities should be deployed in the area. At this time it should be possible to cancel the detailed measurement programme if key facilities are unserviceable or if the front does not behave as expected. It will also be possible, using radar network data and satellite imagery, to provide a more accurate estimate of the frontal movement than that provided earlier. Final decisions on the timing of aircraft flights will be made about 3 h before the expected take-off time. This plan should ensure that those facilities which can provide data for only limited times are fully utilized, though it does not prevent the operation of some facilities for longer periods provided they include the period indicated.

The observational phase will be followed by a period of processing and analysing the large volume of data produced. These data will be exchanged freely among groups actively participating in the project. It will be necessary to ensure that the special data sets are archived in an accessible manner and that the soundings and rainfall records are speedily gathered and combined into convenient data sets. The participating groups will have to agree formats for data exchange. It will be essential to ensure that those groups whose interests are mainly in the interpretation of the observations collaborate closely with those who are active in making the measurements; several groups will be involved in both activities.

3.2 *Outer area measurements*

Radiosondes. Radiosonde stations in the outer area are shown in Fig. 4. In 1987 no permanent weather ship stations will be available within the area, but data from ships of opportunity will occasionally be available through the normal data channels. Where possible, full ascents will be made at 6-h intervals during the intensive operation periods.

Radar network data. The approximate area covered by the various national weather radar networks is also shown in Fig. 4. Data will be available routinely from the network and steps will be taken to ensure that the data obtained during each experimental period are recorded.

Surface observations. Normal synoptic data will be used in the interpretation of frontal weather patterns, etc. Autographic rainfall charts will also be invaluable to support the patterns derived from radar. Additional surface ship observations are also likely to be available at the data-analysis stage.

Satellite data. Maximum use will be made of satellite data both from Meteosat and from polar orbiters. Data from these sources, which should include infra-red and visible imagery, derived winds and temperature retrievals, will not only be invaluable for post-analysis purposes but they will also be essential for the control of the experiment. The data will be made available as near as possible to real time.

3.3 *Inner area measurements*

Some of the data sources which will be used to define the largest scales of motion over the outer area will also be available within the inner area. However, additional sources of data will be used in this area to define the smaller scales of motion, in some cases down to sub-kilometre scales.

Radiosondes. An enhanced radiosonde network is required in the inner area to provide soundings on a scale of about 100 km and to improve the real-time definition of the main frontal region. Soundings to 150 mb will be obtained at 3-h intervals from synoptic stations where possible. In the French component of the experiment this will be achieved by the disposition of three mobile radiosonde stations at Brest, Lannion and Lorient, as shown in Fig. 4. In the UK component the operation of simple radiosonde systems is being investigated to provide some additional partial soundings from Devon or Dorset and Camborne.

Aircraft dropsonde measurements. The British Hercules C-130 aircraft will be capable of producing dropsonde profiles of temperature, humidity and winds below 8 km with horizontal spacing down to about 20 km, though they may only be dropped over the sea (see Fig. 4) or authorized military ranges. Two patterns of dropsondes are planned: a coarse resolution ($\approx$ 100 km) pattern across a front or a finer resolution ($\approx$ 25–30 km) one near surface features of interest. A primary function of these observations is to define the intermediate scales in the environment of the intensive small-scale observations, but isolated radiosonde measurements will also be used to supplement the radiosonde network over the sea in the outer area.

Aircraft in situ observations. Most of the finest scales of observation will be achieved by measurements from aircraft, of which several will be available: the French Piper Aztec, the British C-130 and German Dornier 128. All the aircraft will be equipped to carry out dynamic and thermodynamic measurements, and some will be able to provide information suitable for turbulence studies. The British and French aircraft will also be capable of microphysical observations. The C-130 will be equipped also with chemical measurement facilities and visible, infra-red and microwave radiometers to measure ambient fluxes and to monitor cloud liquid water and precipitation in the column. Such observations might be used for primary studies (e.g. sampling stratospheric intrusions) or secondary experiments.

Radars. As well as the network radars described in Section 3.2, several experimental radars will take part in the experiment. The French Ronsard 5 cm dual Doppler radar facility is a central element of the field programme, with several operating modes in addition to conventional PPI scanning over a 200 km radius. With both radars scanning in successive common planes (the 'COPLAN' mode), high resolution (0.5 km × 0.5 km × 0.25 km) velocity fields can be measured over two areas of 30 km × 30 km, particularly in convective conditions. A vertically-pointing mode provides particle reflectivity and vertical motion with even higher resolution. In more uniform precipitation, mean horizontal and vertical velocities can be evaluated with an effective horizontal scale of about 50 km using an appropriate scanning pattern. The precise siting of this radar facility is yet to be finalized, though it will be in the region around Brest.

The French Rabelais 8 mm Doppler cloud-physics radar, sited near the Ronsard system, should enable the smaller particles in non-precipitating clouds to be detected also, while it is hoped that the UK Chilbolton 10 cm dual polarization radar will be available to provide high resolution three-dimensional fields of precipitation quantity and type within a radius of 200–300 km.

Mesoscale surface network. A network of eight automatic stations will be deployed by the French groups to provide frequent surface measurements over an area. The network's mobile central station is equipped as a forecasting centre with receiving and display facilities for a range of radar, satellite and forecast products, and may provide an appropriate co-ordinating centre for part of the experimental phase. The western and northern French regional networks of automatic stations will provide additional half-hourly surface observations at up to 25 sites.

ST (Stratosphere/Troposphere) radar. A French system of three ST radar units is planned to be sited at Brest, Lannion and Lorient. With a spacing of ≈ 100 km these can produce continuous observations of horizontal and vertical velocities, thus providing much information on small-scale wave structure both in clear air and precipitation conditions. A system of three Doppler sodars at the same sites should provide similar data in the range of 0–500 m above ground level which is not available from the ST radars. It is hoped that a British ST radar will also be available.

Instrumented balloon. It is intended to site a tethered balloon on the Isles of Scilly with instrument packages to measure boundary-layer parameters. The resultant highly resolved observations at several levels in the boundary layer will be of great interest.

4. Conclusions

The range of interactions and scales of importance in frontal systems is of such diversity that a comprehensive view entails resources that are rarely attainable. It is hoped that in the Mesoscale Frontal Dynamics Project the steady progress achieved in observational techniques, numerical modelling and theory in recent years can be consolidated by bringing together the several strands of effort, both in an intensive observational phase and in a period of interrelated theoretical studies. The resulting extension of the present limited data base, as well as the exchange of ideas and testing of theories, should lead to a greater understanding of frontal systems and improved ability to forecast their behaviour.

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551.554:551.515:551.556.1(434.2):629.7

Tornadoes — or microbursts?

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Summary

An aircraft encounter with very severe turbulence, allied to reports of severe damage by tornadoes, is discussed. It is suggested that the damage may not have been caused by tornadoes but by microbursts, such as are described by Fujita (1980).

1. Introduction

On 10 June 1977 I was in a Pembroke aircraft of No. 60 Squadron, Royal Air Force, *en route* from Wildenrath to join Airway R15 west of Norvenich for Florrennes (places mentioned in the text are shown in Fig. 1). A thunderstorm with very severe turbulence was encountered. The following day a German newspaper, the *Erkelenzer Zeitung*, published reports of severe damage, amounting to millions of Deutschmark, caused by tornadoes. The locations of the reported damage are marked (T) in the inset to Fig. 1. This paper discusses these events.

2. The aircraft encounter

At 1320 GMT the Pembroke left Wildenrath and climbed to 8000 ft (approximately 2600 m). I was standing just aft of the crew compartment door and was able to observe the weather and see the flight instruments. During the climb there was 7 oktas of altocumulus and altostratus with a base at about 15 000 ft; the cloud was thick to the south-west and west but thinner towards the east. The visibility was 5–10 km. At 1336 GMT at 50°49′N, 6°20′E broken cumulus and stratocumulus appeared below and there was slight rain at the flight level. We then went into cloud, apparently lowering altocumulus and altostratus, and encountered slight turbulence. At 1337 GMT we entered a severe thunderstorm and experienced very severe turbulence. I was momentarily lifted off the floor and had great difficulty in gaining a passenger seat and securing the seat-belt. The aircrew reported a rate of descent of 4000 ft/min (20 m s^{-1}) followed almost immediately by a rate of ascent, with all power off and the aircraft nose held down, of 2000 ft/min. The ground controller allowed an immediate 180° turn and the aircraft returned to Wildenrath and landed at 1400 GMT, just ahead of the storm. The turbulence was by far the worst that I have ever experienced in more than 1600 hours of meteorological reconnaissance duties and numerous flights as a passenger.

