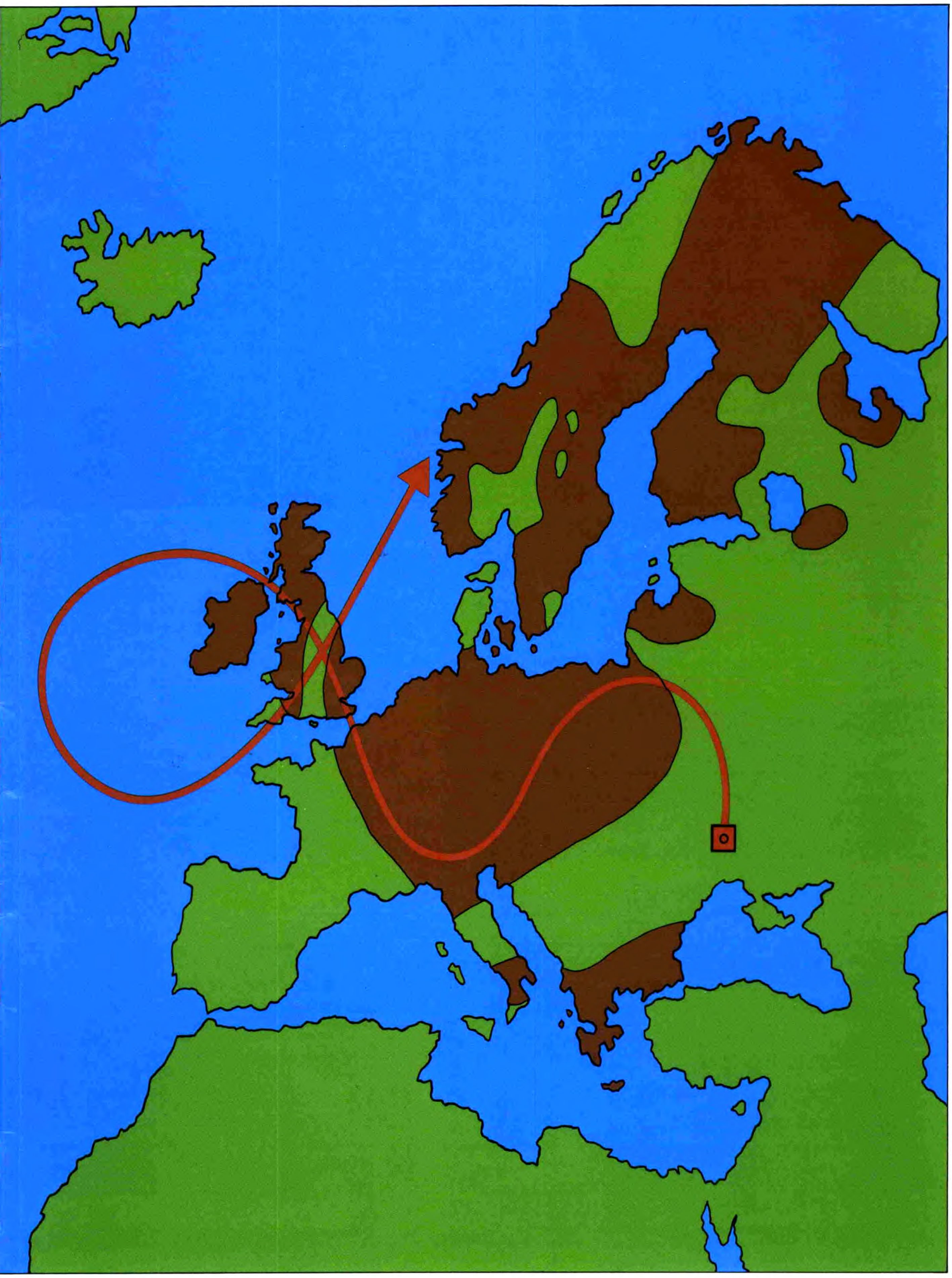
Annual Report 1986

Meteorological Office



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Annual Report 1986 Meteorological Office

Presented by the Director-General
to the
Secretary of State for Defence

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LONDON HER MAJESTY'S STATIONERY OFFICE

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The cover shows the estimated path over Europe of the radioactive cloud resulting from the explosion at the Chernobyl nuclear power plant. The areas probably affected by radioactive rainfall are coloured brown.

The false-colour photograph on the back cover is from an image taken by an infra-red sensor on board the NOAA-9 satellite as it passed over the Ukraine less than 24 hours after the explosion.

The water in the cooling ponds for the power plant shows as red, about 17 °C, while the water from the River Pripyat flowing around them shows as yellow and then green, about 7 °C; both representative of normal operations.

The picture was produced using the HERMES system which normally is used to obtain information about sea and land surface temperatures for meteorological purposes and for the occurrence of cloud and fog.

Foreword by the Director-General

Early in 1986, in a review which I carried out of the present work of the Office and its future development, I emphasized three factors that particularly contribute to the Office's success and efficiency: its integrated nature (in that it serves both the civil and Defence sectors and its research and operational activities are closely tied together), the way in which effort in the Office has been focused into key areas, and the quality of its staff.

Each year two special topics are chosen for presentation in the Annual Report in greater detail; in this Report the first is concerned with the Office's public services and the second with the meteorological aspects of the accident to the Chernobyl nuclear reactor. As a result of that accident it has become clear that better procedures must be developed for dealing with the effects of such an emergency and better co-ordination achieved by the national and international agencies involved. Meteorological factors are, of course, dominant in spreading radioactive material from such an accident; the Meteorological Office is participating fully in the discussions taking place.

As the accuracy and quality of forecasts improve, evidence of their usefulness is becoming increasingly apparent. The benefit to airlines was recognized by the award of the 1986 Esso Energy Award by the Royal Society to a team of scientists from the Meteorological Office for their work in developing the latest global computer forecast model. Forecasts of upper winds from this model employed in route planning enable many world airlines to achieve substantial fuel savings.

With the move of the Royal Air Force from Stanley to Mount Pleasant in the Falkland Islands, the uniformed Mobile Meteorological Unit was withdrawn after nearly 4 years continuous service in the South Atlantic. Civilian-staffed meteorological offices are now established at Mount Pleasant and at Wideawake on Ascension Island.

During the year a full-time forecasting presence was established at the Royal Artillery Range on South Uist in the Hebrides to enable adequate meteorological assistance to be given in the planning and execution of trials. The rapidly changing and often hostile weather of the Outer Hebrides, combined with the stringent safety conditions of the trials, presents a considerable meteorological challenge.

The Office is constantly pursuing new means both of providing particular customers in industry and commerce with specialized services on a repayment basis and of communicating general forecasts effectively to the public at large. At the end of 1986 'Weathercall' was introduced. Provided in conjuction with British Telecom and Telephone Information Services, this is a new 'dial-up' weather service covering the country with more detailed and more frequently updated weather information than has previously been available by this means.

The first Outstation Display System was installed at RAF Lyneham in October. This marks the beginning of a program to replace the current overloaded and obsolescent communications serving forecasting offices around the country. The new Weather Information System will take advantage of modern digital data transmission techniques and soft-copy displays to give forecasters readier access to a wider range of data and guidance products.

Changes which may occur in the climate of the earth are dependent not only upon what happens in the atmosphere but also on the changes which may occur in the ocean. The motions of the atmosphere and the ocean are coupled together, the ocean circulation being driven by the wind stress on the surface while the atmospheric circulation is highly sensitive to the heat input from the ocean. Computer models of the atmosphere and oceans coupled together are being developed within the Office and first experiments are encouraging. The Office has been grateful for the contribution made to this work by Adrian Gill whose death in April only a month after his election to Fellowship of the Royal Society represents a real loss to the subject.

Evidence of the strong connection between sea surface temperature (SST) patterns and the atmospheric circulation has been accumulating in recent years. Recent work in the Office has shown that for tropical Africa the correlations are sufficiently strong for useful prediction of weather over a period of several months ahead to be made on the basis of the observed pattern of SST anomalies. In June an experimental forecast was made of rainfall during June, July and August for tropical regions of Africa. It proved a useful input to African Meteorological Services and turned out to be surprisingly accurate.

During the year 16 nations of the European meteorological community set up a new organization, EUMETSAT, to be responsible for the operation of Meteosat, the meteorological satellite in geostationary orbit over the Greenwich meridian at the equator. The Office has provided its first Director, John Morgan, who until his appointment was Assistant Director (Satellite Meteorology). The Meteorological Office is also playing a significant part in the organization of the newly formed British National Space Centre, in particular in the formulation of a national program for earth observation.

Thanks to the competence of the staff and their co-operation in assisting with the introduction of automation the Office has been able to expand its program of activity while cutting its staff numbers very considerably (approximately by 30% over the last 12 years). The Office is continuing to attract high-quality recruits although it is of concern that more attractive pay and conditions outside Government service attract a number of scientists away from the Office in early or mid-career.

Support for science as a whole in the country is a subject on which many are currently expressing concern. When asking for necessary increased resources, British scientists need also to emphasize that the United Kingdom is still a good place in which to pursue science and to publicize the fact that there are areas such as meteorology where we continue in a world-leading position.

Contents

Functions of the Meteorological Office

The Meteorological Office is the State Meteorological Service. It forms part of the Ministry of Defence and is administered by the Air Force Department. The Director-General is responsible to the Secretary of State for Defence through the Parliamentary Under Secretary of State for Defence Procurement.

The general functions of the Meteorological Office are:

(a) The provision of meteorological services for the Army, Royal Air Force, civil aviation, the merchant navy and fishing fleets; provision of basic meteorological information for use by the Royal Navy; and liaison with the Director of Naval Oceanography and Meteorology.
(b) The provision of meteorological services to other government departments, public corporations, local authorities, the Press, television, radio, industry and the general public.
(c) The organization of meteorological observations, including observations of radiation, atmospheric electricity and ozone, in the United Kingdom and at certain stations overseas.
(d) The collection, distribution and publication of meteorological information from all parts of the world.
(e) The maintenance of the observatory at Lerwick.
(f) The provision of professional training in meteorology.
(g) Research in meteorology and geophysics.

The Meteorological Office also takes a leading part in international co-operation in meteorology. The Director-General is the Permanent Representative of the United Kingdom with the World Meteorological Organization, and acts in concert with the national Directors of the other Meteorological Services in western Europe in the co-ordination of their programs.

Meteorological Committee

Terms of reference:

(a) To keep under review the progress and efficiency of the meteorological service and the broad lines of its current and future policy.

(b) To keep under review the general scale of effort and expenditure devoted to meteorological services and research.

(c) To ensure the maintenance of adequate contact between the Meteorological Office and those who use its services.

Membership as at 31 December 1986:

Chairman:

Sir Peter Swinnerton-Dyer, KBE, FRS

Members:

Mr G.C. Band

Professor A.H. Bunting, CMG

Professor H. Charnock, FRS

Mr D.A. Davis

Professor P.H. Fowler, DSc, FRS

Mr J. Miller, FIOB

Mr R.A. Smith

Mr J. Wilson

*Mr M.A. Gamester (Representative, Civil Aviation Authority)

*Dr J.T. Houghton, CBE, FRS (Director-General, Meteorological Office)

*Air Vice-Marshal L.A. Jones, CB, AFC, (Assistant Chief of the Air Staff (Operations)); alternate, Group Captain A.M. Bowman

*Captain J. Marsh, RN (Director of Naval Oceanography and Meteorology)

*Mr J.M. Stewart (Deputy Under-Secretary of State (Personnel and Logistics))

Secretary:

*Mr P. Fraser (Secretary, Meteorological Office)

**ex officio*

The Committee met four times in 1986

Meteorological Committee — research subcommittee

Terms of reference:

To advise the Meteorological Committee on the general scientific lines along which meteorological and geophysical research should be developed within the Meteorological Office and encouraged externally. It shall review progress and report to the Committee annually at their meeting devoted to consideration of the research program.

Chairman:

Professor H. Charnock, FRS

Members:

Professor Sir Robert Boyd, FRS

Professor B. Hoskins

Professor J. Monteith, FRS

*Dr D.N. Axford (Director of Services, Meteorological Office)

*Mr D. Barber (Chief Scientist, Civil Aviation Authority)

*Group Captain A.M. Bowman (Deputy Director (Navigation))

*Dr D. Everest (Representative, Department of the Environment)

*Mr A. Gilchrist (Director of Research, Meteorological Office)

*Dr J.T. Houghton, CBE, FRS (Director-General, Meteorological Office)

*Mr I. Mackintosh, (Head of Electro-optics and Microwave Group, Royal Signals and Radar Establishment)

*Captain J. Marsh, RN (Director of Naval Oceanography and Meteorology)

Secretary:

*Mr T.D.A. Fairlie (Meteorological Office)

**ex officio*

The Committee met three times in 1986.

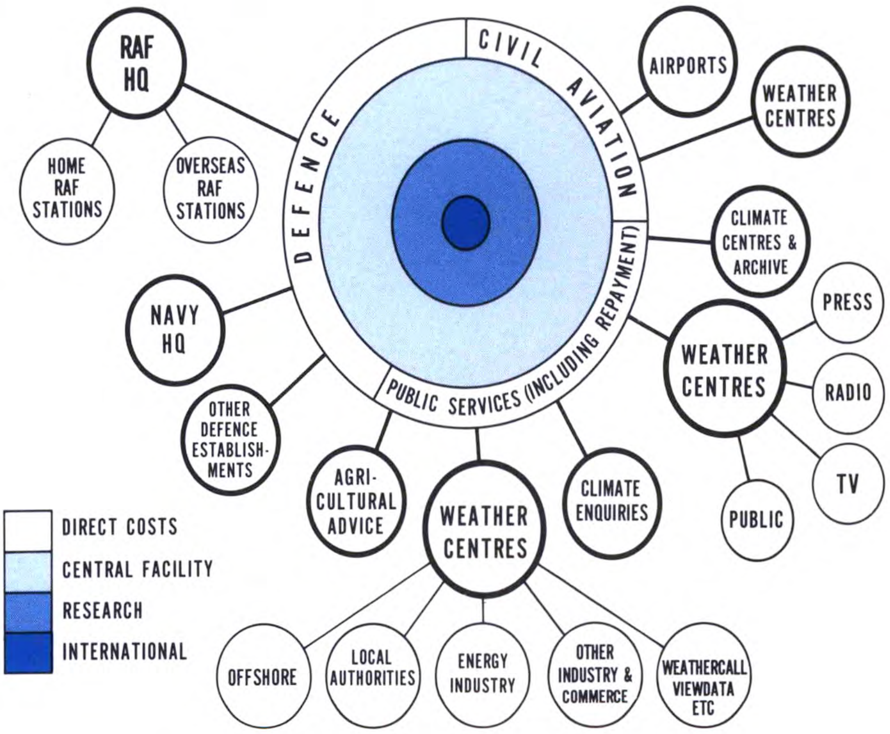
Introduction

The Meteorological Office produces weather forecasts and weather and climate information for a wide variety of users. For the general public, forecasts covering the British Isles and Europe are disseminated by Weather Centres located in the major cities of the United Kingdom mainly through the Press, radio and television. Weather Centres also serve a variety of other customers in industry and commerce on a repayment basis; notable among these are services for the offshore industry, the energy industry and local authorities.

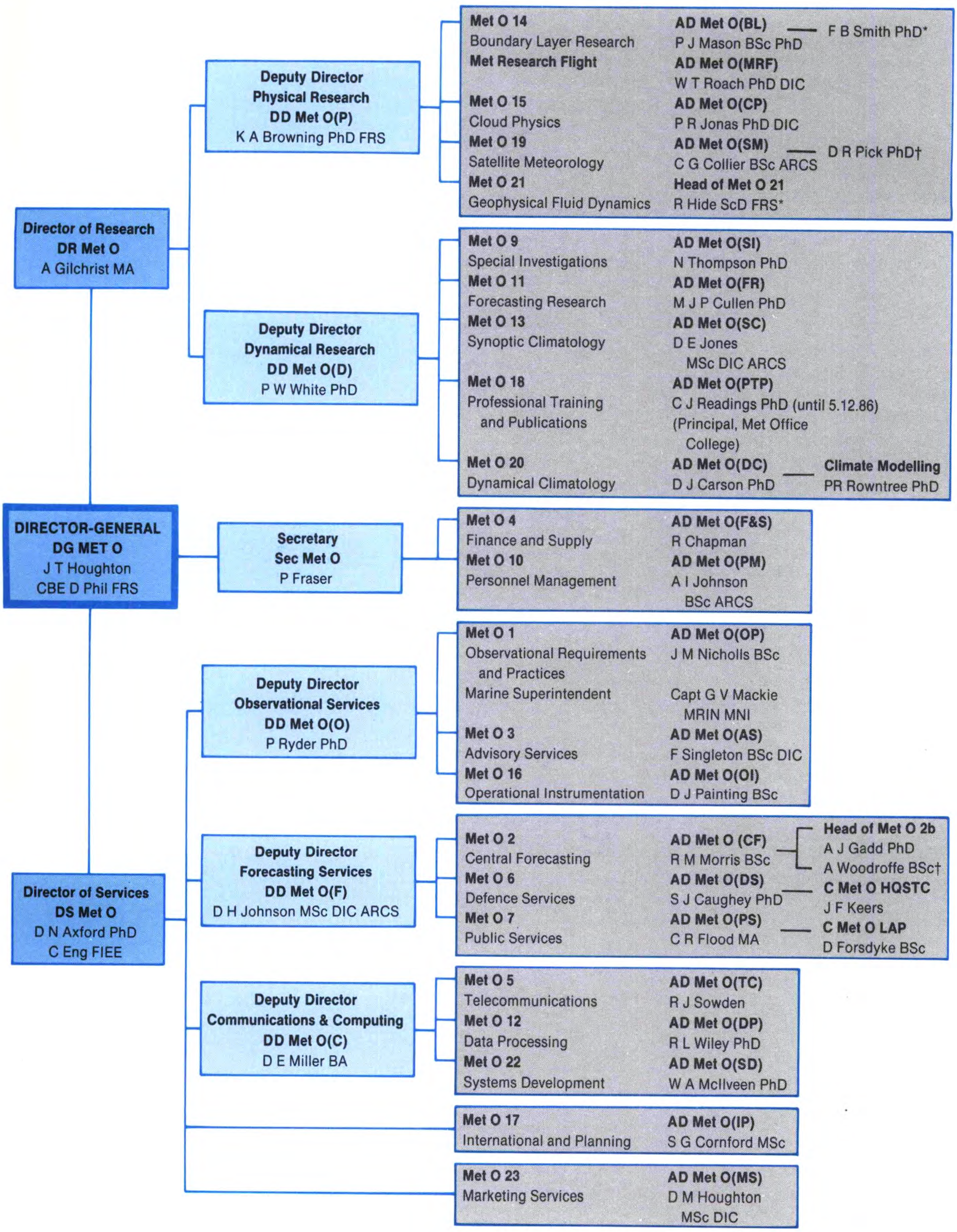
Forecasts for Defence are provided by Office personnel at Royal Air Force stations; the Naval Headquarters at Northwood, the Army and other Defence establishments are also provided with forecasts. For civil aviation, forecasts covering the whole world are provided to pilots and aircrew at major UK airports, to airlines for flight-planning purposes and to general aviation. Weather information for farmers is directed through Office personnel working with the Agricultural Development and Advisory Service of the Ministry of Agriculture, Fisheries and Food. The Meteorological Office is also the source of weather and climate data, and of advice, given to various sectors of government, public and private sector industry, and the general public.

The source of the information provided to the customers and users listed above is the generation of numerical weather forecasts that cover the whole globe and extend for a few days ahead. These are made twice a day; the tools required are world-wide observations, global communications and large computer models of the atmospheric circulation. Experienced forecasters then assess the models' outputs and the latest observations, and interpret them in terms of the particular weather information required by the customer. This central forecasting operation takes up rather more than half the total resources of the Office. (See the diagram where the central operation is represented by the inner parts of the central circle in which area is roughly proportional to resources.)

This report begins with sections describing this central operation; services for the major users of meteorological information are then presented, and later sections deal with various parts of the research,program which, although it represents only about 11 per cent of the Office's resources, is vital in maintaining the quality and effectiveness of the service activities. Finally, detailed administration and financial information is provided.



Meteorological Office organization



* Individual merit † Special appointment

Observations and instrumentation

Introduction

Regular, reliable and accurate measurements of many meteorological variables, both from the surface and in the atmosphere, are the basic input to the wide range of forecasts produced by the Meteorological Office. Observations are also essential to the provision of many consultancy, advisory, and information services.

To supply these data a series of observing networks of different types and using a variety of observing technologies has been established. Many stations are manned but modern automatic data-gathering systems are also being introduced to provide information from uninhabited regions and to replace the observing capability which is lost as manpower is reduced. Technology is being developed but is not yet available to enable all necessary observational data to be obtained automatically; for example, instrumental measurements of visibility, cloud type and structure, and precipitation type are not at present an adequate substitute for human estimates and judgements. Measurements made from conventional surface networks are now being complemented, and to a limited extent replaced, by those derived from remote-sensing systems such as weather radars and satellite instrumentation; complex processing techniques are being developed to exploit fully the application of raw data from such systems.