3. Surface events

On 11 June the *Erkelenzer Zeitung* carried reports of severe damage at 1530 h (1330 GMT) at Gerderhahn — 'hardly a house spared by the tornado', 'countless roofs have been torn off houses', 'trees of one metre diameter were uprooted and lay 20 metres away' and 'a farmer found his car ... 15 metres away'. Damage was also reported at Klinkum where 'a sudden tornado caused considerable damage ... to several buildings in an approximately 200 metre long strip', 'trees were uprooted', 'on one farm the roof was torn off the bull shed' and 'one eyewitness reported that balconies flew about 100 metres through the air'. The newspaper reported that similar damage was said to have occurred in Suesterseel and Selfkant after the heavy storm at about 1530 h (1330 GMT); the paper had photographs showing the

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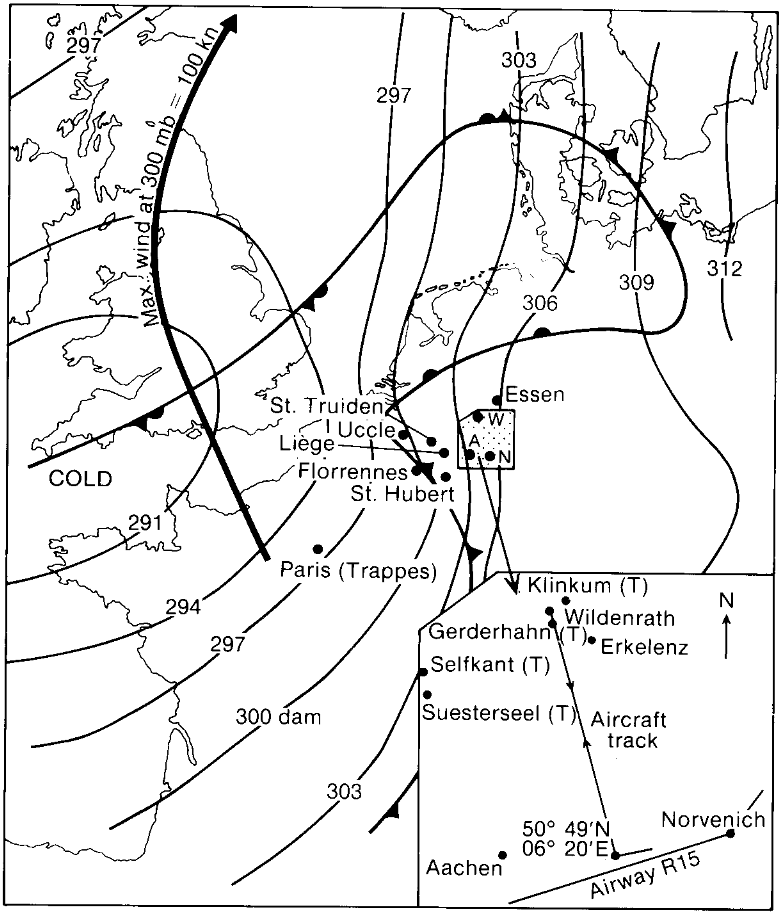

Figure 1. 700 mb analysis for 1200 GMT 10 June 1977 with surface frontal analysis and maximum wind at 300 mb superimposed. Locations of tornado-like damage are marked (T) in the inset.

damage. The Senior Meteorological Officer at RAF Wildenrath reported that two trees had fallen near the main entrance to the airfield.

At 1355 GMT the barogram at Wildenrath recorded a pressure jump of 3 mb. The temperature fell 6 °C and relative humidity rose rapidly from 72% to 96%.

4. Conditions for severe local storms

Roach and Findlater (1983), amplifying the findings of earlier workers, listed the conditions which should be satisfied for severe local storms to form. There should be:

(a) A supply of warm moist air at low levels. The possibility of severe storms should be considered if θ_w exceeds about 15 °C, but cannot be ruled out at lower values.

(b) A great depth of instability.

(c) A large amount of convectively available potential energy, indicated by the excess of surface or low-level wet-bulb potential temperature over the saturation wet-bulb potential temperature in the middle or upper troposphere.

(d) A vertical wind shear in excess of 5 or 6 m s^{-1} km^{-1} throughout the convective layer. The presence of strong directional shear between the surface and the 850 mb level, together with a difference in wind speed in excess of 15 m s^{-1} between these two levels (intense warm advection), is particularly favourable for storm formation.

(e) A trigger action caused by daytime surface heating, low-level convergence, or orographic uplift.

(f) Northward advection of air warmed over Europe, especially Spain, which may form a lid to small-scale convection so that low-level moisture is confined beneath it and high buoyancy can develop before the instability is finally released.

In the next section the synoptic situation on 10 June is examined to see to what extent these conditions were fulfilled.

5. Analysis

At 1200 GMT on 10 June 1977 an open-wave depression, which had moved from the Paris area at approximately 12 m s^{-1} on an average heading of 015° true, was about 80 km north-west of Uccle. The 1200 GMT frontal analysis has been superimposed on the 700 mb analysis in Fig. 1. At 700 mb there was a pool of cold air just off the south-west peninsula of England and a south to south-west flow over the Low Countries, the western part of the Federal Republic of Germany and northern France.

A vertical cross-section for 1200 GMT has been constructed along the line Trappes–St. Hubert–Essen using all available upper-air and surface data (Fig. 2). It shows cloud, wet-bulb potential temperature and the component of wind from 190° true. The aircraft observations were adjusted spatially to 1200 GMT taking the northward movement of the front as 12 m s^{-1}.

From Fig. 2 it can be seen that values of θ_w exceeded 17 °C throughout the warm sector (condition a) and that there was a considerable depth of instability evident in the upper-air soundings, particularly St. Hubert, Uccle and Essen (see Fig. 3), which satisfies condition b. At Uccle the surface $\theta_w = 18$ °C while at 550 mb $\theta_w = 16$ °C (condition c). There was also evidence of strong low-level warm advection; the wind shear between the surface (south-easterly at 5 m s^{-1}) and 850 mb (160° true at 20 m s^{-1} at Uccle) satisfying condition d. Daytime heating was present to assist in the release of the instability (condition e) and the shallow stable layer present between 900 and 880 mb on the Essen ascent may have been sufficient to suppress the instability earlier in the day (condition f).

Thus overall, conditions were favourable for severe storm development. But not all severe storms generate tornadoes. In their research on the linking of severe storms and tornadoes, Fawbush *et al.* (1951) found that the presence of a relatively narrow tongue of warm moist air at low levels was essential to the formation of tornadic storms. They also showed that there must be a band of strong winds aloft between 3000 and 6000 m. In the case under discussion there is such a jet around 3000 m (700 mb) in the region of the frontal wave (Fig. 1). On the vertical cross-section (Fig. 2) the jet is evident and overrides the tongue of high θ_w air at the surface in the warm sector.

In developing a tornado forecasting model, Beebe and Bates (1955) found that a pattern of convergence at low levels surmounted by horizontal divergence aloft is necessary to provide a mechanism for organizing the release of convective energy. They stated that the region of convergence to the left of the low-level jet axis combined with the region of divergence at the right entrance of the upper-level jet was a particularly favourable combination. From Fig. 1 it is evident that on this occasion the storms appear to have developed in such a region.

The conditions would appear to be favourable for tornadic development. However, the evidence from the aircraft behaviour, coupled with the pattern of damage, leaves room for doubt. The surface damage does not readily fit with the expected linear pattern of damage normally associated with a tornado (Smith 1981). The line in this case might reasonably be expected to be normal to the approaching cold

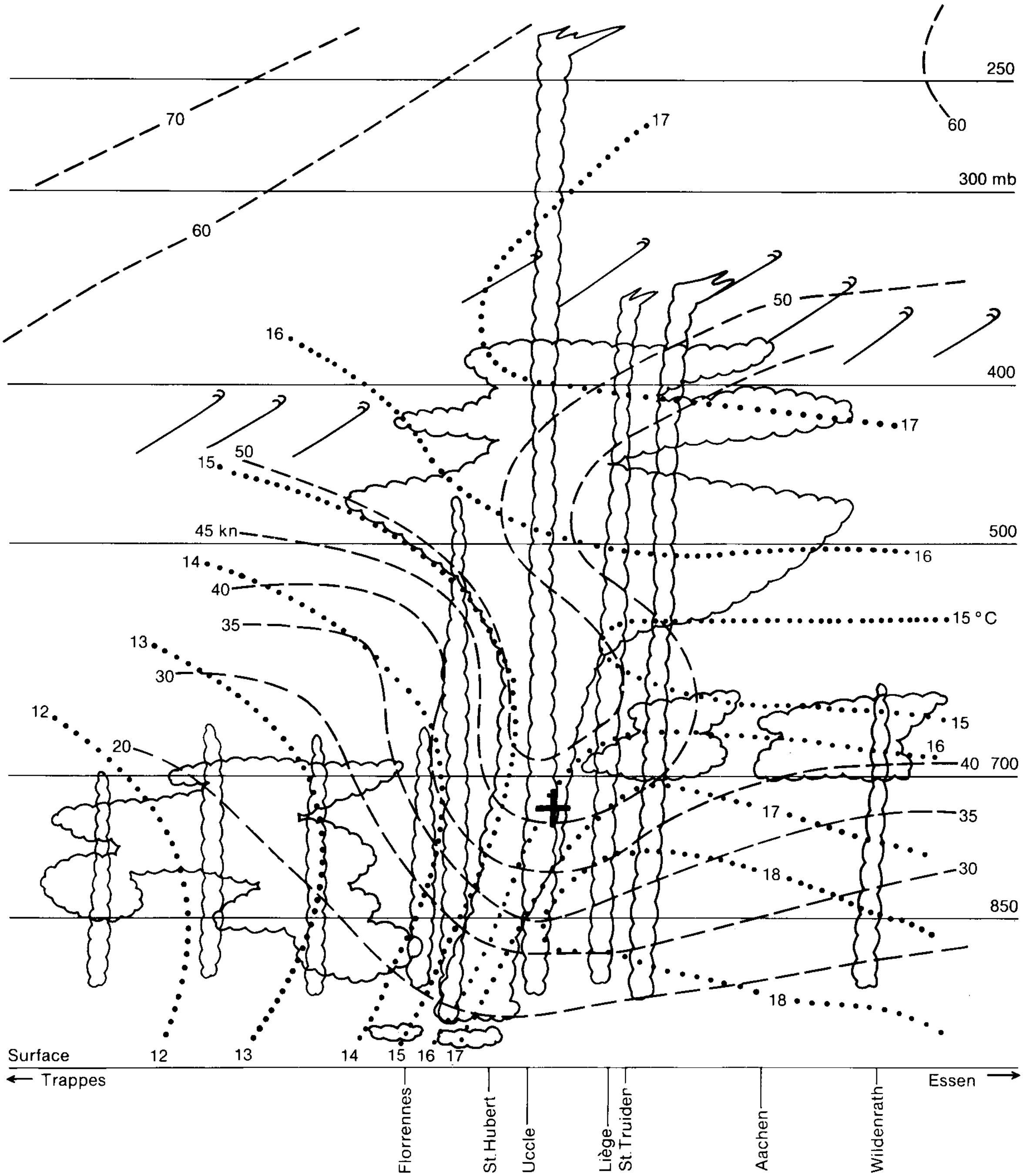

Figure 2. Vertical cross-section for 1200 GMT 10 June 1977, constructed along the line Trappes–St. Hubert–Essen, showing wet-bulb potential temperature (dotted line), component of wind (kn) from 190° true (dashed line) and cloud structure. The frontal surface is more or less coincident with the 15 °C isopleth. The estimated position of the aircraft at the time of encountering the thunderstorm is marked by a cross.

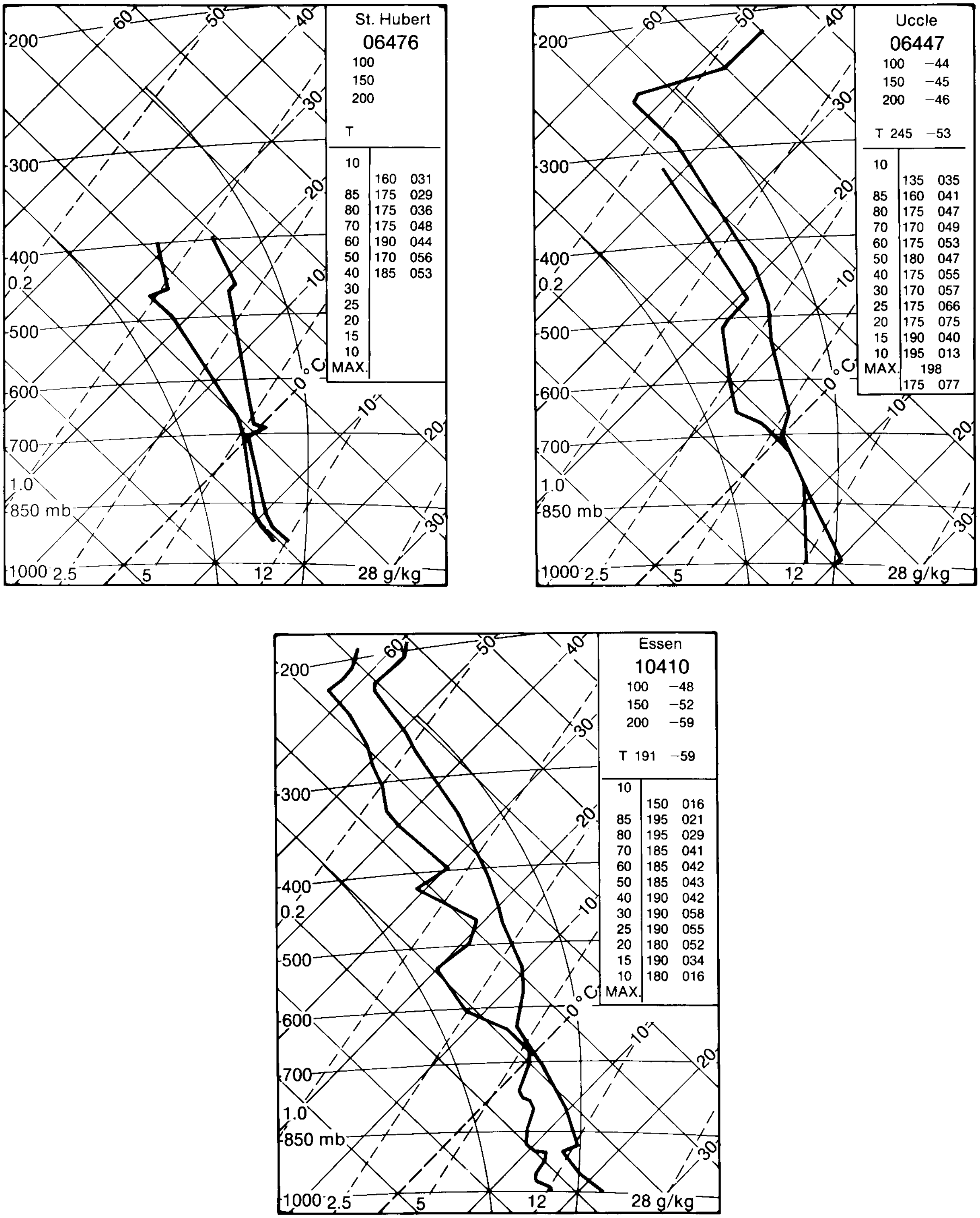

Figure 3. Radiosonde ascents for 1200 GMT 10 June 1977 for St. Hubert, Uccle and Essen.