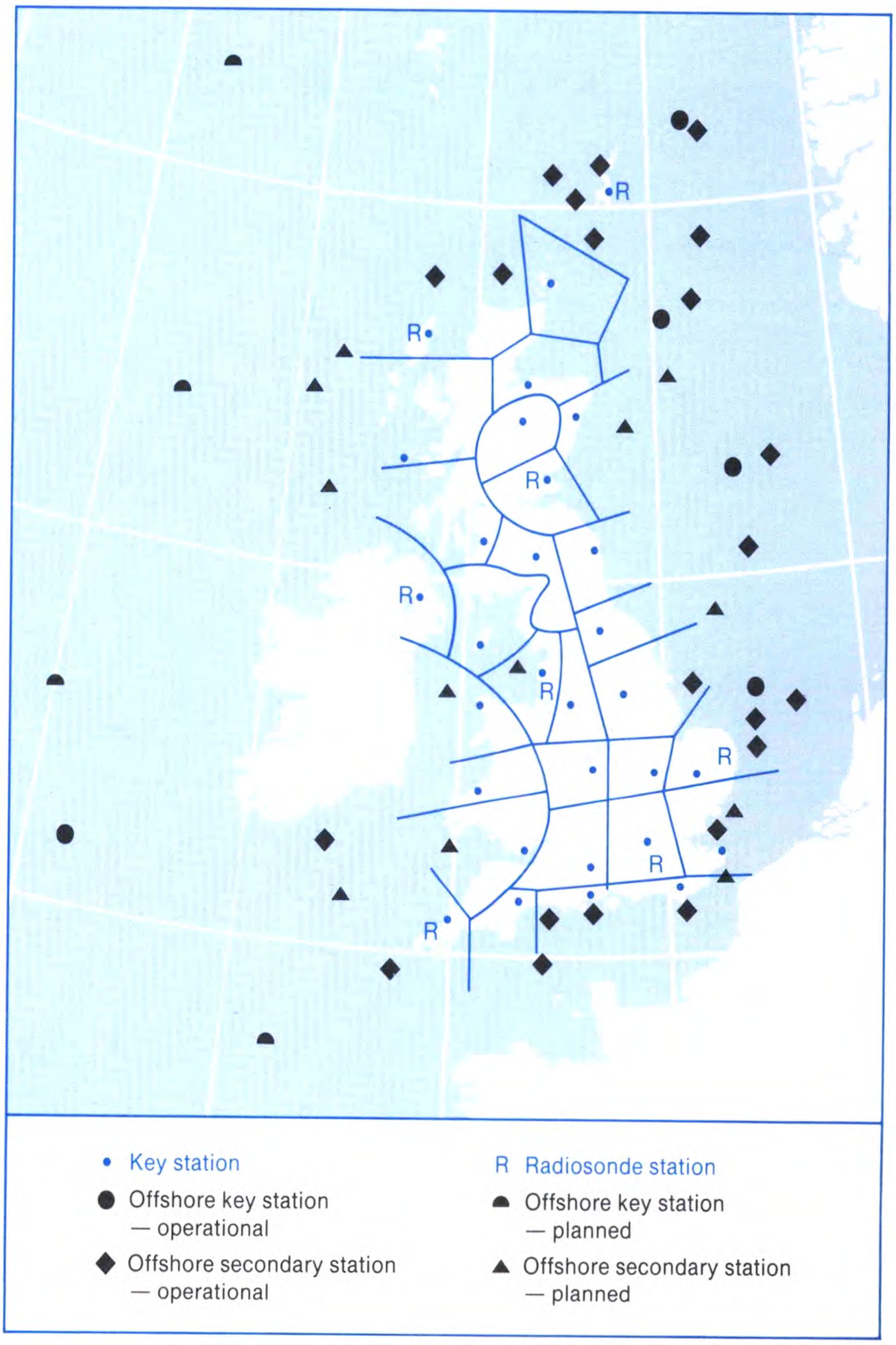
Surface observations over land

To define the existing state of the weather on the broad scale at or near the surface, a network of observing stations with a spacing of about 150 km over land is needed. Accordingly a 'key' station has been established in each of 30 geographical areas, which have approximately homogeneous meteorological characteristics. Key stations are professionally manned, and accurate observations are made both by visual means and by instruments measuring pressure, temperature, humidity, wind and rainfall amount. Generally, observations are made at hourly intervals, though at airfields in particular a continuous watch is maintained and the results are made available at half-hourly intervals when the airfield is open.

To take account of the impact of orography on current weather and on forecasts for specific localities, regular observations are obtained from a denser network of 'secondary' stations. The Office mans 55 such stations, mostly at airfields at which a forecast service is provided. Observations are also made, by non-Meteorological Office staff, at 138 auxiliary stations. Additionally, 40 automatic weather stations (AWS) are installed in unpopulated areas and at locations where they are the most economic means of providing data regularly. It is planned that a further 23 AWS will be installed over the next few years.

An extensive data base is required to support climatological services to customers such as those in the

The UK network of land-based 'key' stations, each one in an area with homogeneous meteorological characteristics. Also shown are radiosonde stations and the network of marine observing stations.



engineering industries, insurance companies and legal professions. At 55 stations, manned by the Office and designated as 'Principal Climatological Stations', autographic records are kept, which enable, for example, extremes of windiness and rainfall intensity to be derived. At a further 450 'Ordinary Climatological Stations', operated mostly by other authorities or volunteers, observations of extreme temperatures and rainfall are made at least once daily. A small network of 'Reference Climatological Stations', each providing over 30 years of homogeneous records, is maintained to help determine climatic trends. Additionally, rainfall is measured for hydrological and climatological purposes at 4800 sites operated by the Water Authorities, river Purification Boards and private individuals.

The Meteorological Office is extremely grateful to the very many dedicated voluntary observers supplying climatological and rainfall data. Summaries of data both from these stations and from official Meteorological Office stations are published in the *Monthly Weather Report* and in an annual summary of rainfall data. Both these publications have pedigrees of over 100 years. Many original records are retained in document archives under the terms of the Public Records Act, but most data nowadays are also stored in computerized archives.

Work continued in the evaluation of new automated sensors and the introduction of new systems into service:

- An international ceilometer (cloud base recorder) intercomparison was hosted at the Beaufort Park experimental site, near Bracknell, from February to July. Eleven systems, including seven different types, were provided by Finland, Sweden, the Federal Republic of Germany, the Netherlands and the USA. Cloud-base heights, together with data on other meteorological elements, were recorded on central logging equipment at 1-minute resolution. Measurements by the five types of laser cloud-base recorders were in good agreement generally although systematic differences of up to 50 m were evident. Triangulation methods produced larger differences. Detailed analysis of performance in different weather conditions (fog, snow, etc.) continues.

- Five of the eleven Marconi short baseline visibility sensors procured in 1985 were under trial throughout the year. The results obtained so far have been disappointing; the performance falls well short of the requirement. Ways of improving the instruments are being sought; especially to solve the problem of inconsistency of performance between identical instruments exposed to the same environment.

- Considerable progress has been made on long-standing problems associated with automatic measurements of soil temperature. Numerical models of heat flow in the soil and in thermometer housings have shown how measurements of temperature from electrical resistance thermometers embedded in soil can be much more accurate than those from conventionally exposed mercury-in-glass thermometers.

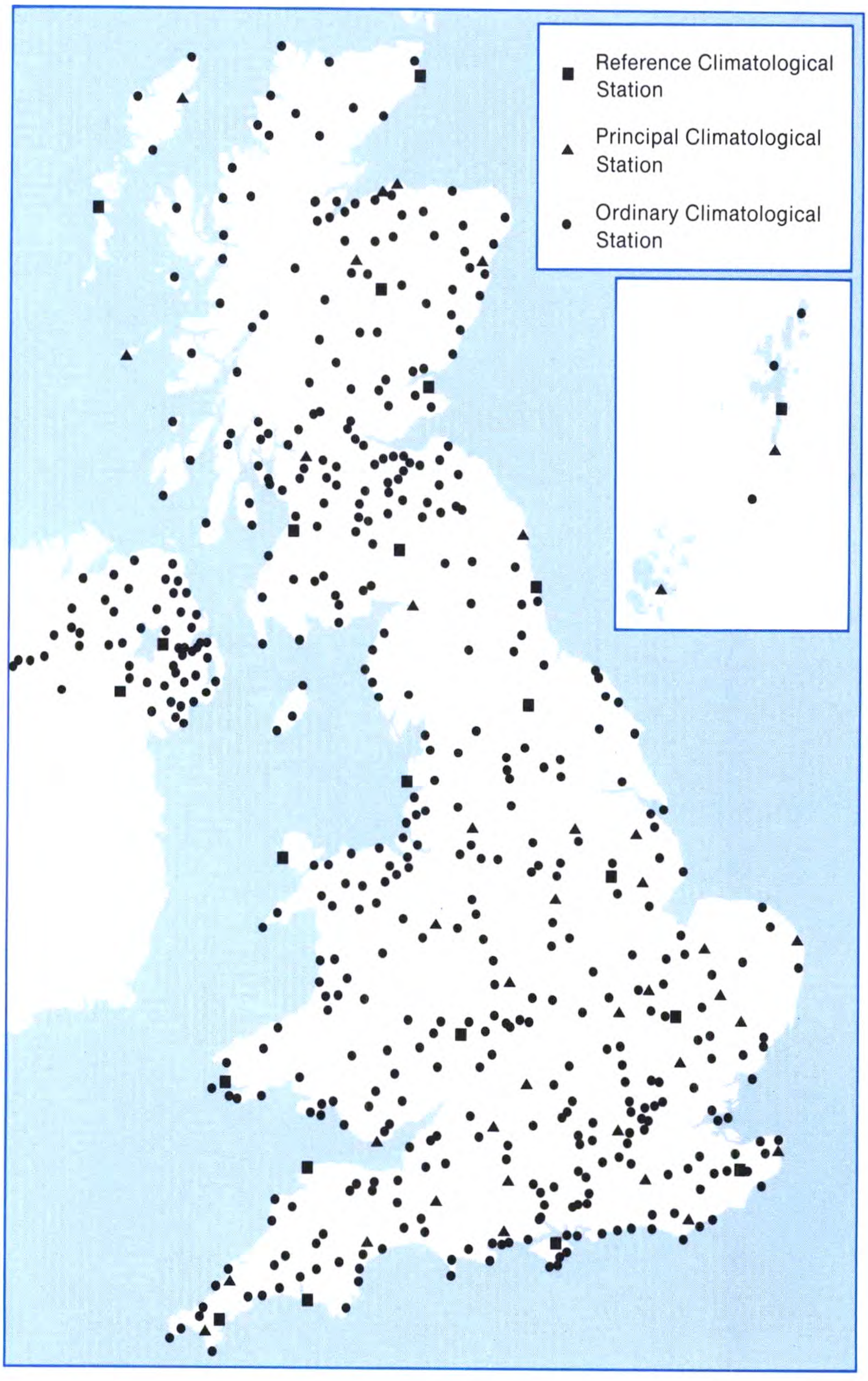
- Excellent results have been obtained so far from the new solid state event recorders attached to the tipping-bucket rain-gauges for the recording of short-period rainfall events. A further batch of recorders is expected in 1987 which, together with the enhancement of the automatic weather stations already in use, will provide a uniform network of more than 200 sites throughout the United Kingdom, all providing hourly rainfall data.

- Procurement of 28 runway cross-wind resolvers for the RAF was well under way during the last quarter of the year and the prototype replacement Digital Anemograph Logging Equipment has been completed ready for user trials.

Marine observations

The figure on page 1 shows the network of existing and planned fixed, marine

The UK network of climatological stations.



The prototype replacement Digital Anemograph Logging Equipment.

weather stations around the United Kingdom. Nine key stations which report a comprehensive range of elements every 3 hours are required in support of general forecasting. A network of 15 secondary stations operates to provide additional data for short-period forecasting purposes especially for the offshore oil and gas industries in the North Sea. Work continues on the development of marine automatic weather stations.

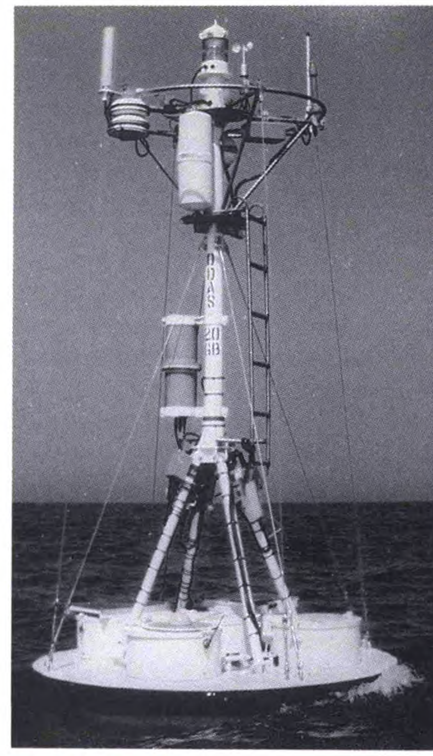
The COST-43 (European Co-operation in Science and Technology) drifting buoy projects have continued, and deployments commenced in the Southern COST-43 Operational (drifting buoy) System (SCOS) in the Azores region of the North Atlantic at the end of the year. Two of the five buoys provided by the United Kingdom for the first year of operation of the System of Operational Buoys in the Atlantic (SOBA) Project (south-west of Iceland) failed after launch; however, the network was maintained throughout the year and a further seven buoys (two for the SCOS project) of a different type were purchased.

Further delays in placing contracts for additional work on the Ocean Data Acquisition System (ODAS) 451/452 buoys (a joint United Kingdom/Iceland project under COST-43 to maintain a buoy station near 67°N, 13°W for a period of 2 years) postponed the deployment of ODAS 451.

The ODAS 20 buoy was successfully launched and deployed in the southern North Sea at 55° 20′N, 02° 20′E in July and the prototype buoy manufactured by Thorn–EMI Ltd was recovered after almost 1 year's successful operation in Lyme Bay. Both these buoys use the Meteosat/GOES satellite data collection system and both carry a satellite navigation beacon to aid recovery in the event of mooring failure. The UK/French 'Bosco' buoy suffered damage during severe weather in the spring. It was fully repaired during July by a joint UK/French team with ship and mooring services provided by the Directorate of Marine Services (Naval).

Progress was made with the program to install automatic weather stations on unmanned light-vessels. Invitations to tender for the supply of suitable equipment to install on two such vessels were issued to firms in December.

Meteorological observations are collected regularly on board ocean-going vessels and transmitted by radio, sometimes through a satellite link to shore-based centres. The United Kingdom Voluntary Observing Fleet consists of over 500 vessels (passenger liners, container ships, tankers, ferries, coasters and supply ships) out of a total of 7600 operated by 48 countries as part of the World Meteorological Organization Voluntary Observing Ship scheme. In spite of the decline in the number of ships sailing under the British flag, the number of observations made is at its highest level ever. A further 8 vessels, making a total of 16, are being equipped with the Meteorological Observing System for Ships (MOSS) which automatically formats manually entered surface observations and broadcasts them via geostationary satellite. Over the last year more than 94% of ships' weather reports transmitted by the system have arrived at Bracknell within a few minutes of observation time. Some of the tracks followed by MOSS-carrying ships are shown in the figure below.



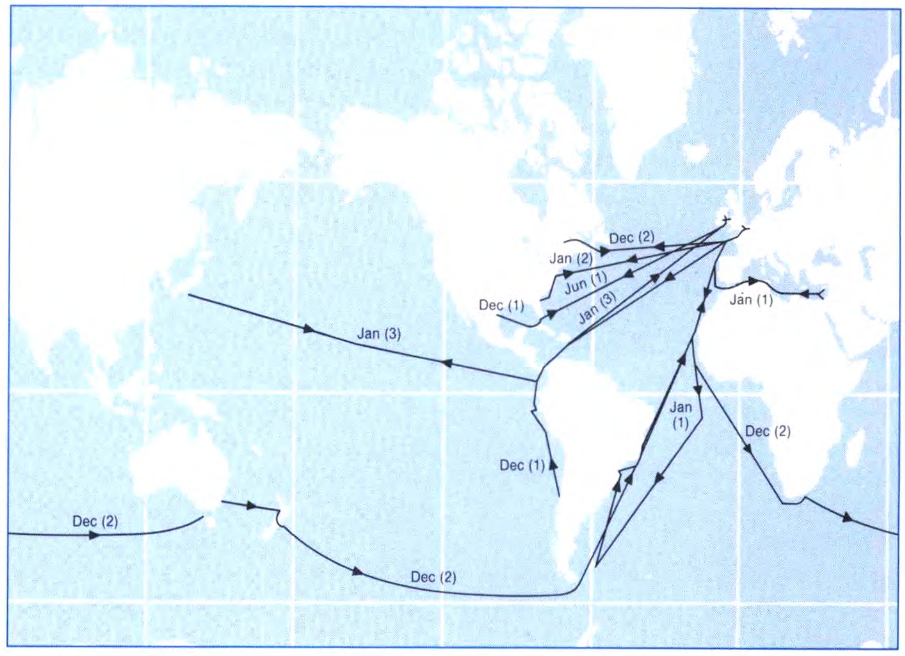
The ODAS 20 buoy.

The weather radar network

The UK weather radar network continues to provide composite precipitation data at 15-minute intervals to forecasting offices. The same data are also provided, on a repayment basis, to Devon County Council and a number of Water Authorities, to assist in their day-to-day operations.

Off-line data also continue to be provided, these again on a repayment basis, to a large number of customers. The data proved to be extremely useful to workers at the Imperial College of Science and Technology who were

Some of the tracks followed by MOSS-carrying ships. The month when MOSS became operational is shown, together with the number of ships on that route (in brackets).



assessing the wet deposition of radionuclides following the accident at the Chernobyl nuclear power station.

Sites have been identified for five new radars which are being manufactured by Plessey Radar Ltd. The Northern Ireland radar will be installed at Castor Bay on the south-eastern shore of Lough Neagh and the two Wessex radars in Dyfed and Devon. The two radars procured by the Directorate of Naval Oceanography and Meteorology (DNOM) will be sited at Predannack in Cornwall and a site in Dorset. The latter two will replace the ageing S-band radars at Camborne and Upavon.

Agreement has been reached between the Meteorological Office, Anglian Water and the Severn–Trent and Yorkshire Water Authorities jointly to fund a sixth new radar which will be sited just north of Lincoln. It is hoped to extend the network into Scotland once this extensive procurement and installation program in England, Wales and Northern Ireland has been completed.

Thunderstorm location

A network was maintained of four stations in the United Kingdom and one at Gibraltar for the location, by direction-finding methods, of thunderstorms. Hourly positions of major thunderstorms over much of Europe and the eastern Atlantic are determined in daytime.

Five UK outstations for the new arrival time difference location system have been installed; similar equipment will be installed at Cyprus and Gibraltar in

At 0100 GMT on 3 September 1986 a cold front from the south-west approaches to Yorkshire gave rise to a belt of continuous rain while showers were beginning to form to the north-west as a result of the development of a small depression over northern England. The picture shows the output from the weather radar network for that time.

1987. The outstations are being integrated with the Bracknell-based control station and system trials will take place in mid-1987.

Observations of solar radiation

Equipment that can measure and record global and diffuse short-wave solar radiation is operated at 14 Meteorological Office stations. The pyranometers at these and at 24 independent co-operating stations are inspected by staff of the National Radiation Centre (NRC); additionally, they are periodically calibrated against a reference pyrheliometer which is itself compared every 5 years against the WMO 'Standard Group' held at the World Radiation Centre in Davos, Switzerland.

The NRC is one of the three Principal Radiation Stations in the United Kingdom which make a wider range of measurements, for example of radiation incident on inclined surfaces and direct solar radiation. The NRC also undertakes a range of investigational work; the performances of experimental pyrgeometers, new commercially available pyranometers, and printing integrators were examined during the year. Training courses are also provided, and in June instruction on all aspects of solar radiation measurement was given to technicians of the Caribbean Meteorological Institute, Barbados on a course organized by the Commonwealth Science Council.

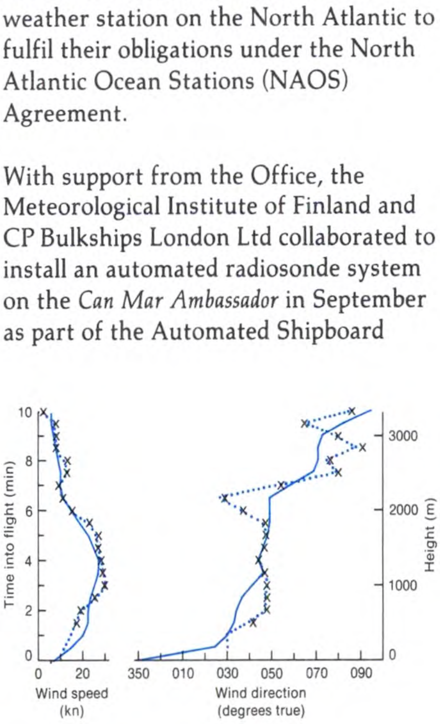
Upper-air observations

The figure on page 1 shows the location of the eight stations in the United Kingdom from which regular measurements of temperature, humidity and winds are made to heights of around 30 km. Temperature and humidity measurements are made at 0000 and 1200 GMT daily by radiosondes carried by freely ascending balloons. Upper winds are determined by tracking the sounders by radar. Additional wind-only measurements are made at 0600 and 1800 GMT. Data from such ascents, conducted on a world-wide basis, form part of the basic input to numerical forecast models. The atmospheric profiles of temperature and humidity also give the local forecaster valuable information to assist in the forecasting of cloud and fog. A major program of refurbishment of the 20-year old radars used for determining the upper winds has been started and it is hoped that this refurbishment will extend the life of the radars by some 10 years. Radiosonde stations are also maintained overseas at Gibraltar, St Helena, and Mount Pleasant, Falkland Islands.

Field investigations of the performance of systems which make and process upper-air measurements have continued. The figure below shows some results from a comparison of three wind-finding systems, namely the present operational tracking radar, a new portable radar system, and a Navaid radiosonde which receives and retransmits low-frequency radio signals of the type used for aircraft navigation. The aim of the trial was to assess the suitability of the systems for defining detailed low-level wind structure at military ranges. The portable radar showed an ability to make measurements at lower levels than the operational fixed radar, whilst the Navaid radiosonde was unable to resolve the detailed atmospheric structure. A trial, to assess the utility of data from a monostatic acoustic sounder for forecasting purposes, was completed at RAF Waddington.

Ocean Station Vessel (OSV) *Cumulus*, the purpose-built vessel acquired from the Netherlands for 1 pound sterling at the end of 1985, replaced OSV *Starella* in mid-January and commenced single manning at station 'L' (57°N, 20°W). On her 33-day voyages *Cumulus* spends 27 days on station and 3 days each way in transit; about 36 hours are spent on turn-round at her Greenock base. Hourly surface observations and 6-hourly upper-air soundings by radiosonde are made both on station and in transit. The United Kingdom, Norway and the USSR each man one ocean weather station on the North Atlantic to fulfil their obligations under the North Atlantic Ocean Stations (NAOS) Agreement.