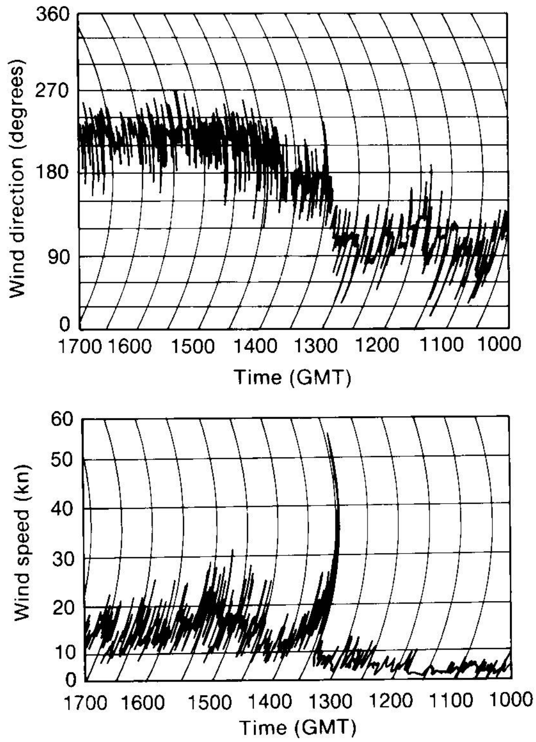

Figure 4. Anemograph traces for Aachen on 10 June 1977.

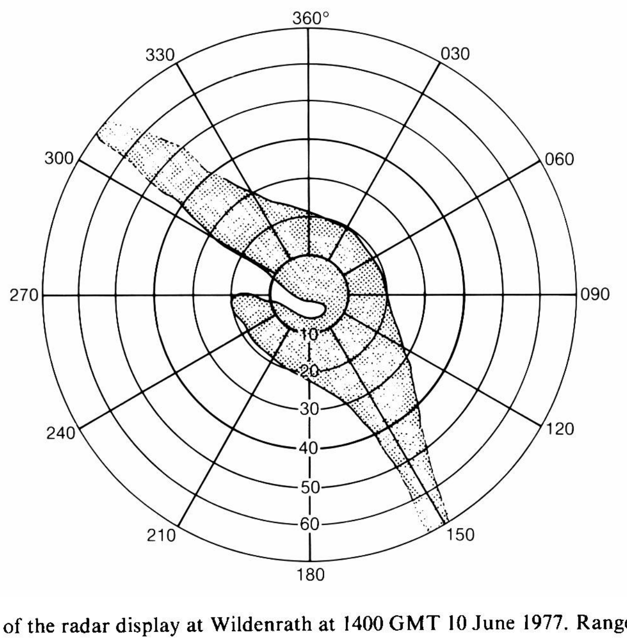

Figure 5. Sketch of the radar display at Wildenrath at 1400 GMT 10 June 1977. Range in nautical miles.

front and indeed Klinkum and Suesterseel/Selfkant lie in such a straight line, but they are some 25 km apart and the damage was reported at both places simultaneously. Such evidence suggests a larger-scale feature than a tornado.

6. Microburst?

Fujita (1978) has defined a downburst as a strong downdraft inducing an outward burst of damaging winds at or near the ground. Such features range in scale from tenths to tens of kilometres. In a later paper Fujita (1980) defined a small-scale downburst (horizontal dimensions of about 5–10 km) as a microburst.

A microburst is defined as having four distinct phases:

(a) Descent.

(b) Contact — the microburst makes contact with the ground.

(c) Outburst — the outflow spreads out violently within a 100–200 m layer above the ground.

(d) Dissipation — the microburst becomes exhausted within a few minutes, but the outflow continues to expand (like a giant smoke ring) but weakening.

Fujita (1978) reports that downburst damage is often highly localized, resembling that of tornadoes, and that even an experienced investigator cannot always identify the nature of the storms without mapping the directions of the damaging winds over a large area. Unfortunately this was not possible in the present case. However, none of the newspaper reports mention debris twisting or whirling. Trees were described as having been uprooted which seems more indicative of winds from a single direction; the newspaper photographs of fallen trees show them snapped off fairly cleanly near the ground, there is no sign of twisting.

Fujita indicated that a microburst is characterized by a single rapid surge and fall of wind speed which is relatively gust free; the anemograph traces for Aachen (Fig. 4) and Wildenrath (not shown) seem to fit this description. He also pointed out that radar reflectivity in and around a strong microburst could be lower than the surrounding area due to rapid evaporation in the descending air. The Senior Meteorological Officer at RAF Wildenrath was in the air traffic control tower as the storm approached. At his request the air traffic radar was being operated in a weather detection mode. No photographic facilities were available but, after the storm had passed, he produced from memory the sketch of the radar display which is shown in Fig. 5. There is a channel in the echo which would fit Fujita's supposition.

7. Conclusions

Considerable tornado-like damage was reported in the Wildenrath area on 10 June 1977 and many of the conditions conducive to tornado development were present. However, in view of the evidence available — the pattern and distribution of damage, the radar echo and the anemograph traces — it is suggested that the damage was caused by microbursts rather than tornadoes.

8. Acknowledgements

This note was developed from an Extension Forecasting Course project at the Meteorological Office College and the assistance of the instructors, Mr Wickham and Mr Spalding, was much appreciated. Thanks are also due to Mr Grant and Mr Findlater (Special Investigations Branch, Meteorological Office), Mr Thomas (RAF Wildenrath) and Herr Rolofs (Deutscher Wetterdienst) for supplying material on which this article was based, and to Mr Drysdale (Lossiemouth High School) for providing full translations of the newspaper reports. Thanks are particularly due to Dr Bennetts (Defence Services Branch, Meteorological Office) who gave a great deal of assistance with the final draft.

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Wind and the summer of 1985

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Summary

Calculations of a windiness index formulated by Smith (1982) for the period 1965–79 have been extended to include an analysis of 1980–5 data. The relative windiness of each season and year (1970–85) is discussed with particular emphasis on the summer of 1985. Finally 1985 is placed in its long-term context using estimated windiness index values for 1881–1980 obtained from pressure fields.

1. Introduction

The need for some quantitative measure to enable a comparison of windiness to be made for months, seasons and years has long been evident. Smith (1982) devised two methods of producing an index to assess relative windiness, one using anemograph records, the other based on surface pressure gradients from six grid points around the British Isles. The latter provides broad, regional values for the United Kingdom and can be used to produce values from 1881 onwards. However, the use of anemograph data, although limited by the relatively short period of reliable data available in machinable form, allows the investigation of relative windiness for specific locations.

Stainer (1986) expressed the view, based on observations in Bristol, that the summer of 1985 was 'exceptionally poor', 'mainly due to the strong wind compounding the below average temperatures and above average rainfall'. The comments referring to temperature and rainfall will not be investigated here. However, using anemograph data, the windiness of the summer of 1985 will be compared with other years having machinable data available and, using Smith's work, a general view of 1985 obtained.

2. Calculation of index values

One of the main requirements for the production of a windiness index from anemograph data is a long record of homogeneous data at a number of stations. In 1981, Smith was limited to 17 stations containing homogeneous data for the period 1965–79, of which three contained some estimated values. A detailed description of the index calculation process is provided by Smith (1982). Briefly, the initial stage consisted of calculating the standardized anomaly of each month's mean speed relative to a long-period (1965–79) monthly average (a standardized anomaly being the difference between the mean speed and the long-period average for a month, divided by the standard deviation of the means of the

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month in question). The anomalies were observed to vary across the country in a consistent fashion and, as a result, the United Kingdom was divided into three regions — north, central and south (see Fig. 1) — reflecting the predominantly zonal movement of synoptic-scale features.

The final index consisted of the arithmetic mean of the standardized anomalies over the stations in each region. Annual and seasonal indices were also derived and expressed as a proportion of the standard deviation of the season (year) for the period 1965–79.

Since 1980, three of the original anemograph stations have either closed or can no longer be considered to possess a homogeneous record. Stations from which hourly mean wind speeds were used to produce the long-period (1970–84) monthly average for this study are shown in Fig. 1. Index values have been calculated for each station from 1970–85 together with regional, annual, summer (April–September) and winter (October–March) values.

3. Results

Annual, summer and winter index values for 1970–85 are illustrated in Figs 2–4. In Fig. 2, the annual values obtained by Smith for 1970–80 are also included, both for comparison purposes and to indicate the sensitivity of the technique to the use of different stations and the different period used for the long-term average. The reasonably good agreement between the two sets of values gives confidence in the robustness of the technique.

It is apparent that marked differences do occur between the regions as well as from one year to the next. Considering the annual values in the northern and central regions, 1977 was the windiest in the 16-year sample, but in the southern region 1974 was the windiest. The most important feature of these annual index values, however, is that, for all three regions, 1985 as a whole was less windy than the 1970–84 average. In fact, for the northern region, 1985 was the 'quietest' year in the study period.

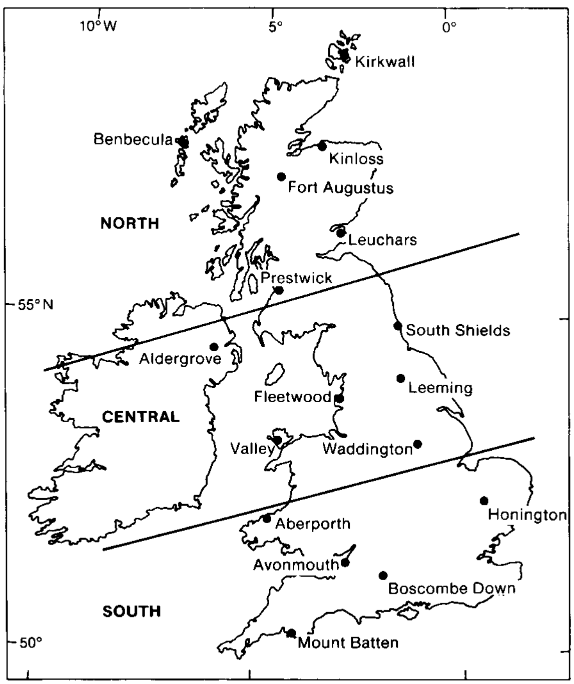

Figure 1. Regions and individual stations used in the calculation of indices.

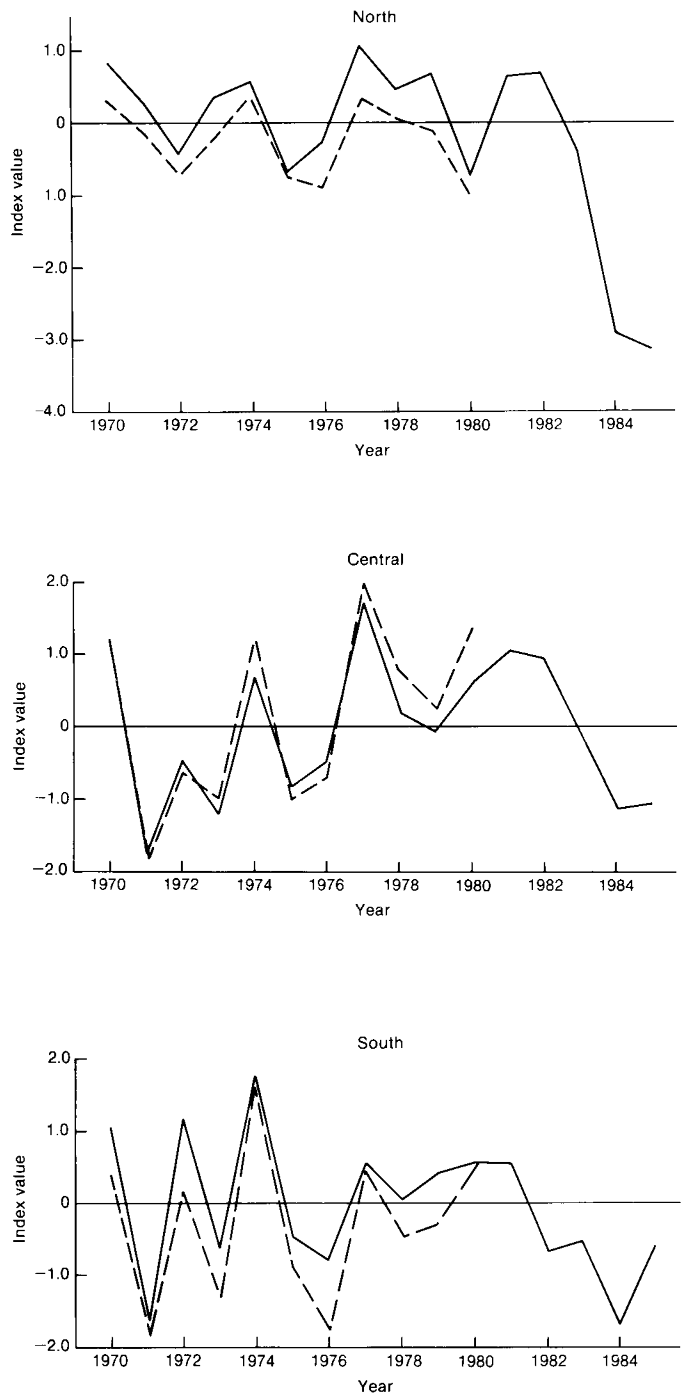

Figure 2. Index values for the year, based on 1970–84 average, for the three regions shown in Fig. 1. Dashed lines show annual values obtained by Smith (1982) based on 1965–79 averages.

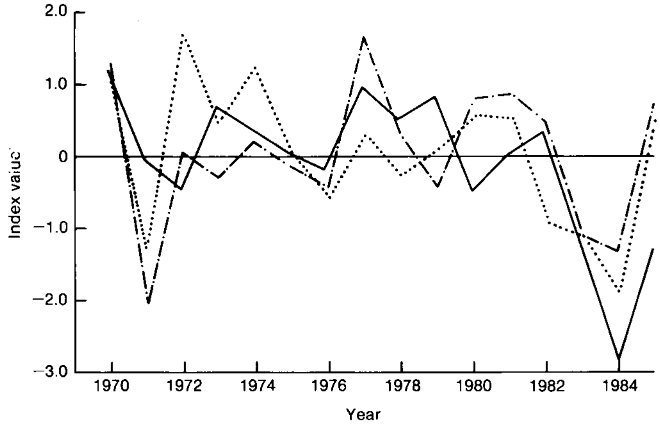

Figure 3. Index values for summer season (April–September), based on 1970–84 average, for the three regions shown in Fig. 1 (—— north, —·— central, ········ south).

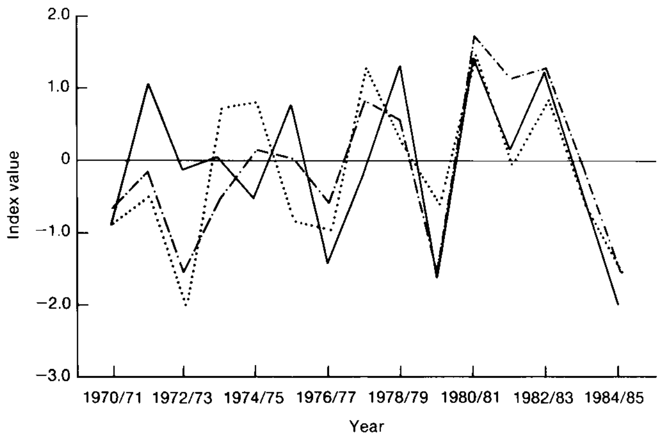

Figure 4. As Fig. 3 but for winter season (October–March).