With support from the Office, the Meteorological Institute of Finland and CP Bulkships London Ltd collaborated to install an automated radiosonde system on the *Can Mar Ambassador* in September as part of the Automated Shipboard



Radiosonde intercomparion between the operational radar (xxx), the new portable radar (....) and the Omega Navaid radiosonde (——) carried out at Beaufort Park on 20 November 1985.

Aerological Programme (ASAP). Upper-air data will be available on the ship's regular voyages between Felixstowe and Montreal and will provide a valuable supplement to weather ship data.

Directly measured upper-air data will remain sparse over oceanic areas in spite of the continued operation of three Ocean Station Vessels and the introduction of ASAP. A new avionics system known as ASDAR (Aircraft to Satellite Data Relay) has been developed to collect meteorological data on board commercial aircraft which overfly data-sparse areas, and to transmit the data automatically via satellite to the telecommunication networks. The company to whom the design and development contract has been awarded ceased trading in March, and intensive negotiations have continued with a sister company concerning transfer of the contract.

Detailed plans drawn up for the Operational World Weather Watch System Evaluation — North Atlantic (OWSE–NA) have received widespread international agreement. The evaluation comprises, for all observing systems deployed on, over and around the North Atlantic, a 2-year (1987–88) assessment of the impact of the resulting data on forecasts and of problems concerning procurement, installation, operation, maintenance and performance of the systems and their data communication channels.

Observations from satellites

The Office continues its program of provision and development of instruments for observations from space of the earth and its atmosphere. All the elements of this program involve co-operation with other national and international establishments.

The Office is collaborating with the Rutherford Appleton Laboratory (RAL), the University of Oxford, and the Mullard Space Science Laboratory (MSSL) in the provision of the Along Track Scanning Radiometer (ATSR) for the European Space Agency (ESA) Earth Resources Satellite (ERS-1). This radiometer is due to fly in 1989 and will provide measurements of sea surface temperature to an accuracy of better than 0.5 °C. The Office is responsible for the detailed design of the detector assembly in the focal plane of the ATSR viewing telescope. The engineering model focal plane assembly has been assembled and passed its vibration test and the thermal design validated. A specially equipped clean room has been commissioned and an alignment facility set up. Test infra-red calibration targets for the detector assembly have been made and the associated electronic equipment is in the process of evaluation. Calibration targets for the ATSR have been designed and are under construction in the Meteorological Office workshops. A contract for procurement of the target controller through industry has been authorized.

Support for the US polar-orbiting satellites continues through the provision of the remaining units out of a total of nine Stratospheric Sounding Units (SSUs) and the development of the Advanced Microwave Sounding Unit B (AMSU-B). The SSU F2 launched in June 1979 continued to provide stratospheric soundings. The SSU F5 on NOAA-9 also continues to provide stratospheric sounding data; however, one of the radiometer channels has become very 'noisy'.

The UK/USA program leading to the provision of AMSU has continued. The AMSU-A instrument, which provides temperature sounding data from the surface to 1 mb, will be provided by the National Oceanic and Atmospheric Administration (NOAA) through a contract with Aerojet Electro Systems. The Meteorological Office has agreed to provide the B unit, which will give humidity profiles and information relating to clouds and precipitation. A hardware development contract continues and a preliminary design review has been held. Two other contracts were placed with industry for the provision of detailed cost estimates and technical feasibility studies.

In parallel with the industrial effort on AMSU-B the Office is developing a supporting scientific program. This work has two aspects. Firstly radiometric calibration: an in-house AMSU-B calibration facility has been costed and an accommodation bid prepared. Design work on the internal and external microwave calibration targets has been undertaken in the Office with support from the University of Bath and the National Physical Laboratory. Secondly spectroscopy: an experimental program is under way involving the RAL and the Laboratorie de Météorologie Dynamique (LMD) at Palaiseau, France. Equipment has been set up and measurements at AMSU-B frequencies have been made of the microwave properties of water in its three phases. The Hercules C-130 aircraft of the Meteorological Research Flight has been modified to enable a supporting measurement program for atmospheric measurements to be undertaken, again in collaboration with LMD.

For the future the Office has started to collaborate with other European scientists on design studies for the microwave and infra-red sounders required for the second-generation Meteosat. Two reports have been produced defining the basic sounder requirements and an additional report prepared describing possible enhancement of the basic infra-red sounder. These were reviewed by an ESA-sponsored workshop at Ravenna, Italy. The Office acted as user consultants to British Aerospace during the first industrial study phase on the microwave sounder.

OSV Cumulus.

Central forecasting services

The Central Forecasting Office (CFO) at the Meteorological Office Headquarters in Bracknell has a number of national and international functions. It is a Regional Meteorological Centre (RMC) within the World Meteorological Organization World Weather Watch system, a National Meteorological Centre (NMC) for the United Kingdom, a World Area Forecast Centre (WAFC) and a Regional Area Forecast Centre (RAFC) of the International Civil Aviation Organization.

The RMC responsibilities include the preparation and dissemination of charts containing analysed fields of selected weather elements such as pressure, temperature and wind. The analyses are prepared from observations received through telecommunication channels at Bracknell. Charts containing forecast fields of weather elements are also prepared for dissemination by facsimile, and forecast information in coded alphanumerical format by teleprinter. Shipping forecasts are prepared twice daily for the eastern North Atlantic and four times daily for the North Sea and adjoining waters on the UK continental shelf. These are sent for broadcast by the BBC and coastal radio stations.

The NMC responsibilities include the issue of guidance to regional forecasting offices within the United Kingdom. As well as describing the general trend of weather developments over the next 5 days, it contains advice on the interpretation of numerical weather prediction output which is disseminated in chart form directly to outstations by means of dedicated facsimile broadcasts. The most detailed guidance is given for the first 24 hours and, in particular, the CFO ensures that warnings of severe weather such as heavy rain, blizzards, dense fog and icy roads are disseminated for public information as quickly as possible through radio and television broadcasts. The quality control of the data from the expanding network of weather radars became a responsibility of the CFO towards the end of the year with the installation of the necessary interactive computer graphics system. Further development of this facility is expected to lead to better accuracy in short-period forecasts of the movements of rain bands and thunderstorms.

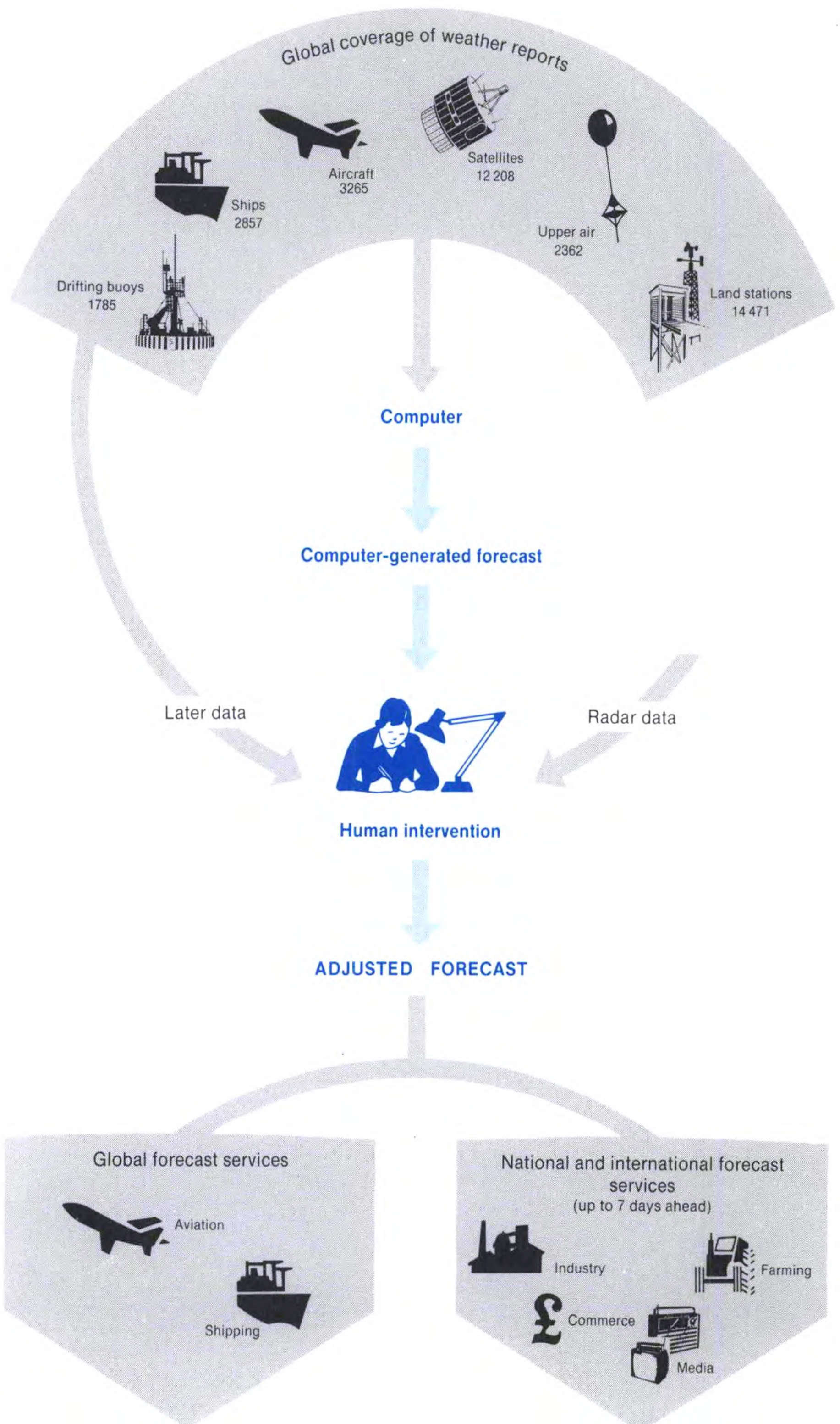


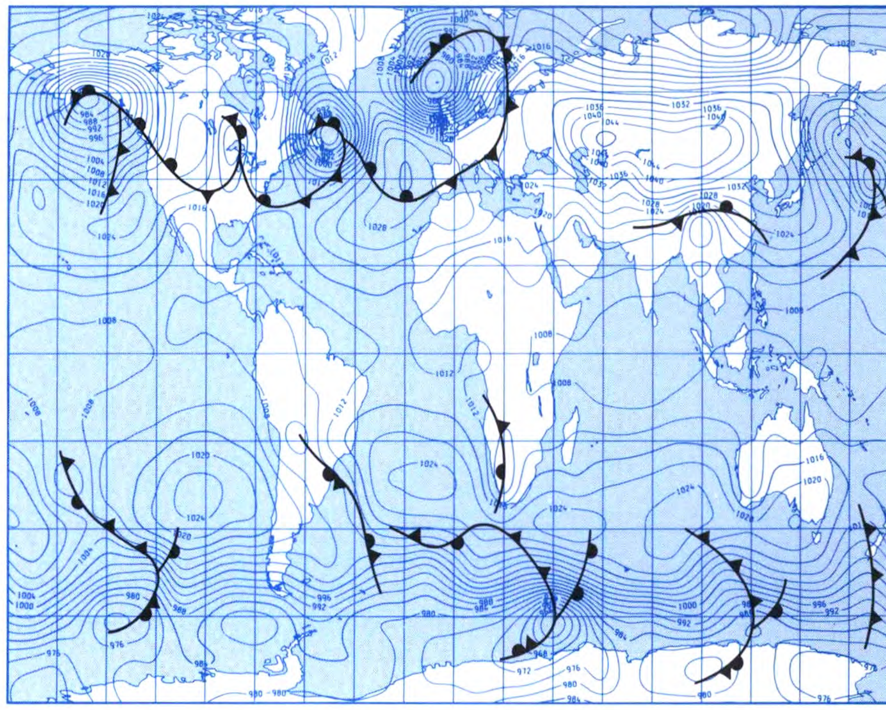
Diagram of flow – from observation to forecast. Numbers indicate the mean number of observations received each day for use in the global data assimilation cycle. Global forecasts are run twice a day from 0000 and 1200 GMT analyses.

As a WAFC the CFO is required to provide forecasts of upper winds and temperatures for flight planning for all parts of the world. The aviation forecasters in the CFO closely monitor the numerical model output of winds and temperatures which are supplied directly to commercial air operators and to other National Meteorological Services for issue to the airlines which they serve. The RAFC function includes the preparation of charts of significant weather which may be hazardous to aircraft *en route*. These hazards include turbulence encountered in clear air as well as that associated with large cumulonimbus clouds in which icing may occur. Charts of winds and temperatures and of significant weather are despatched to airport offices for issue to aircrews for use on the flight deck.

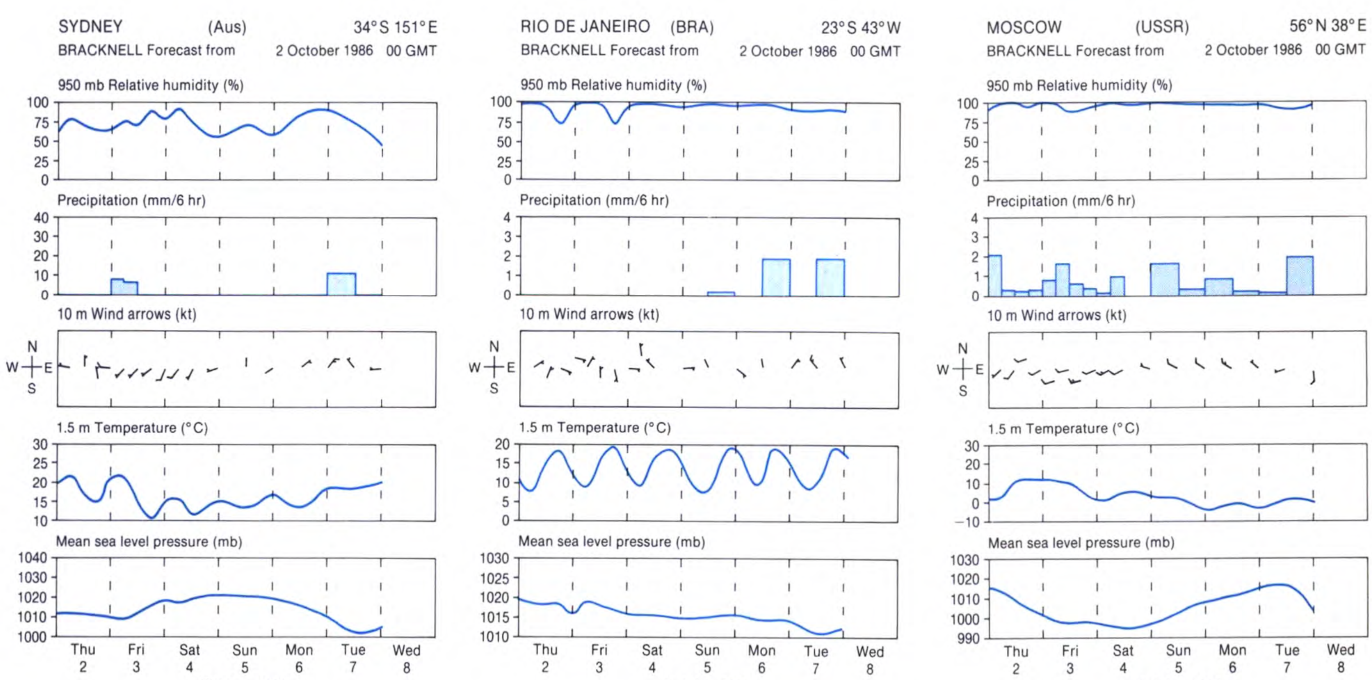
In carrying out the range of work described here the CFO relies upon the output of a suite of numerical weather prediction models. However, computers cannot create good forecasts from poor initial analyses and there are many areas of the world where observations are sparse. For these reasons a significant amount of human resource is devoted in the CFO to the monitoring and fine tuning of the numerical model analyses before the forecasts are computed. The skilful interpretation of satellite imagery plays an important part in this process.

The numerical model provides useful guidance in predicting up to 5 days ahead the general synoptic developments, that is, the behaviour of depressions, anticyclones and fronts. Even so, the forecasters can add value to these forecasts, especially for short periods ahead (up to 36 hours), from their perception of known problem areas with the model. For example, very small-scale features may not be correctly handled or there may be important defects in the analysis, which become apparent only after the receipt of late data.

Forecasts of weather elements such as surface wind and temperature, precipitation, cloudiness and even fog can now be forecast directly by the numerical models. Therefore, the forecaster no longer has to deduce the nature of these elements solely from predictions of the pressure and temperature fields as was once the case. However, the physical processes involved are so complex and the weather features concerned may be so small that skilful forecasters can often improve upon the computer output from their experience of the way in which the weather tends to behave and their knowledge of the effects of the local geography.



Numerical model 5-day forecast of mean-sea-level pressure (mb) with associated fronts added by hand.



Forecasts, as time series of specific weather elements for individual localities, as produced by the numerical model.

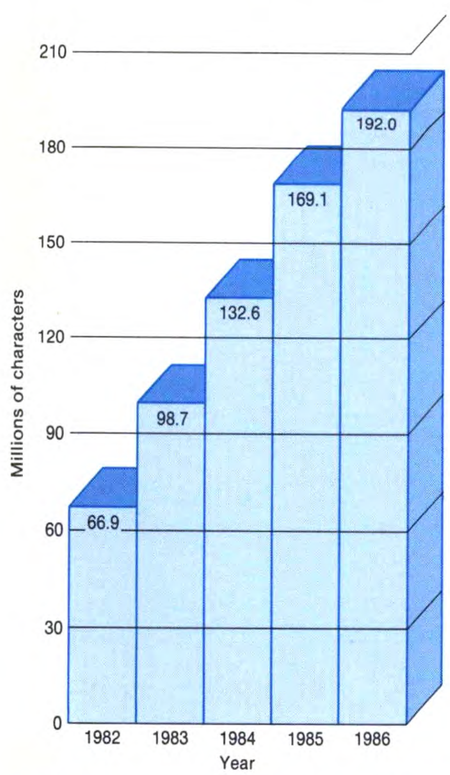
Telecommunications

The Meteorological Telecommunication Centre

The Meteorological Telecommunication Centre (Met TC) at Bracknell has two main functions. Firstly, collection of observations from the United Kingdom, and of aircraft, ship and buoy observations from the eastern North Atlantic as a contribution to the exchange of observations from around the world over the World Meteorological Organization's (WMO's) Global Telecommunication System (GTS). Secondly, the dissemination of forecast products from Bracknell and other meteorological centres nationally and internationally. These products are in the form of both data and charts.

International networks

Several new international connections were made to Bracknell during the year, perhaps the most notable being a link with the Hydrometeorological Centre, Moscow. This link provides a more complete service of observational data from Asia and the Far East for use in the Bracknell global model, and an improved availability of data from North and South America to the Moscow centre.



Number of characters handled in the Met TC on one (November) day over the past 5 years.

Other new connections included Madrid and Lisbon, greatly improving reception of numerical and pictorial products at these centres.

Much progress was made in developing the ability to use the standard X25 protocol of the International Telegraph and Telephone Consultative Committee on the links between Bracknell and neighbouring GTS centres. Implementation of this protocol in place of the current character-oriented WMO protocol on the links will take place early in 1987. This change will improve data and forecast-product exchanges through the use of more efficient bit-oriented code forms.

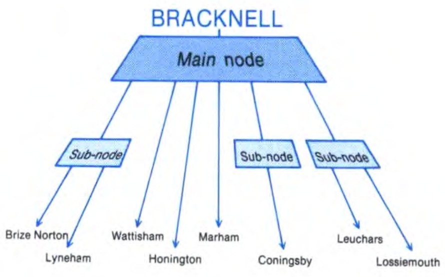
Planning and development

The telecommunication system which collects meteorological information and distributes it to approximately 120 locations in the United Kingdom is based on techniques first established in the late 1950s. These techniques are no longer adequate for the support of the Office's activities and are also increasingly expensive to run.

Digital high-speed lines are now available throughout the United Kingdom, and it is intended that the future telecommunications and display terminal system, the Weather Information System (WIS), will use these lines. This use will both speed the delivery of existing products to forecasters and provide capacity to transmit the many new products which will become available over the next few years.

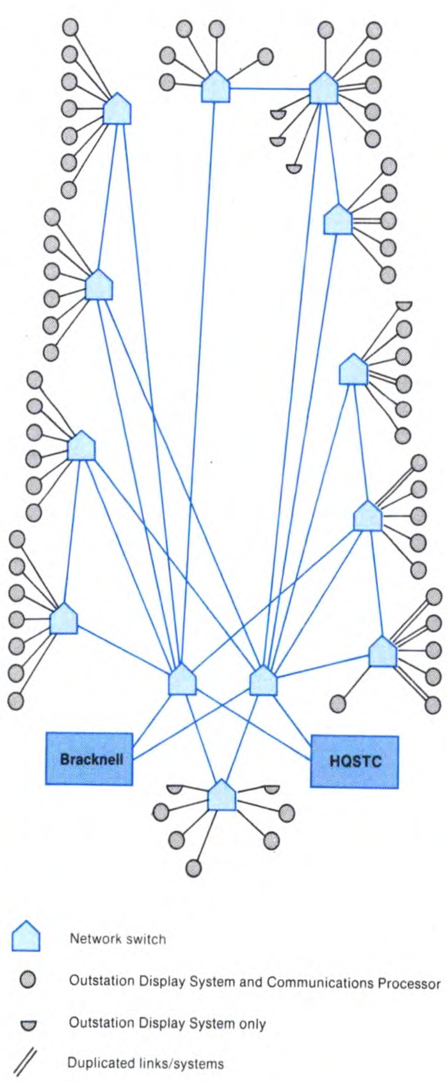
As a result of a feasibility study it was decided to install a complex network providing two types of service on different channels; one channel with sophisticated error control and addressing and alternative routeing arrangements, to carry the data which must arrive at the outstations without corruption; and a second high-capacity channel, using less elaborate transmission control methods, which will be able to carry the large amounts of image data from satellites and weather radars. The latter channel will be fed from Lasham where the Meteorological Office/Royal Aircraft Establishment satellite ground station is situated.