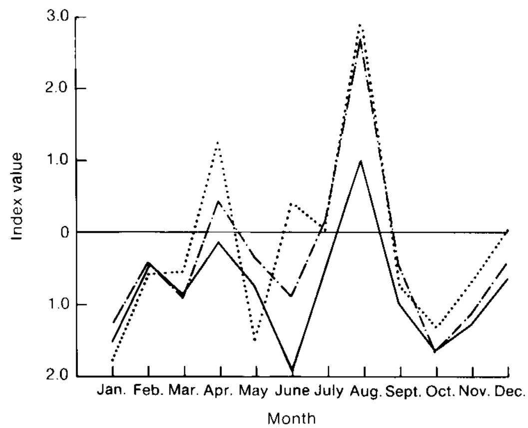

Figure 5. As Fig. 3 but for monthly values during 1985 only.

The positive anomalies during the summer of 1985 over southern and central regions (Fig. 3) indicate that this season could be classed as windy. In contradistinction, the preceding winter for the same regions could be classed as quiet, with large negative anomalies present (Fig. 4). The windiest winter in the study period for all regions occurred in 1980/81 while the calmest was 1972/73 in the south, 1979/80 in the central region and 1984/85 in the north.

Fig. 5 illustrates the monthly index values for all regions in 1985, thus establishing which months were responsible for the high summer index value and those areas most affected. August is clearly the month with the highest index value. In the northern region, only August had higher wind speeds than the 15-year monthly average. In the central region, April was also relatively windy, but for the southern region April, June and August were windier than the 15-year average for each month with July and December approximately average.

Geographical variations in windiness are shown in Figs 6(a) and (b). In Fig. 6(a) the annual index values are illustrated for each of the 17 stations. They indicate that south-west Wales had a windier year in 1985 than the 15-year average and this is further emphasized by the fact that the highest index values for the summer months occurred in Wales, with western coasts in southern and central Britain also relatively windy (Fig. 6(b)).

4. 1985 — the long-term perspective

From a comparison of the 1985 anemograph data and the 15-year averages from 1970–84, it is apparent that the summer months of 1985, particularly August, were relatively windy in southern and western areas despite the fact that as a whole 1985 was quiet. But how representative are these 1970–84 averages of the long-term wind conditions?

Smith (1982), using the surface pressure gradients between six grid points around the British Isles, obtained estimates of the windiness index from 1881 and compared them with those produced using 1965–79 averages. He observed that there was a slight tendency for errors in the estimated values to be greater in summer than in winter months, possibly as a result of the weaker relationship between pressure differences and surface winds at low speeds. In addition, he believed that changes in the analysis of surface pressure in 1972 may have led to lower estimates in the north prior to that date. However, he concluded that since 1968 there had been a high proportion of below average speeds for all regions compared to the 1881–1980 average. This trend has continued in the 1980–5 period.

Corrections for each month were calculated using the 1970–80 values to compensate for the differing averaging periods and stations selected (Table I). This enabled approximate values of the windiness index for 1981–5 (Table II) to be included with the 1881–1980 values and a long-term view of 1985 was obtained using the mean values for each month over all regions. Several features were apparent:

(a) January 1985 was the quietest since January 1881,

(b) October 1985 was the quietest since October 1966,

(c) summer 1984 was quiet with all 6 months recording a negative anomaly when averaged over the three regions (since 1881, this phenomenon has occurred only twice, summer 1971 being the other occasion), and

(d) although August 1985 was windy, a higher index value (i.e. windier month) occurred in August 1961.

5. Conclusions

Although index values for south-west England and Wales indicate that the summer of 1985 was windy, it is obvious that the major contribution came from the month of August thus coinciding with the major holiday period. Northern and central regions had many summer months with index values below

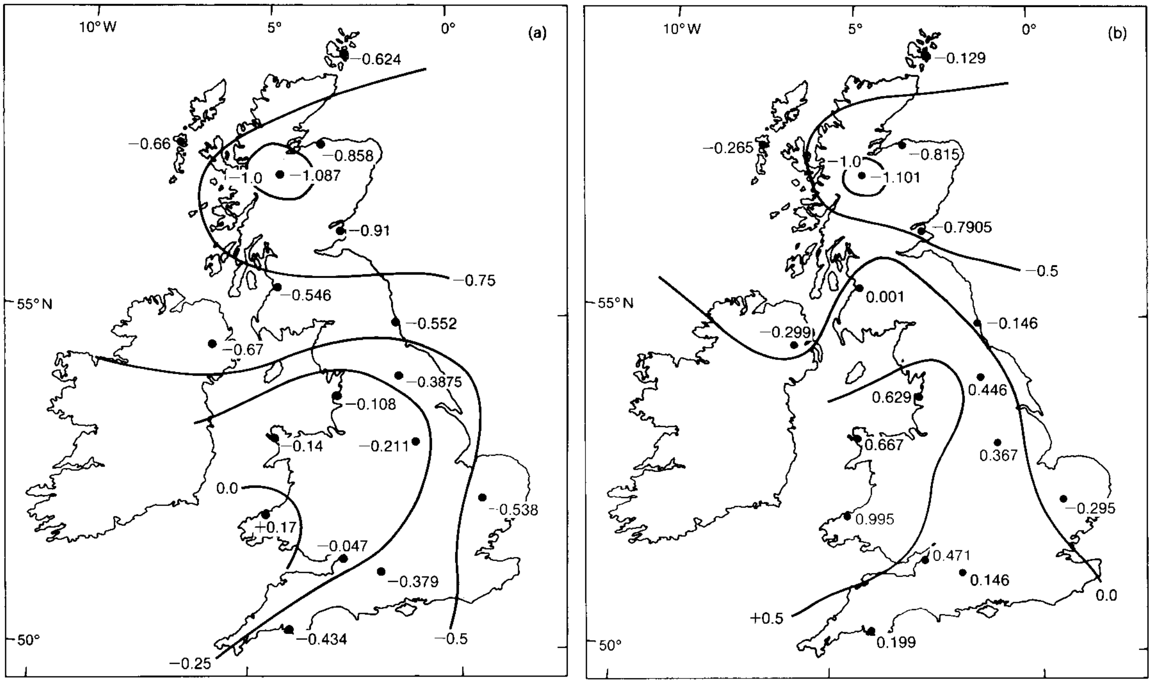

Figure 6. Geographical variations in the index for (a) the year 1985 and (b) the summer of 1985 for the stations shown in Fig. 1.

Table I. *Corrections calculated to compensate for using 1970–84 averages instead of 1965–80 values and for using anemograph data for differing stations. Calculated from data for 1970–80 to produce a national mean value for each month.*

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Correction	−0.16	−0.03	0.11	0.35	0.2	0	0.14	0.11	−0.24	−0.27	−0.06	−0.03

Table II. *Monthly indices averaged over the three regions shown in Fig. 1 for the period 1980–5 (values for the period 1881–1980 can be found in Smith (1982))*

Year	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1980	−1.2	−0.8	−0.3	−0.3	−0.3	0.7*	0.7	0.9	0.7	0.9	0.6*	0.9
1981	0.1	0.6	0.6	−0.6	0.3	1.2	0.4	−0.7	0.2	0.7	0.5	−0.6
1982	−0.3	0.7	0.4	−0.8	−0.4	−0.9	−0.8	1.6	0.2	0.4	0.6	−0.1
1983	1.9	0.2	0.1	−0.9	−0.6	−0.4	−1.8	−1.1	1.0	1.4	−1.6	0.1
1984	1.0	0.1	−1.5	−1.3	−1.7	−0.5	−1.1	−1.2	−0.2	0.5	−0.4	−0.8
1985	−1.4	−0.4	−0.9	0.2	−1.1	−0.8	−0.2	1.9	−0.5	−1.3	−0.9	0.1

* Indicates relatively large regional differences

the 15-year average and, if the mean of the three regions is calculated, the summer as a whole may be described as slightly less windy than average. In addition, since the 1970–84 averaging period is itself characterized by having index values predominantly lower than the 1881–1980 average as calculated by Smith (1982), 1985 may be considered a quiet year.