A plan has been developed to implement these new services in several phases over the next five years. The figure below shows the initial configuration, for which installation commenced in October and which should be completed soon after the end of the year. This



Initial configuration of the new network.

network will initially operate in a broadcast mode to serve eight key RAF stations. In the second phase, the network will be upgraded by the addition of a minicomputer-based network control node at Bracknell and by the addition of microcomputer-based Outstation Communications Processors (OCPs) at each outstation. These



Proposed final network.

processors will make inter-station communication available, and will enable the return path from outstations to Bracknell to be utilized for the collecting of observations. They will also remove much of the communication load from the display terminal system and provide facilities for the network mentioned earlier. These plans allow for network node and OCP software to be developed in stages to meet the increasing sophistication of network operations and hence for installation and development activities to proceed in parallel, thereby making the most-needed facilities available as early as possible. The figure (bottom right opposite) illustrates the proposed final network with its complex array of connections that provide alternative paths for traffic in the event of line or node failures.

The display systems to be served by the network are known as Outstation Display Systems (ODSs). These will provide the following functions:

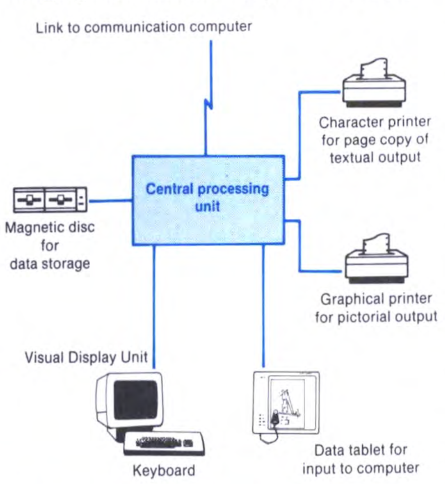
- Convenient displays of the various types of data that the forecaster requires.

- The means of running programs which will assist in the preparation of forecasts.

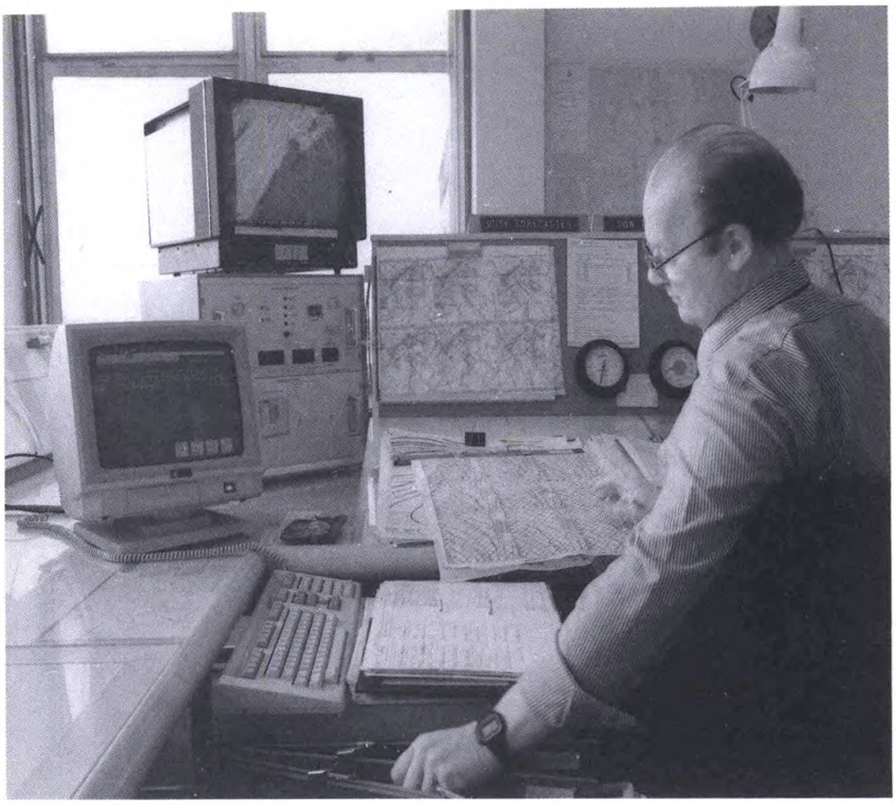
- The means of generating the formats in which the forecasts are communicated to customers.

ODSs were procured from Digital Equipment Corporation for installation at the eight stations shown previously. The first system was installed at RAF Lyneham during October.

The figure below shows the components of an ODS in schematic form. The initial systems have limited functions since at this stage only basic alphanumeric data will be available. Radar and satellite imagery data will not be provided until



The components of an Outstation Display System.



The Lyneham Outstation Display System.

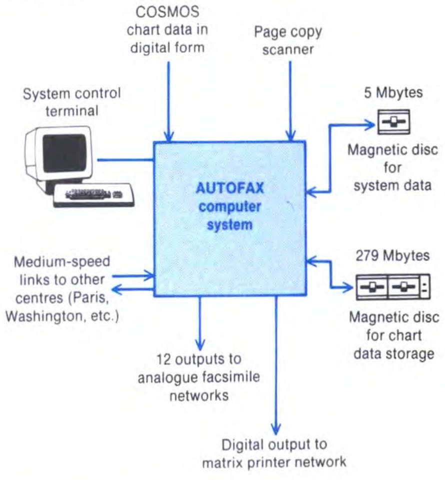
later in the implementation program and the systems will then be enhanced to the full specification. These stages will allow time for the efficient development of ODS software and for information gained from the experience of users at the initial installations to be used to ensure that the final systems meet the full requirements effectively.

A system called AUTOFAX, which handles charts in digital format, was implemented during the year. Products received from the Office's large data-processing computer system, COSMOS, over an intercomputer link are passed to the facsimile networks with no manual handling. AUTOFAX was dealing with some 250 charts each day by the end of the year and has improved considerably the timeliness of delivery of most products. Eventually all facsimile exchanges through the Met TC will be dealt with by this system.

The system is also being developed to provide chart output in digital form. It will provide charts in this form to WIS and, in the initial installations, these products will be printed using inexpensive matrix printers capable of providing individual charts in 3–4 minutes instead of the 18 minutes or so for transmission of a comparable chart by current analogue facsimile methods.

Investment in message-preparation systems to improve the efficiency of distribution of forecasts from the public service forecast offices continued and a system was installed during March in the Main Meteorological Office at Manchester. A number of suppliers were invited to tender for further systems, based on general-purpose microcomputers, and systems were installed at Bracknell, and at Southampton and Nottingham Weather Centres. A further system has been supplied to the Meteorological Office College for training purposes.

The collecting of observations made by Meteorological Office outstations and also by the many auxiliary observers is a complex process and the advent of microprocessor technology will allow some rationalization to take place. A preliminary trial of a collecting system using small microcomputer-based data-entry systems was held during the summer. As a result of this trial the first phase of an operational system was started.



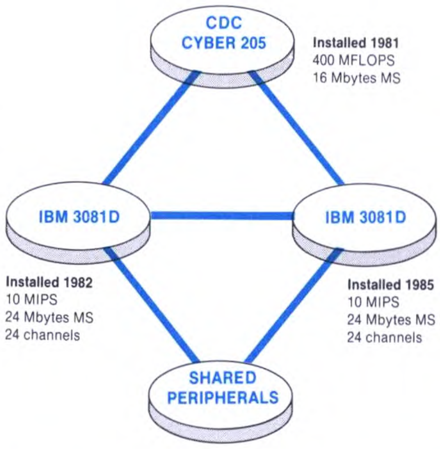
The AUTOFAX system.

Computing and data processing

The main computing service in the Office is provided by a system of processors and peripherals known as COSMOS. The main functions of COSMOS are to organize, for numerical weather prediction and climatology, observational data received through the Meteorological Telecommunication Centre (Met TC), to provide a facility for running numerical models with intensive demands on computing resources, and to prepare the output from numerical weather prediction schemes in a form convenient to forecasters and other users both inside and outside the Office. In addition, COSMOS provides a general data-processing facility to support revenue-earning services, research, development and administrative operations.

The heart of COSMOS is formed by three linked computers: a Cyber 205 manufactured by Control Data Corporation, and two 3081Ds made by International Business Machines Corporation (IBM). The system runs 24 hours a day, 365 days a year so that regular weather forecasts can be made. The Cyber 205 handles all numerically intensive work, in which role it is some 50 times as effective as mainframe computers such as the 3081D. The Cyber is less well suited to general data-processing operations and so these are carried out on the 3081Ds. Either of them can run all the work needed for numerical weather prediction, leaving the capacity of the other for all other data-processing services and as a back-up in case of failure. A large number of peripherals such as disc drives (providing 39 gigabytes of on-line storage space), magnetic tape drives, printers, fiche printers, plotters for use with paper and photographic film and, of course, terminals and links to other computers are connected to the processors in COSMOS.

Tasks allied to weather forecasting have the highest priority in computing and data processing, and about a third of the COSMOS resources are devoted to it. An important part of the job of the COSMOS operators is to ensure that the numerical models used in operational weather forecasting run



Current central computing facility (MS — main storage, MIPS — millions of instructions per second, MFLOPS — millions of floating-point operations per second).

according to schedule and that preparation of output is completed by the deadlines. The operational models are those that deal with the atmosphere on global and regional scales and also with waves and sea state. Trials of a local area model have now been running for some time and it is clear that much more than the capacity of the Cyber 205 will be needed to allow effective operational running of this new model. Greater capacity will also be required so that improved versions of other models, needed to meet demands for new and improved weather forecasting services, can be run.

The large and complex computing facilities of COSMOS need much effort to ensure that users of the system get the service they require and that the system is efficiently used. Systems programming is dealt with on the Cyber 205 and 3081Ds by a small team which installs new versions of operating systems, tailors them to the Office's needs and takes action when faults are found. Any changes introduced are very tightly controlled to avoid the introduction of new problems. Other teams run accounting suites, advise on programming techniques and answer users' queries. A special exercise this year was a capacity planning study using software loaned under licence by the Central Computer and Telecommunications Agency.

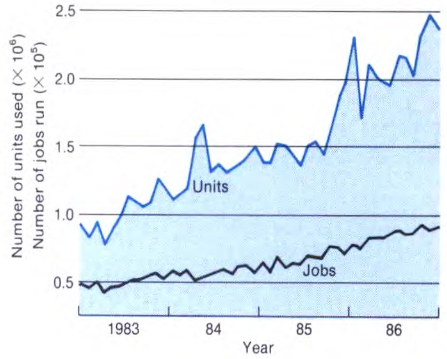
Automated methods are finding increasing application in the Central Forecasting Office (CFO). The IBM part of COSMOS is used to plot observations on charts for use by forecasters and also to present the results of numerical forecasts in graphical form on paper or on graphics terminals as appropriate. The plotting of observations and output from forecast models has traditionally been done in the computer room. Software has now been developed to give users direct control of plotters through Personal Computers connected to COSMOS. The first application will be to provide facilities for forecasters, after examining and working on charts, to replace them on the plotters in the CFO so that late information can be added automatically. Visual display terminals are used to display observational data in alphanumeric and graphical formats; forecasters may also compose textual messages, e.g. routine forecasts and warnings of severe weather, using word processors, for automatic transmission via the Met TC.

Two studies were completed during the year. In the first, proposals were made for the necessary extension of the existing facilities and techniques which will occur as a result of the transfer of responsibilities from Heathrow to Bracknell. In the second, a more radical change, taking full advantage of developments in Information Technology, was proposed for implementation in about 1990. This would reorganize the facilities and integrate many of the functions and data flows which at present are separate. The opportunity for further exploitation of Information Technology to improve the interface between man (forecaster) and machine (computer) was the subject of a major internal review.

Forecasters and other users of computers in the Office require the data relevant to their tasks to be in the right place at the right time. With an increasing number of computers, the majority dedicated to particular applications, including the capture, processing and dissemination of a growing volume of information, the problem of interconnections that will permit data to flow efficiently from sources to destinations becomes not only technically difficult but also critical to success. A plan for creating a high-speed Central Data Network (CDN) connecting the principal operational and research systems has been developed. CDN will be implemented in stages over the next few years. The major source of data on CDN will be the planned system (AUTOSAT-2) for processing digital satellite imagery; this will be installed at the Royal Aircraft Establishment site at Lasham. AUTOSAT-2 will generate and distribute digital images from satellites, by contrast with AUTOSAT-1 which presently disseminates imagery primarily over analogue facsimile channels. AUTOSAT-1 will continue in service until the Weather Information System is able to deliver the products of AUTOSAT-2 to all forecasting offices. CDN will carry the products to Bracknell for distribution to COSMOS and to other computer systems at Headquarters.

Data bases are increasingly becoming the life-blood of institutions and enterprises; the Office is no exception. COSMOS holds a number of collections of data, each organized according to the particular structure of the information, its mode of usage etc., and stored on magnetic disc and tape media. The largest collection is the archive of climatological records accumulated over many years from diverse sources. Different types of climatological record have different formats and so the archive is organized as a series of distinct data bases. The major effort to develop the software which supports the capture, quality control, storage and retrieval of data in the archive was concentrated in the 1970s and early 1980s. Most day-to-day aspects of archive management and the development of applications are now the responsibility of those sections within the Office that make routine use of the data bases, e.g. to answer customer enquiries. Those elements which remain under central control, mainly concerned with extraction of the records from the near-real-time Synoptic Data Bank (SDB), have been extensively rewritten during the year to improve reliability and ease of maintenance.

When the first data bases on COSMOS were conceived there was no choice but to design and implement the basic software in house. In recent years a wide choice of proprietary software for data management has become available and the Integrated Database Management System (IDMS), supplied by Cullinet, is installed on COSMOS to provide the basis for an increasing number of projects. The largest user of IDMS is the Management Accounting and Information System (MAIS). Each year the scope of MAIS is extended, with invoicing having received particular attention this year; systems for logging enquiries and monitoring expenditure are currently being designed.



Units used and jobs run monthly on the COSMOS computer, 1983–86.

Since July it has been possible for anyone with access to a COSMOS terminal to search the data base of accessions to the National Meteorological Library; in August the data base of agrometeorological information, which also uses IDMS, became fully operational. Consideration is also being given to implementing the next generation of the SDB using IDMS because of the simpler development and maintenance that would result. The continued development of IDMS, and its on-line facilities, allows a wider range of applications to be implemented by a diminishing pool of experienced programmers.

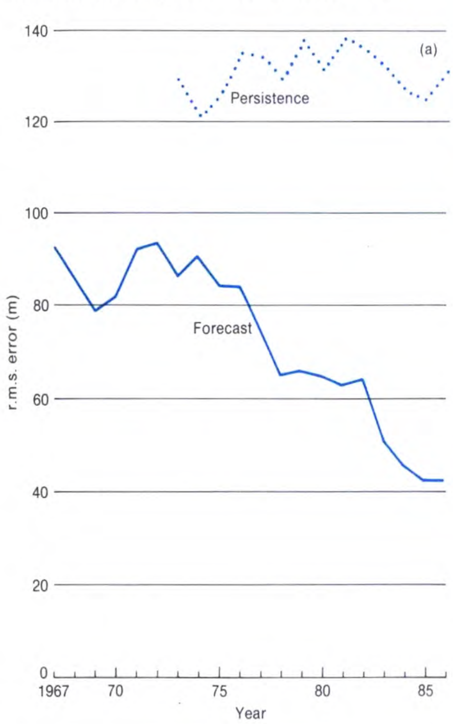
The main emphasis for computing in the Office remains on the support of scientific tasks, but overall success in meeting the Office's objectives also requires efficient management which can be helped by good administrative services. As in industry, the Office looks to Information Technology to increase its effectiveness. MAIS was the first venture of this type and its scale is clearly appropriate to the mainframe system in COSMOS. Microcomputers running packages for word processing, spreadsheets and small data bases are being used quite extensively, often doubling as terminals to COSMOS or minicomputers. More widespread and better-integrated implementations of office technology are being considered.

Automatic plotting machines in the COSMOS computing installation.

The forecast model and its performance

The two versions of the 15-level forecast model, the global version and the fine-mesh version, have been operational since September 1982. Sequences of verification statistics show increases in the skill of the models, sometimes as the result of major changes in formulation, but also through the cumulative effect of smaller improvements in the analysis–forecast system.

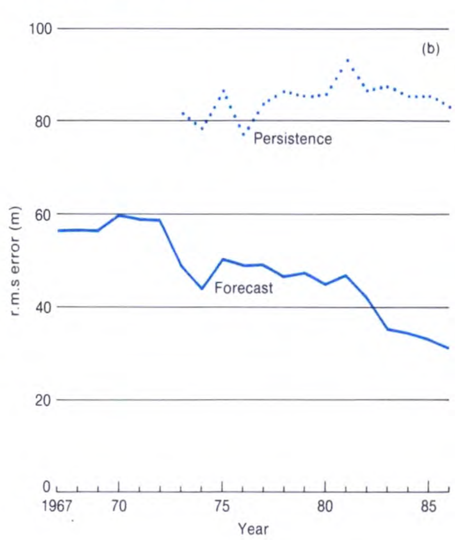
Operational numerical weather prediction (NWP) at Bracknell now has a history extending over 20 years. The figure shows a verification statistic that has been available during the whole period — the root-mean-square error of 48-hour forecasts of 500 mb height in the North Atlantic region, verified using analyses. The errors are much larger in the winter than in the summer, so results are shown separately for January–March and for July–September in each year. The errors of assuming no change in the initial state, known as persistence errors, are shown for comparison. In broad terms the numerical forecast errors have been halved over the 20-year period, from around 70% of persistence in the early years to around 35% today. The average errors for today's winter-time forecasts are smaller than those for the summer months in all years earlier than 1982.



The NWP carried out at Bracknell is distinctive in several respects when compared with the current practice at many other operational modelling centres. Firstly, the starting conditions for forecasts are obtained by repeated insertion of observations into the prediction models, without any separate calculations that would enforce mathematical constraints. Secondly, the global prediction model uses finite difference techniques, rather than spectral methods, to approximate the governing partial differential equations. Thirdly, the fine-mesh model uses the same scientific formulation, indeed the same computer coding, as the global model, differing only in its halved horizontal grid spacing and its limited area of coverage.

The global model has its grid points spaced at intervals of 1.5° in latitude and 1.875° in longitude, which is close to the maximum resolution for global coverage that can be used efficiently with the Office's current supercomputer — the Cyber 205. Global forecasts up to 6 days ahead are computed twice daily, from 0000 and 1200 GMT starting conditions derived using observations arriving at Bracknell by 0320 and 1520 GMT. Results up to 36 hours ahead are available by 0415 and 1615 GMT, and the complete 6-day forecasts by 0500 and 1700 GMT. The global model is required to fulfil the Office's responsibilities in Defence and as a World Area Forecast Centre for civil aviation, in support of marine and other commercial services world-wide, and as one of the sources of guidance for medium-range forecasting.

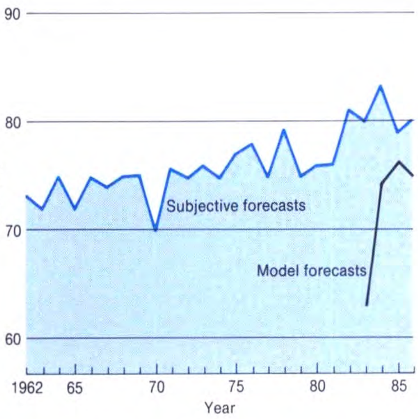
Forecast root-mean-square (r.m.s.) errors for 48-hour numerical forecasts in the North Atlantic region, averaged for two 3-month periods in each of 20 years, compared with persistence: (a) January, February, March, (b) July, August, September.



Despite the acknowledged successes of the global model, it is known that its horizontal resolution — high by most standards — still limits certain aspects of forecast performance. Comparison with the identically formulated fine-mesh model has provided a reliable indication of the benefits that will be obtained from halving the grid spacing of the global model when sufficient computing capacity is available. The benefits are particularly clear for forecasts of jet streams, which are much better resolved by the finer mesh, and in cases of very rapid intensification of the smaller-scale low pressure systems over the North Atlantic and elsewhere. Many tropical weather systems also are inadequately resolved by the present global grid.

The fine-mesh model has its grid points spaced at intervals of 0.75° in latitude and 0.9375° in longitude. This is made possible within the present computing capacity by restricting the area of coverage to the region 30–80°N, 80°W–40°E. At the lateral boundaries of this region the calculations make use of information from integrations on the coarser grid. Forecasts to 36 hours ahead are computed twice daily, from 0000 and 1200 GMT starting conditions derived using observations arriving at Bracknell by 0200 and 1400 GMT, with results available before 0300 and 1500 GMT. For national and regional purposes, the use of the fine-mesh model leads to increased accuracy in forecasts of the positions of fronts, of the near-surface wind fields used in marine applications, and especially of precipitation.

The accuracy of precipitation forecasts has been monitored over the years by recording the success rate of forecasts, made each day by the Senior Forecaster in the Central Forecasting Office (CFO), as to whether or not there will be precipitation in the London area the following day. A gradually improving skill is revealed, with a more marked improvement after the introduction of the 15-level model in 1982. For the past 4 years the success of unmodified fine-mesh numerical forecasts of precipitation has also been recorded. The model's skill has improved over the 4 years, and this may be attributed to several refinements of relevant aspects of the formulation. The subjective forecasts are still superior to the unmodified model forecasts, though today's model forecasts are superior to the subjective forecasts of the 1960s, when no direct numerical guidance on precipitation was available to the forecasters.



Percentage of correct precipitation forecasts for the London area, 1962–86.