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Conference report

Computers and Climatic Data, Building Research Establishment, Garston, England, 10–11 June 1986

The Conseil Internationale du Bâtiment (CIB) is an international organization devoted to building research and documentation. It operates through a number of working commissions, one of which (W71, responsible for building climatology) held a 2-day seminar, Computers and Climatic Data, at the Building Research Establishment (BRE) at Garston, England on 10 and 11 June 1986. The seminar was organized by E. Keeble of the Environmental Physics Division at BRE.

Building science applications involving computers and climatic data include estimation of site-specific peak wind loadings, interpretation of energy use, and design to produce buildings which are comfortable and energy efficient.

The size of meteorological data bases and the complexity of a system composed of a building, its occupants and the external environment make computers ideal for investigating the relationship between a building and the weather.

Extreme wind conditions can have a catastrophic effect on buildings and structures like cooling towers, bridges and tower cranes. N. Cook (BRE) demonstrated a computer program (STRONGBLOW) used for calculating wind-gust design data for any UK site and any building height. This program relies on observed wind data received from the Meteorological Office and on-site characteristics supplied by the user, including local topography and surface roughness as a function of both direction and distance. It generates estimates of the 4-, 8- and 16-second gust speeds for a 50-year return period, for 12 equal sectors of the compass. STRONGBLOW is commercially available on microcomputers compatible with IBM personal computers.

Similar methods for calculating wind characteristics were used in interactive programs demonstrated by C. Sacré (Centre Scientifique et Technique du Bâtiment (CSTB), Nantes, France) to estimate the likely output of wind turbines as a function of site characteristics, and by S. Lockley (University of Newcastle upon Tyne) who demonstrated the use of Computer-Aided Design (CAD) graphics to assess exposure to wind-driven rain, which can affect both the fabric and energy use of a building.

The ABACUS computer unit at the University of Strathclyde is a leading UK group working in the field of CAD applied to environmental simulation in buildings. The Environmental Systems Performance (ESP) program is a detailed model capable of providing visual information about many aspects of the performance of a building — down to the transient response of temperatures within the layers of a wall structure, for example. Demonstrating ESP on a Whitechapel MG1 Workstation, J. Clarke (University of Strathclyde) recognized that lack of empathy with computer systems like ESP might be a block to their adoption by designers. He felt that the use of expert scripts giving details about features such as solar shading and overheating, comfort conditions, energy consumption and control-system optimization was the way to develop user output. ABACUS currently has about 90 annual meteorological data bases from Europe and the United Kingdom which can be used with ESP.

Following J. Clarke came P. Martin (Energy Designs and Surveys, Luton) who addressed the problem of providing adequate degree-hour and degree-day data for intermittently occupied buildings. Degree-days give an index, widely used by heating engineers, related to the area accumulated between the external temperature–time graph and a constant temperature (commonly called the base temperature) above which the building does not require heating. Although 15.5 °C is the customary figure, the true base temperature varies with the level of insulation, solar input and casual heat gain. A building's heat requirement should be proportional to the degree-day total. Monthly degree-day data for 17 UK sites are published in the Department of Energy's monthly newspaper *Energy Management* but P. Martin argued that because of holidays and intermittent occupancy this information was not suitable for setting energy targets for schools. He felt that under intermittent occupation a better index would be provided by the degree-hours accumulated during the time the building was actually in use. He illustrated the use of a microcomputer program, TEAM (Targeting, Energy Auditing and Monitoring), which uses temperature data from an electronic module left at a school and energy consumption information provided by utility bills or on-site readings, to decide whether a building is meeting a target energy consumption derived from the historically observed relationship between energy consumption and accumulated degree-hours.

Also in the area of site-specific temperature data, J. Penman (University of Exeter, Energy Study Unit) demonstrated, on a SIRIUS personal computer, a program to predict a site's long-term monthly mean temperature and degree-day figures (to any base temperature) from its geographical co-ordinates and height above sea level. This program relies on polynomial trend surfaces fitted to observed temperature data measured in a particular area. At present this has only been done for the south-west peninsula of the United Kingdom. Other areas could, of course, be analysed. The program gives site-specific information which can be used to estimate average heating requirements, or to correct the published *Energy Management* degree-day data, which for the south-west is measured in Plymouth. The program indicates that sites in Devon and Cornwall may have degree-day totals ranging from about 40% more to 20% less than the Plymouth figures.

Although solar overheating can be a problem, in northern Europe more attention is given to climate as a determinant of space heating requirements. However, at low latitudes the solar input is such that poor design can lead to impossible conditions inside buildings. Other meteorological variables such as temperature, humidity, rain and wind will also influence the type of building structure which produces a comfortable environment in hot climates. Simple guide-lines to good architectural practice in the tropics are provided by the Mahoney Tables, a manual design procedure requiring only monthly values of meteorological variables. However, as with many algorithms in building science, the Mahoney Tables are fairly lengthy to complete and there is an advantage in computerizing them, especially if repeated applications are required as in teaching. This has been done by O.O. Ogunsote (Ahmadu Bello University, Nigeria) whose work was presented by A. Penwarden (BRE).

The problem of shading from direct sunlight has application both in hot climates (to minimize solar gain) and in temperate and cold regions (where maximum solar access will be required in the heating season but shading may be desirable in the summer). The geometry of shading is both complex and variable (because of the sun's seasonal and diurnal movement), and so computers are particularly useful for shading calculations. Two contributions were made on this subject, one from D. Summers (Napier College of Commerce and Technology, Edinburgh) and the other from M. Sattler (Fundação de Ciência e Tecnologia, Porto Alegre, Brazil and University of Sheffield). The first of these was a program (SHADE) developed to predict areas of ground shaded by groups of buildings. This has found application in the Middle East. M. Sattler's program was developed to calculate the shading of buildings and building surfaces by trees as a function of time and season. It was demonstrated as applied to the shading of low-cost housing in Brazil.

The problem of calculating solar inputs was addressed by J. Page (Emeritus Professor at the University of Sheffield) who demonstrated a microcomputer program to calculate solar irradiation and illumination on inclined planes for any geographical location. Meteorological observations generally provide solar data measured on the horizontal plane. Since buildings consist predominantly of vertical planes this ability to go from horizontal to vertical and other orientations is important in calculating solar gains.

The use of shade to provide protection against the sun was illustrated in a series of slides of Italian Renaissance architecture shown by A. Lauritano (University of Palermo) who suggested that transitional spaces between the internal and external environment had been a feature of the architecture of the past and that an abrupt inside/outside interface was a modern characteristic. Transitional spaces could ease the environmental stress on a building envelope and the provision of shade could often provide a comfortable environment outside the building. These ideas were quantified in the computer program ECA (External Climate Assessment). Application of ECA to meteorological data in the Trapani Test Reference Year showed that shade increased, from 40% to 80%, the proportion of time that the external environment was comfortable given sensible choice of clothing. ECA relates individual comfort to the environment through air and mean radiant temperatures, wind velocity, relative humidity, clothing and activity level.

R. Taesler (Swedish Meteorological and Hydrological Institute) described the results of a computer investigation into energy use in housing in an area about 50 km wide around an airfield where meteorological measurements were made. The computer model considered the wind field (which affects air infiltration and surface losses), temperature variation and solar inputs. Variations in energy use of typically 20% were predicted. The orientation of a building with respect to the wind was important and sheltering by surrounding buildings could itself reduce heat losses by 20%, other things being equal. This underlines the importance of shelter to energy efficiency, in northern Europe at least.

It is well known that urban areas are warmer than the surrounding countryside, sometimes by several degrees Celsius. There are several plausible reasons for this, amongst them greater urban albedo, reduced latent heat flux due to rapid urban drainage, heat capacity effects and anthropogenic heat. The relative significance of these factors is, however, uncertain. The analysis of data from the Heat Capacity Mapping Mission (HCMM) satellite, which observes the surface of the earth in the 10.5 to 12.5 micron infra-red atmospheric window from polar orbit, was described by R. Gillies (University of Newcastle upon Tyne) who is investigating the causes of urban heat islands.