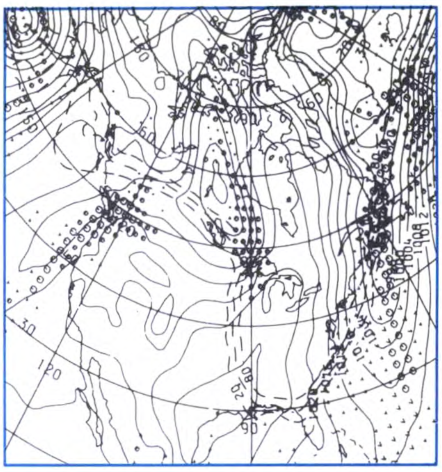
The formulation of the 15-level model may be considered in two parts, the dynamical formulation for the resolved scales, with associated numerical techniques, and the parametrizations of physical and subgridscale processes. (Note, however, that this distinction becomes less tenable as the grid spacing is reduced.) The numerical techniques used in the 15-level model are based on finite difference approximations that are applicable at all latitudes and are equally appropriate for global or limited-area modelling. The techniques include a number of special features that improve accuracy and efficiency, the efficiency being such that integrations of the global model require about 4 minutes only of Cyber 205 time for each simulated day. This impressive computational performance comes about partly through careful programming, and also from the mathematical stability of the method of integration, which allows time steps of 15 minutes to be used in calculating the global forecasts.

The models include a full range of parametrizations of turbulence, radiation, precipitation, convection and orographically induced gravity waves. An important development during 1986 was the inclusion in the fine-mesh model of calculations of soil temperatures at several depths. These calculations have permitted a more faithful representation of exchanges of heat between the lowest layers of the atmosphere and the underlying land surface, leading to much more accurate forecasts of low-level air temperatures, especially on still winter nights.

Several aspects of the parametrizations used in the models have been identified as requiring further attention. These include the representation of subgridscale orographic features — the current parametrization of gravity-wave drag is by no means the last word. Also, soil moisture content is prescribed in a fairly crude way at present, yet it exerts a major influence on low-level temperature and humidity and, indirectly, on the occurrence of showers. Again, boundary-layer transfers must be represented more accurately if forecasters are to be given better guidance on low-level cloudiness. Finally, forecasts of jet streams, frontal circulations and precipitation have been shown to be sensitive to alternative representations of the diffusive effects of subgridscale motions in the horizontal.

Associated with both the global and the fine-mesh models are data assimilation cycles for the analysis of observations to determine the required initial values at the models' grid points. All relevant observations are used, whether derived from land stations, ships, buoys, balloons, aircraft or satellites. After quality control, which plays a crucial role, the selected observations are assimilated into the numerical models by relaxing the grid-point variables towards interpolated values, derived from the observations, after each time step of integration. For the global model, this data assimilation is carried out in a 6-hour cycle, taking account of all observations made within 3 hours of each analysis time. For the fine-mesh model the data assimilation is performed in a 3-hour cycle, so that no observation is more than 1½ hours from an analysis time. Operational trials are being carried out to test a fully continuous data assimilation system, in which the method of repeated insertion of observations is retained, but the period of influence of each observation is determined by the time of the observation itself, rather than by any chosen analysis time.

The inevitably incomplete and imperfect character of the observations available is generally regarded as one of the most serious of the factors that limit further advances in forecast performance. This is leading to an increased emphasis on the quality control and monitoring of observations. A new data base was established to record the values of the observations used in NWP along with their departures from the associated model fields and the quality-control decisions taken upon them. Statistics derived from this data base will help to

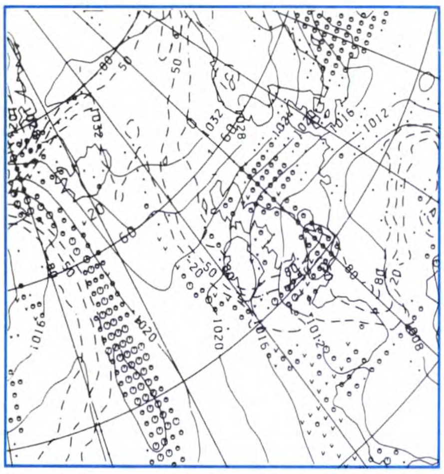


The 5-day numerical model forecast valid at 0000 GMT on 28 January 1986 that successfully heralded the arrival of very cold air in Florida from the north. The three dashed lines are isotherms for the 1000–850 mb layer, interpreted as contours of 20%, 50% and 80% probability that any precipitation will be in the form of snow.

identify persistently unreliable observations, to refine the weighting given to various classes of observation in the data-assimilation calculations, and to improve the algorithms used for automatic quality-control procedures. These procedures are based mainly on internal consistency checks and on comparisons with short-period forecasts and with neighbouring observations. The automatic procedures are complemented by interactive monitoring and intervention carried out by experienced analysts in the CFO, whose contribution can be particularly effective when interpretation of satellite imagery yields information not otherwise available.

To assist the full exploitation of available and planned sources of observations, several studies are in progress to find out more about the effects of individual observations or combinations of observations on the results obtained from the operational models. Such studies entail the review of the enhanced global observing system that was available during the Global Weather Experiment in 1979, the assessment of the likely impact of possible future changes in observational capabilities, and special regional evaluations of the various ingredients in a composite observing system. An operational systems evaluation of this type for the North Atlantic region is currently being prepared.

As in most years, there were several meteorological highlights for the numerical forecasts during 1986. During the early months of the year there were severe cold episodes over North America during January, and over western



The 24-hour numerical model forecast valid at 0000 GMT on 6 February 1986 that correctly indicated the first significant snow of the winter over London.

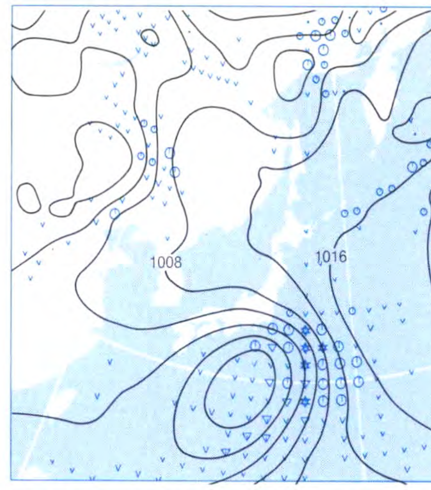
Europe beginning early in February. The guidance from the global model proved to be very reliable in heralding the onset of these cold outbreaks 5 or so days in advance, and also in forecasting the sudden thaw over much of Europe early in March. During the course of the cold spell in Europe the fine-mesh model was used extensively by forecasters to prepare snow warnings, based in particular on the model's predictions of precipitation and of temperature in the lowest kilometre or so of the atmosphere.

Later in the year the numerical forecasts of tropical cyclones in the Pacific aroused considerable interest. It is accepted, of course, that current NWP systems do not handle tropical cyclones, or the subsequent typhoons and hurricanes, with the same degree of accuracy that has come to be expected for extratropical depressions. Nonetheless the forecasts this year give ample encouragement to the view that the next generation of global models, with higher horizontal resolution, refined physical parametrizations and improved data-assimilation techniques, will be capable of providing very useful guidance on such tropical weather systems. Among the fairly successful forecasts made during 1986 may be included those for Typhoon Lola and Tropical Cyclone Namu in May and Tropical Storm Sarah in August. The latter gained particular notoriety by bringing exceptionally heavy rainfall to parts of Japan during a major international conference on NWP that was taking place in Tokyo.

The availability of global and regional grid-point fields of pressure, temperature, humidity and wind from operational NWP opens up the possibility of running various kinds of dependent numerical model. One such example is a model for air trajectories, based on forecast winds at a selected level in the vertical, that was used extensively to estimate the movement of radioactively contaminated air following the accident at the Chernobyl nuclear power station.

Other dependent numerical models have oceanographic applications. Values of surface pressure and low-level wind from the fine-mesh model are used to drive a dependent model for the tidal surges caused by meteorological factors in the European continental shelf region. The low-level winds from both the global and the fine-mesh NWP models are being used to drive new wave models for the prediction of sea state (wind-sea and swell) that were introduced during the year. There is a global wave prediction model that uses the same grid points as the global NWP model, and a European waters wave model, driven by fine-mesh winds, that covers the Baltic and Mediterranean Seas as well as the continental shelf.

Progress was maintained in the development of objective interpretation techniques that provide forecasts for specific purposes. For example, the four main components of the aviation significant weather chart — tropopause level, maximum wind and its level, convective cloud tops, and probability of clear air turbulence — can all now be produced to a satisfactory standard by objective means. Similarly, for near-surface forecasting, the usefulness of NWP results can be significantly enhanced by statistical interpretation that relates the numerical forecasts to the conditions expected at particular

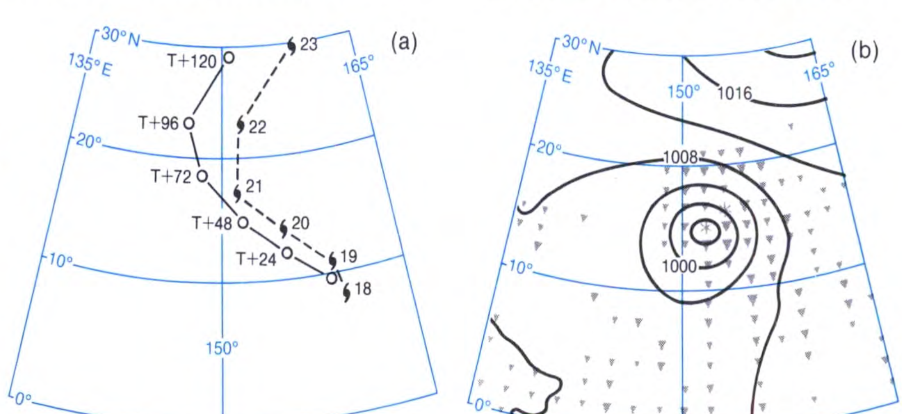


The 6-day numerical model forecast valid for 1200 GMT on 5 August 1986 that indicated the arrival of Tropical Storm Sarah.

locations. Based on the fine-mesh version of the 15-level model, screen maximum and minimum temperatures are now calculated operationally by statistical regression for selected UK stations.

A detailed dynamical and physical interpretation of the fine-mesh forecasts over the United Kingdom is provided by the mesoscale NWP model which is run on a continuous trial basis and produces two 18-hour forecasts each day. Full exploitation of the mesoscale model must await enhanced computer power, but already it has proved to be very successful in its winter-time temperature forecasts, partly as a consequence of the greater orographic detail resolved by the 15 km grid spacing.

The expanding set of dependent models and interpretive calculations assists in the extraction of the maximum possible useful information from the core NWP calculations. Some users wish to use the objectively calculated values directly — flight-planning information for aviation is a notable example. In many other cases, however, the assessment and interpretation of numerical guidance by forecasters, working in the CFO or at outstations, and assisted by the latest observations including satellite and radar imagery, will continue to provide the essential final link in the chain.



Numerical model forecasts of the track and associated weather of Typhoon Lola: (a) Observed (dashed line) and 5-day forecast (solid line) tracks beginning at 0000 GMT on 18 May 1986. Too much movement was forecast in the first 24 hours, after which the forecast speed and direction of movement were very accurate.
(b) Mean-sea-level pressure (mb) and grid-point rainfall from the 48-hour forecast valid at 0000 GMT on 20 May 1986.

Services for Defence

Introduction

Services for Defence account for a considerable proportion (about 40%) of the total cost of the Meteorological Office and approximately 25% of the total manpower. The scale and diversity of this support are illustrated in the table below. Apart from the day-to-day work of providing services for a wide range of Defence activities the Office is concerned with maintaining an organization which is efficient and cost-effective in relation to Defence requirements. Therefore it is important for the Office to have an understanding of the military need and for military commanders to appreciate fully the potential impact of weather on operations. Emphasis is currently being placed on the development of user requirements for services to the Army and Royal Navy and on further revision of the statement of requirement for services to the Royal Air Force.

Headquarters activities

The extensive computer and communication resources at Bracknell provide major support, together with the Principal Forecasting Office at Headquarters Strike Command (HQSTC), for the meteorological offices meeting Defence needs in the outfield. A new communication system which provides high-speed digital links between computer terminals in airfield forecasting offices and the central computers at Bracknell is being developed. The system, known as the Weather Information System (WIS), is well advanced and is being installed at the front-line airfields in RAF Strike Command and at RAF Lyneham and RAF Brize Norton. These developments will mean a much speedier and more efficient service for aircrew.

Research in the Office takes account of Defence needs. Advances in knowledge of the physical behaviour of the atmosphere, the development of remote observing techniques, and high-resolution numerical forecast models, will assist the forecaster at operational airfields in meeting the increasing military demand for detailed short-period forecasts for the lowest few hundred feet of the atmosphere. In this regard developments in mesoscale modelling should improve short-period forecasts of boundary-layer conditions. Some progress is also being made with the problem of radar ducting. During the year detailed guidance was issued to forecasters and a trial to assess the usefulness of numerical forecasts of surface ducts over the sea was organized with the Royal Navy.

The powerful central computer resources provide, in addition to support for national services for Defence, products for routine use by many of the military Meteorological Services of other NATO nations. The United Kingdom plays a full part in NATO meteorological matters and is represented in the NATO Military Committee Meteorological Group, and other NATO agencies concerned with meteorology, by staff from the Office who are advised in naval aspects by staff from the Directorate of Naval Oceanography and Meteorology (DNOM). An important aspect of the international work of Headquarters staff is the maintenance of a close working relationship with the Air Weather Service of the United States Air Force and the German Military Geophysical Office. This co-operation is based on the common need to support military forces in Europe.

Summary of Defence services and staff complements, 31 December 1986

	United Kingdom		Germany and the Netherlands		Mediterranean and South Atlantic	
	Offices	Staff	Offices	Staff	Offices	Staff
HQ Bracknell	1	13				
C Met O HQSTC/HQRAFG	1	6	1	6		
PFO HQSTC	1	52				
MMOs[1]	3	71			3	56
AMOs[2]	2	31	2	29		
Subsidiary forecasting and observing offices:						
RAF	33	265	2	18	1	3
Army aviation	2	11	2	10		
MOD (PE) Army trials establishments	6	44				
NATO Allied Meteorological Office			0	2		
Radiosonde units	4	0*			1	15

* Function integrated with subsidiary forecasting offices at MOD (PE) establishments
[1] MMO, Main Meteorological Office
[2] AMO, Area Meteorological Office

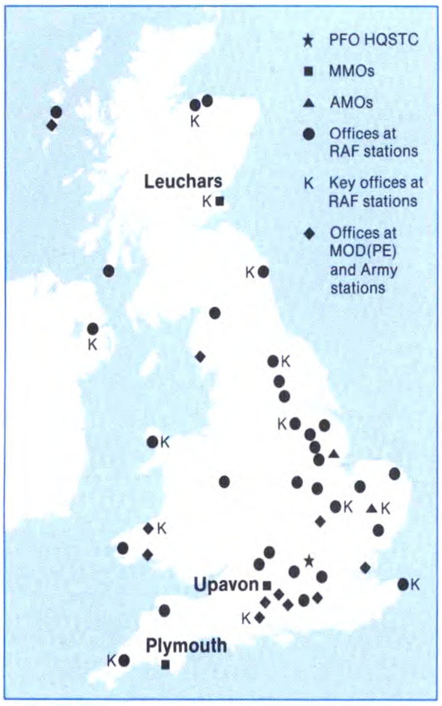
Organization and role of Defence services outstations

The distribution of the meteorological offices that serve the Royal Air Force, the Army Air Corps, and the Ministry of Defence Procurement Executive (MOD(PE)) and Army trials establishments in the United Kingdom is shown overleaf. Meteorological offices overseas are located at RAF Brüggen, Gütersloh, Rheindahlen, Laarbruch and Wildenrath and with the Army Air Corps at Detmold in the Federal Republic of Germany; at RAF Gibraltar; at RAF Akrotiri in Cyprus; at RAF Wideawake on Ascension Island; and at RAF Mount Pleasant in the Falkland Islands.

The organization of stations is kept under continuous review to ensure that the network meets the military requirement in the most efficient manner. For example, plans are well advanced to merge the Main Meteorological Office (MMO) at RAF Mount Batten with the airfield office at RAF St Mawgan.

The interest of the Army in meteorology has increased in recent years. In addition to the support provided for the Army Air Corps the post of Staff Meteorological Officer (SMO) was established with 1(BR) Corps. The SMO deploys with Corps Main Headquarters in field exercises and is helped by a Mobile Forecasting Unit located with Corps Rear Headquarters.

Meteorological support to the Royal Navy is provided in the form of observational data and numerical forecasts prepared at Bracknell. Close liaison is maintained with the DNOM. This co-operation ensures that meteorological support for Defence activities from the Office and the Royal Navy is co-ordinated both nationally and within NATO.



Meteorological offices at Defence establishments.

Weather has always been an important factor in the design, development and proving of ballistic and missile weapons systems. The work connected with this Defence activity continued at the six Range Stations which are equipped with the usual meteorological instruments and have a mobile ability to make measurements in the field at the site of trials. The structure of the atmosphere is measured frequently during range activities to provide data for trials management, retrospective analysis and range safety considerations.

Support to emergency services

The Office contributes to the management of certain national emergencies in peacetime. If a chemical or nuclear accident results in the release of toxic pollution into the atmosphere this contamination may be subject to two meteorological processes: it may be carried away from its source by the wind and it may be 'washed out' of the air by the rain and concentrated upon the ground. The forecaster must predict where the plume or cloud of pollutant will go and how fast it will travel. The forecast contains advice which allows the emergency managers to calculate the concentration of the pollutant and its deposition on the ground.

Chemical emergencies are, in general, expected to be short-lived, therefore immediate advice must be available at any time. At the onset of a chemical emergency any meteorological office with a forecaster on duty might be asked to give a short-term forecast to the agency in charge of the incident. This office then hands over respsonsibility to a Regional Meteorological Office where greater resources can be concentrated on the problem. There are nine Regional Meteorological Offices able to give a 24-hour service. To assist emergency managers in deploying their resources most effectively, advice is provided to help identify areas at risk and special attention is given to heavier-than-air gases and to the complications caused by fire at the source of the release. The industrial sites governed by the Control of Industrial Major Accident Hazards (CIMAH) legislation, County Emergency Officers and officers in the Police and Fire services have all been apprised of the procedures to be invoked when meteorological help is needed for accident management.

The arrangements for chemical emergencies are new, created in response to the CIMAH regulations. Procedures for supplying meteorological support in nuclear emergencies have been available in one form or another since the first nuclear power station was commissioned. Essentially, the meteorological response is similar in both chemical and nuclear emergencies except that it may need to be sustained if significant quantities of long-life radioactive particles are emitted. When an emergency is notified, the associated office obtains a current weather report from the site and this is built into a weather forecast which is revised as time goes by. The procedures related to nuclear emergencies also apply to accidents to material in transit or from military sources during peacetime.

The task of forecasting for emergencies is greatly assisted and quickened by the use of the trajectory program in the Central Forecasting Office at Bracknell. The latest computerized forecast data are used to construct a map showing where the wind will carry a pollutant for up to 36 hours ahead. The same program can also be made to work in reverse and can determine the air trajectory back in time to the moment of the incident. The offices which support the managers of chemical and nuclear accidents can demand the trajectory program output at any time. They can also get help from the products of the rainfall radar network to resolve questions connected with 'wash-out' of contamination from the air by rain.

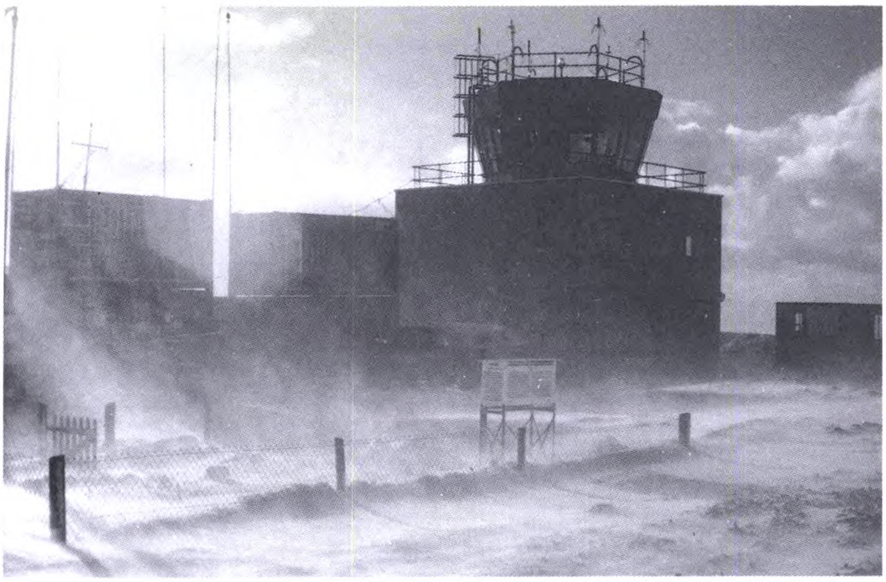
The procedures related to chemical and nuclear emergencies are exercised by the offices concerned, in collaboration with the nuclear industry and the emergency services. Lines of communication are tested and verified both to and from the offices, and staff are rehearsed to react promptly to a real emergency.

Meteorological services on the Falkland Islands

With the move of the Royal Air Force from Stanley to Mount Pleasant, the Mobile Meteorological Unit (MMU) was withdrawn from Stanley after nearly 4 years continuous service there and the civilian MMO took over all its functions in support of operations in the South Atlantic theatre. These included the provision of forecasts and meteorological advice to the Commander British Forces Falkland Islands, to the Royal Air Force for operations from Mount Pleasant and to Army units. Forecasts are provided to the Royal Navy for the Falkland Islands Protection Zone, and the small local media requirement is also covered.

The region is meteorologically a data-sparse area. The MMO receives from Bracknell the limited surface and upper-air observations in the region on a telegraph satellite link, the data being compiled from the Global Telecommunication System. Forecast

Interior of the new Main Meteorological Office, RAF Mount Pleasant. (Photograph by courtesy of Mr P.R.S. Salter)



Meteorological office enclosure at Mount Pleasant Airport, August 1986. (Photograph by courtesy of Mr P.R.S. Salter)

surface and upper-air charts for the South Atlantic are received on a second dedicated satellite circuit (digital facsimile link). These are products of the Bracknell 15-level global model and include upper-wind and temperature information in a form suitable for aircrew documentation, sea swell and wave charts, and other dedicated products to assist the senior forecasters in their difficult task.

At Mount Pleasant itself, ground stations capable of receiving polar-orbiting and geostationary weather-satellite data are in operation, and towards the end of the year radiosonde equipment for the measurement of upper-air parameters was brought into service — an on-site hydrogen generator providing the gas for the balloons.

The provision of meteorological instruction to military aircrew by meteorological staff

Under the current RAF command structure the provision of meteorological tuition is concentrated at seven Support Command stations but brief introductory and familiarization lectures are also provided at most operational airfields in the United Kingdom and overseas.

RAF pilots undergoing initial training learn their basic meteorology by means of a structured teaching package which was prepared by HQ RAF Support Command with Meteorological Office staff providing technical advice. The package comprises a mixture of self study and guided tutorials and covers sufficient meteorology to make the students more aware of dangerous weather conditions and understand the day-to-day advice provided by their local forecasters. Progress tests are set to assess assimilation. Pilots undergoing instructor training, or transferring to multi-engine or rotary-wing aircraft, are provided with appropriate instruction prepared by Office staff in consultation with RAF authorities. Royal Navy pilots undergoing initial training receive similar instruction by arrangement with Royal Navy authorities.

In addition to instruction in basic meteorology, RAF navigators are given guidance in the interpretation of flight documentation issued in the United Kingdom and at overseas locations. Air Engineers and Air Electronics Officers also receive instruction appropriate to their flying roles. RAF Air Traffic Control staff and Royal Navy Fighter Controllers are instructed in the interpretation of meteorological data.

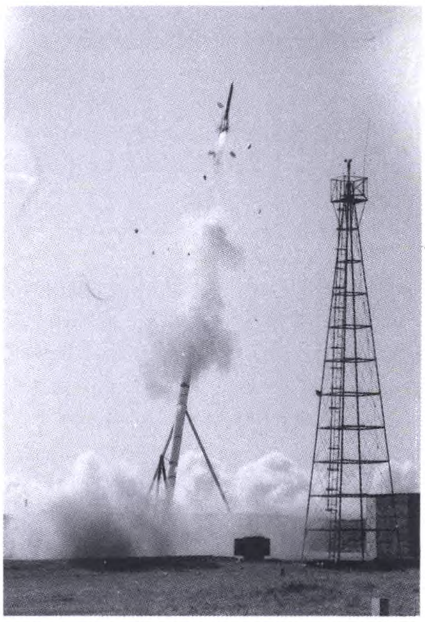
In all, some 1800 students receive training each year and this involves Meteorological Office staff in some 3000 hours of face-to-face contact. A considerable amount of effort is also required for lesson preparation and marking examination papers.

Meteorological services at the Royal Artillery Range, Hebrides

Since 8 September 1986, a full-time forecasting presence has been maintained at the Royal Artillery Range, Hebrides. The range is sited on the north end of the island of South Uist and extends westward into the North Atlantic. The Royal Artillery have recently updated the meteorological instrumentation and facilities at the range and now own and operate their own upper-air sounding system by flying lightweight radiosondes and measuring winds using the local Loran-C navigation aid broadcast. The surface anemometer network has also been refurbished and data from these masts, together with the output of the upper-air system, are available to the forecaster. The output of an on-site satellite receiving station for the products of both geostationary and polar-orbiting weather satellites is also available. Many of the forecaster's products can be achieved only after much computation and they are required urgently in a form which is computer legible. To help the forecaster to provide these special data, the information from the surface and upper-air systems is fed directly into a microcomputer in the forecasting office.

The forecaster plays a vital role in the planning and execution of trials close to shore and far into the Atlantic. On the one hand, great emphasis is placed on the wind structure, icing and visibility which comprise the low-level flight conditions of remotely piloted aircraft so that they can be seen as targets by anti-aircraft batteries on the ground. The miniature aircraft then have to be recovered to small landing fields without damaging neighbouring property or facilities. On the other hand, the forecaster is required to define the weather up into the stratosphere and out to sea for hundreds of kilometres to find a suitable weather 'window' through which to aim a target for warship training. The safety measures for this trial are dominated by meteorology; the object is not to hit the warship but to land in a strictly limited area of sea close by. The rapidly changing and often hostile weather of the Outer Hebrides, combined with the stringent safety conditions of the trials, present a challenge to the meteorologist which is unique in the United Kingdom.

Petrel firing at the Royal Artillery Range, Hebrides. (Photograph by courtesy of British Aerojet)



Services for civil aviation

The meteorological services provided for civil aviation in the United Kingdom conform closely to the relevant Standards and Recommended Practices of the International Civil Aviation Organization (ICAO). Within the terms of the ICAO regulations the Civil Aviation Authority (CAA) is the meteorological authority for civil aviation matters. The role of the Meteorological Office is to provide professional advice to CAA and to provide meteorological services according to its requirements on a repayment basis. The greater part of the costs of about £15 million per annum are recovered by CAA as part of the *en route* charges levied on aircraft using the air navigation services within UK airspace.

Savings to international civil aviation through use of the improved global upper-wind and temperature forecasts available from the Meteorological Office at Bracknell, have been calculated at about £50 million per annum. In recognition of this the Royal Society presented the 1986 Esso Energy Award for major contributions to energy saving to a team from the Office.

International responsibilities

The organization of meteorological services for civil aviation is centred upon the ICAO World Area Forecast System (WAFS) which was implemented in November 1984. At the heart of this system are two World Area Forecast Centres, one at Bracknell and one in Washington. Each provides global forecasts in digital form for a series of levels, twice per day, for 12, 18, 24 and 30 hours ahead. These forecasts are sent to associated Regional Area Forecast Centres (RAFCs).

At the ICAO Informal WAFS meeting in London in early October, progress on computer-generated significant weather forecast data and likely model developments during the next 3 to 5 years were considered. The meeting concluded that the forecasts were likely to be required to be issued more frequently and in greater detail than at present both for flight-planning purposes and for more precise and accurate definition of the significant weather.

The Meteorological Office at Bracknell provides one of the three RAFCs in western Europe responsible for the conversion of digital data into chart format for distribution to State Meteorological Services and airports within the region. Four airlines (British Airways, Scandinavian Airlines System, Japan Air Lines and Pan American Airways) accept the global grid-point data directly from Bracknell for use in computerized flight planning. Two communications companies acting on behalf of other airlines also take these data. They are the Société Internationale de Télécommunications Aéronautiques and Aeronautical Radio Incorporated. These companies provide the data either in their original form or processed as flight-planning information to operators such as Air France, Lufthansa, Swiss Air, Delta Airlines, American Airlines and many others.

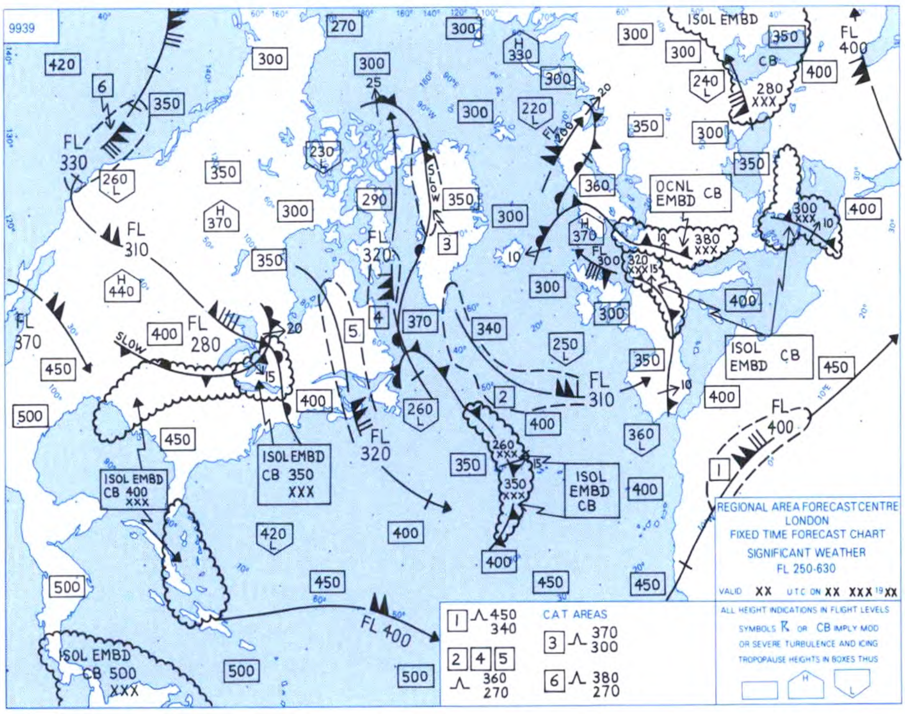
Before take-off, flight crews are provided with charts of the winds and air temperatures and of the significant features of the weather likely to be encountered *en route* to their destination. The RAFC at Bracknell provides the significant weather charts for all flights westbound across the North Atlantic from airports in Europe. The Central Forecasting Office (CFO) at Bracknell serves as the Meteorological Watch Office (MWO) for the Shanwick Oceanic Control Area. The function of an MWO is to generate warnings of hazardous weather within an airspace. These warnings can be passed directly to aircraft in flight by the appropriate air traffic control unit and update the information provided before take-off. Forecasting offices at London/Heathrow Airport and in Glasgow have similar responsibilities as MWOs for the London and Scottish Flight Information Regions respectively.

National respsonsibilities

Civil aviation in the United Kingdom covers a wide spectrum of activities ranging from supersonic commercial passenger transport to hang-gliding. However, some essential needs are common to all kinds of flying. Warnings are issued to aerodromes whenever weather conditions which could be a hazard to the safety of aircraft in flight, during landing or take-off, or when parked on the ground, are expected.

At most civil airports, weather observations are made, usually half-hourly, when the airfield is open. In most cases the observations are

Significant weather chart for transatlantic flights.



transmitted in the form of METeorological Aviation Reports (METARs) by teleprinter on the Aeronautical Fixed Telecommunication Network (AFTN) to the CAA message switch at Heathrow. From there they are disseminated nationally through the OPerational METeorological (OPMET) teleprinter circuits and, for most major airfields, internationally over the Meteorological Operational Teleprinter Network, Europe (MOTNE). Terminal Aerodrome Forecasts (TAFs) which cover a 9-hour period are prepared routinely for major airfields every 3 hours and are also exchanged via AFTN and MOTNE. Copies of bulletins of TAFs and METARs are made available locally at aerodromes to supplement the flight forecast documentation supplied in chart form.

Forecasts of minimum pressure values are prepared every hour in the CFO for each of 21 Altimeter Setting Regions over and around the United Kingdom. The area of coverage to the north of Scotland was improved in April with area 'Cormorant' being renamed 'Marlin' and a new area 'Puffin' introduced which extends to 63.5°N. Provision of these forecast pressure values is an important safety measure. They aid the safe clearance of high ground by low-flying aircraft and the safe vertical separation of aircraft. The forecast values are distributed by Meteorological Office teleprinter channels and by AFTN. They are used primarily by aircraft in flight outside controlled air space.

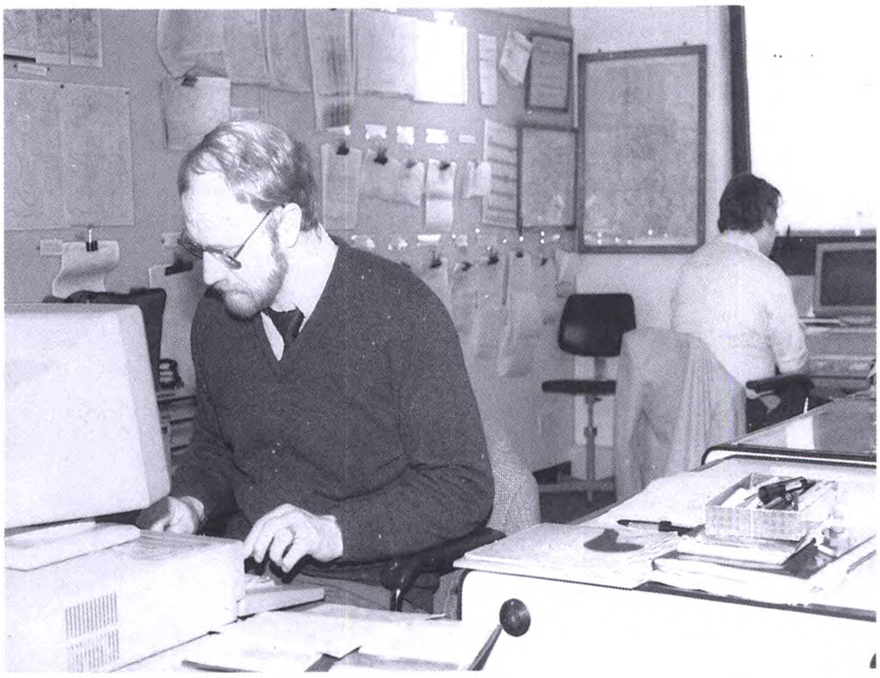
The Meteorological Office, on request from the Accident Investigation Branch of the Department of Transport, provides detailed information on weather which may be relevant to an aircraft accident. This takes the form of copies of actual weather reports from observing offices near to the place of the accident and of the relevant forecasts and warnings valid at the time, together with a résumé of the general weather situation. Investigations assisted during the year included that into the crash-landing of a commercial passenger aircraft at the East Midlands Airport and one into a fatal microlight accident in Devon.

General aviation

The documentation prepared in the RAFC satisfies the requirements of international commercial air transport; for flights above 10 000 ft within the European region and above 25 000 ft elsewhere, significant weather charts and upper-wind and temperature charts are available. However, general aviation is for the most part concerned with flights below 10 000 ft and its requirements are rather different. The range of activities includes recreational flying in private aircraft, gliding, hang-gliding, microlight flying and some commercial activities such as crop spraying, aerial surveying and air taxiing.

The Principal Forecasting Office at London/Heathrow Airport issues a forecast in chart form five times daily of the weather conditions from the surface up to 15 000 ft over the United Kingdom. This is supplemented by an appropriate upper-wind and temperature chart. These charts, plus appropriate TAFs and METARs, are distributed to airfields equipped with the means of receiving them and provide sufficient information for most users. In addition, numerous area forecasts, many of them relating to the vicinity of individual airfields, are provided for general aviation from forecasting offices throughout the country.

This system is planned to change in the future. After considerable consultation, the CAA has reached agreement with civil aviation users on the restructuring of services for general aviation. Whilst details remain to be settled, this is likely to take the form of a comprehensive automatic telephone service with the need to speak personally to a forecaster much reduced, although this will still be possible. The new service is likely to be introduced during 1987.



New forecasting office at Manchester.

Services for commerce and the general public

Introduction

To many people, the forecasts presented daily on radio and television might appear to be the main service provided by the Meteorological Office. However, this is very far from the case and many companies take advantage of the very wide range of special services now available. Depending upon the particular customer, the service might consist of a combination of weather data for design or insurance purposes, detailed weather forecasts for operational decision-making, or medium-range forecasts for planning, together with expert advice based on that information. The information provided is closely matched to the specific application of the customer and can cover the full range of weather elements, from temperature and rain to such things as wave heights (for the offshore industry) and road surface temperatures (for the highway authorities). Further, services are not limited to the United Kingdom; any part of the world can be covered.

The Meteorological Office is placing an increasing emphasis on these commercial activities. It is expected that repayment income to the Office for its specialized services will be increased significantly, thereby reducing the contribution needed from the general taxpayer. Additional effort has been put into marketing. During the year the Office's strategic marketing plan was advanced and several of its component parts were developed and adopted. In particular, the Trading Plan, which defines the strategic objectives over the next 10 years and provides a basis for determining the priority to be given to each market sector, was agreed. Consultants were actively involved in a number of market sectors and contributed substantially to the adoption of a more commercial attitude and approach on the part of staff involved in promoting and selling services.

Increasing attention was given to the intrinsic economic value of weather information and to the way it is provided to company decision-makers so that its value can be realized in terms of better company performance. This involves the formatting of weather information so that it relates directly to the questions the company decision-maker has to answer. Many companies are able to make strategic or tactical decisions in the light of weather information and have already benefited substantially from this approach.

There is a growing demand for advice based upon past weather observations. Typical examples involve the analysis of particular weather elements (wind, fog, etc.) for design purposes and the detailed investigation of a particular event for a legal or insurance matter. Many routine requirements can be met from computer-generated output with the minimum of human effort but, depending upon their individual nature, non-routine enquiries usually require a more personal approach and are therefore much more labour intensive.

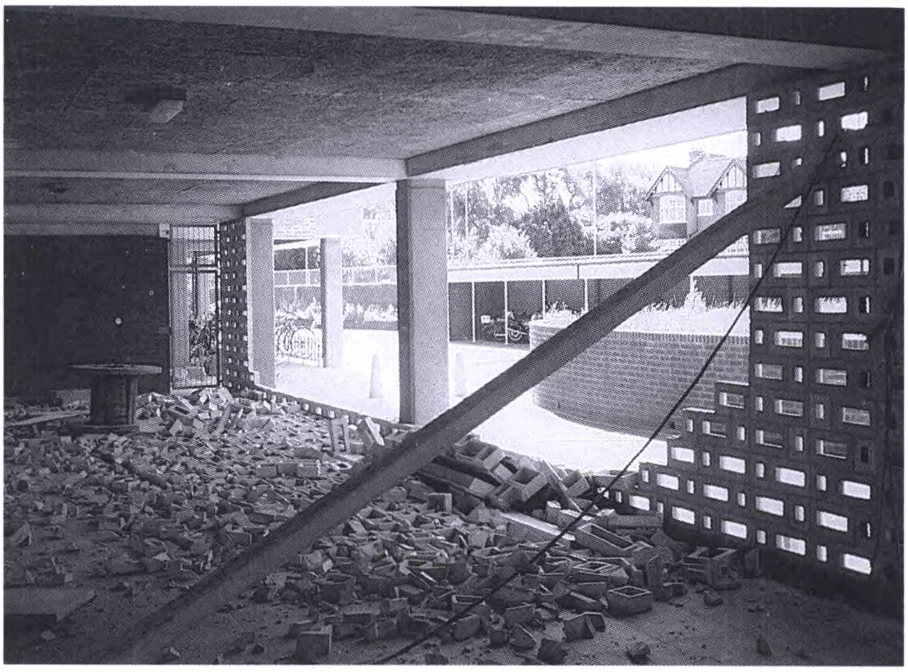
For operational decision-making and planning, advice is likely to be based on weather forecasts (or recent observations). Forecasts, tailored to the particular needs of the client, can be supplied on a regular basis, perhaps twice daily. This advice might be allied to a warning service, in which advanced notice of specified types of adverse weather can be given. Warnings to the public are usually issued on radio and television but agencies receive messages tailored to their particular need by more direct means, e.g. telex. Another variant is the consultancy service where the value lies in a discussion of the weather with a forecaster via an ex-directory telephone line at a time to suit the customer. This is particularly effective where the individual's requirements vary from day to day as for example in agriculture or building and construction.

Warnings of adverse weather issued

Land	Coastal and offshore
Heavy or drifting snow	Gales and storms
Rapid thaw	Tidal flooding
Dense fog	Negative surges
Gales	
Frost	
Icy roads	
Thunderstorms	
Prolonged heavy rain	

Overall, the aim is to match the service closely to the customer's needs. One of the strengths of the Office is the country-wide network of Weather Centres, which allows a more personal and local service to be provided. Staff become familiar with the weather peculiarities in their part of the country and are well able to take account of weather variations dependent on the local geography. Guidance on the

Honeycomb wall at the Meteorological Office Headquarters demolished by strong winds.



Locations of Weather Centres (solid circles) and offices for data enquiries and analyses (open circles).

evolution of the weather systems is provided centrally, with numerical weather prediction models playing an important part. These models continue to improve and the useful forecast period can now be extended to 8 days ahead.

This has stimulated more effort into providing information of direct interest to those whose activities are affected by the weather and consequently the applications are increasingly becoming more diverse. Many of these are covered in the following sections.

The media

The Meteorological Office provides a wide variety of services to the general public through the media. These continue to develop as advantage is taken of new opportunities. Some are more specialized to assist with particular leisure activities such as sailing or climbing.

Television

Television provides the major source of weather information for most people. The live presentations on national BBC television by the Meteorological Office Weathermen, aided by award-winning computer graphics facilities, have been particularly successful. A major expansion of the service took place late in the year when BBC Daytime Television, with hourly live presentations direct from the Weathermen's new office at BBC Television Centre, was introduced. In addition to the national TV Weathermen based at London Weather Centre, live regional broadcasts are made by forecasters based in provincial Weather Centres. Services are provided for five ITV companies and in three BBC regions. Most other BBC regions and ITV companies also receive forecasts from the Office, either in the form of scripts to be read by newsreaders or as personal briefings for the companies' own presenters.

Radio

A similar mix of presentation styles to that on television occurs on radio. Nationally, the live BBC Radio 4 forecasts are broadcast from a studio in the 'shop window' at the London Weather Centre and listeners in Scotland, Wales and Northern Ireland can hear a mixture of live and scripted forecasts for their own regions. Weather is also an important feature on local radio, both BBC and IBA. During the course of a year, over 90 000 broadcasts on the weather are made by Meteorological Office forecasters. Many of these broadcasts take the form of an informal conversation between forecaster and presenter.

Newspapers

Newspapers, both national and local, have relied heavily in recent years on the routine issue to the Press Association of area forecasts and reports on the previous day's weather. The inception of new technology in the newspaper printing business and a greater awareness of the possibilities for forecast presentation have given an impetus to the development of new methods tailored to their needs. With the help of a specialist consultant, considerable progress was made during the year in promoting these new opportunities. Several national newspapers have improved their weather presentations and some local newspapers are also taking advantage of an extended range of Meteorological Office services.