Any assessment of climate impact on building energy use requires meteorological data as input. The University of Sheffield, in contract to the UK Science and Engineering Research Council, has been assembling a meteorological data base for UK researchers. This takes hourly data from seven sites, typically over an 8-year period although for one site (Kew) 19 years of data are available. The data cover solar radiation (beam and diffuse), temperature (wet- and dry-bulb), pressure, wind speed and direction, rainfall (amount and duration) and coded weather descriptions. This information can be accessed via the Joint Academic NETwork (JANET) computer network. The development of the data base at Sheffield and an associated data base management system (INFOMET) was described and demonstrated by C. Gibbons.

Statistical descriptions of climatic regimes provide a possible compact alternative to extensive sets of meteorological data. In the second part of his demonstration, C. Sacré (CSTB, Nantes, France) described techniques for simulating cross-correlated sequences of meteorological data as time series described by Markov chains. Seven variables spanning temperature, humidity, wind, solar input and atmospheric pressure were covered.

The formal presentations were followed by a visit on the following day to Milton Keynes Energy Park where the intelligent use of local topography, plant shelter belts and building orientation allowing solar access will contribute to a saving of perhaps 10% in energy use. This is in addition to other savings achieved by energy efficient building design. The principles involved were explored by R. Griffiths, a landscape architect with the Milton Keynes Development Corporation.

The CIB-W71 co-ordinator is V. Torrance (Heriot-Watt University) who, with J. Page (University of Sheffield), shared the chairing of this seminar. The presentations clearly showed the usefulness of computers in fields like building science and climatology which deal with complex systems and large amounts of data. The next CIB-W71 seminar, New Developments in Building Climatology, will be in Moscow in May 1987.

J.M. Penman

Notes and news

IAMAP Scientific Assembly, Reading, 1989

The International Association of Meteorology and Atmospheric Physics (IAMAP) was founded in 1919 and aims to:

(a) promote meteorological research and investigation into all aspects of atmospheric physics, particularly those fields which require international co-operation, and

(b) provide a forum for the discussion of results and trends in research.

IAMAP organizes a Scientific Assembly every 4 years, and the next one will be held at the University of Reading from 31 July to 11 August 1989. The topics to be covered will be decided at the General Assembly of the International Union of Geodesy and Geophysics which takes place in Vancouver during August 1987. It is expected that further information about the IAMAP Scientific Assembly will be available in September 1987 from Ross Reynolds, IAMAP Local Organizing Committee, University of Reading, Department of Meteorology, 2 Earley Gate, Whiteknights, Reading RG6 2AU.

Books received

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

Contemporary climatology, by A. Henderson-Sellers and P.J. Robinson (Harlow, Longman, 1986. £9.95 (paperback only)) presents a synthesis of contemporary scientific ideas with topics including: local and regional climates, applications of climate information and an analysis of the formulation of climate models with a view to predicting future climates. Its intended readership includes people from other disciplines and without strong scientific background.

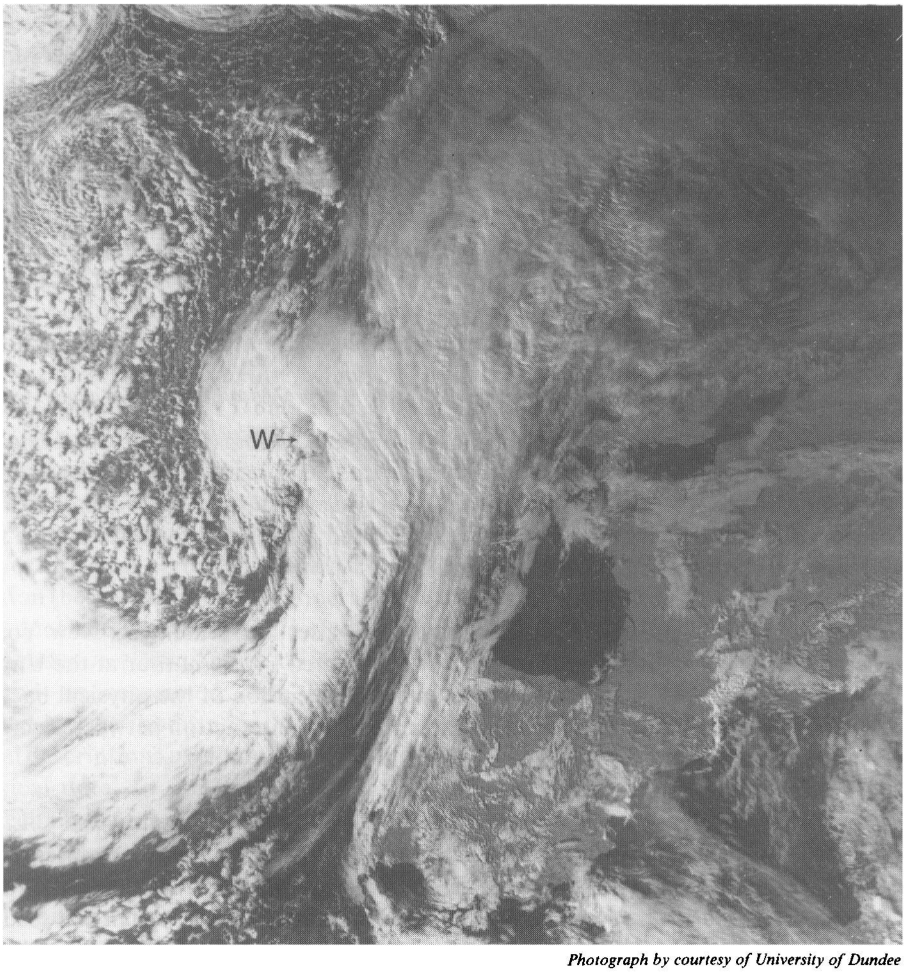
Physical fundamentals of remote sensing, by E. Schanda (Berlin, Heidelberg, New York, Tokyo, Springer-Verlag, 1986. DM 48.00) is based on a course presented by the author at the Universities of Bern and Toulouse in recent years. It aims to awaken an appreciation of the physical background of remote sensing and create an awareness of the importance of the interaction between electromagnetic radiation and matter for the optimal use of remote sensing.

An introduction to three-dimensional climate modelling, by W.M. Washington and C.L. Parkinson (Oxford University Press, 1986. £25.00) is a guide to the development and use of computer models of the earth's climate. The book describes the basic theory of climate simulation, including the fundamental equations and relevant numerical techniques for simulating the atmosphere, ocean and sea ice. Results for a variety of past, present and future climates are shown and compared with observations.

Satellite photograph — 12 November 1986 at 1457 GMT

The NOAA-9 visible image indicates a broad zone of thick cloud separating a large complex region of low pressure over the Atlantic from anticyclonic conditions over central Europe. A small northward-moving wave depression (labelled W) that deepened by about 10 mb between 1200 and 1800 GMT is clearly identified by a mass of thick cloud at the rear edge of the frontal cloud band. Vigorous convective cells are observed immediately behind the wave and to the west where cold air is flowing over the warmer sea. In the north-west corner of the picture several vortices are present within the low pressure complex, those along the picture edge being associated with an occluded front.

Considerable cloud detail is present over Europe. The non-fibrous appearance and the length of the shadows indicate that much of the cloud is at medium levels, although an area of fog or low cloud is seen over Belgium. Numerous short lee-wave trains are apparent over the British Isles.



Photograph by courtesy of University of Dundee

Meteorological Magazine

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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.

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Meteorological Magazine

February 1987

Vol. 116
No. 1375

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Back numbers: Full-size reprints of Vols 1–75 (1866–1940) are available from Johnson Reprint Co. Ltd, 24–28 Oval Road, London NW1 7DX. Complete volumes of *Meteorological Magazine* commencing with volume 54 are available on microfilm from University Microfilms International, 18 Bedford Row, London WC1R 4EJ. Information on microfiche issues is available from Kraus Microfiche, Rte 100, Milwood, NY 10546, USA.

ISBN 0 11 727966 8 ISSN 0026–1149

Printed for HER MAJESTY'S STATIONERY OFFICE
by Delco Printing Co Ltd 2/87 Dd. 739131 C1425