Videotex

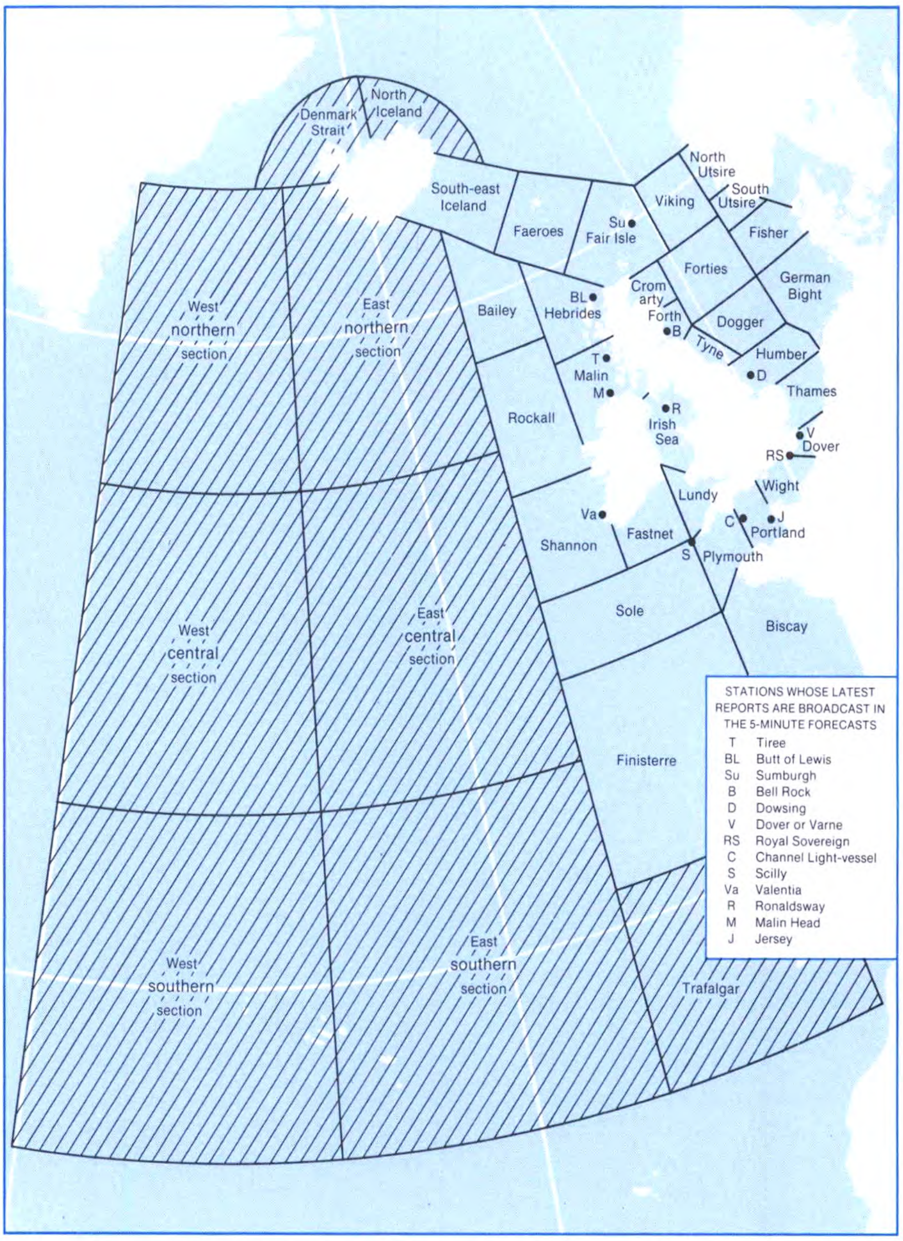
Annual accesses to the Meteorological Office pages on British Telecom's (BT's) viewdata system, Prestel, continued to increase and passed the 3 million mark in 1986. Weather information continues to be one of the most popular services on viewdata. As well as a range of forecasts for periods up to 5 days ahead, there is a world-wide selection of reports of actual weather and statistics. Further specialized services are accessible through Prestel Closed User Groups and private viewdata systems by special subscription. These include those for agriculture on Prestel's 'Farmlink' and ICI's 'Agviser'. Dedicated information for specific customers may also be transmitted via viewdata as is the case with new services to some of the county councils.

Telephone

Significant developments took place during the year in the provision of weather forecasts to the public via recorded telephone messages. Weatherline, one of BT's long-standing 'Guideline' services, received a total of 30 million calls in the year to March, a figure only exceeded once before. The most recent Guideline, Marineline, containing weather forecasts of particular relevance to coastal areas, attracted over 1 million calls in its first year as a national service. Even with accesses of this order, however, the economic viability of the service remained in doubt.

The Weathermen's new Daytime Television studio. (Photograph by courtesy of the British Broadcasting Corporation)

It was apparent that opportunities to expand the range and improve the quality of telephone services were becoming available through the introduction of new technology into this area. A further impetus was provided by the privatization of BT, allowing a range of new services to be created by independent organizations on the BT network at premium call rates. In November the Office began the first of a new series of automatic telephone services. 'Weathercall', provided by Telephone Information Services, gives detailed area forecasts which for the first time cover the whole of the United Kingdom. These are available nationally using the special STD code 0898. Recording quality was improved and messages always start with the beginning. Further development of premium rated services is planned for 1987.



Boundaries of sea areas, as used in weather forecasts transmitted by the BBC and British Telecom International. The hatched areas, also Biscay, Sole and Finisterre, are included in the Atlantic Weather Bulletin for shipping transmitted by Portishead Radio. The plain areas are included in the bulletins broadcast by the BBC, British Telecom International coastal radio stations and on Prestel.

Land transport

A knowledge of expected weather is clearly very important in dealing with the problem of keeping the roads clear of ice and snow during the winter months. This task, which is the responsibility of the local (county, district and regional) authorities' highways departments, results in a typical annual expenditure in excess of £120 million over the United Kingdom. Services to these authorities, historically provided in the main by means of brief coded warning messages, have been extensively redesigned over the last 2 years. A much more comprehensive forecast and information service is now available and should lead to substantial savings for local authorities.

Trials of the various elements were successfully carried out with a small number of county authorities during the winter of 1985/86. The results of the trials led to further refinements in the service which was subsequently launched, on a nation-wide basis, in time for the 1986/87 winter. To accommodate the variety of communication facilities available to the authorities a flexible approach was adopted, with information provided by computer-to-computer telephone link, viewdata, document facsimile and telex. An important feature is the ability to convey information in pictorial form.

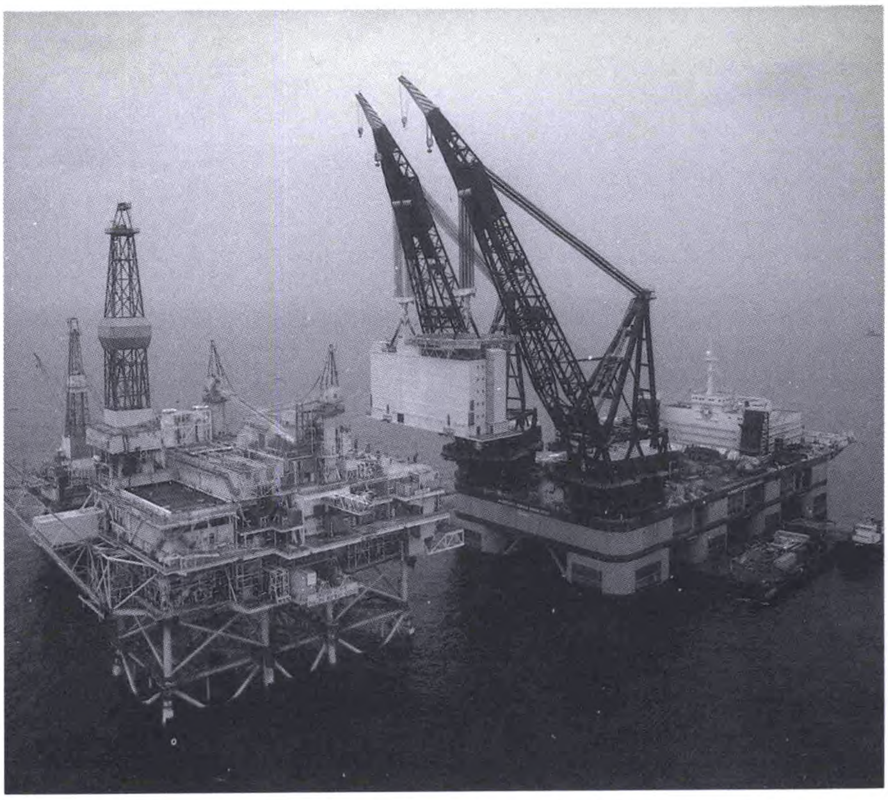
The new service, called appropriately 'Open Road', is designed to take advantage of several new developments in the technology of monitoring and predicting ice formation on roads. Many highway authorities recognize the need for more measurements of road surface state, including temperature, wetness and salinity, and have installed sensors that provide these data via telephone lines to a central display. Forecasts of hour-by-hour variations in road surface temperature and wetness are available by using a microcomputer program developed jointly with the University of Birmingham and the Department of Transport, while hard copy of radar imagery annotated by the forecaster provides up-to-the-minute information on the distribution of rain and snow. Other elements of the service comprise conventional weather forecasts giving short-term detail, trends to 5 days ahead and a telephone consultancy with local Weather Centre forecasters.

Rail transport is also affected by the weather and therefore benefits from weather advice. In winter, warnings of ice and snow are provided to British Rail. These are particularly useful for the Southern Region for whom ice on the conductor rail can cause severe difficulties for the heavy commuter traffic. The summer months present different problems. The use of continuously welded rail on railway lines requires precautions to be taken if high rail temperatures are expected and for this purpose British Rail are supplied with forecasts of air temperature and cloudiness.

Shipping

The Meteorological Office provides various kinds of weather information for commercial shipping operating in home waters and the eastern North Atlantic. Gale warnings, shipping forecasts and weather bulletins are broadcast by the BBC and British Telecom International. These advisory services are supplemented by the facsimile transmission from Bracknell of weather charts covering the North Atlantic and adjacent areas, which consist of surface analyses, weather forecasts, sea state and sea-ice conditions.

Fishing fleets, coastal shipping and sailing craft are catered for by special forecasts and by various strong wind warning services; the latter include one provided between Easter and October, whereby warnings are disseminated through local radio stations. Additional broadcasts of gale warnings and weather forecasts are made by Navtex, a shipboard system using a dedicated telex receiver for automatic reception of selected information broadcast by British Telecom. Distress and navigational messages for shipping in coastal waters are also broadcast by this method. The area over which Navtex can be received is gradually being extended; originally a coastal area service for the United Kingdom and the Continent, the system is being adopted by many countries to provide marine safety information for shipping in their coastal areas.



The McDermott barge in the Ekofisk field in the North Sea. (Photograph by courtesy of McDermott Engineering Ltd and Phillips Petroleum Company (Norway))

Routeing advice for ships of 13 foreign nations, in addition to those of several British companies, was provided by Metroute. This ship routeing service of the Meteorological Office provides shipmasters with advice on the safest and most economical routes, taking into account the known ship-performance characteristics and the global numerical weather prediction. The service is world-wide and covers marine structures and tows as well as conventional shipping of various kinds; for example, the routeing from Rotterdam to Fremantle via the Panama Canal and the Galapagos Islands of the yacht *Flyer* for the Netherlands' ocean sailor, Cornelis van Rietschoten, was undertaken during the year. Other contracts included: routeing of the entire fleet of Aqua Lines of Bangladesh on voyages in the Atlantic, Pacific and Indian Oceans; forecasts for the 17-day passage from San Carlos to the English Channel of a self-propelled drilling rig; towage from Tunisia to Invergordon, Gibraltar to Germany and Sharjah to Germany; routeing of four yachts across the Atlantic in the summer; and tropical storm advisories for the Indian Ocean over a 3-month period.

Complementing the ship routeing activities is the sea-ice service which provides weekly ice situation charts for appropriate areas of the North Atlantic and the Baltic Sea.

Storm Tide Warning Service

The calamitous flooding of some east coast areas in 1953 led to the introduction of the Storm Tide Warning Service which provides extreme tide level warnings to coastal Water Authorities. The Thames Barrier at Woolwich, for which a special watch is kept, was closed once as a precaution during the year on the advice of the Service, although in the event the tide did not reach the danger level anticipated from the threatened storm surge. Negative tide surges, particularly in the Thames Estuary and the Strait of Dover, may be a hazard to ships of deep draught, and warnings of such events are therefore issued for shipping; similar warnings are issued to the Central Electricity Generating Board so that cooling water intakes at power stations can be adjusted. Exchanges of information on tidal factors were made with a team of visiting Belgian scientists in connection with their plans for the sea defences of the River Scheldt estuary.

The offshore industry

This was a traumatic year for almost every sector of the offshore industry. The drop in the price of oil, from $30 a barrel at the end of 1985 to under $10 for a time in the spring of 1986, created great financial pressures within the industry. The oil companies dramatically reconsidered their plans and work-loads. This process has affected the many secondary industries that provide back-up facilities and services. Revenue earned by the Meteorological Office from forecasting services to the offshore industry was down from the previous year as a consequence, but continues to be substantial. The value of the service remains high and has been enhanced by the extraction from the numerical models of high-quality wind and wave information for individual sites.

Most of the forecasting services to the offshore sector are carried out from London Weather Centre and from Aberdeen. Subsidiary offices at Sullom Voe in Shetland and Kirkwall in Orkney support operations at the main terminals in the northern isles, while Norwich Weather Centre has become increasingly involved with the Great Yarmouth offices of the oil companies in forecasting for the southern North Sea fields.

As well as requiring forecasts once or twice every day, usually by telex, many companies take advantage of personal briefings at their company offices in Aberdeen carried out by forecasters from the local meteorological office. Sensitive operations offshore require the presence of a forecaster who maintains close personal contact with the operations team and assists in the frequent critical decisions which have to be made. Such a service has long been a hallmark of the Office, and as many as four forecasters have been deployed at North Sea locations simultaneously. During 1986 forecasters were provided on BP's Buchan Alpha platform through the winter to provide on-the-spot advice on the weather to help keep production at the highest level. Others were at

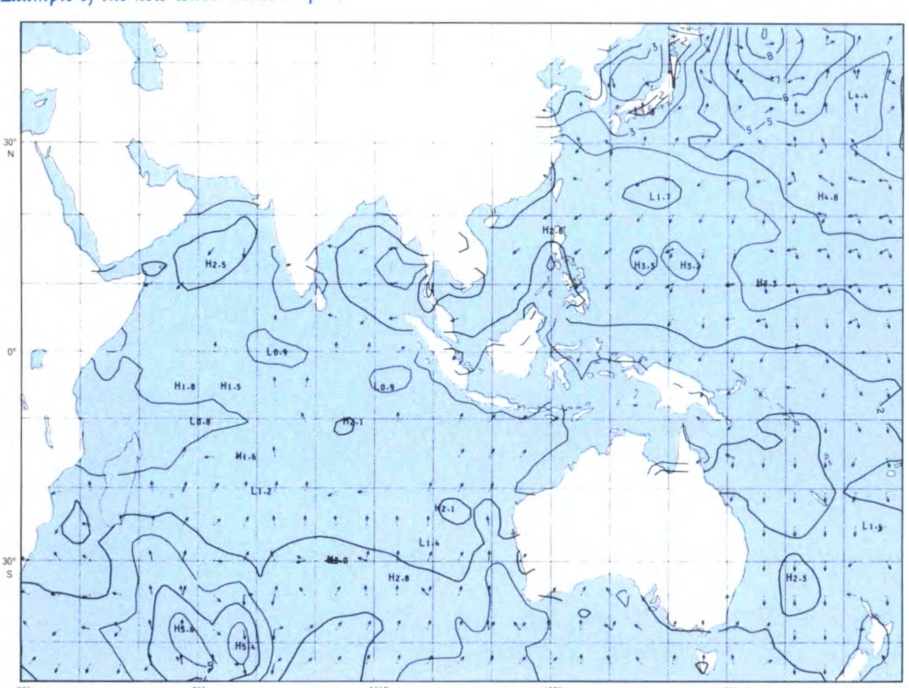
Chevron's Ninian field and on the new McDermott barge DB102 on contract to Phillips Petroleum Company (Norway) in the Ekofisk field. The DB102 job was concerned with a 'waterflood' project whereby water is injected into the well so that an extra percentage of the reserves is captured. Reaction to the Office's presence on projects of this type has been highly favourable.

Other jobs undertaken during the year included the provision of a forecaster at Methil for the load and tow of Total's North Alwyn 'B' jacket, forecasts for the tow of Santa Fe's rig 'Santa Fe 140' from Egypt to the North Sea and for the building of a harbour on the coast of Algeria. These latter examples demonstrate the growing international nature of the service. The capabilities of the Office in this respect were further enhanced by the operational launch of the new global wave model during the year. Forecasts can now be produced for oil company operations anywhere in the world. A sample of the output from the model is shown below; services based on such products are likely to become required more often.

Output from the new model was also supplied in support of Richard Branson's successful record-breaking transatlantic voyage in the high-speed motor boat *Virgin Atlantic Challenge*. A meteorological consultant was employed by the team and vital information was provided to him from London Weather Centre and the Central Forecasting Office both before and during the trip.

In addition to the forecasting requirement, oil companies need meteorological information when designing structures capable of withstanding possible storms in their areas of interest and when planning future work as efficiently as possible. The Marine Advisory Group at Bracknell provides detailed analyses of likely conditions, using the vast amount of data amassed in the world-wide data bank of observations.

Example of the new wave model output.



The energy industry

There are considerable benefits for the electricity and gas supply industries in using meteorological advice. Energy demand is well correlated with temperature, wind strength, sunshine and rainfall, and by responding to Meteorological Office forecasts of these elements the Central Electricity Generating Board and British Gas can anticipate the likely energy requirement and ensure that it can be supplied efficiently. This occurs on both a national and a regional basis. The forecasts contain quantitative information at 3- or 4-hour intervals up to 36 hours ahead for a number of sites representative of major conurbations.

There are many other uses for weather information within the industry. The regional electricity boards make extensive use of weather forecasts in the maintenance of installations and power lines. The energy user is also catered for through the provision of weather information for industrial space-heating needs, frost protection and humidity control. Of major public interest is the routine service that supplies weekly temperature data to the Department of Health and Social Security to identify periods of exceptionally severe weather when an extra fuel allowance is made available.

Manufacturing and retail

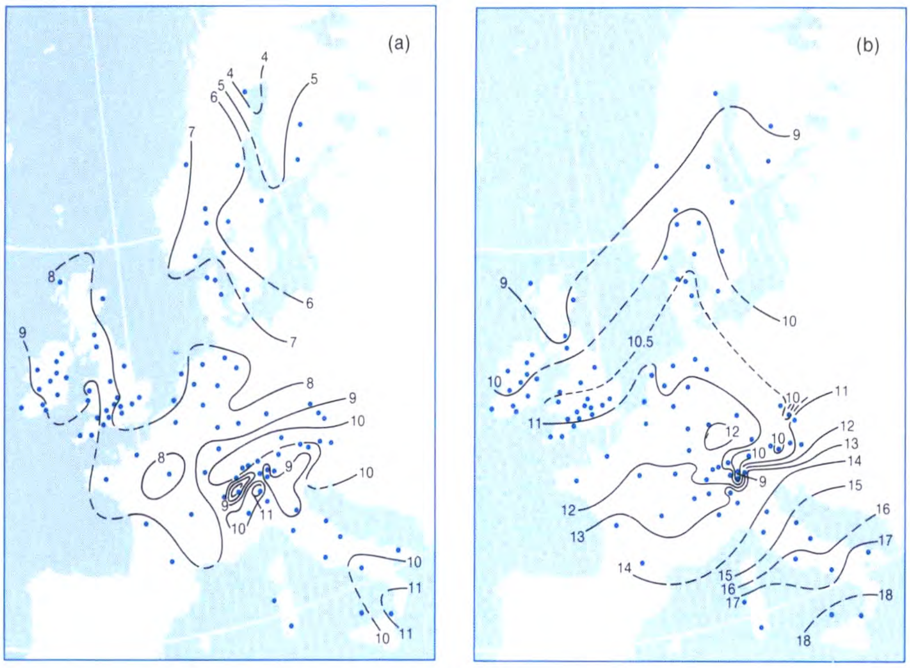
The weather can affect the demand for goods and in some cases their cost and quality. Both buyer behaviour and availability of raw materials can be affected. Accurate weather information allows companies to anticipate demand, organize transport and distribution, maintain proper stocks, deploy staff and plan advertising. Such considerations apply particularly to the retailing of fresh food, although sales of many other products such as garden equipment, clothing, heating oil and recreation equipment also fluctuate with the weather. Forecasts are especially valuable when major weather changes are anticipated, for example the onset of severe cold weather after a mild spell.

Improvements in the accuracy of forecasts beyond 2 days ahead have made it possible to offer a wide range of services to retailers, wholesalers and manufacturers. One particularly valuable development is the analysis of potential relationships between individual companies' sales data and a wide range of weather variables available from the Meteorological Office computer data base. These techniques, which can indicate sales response to variations in the weather on various time-scales, can be of considerable benefit when used in conjunction with tailored forecasts. The combination of past data and forecasts gives the client a deeper insight into forthcoming changes in sales.

Building and construction

A small unit, partly funded by the Building Research Establishment (BRE), pays particular attention to the provision of information to the building and construction industries. Collaborative work with BRE has concentrated on studies of the exposure of buildings to wind-driven rain and on the use of wind-breaks around buildings to reduce energy losses. Weather can affect adversely many outdoor construction activities and, in this connection, a survey of wind-chill investigations was undertaken for BRE. This work proved useful for answering the many enquiries relating to the severe weather of February. There has also been interest in assessing the likelihood of fog on existing and new roads including, in particular, the M42 near Birmingham, the proposed M20 between Maidstone and Ashford, and the Leicester western by-pass.

Weather is a crucial factor during much of a construction project. Climatological data can assist in determining site layout, choice of materials, and the size



A grass growth model including effects of soil moisture deficit was applied to meteorological data from 100 stations throughout Europe. In spite of large variations in radiation and temperature between regions, the generally lower and less reliable summer rainfall of the warmer areas leads to roughly similar annual yields across Europe (a), though a general trend of decreasing production with increasing latitude is evident. Only when the soil moisture limitation is removed by irrigation is the real production advantage of the warmer, sunnier climates realized (b). Such models can be used to assess the effects of climatic change on agricultural productivity, or the suitability of a crop to a climatic region. Numbers indicate tonnes of dry matter per hectare.

of drainage and heating systems. When tenders are submitted, weather data can help to plan the construction method and to estimate the project duration while during the actual construction, forecasts can assist in tactical decisions. Local personal contact with the forecaster through the 'Consultancy Service' is particularly useful and, in addition, detailed routine forecasts can be made available for those sites which are particularly weather sensitive.

Weather data are used to monitor progress on site and, subsequently, the validity of design criteria. For this specific purpose Metbuild, a monthly 'downtime summary', was introduced in January after extensive market research. Metbuild gives weather information to enable assessment of the number of working hours lost on each day due to high winds, low temperatures and rainfall, using thresholds relevant to the industry. Extensive archives of data held on computer can be analysed to produce information relevant to the requirements of each phase. For example, frequency distributions of elements, estimates of extreme values and weather summaries can be supplied just for the working day.

Agriculture

In the United Kingdom farming remains one of the largest and most weather-sensitive industries as evidenced by the weather-associated variations in gross output. European Economic Community (EEC) agricultural policies are causing farmers to minimize costs rather than maximize production and the special role of meteorologists is to help farmers and growers to work with the weather, rather than against it. There is, thus, increasing reliance placed by the industry on weather services, particularly day-to-day tactical weather advice. The number of farmers who use the Weather Forecast Consultancy Service and the agricultural viewdata systems Farmlink and Agviser increased over the year.

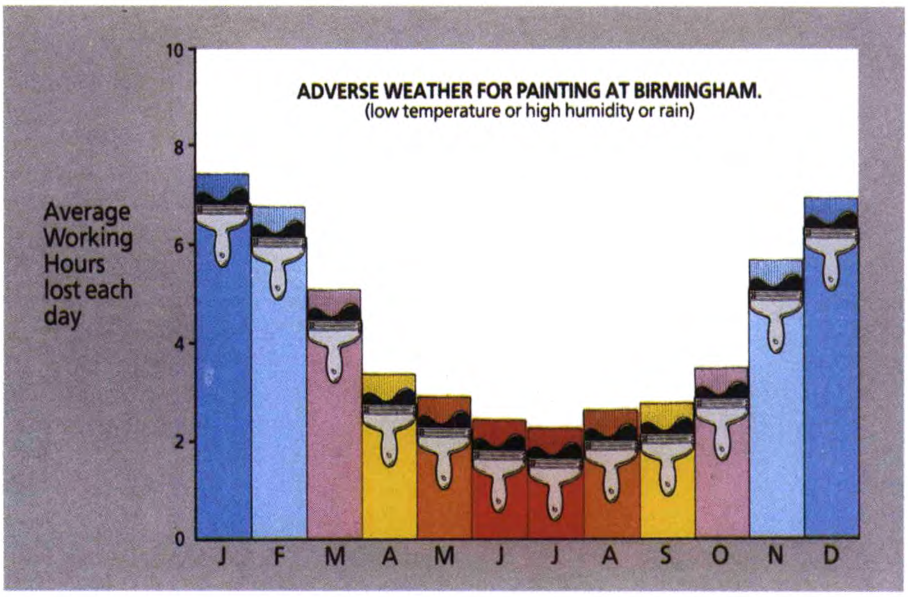
In addition to the operational forecast service, 12 agrometeorologists are located at the six regional headquarters of the Ministry of Agriculture, Fisheries and Food Agricultural Development and Advisory Service (ADAS) in England and Wales. Supported by a group at Bracknell, these advisers respond to the changes in requirements and priorities for the industry by identifying problems where agrometeorological research and development can be most productive. The decision that ADAS should begin to charge for its advisory work has led to the agrometeorologists defining and developing future revenue-earning services for ADAS. One example is the now operational, versatile irrigation program which is unique in its use of forecast rainfall information.

Because of financial restrictions and staff cuts imposed upon ADAS, agrometeorologists now help to maximize the use of resources in a wide range of ADAS research projects as well as pursuing their own investigations. Over the past year investigations have included cereal growth studies, the monitoring of environments within naturally ventilated pig houses and chick transporter lorries, the effects of weather on potato blight incidence and crop pest populations. Progress has been made in the use of off-the-shelf meteorological instruments and data loggers for the monitoring of the weather on a site-specific basis.

A key tool of the ADAS-based meteorologists is a network of microcomputers with direct access to the COSMOS (the Office's central computer system) data archives and to the agrometeorological data base, FARMAID, launched operationally in August. Agrometeorologists can readily extract statistics of particular weather variables and products calculated from weather data, such as evaporation, wind-chill, crop disease indices or work days. FARMAID is being developed further to give easy and direct access to weather data for the past 2 years and a wide range of agrometeorological computer programs. Customized agrometeorological products can be generated from FARMAID and passed routinely to customers.

The ability of the regional agrometeorologists to handle increasing numbers of enquiries improved markedly after the introduction of the microcomputer network in 1985. However, the more traditional methods of communication still have their place and agrometeorologists give many talks and lectures to local agricultural and horticultural groups.

Agrometeorologists at Bracknell assist regional colleagues by the development of new agrometeorological products and methods. They also carry out investigations of a more theoretical nature than is appropriate for the applications-oriented regional staff or that require the large computer resources at Bracknell. Studies have continued of the field ripening of cereals, and work was completed on a mathematical model of straw burning. Agrometeorological enquiries handled at Bracknell ranged from the effects of weather on bees in London to the more common pesticide spray drift questions.



An example of the information that can be provided for the building industry.

Services supplied routinely from the Headquarters group of agrometeorologists direct to the industry included calculations of accumulated temperature data for assessment of the optimum time for application of nitrate fertilizers and summaries for the farming year relating weather to agricultural activities.

A quantitative study was made for the EEC of the effects of climate variability and climate change on herbage production from intensively managed grassland in western Europe. The study also showed how irrigation could be used to increase production in the warmer, sunnier parts of Europe.

The water industry

Liaison has continued with organizations concerned with water supply, use and control and, in particular, with the Institute of Hydrology. Data are supplied to many customers involved directly or indirectly with water resources in the United Kingdom and specialized services are offered to engineers involved in drainage, flood prevention and water supply schemes. Water Authorities in England and Wales have contributed financially to the UK weather radar network and use precipitation data from it. The industry in general also takes forecasts for advice on the likelihood of heavy rainfall over designated catchment areas. This service has been enhanced by the availability at most public service offices of the radar-derived precipitation data and numerical forecasts of rainfall amounts. A routine weekly service to the water industry, agricultural concerns, consulting engineers and local government is the Meteorological Office Rainfall and Evaporation Calculation System (MORECS). In support of MORECS a climatological data set has been constructed based upon retrospective calculations of the water balance of Britain for the period since 1961. Statistics from this data set are being derived and will assist in answering enquiries concerning long-period effective rainfall, evaporation and soil moisture deficit.

The development of PARAGON, the archiving system for combining radar and rain-gauge data, has progressed and is now working using radar data received on magnetic tape. PARAGON has been used to compile an archive of rain-gauge calibration radar data back to 1981. These data are used to answer rainfall enquiries not readily answerable by gauge data alone. The utility of PARAGON will be greatly increased when data can be collected on line; enquiries should then be answered with less delay than at present. Investigations are continuing into the use of radar in conjunction with rain-gauge observations.

Legal and government

Enquiry bureaux at Bracknell, Edinburgh and Belfast provide a widening variety of advisory services for England and Wales, Scotland and Northern Ireland respectively. Individual

The Met. Office
Open Road

Products used for the 'Open Road' forecasts.

consultancies are extremely diverse with services to the legal and insurance professions being particularly in demand. There has been a marked increase in work undertaken for the police, particularly in respect of serious crime. In addition to the provision of advice, staff are occasionally called to court to act as expert witnesses. On one occasion opinion was sought on dates when there could have been icicles on a particular building and in another case the time at which rain began to fall was important. In the event it was possible to give an estimate to within 5 or 10 minutes.

Litigation, existing or planned, is also the subject of many marine enquiries. Such cases may relate to loss of life or personal injury, to structural damage or to breach of contract. Members of staff are sometimes called upon to give expert evidence before the Wreck Commissioners, as in the enquiry over the loss of the barque *Marques*.

Enquiries are received about the climatology of other countries. Some can be answered directly from material held in the National Meteorological Library but others require some interpretation. The increasing volume of climatological data held on COSMOS is widening the range of services that can be provided. One interesting example was the appearance of a member of staff as an expert witness for a major UK engineering firm. The firm claimed further payment from the Nigerian Government because of the disruptive effects of unseasonable rainfall which delayed the construction of the Oyan Dam.

The year saw an increase in the number of enquiries related to pollution of the environment. In liaison with the Health and Safety Executive, a selection of analyses of weather data considered relevant to the *Control of Industrial Major Accident Hazard Regulations (1984)* was prepared. The Warren Springs Laboratory, Department of Trade and Industry, was supplied with an extensive amount of meteorological data for use with its air pollution model, and the Chernobyl accident resulted in many enquiries regarding rainfall amounts and distribution. Analyses of wind and rainfall data were undertaken for the Safety and Reliability Directorate of the United Kingdom Atomic Energy Authority.

The Met. Office

Making the weather work for you.

The Office's marketing logo.

Publicity

Publicity and public relations remain important areas for the Office. Enquiries from the Press and other media continued at a high rate throughout the year. As usual they peaked on the occasions of the more unusual and dramatic weather events, but there was also considerable Press interest in some of the specialist commercial services available from the Office and the substantial cost savings which can be achieved by using them.

Consultants were closely involved in the operation of a coherent advertising strategy, including the production of brochures and campaigns in the specialist Press. The brochure *Profitable Weather* was aimed at the retail trade; another entitled *Open Road* detailed services designed to support highways maintenance operations by county authorities. A promotional leaflet describing the Office's contribution to the success of the *Virgin Atlantic Challenge* was distributed to many existing and potential customers. Support for the sales team was given high priority, and special video presentations and high-quality flip-chart presenters directed at specific market sectors were produced.

A start was made on updating the displays in the windows of Weather Centres, and the London Weather Centre showroom was completely restyled in keeping with its increased commercial role. Similarly styled displays were subsequently installed at Manchester and Southampton Weather Centres.

Although spending on exhibitions was much reduced in comparison with earlier years it was well targeted and maximum use was made of portable systems capable of adaptation to a variety of markets. Stands were mounted at the Offshore Technology Conference in Houston, Texas, at 'Hydrocarbons '86' in Great Yarmouth and at four agricultural shows. A 2-day exhibition and seminar staged by the Office in Aberdeen and supported by a number of local industries proved particularly successful.

Summary

Both industry and the general public now have access to much better weather information. The improvement in the accuracy of weather forecasts and the growing volume of observational data have helped considerably. Also important, however, is the effort being put into both developing and providing the right service for the customer.

The range of meteorological services continues to expand and the Office is constantly seeking new markets. All industries which are weather sensitive, even in part, can benefit from the services offered. Simply accepting the vagaries of the weather is an expensive alternative.

Introduction to the research program

Chernobyl

At the end of April, the Chernobyl accident forced itself upon the attention of the Meteorological Office because of the obvious dependence of the consequential pollution on meteorological factors. At a detached level, the events were full of scientific interest. The facilities which had been built up in the past to deal with other problems such as acid rain and the spread of dust were able to provide useful forecasts of the spread of the pollution. The radioactive cloud travelled coherently over a very long distance, and some nuclides were only deposited when, over the United Kingdom, the cloud met rain usually in the form of showers which were observable only by means of weather radars. An account of the incident from a meteorological viewpoint is given in the following article. There is still much to learn, not least how to cope nationally with any similar future events. It is hoped that means will soon be available to combine the meteorological and radiological information to give the public proper advanced warning of any high depositions.

Forecasting

The great bulk of the research program is directed to improving the Office's forecasting capability. The improvements over the past decade or so have been spectacular with approximately a 2-day increase in predictive capability in forecasts for several days ahead. Increasingly now, attention is being switched to improving the detailed forecasts for up to 12 or 18 hours ahead. Not only is there a large market for such forecasts, but a more objective system for producing them would increase forecasters' productivity enormously. The research has to be on a broad front for there are problems of many kinds — observational, numerical and theoretical. The conventional observations are generally too few to give the necessary detail, and the small-scale weather systems, important at these time-ranges, are far less well understood than larger systems like depressions and anticyclones. Observationally, the exploitation of satellite and radar images is the obvious way forward, and strenuous efforts are being made to produce more precise information from these remote sensing techniques. A FRONTIERS equipment, which presents the information electronically for easy manipulation by forecasters, has been set up in the Central Forecasting Office and forecasters have been trained in its use. Work continues to improve FRONTIERS, and to derive additional satellite products for distribution to outstations. To obtain *in situ* observations of mesoscale systems, which can guide the interpretation of remotely sensed measurements as well as clarifying the dynamical processes, specific experiments are needed. In early summer 1986, the airflow over hills in South Wales was measured intensively and detailed preparations have been made for two experiments in 1987 which will involve the Hercules aircraft of the Meteorological Research Flight. The first which is in co-operation with the French will probe the motions around cold fronts in the English Channel, and the second, later in the year off the USA, is a larger international experiment to clarify the mechanisms maintaining or dissipating marine stratocumulus.

For numerical prediction, the mesoscale model is being tested quasi-operationally twice a day, and substantial improvements to its formulation have been made as a result. Products from it will soon go to some outstations for further evaluation. However, the true operational use of the model awaits a more powerful computer and the assimilation of suitable data from the FRONTIERS system.

At a more abstract level, airflows over and around orography have been studied using a variety of mathematical techniques with a view to improving the mesoscale numerical model.

As a result of these various activities, forecasts for the short range with more geographical detail and greater accuracy can be expected over the next 5 years or so.

Climate

Climate, and the requirement to advise the Government and the public on possible changes, is, after forecasting, the largest area of research interest, though, at a practical level, the activities in the two areas are closely inter-related. Research indicated that the summer rain in the Sahel is related to sea surface temperatures. This led to a forecast of the 1986 summer rain being supplied to Meteorological Services in Africa, a gesture which was much appreciated by them. The dependence of climate on conditions at the earth's surface, of which this is one example, is being explored comprehensively using numerical models. The development of improved meteorological capability in Africa is being discussed with the Overseas Development Administration and internationally.

The effect of carbon dioxide and other trace gases on climate has become more important in the public perception. UK efforts in this area are dwarfed by those in the USA, but the independent Meteorological Office work has led to fruitful co-operation, and an Office scientist has co-authored the section of the US Department of Energy's latest assessment on the meteorological aspects of the problem. The work also attracts the support of the European Economic Community.

The increase in trace gases may be responsible for the 'Antarctic ozone hole' observed in the last few years. The contribution by the Meteorological Office, linking three-dimensional dynamics with chemical modelling along trajectories, is again an individual approach which has enabled the Office to play a significant part in the very large international scientific effort.

The Office's research program is enabling a better service to be provided to the nation as well as increasing our fundamental understanding of weather and climate. The possibilities for further improvements are being followed up, particularly through the exploitation of large computers and satellite information.

Chernobyl — the radioactive plume and its consequences

The accident

During the night of 25/26 April 1986, tests were being carried out on the generator and the electrical systems of one of the reactors at the Chernobyl nuclear power station in the Ukraine. Because these tests did not directly involve the reactor itself, the authorizing committee in Moscow had failed to give sufficient consideration to such safety precautions as were necessary to ensure the reactor's continued stability. This omission, together with other serious errors of judgement by the electrical engineers during the tests, resulted in an unforeseen very dramatic rise in core temperature at about 0123 local time. This rise caused an explosive generation of steam and rapid chemical reactions which dislodged the enormous 1000-tonne cover plate and spewed burning debris over the site.

Since the reactor had been in full use for well over 2 years, the core content was rich in a wide range of fission products. Many of these were highly 'active'. The 'activity', or the rate at which these various products transform to form other products, is measured in units of disintegrations per second, or becquerels (Bq). Roughly 2×10^{18} Bq of activity escaped in the 10 days after the accident, of which about a third was released on the first day. Two of the products released in quantity, which were most important from a health point of view, were iodine-131 and caesium-137.

In an attempt to contain and filter these releases, the authorities dumped many tonnes of boron carbide, dolomite, sand, clay and lead on top of the reactor from helicopters, at no small risk to the pilots concerned. As a result, by day 5 the emissions had fallen by 90%, but later rose again due to partial penetration of this dumped material, until by day 11 the situation was brought under final control and emissions virtually ceased.

In this early period 29 people died trying to contain the accident, whilst some 200 others, mainly station personnel, sustained injuries from exposure to over 2000 times the normal annual dose from background levels of radiation.

During the first few days

First recognition outside the USSR that a disaster had occurred came when monitoring instruments at Forsmark, a Swedish nuclear plant north of Stockholm, set off alarm signals on the morning of Monday, 28 April. After repeated questioning by the Swedish Ambassador in Moscow, the Soviet authorities released the first details of the accident on the Monday evening. By Tuesday morning the Central Forecasting Office at Bracknell were calculating forward trajectories starting from Chernobyl using forecast winds calculated at the 850 mb pressure level. These trajectories suggested that, whilst there was no immediate risk to the United Kingdom, there was a possibility the plume might cross Britain by the end of the week. However, questions abounded: Was the release continuing? How much was being released? What was the effective height of release? What winds should be used? Where had the plume got to? In these early days vague press reports were all that there was to go on, and this hampered the prediction of the movement of the radioactive plume. (It later became evident that widespread measurements were made and, even though irregular, they proved invaluable in post-accident analyses.)

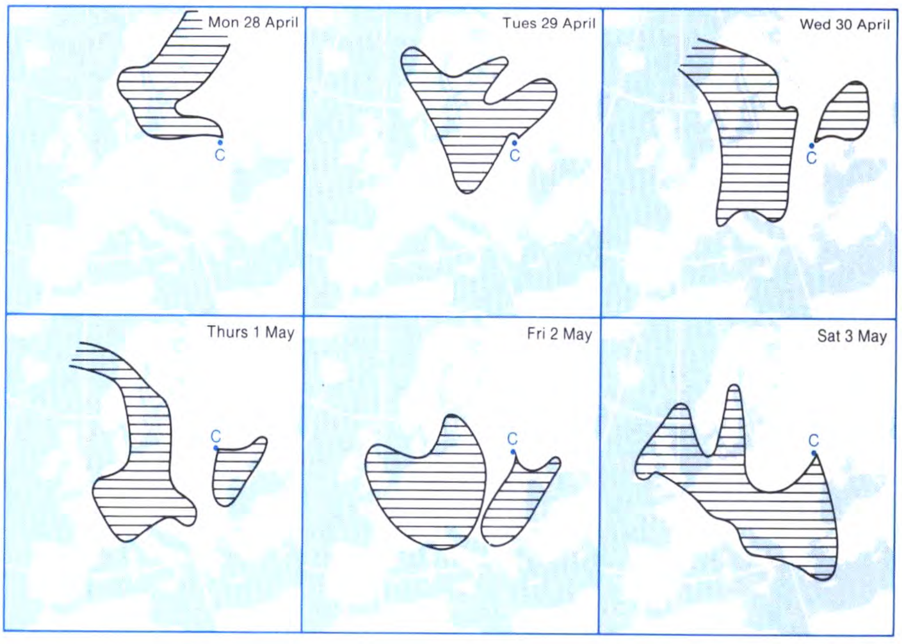
Late on Wednesday reports of radioactivity measured in northern Italy and in Monaco were received through the UK National Radiological Protection Board (NRPB). Although the time of these measurements was uncertain, it became reasonably probable that the winds would carry the plume to Britain on the Friday (2 May), and this information was issued on Thursday morning.

The forecasters and press officers were kept extraordinarily busy during this period presenting evidence to visiting television film crews and answering numerous enquiries. Staff with specialized interests also became heavily involved, and helped to meet the demand from the media for informed comment. Liaison between the Office and other groups was generally good, despite the enormous work-load suddenly thrust upon all concerned.

The plume over Europe

A fairly clear picture of the daily sequence of plume outlines has been obtained by combining measurements of radioactivity with more detailed trajectory analyses carried out later. Winds at 950 mb, typical of the daytime mixing layer, were used to obtain these trajectories. The figure below shows the

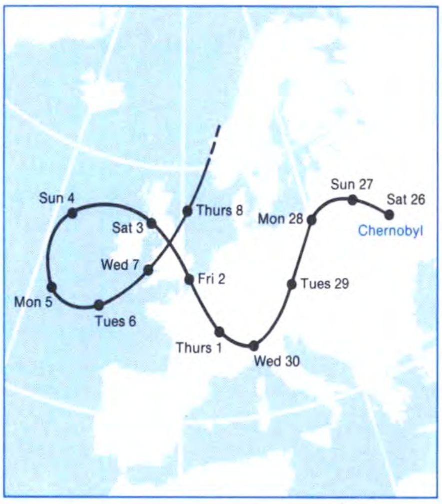
Outlines of the plume from Chernobyl (C) based on measured concentrations and trajectories.



sequence up to Saturday, 3 May, when part of the plume was virtually covering the United Kingdom. Owing to a rather complex and variable meteorological situation over Europe, the plume first moved north-westwards from Chernobyl over the Baltic Sea into Scandinavia. Here the plume split into three 'fingers'. One moved away to the east across northern parts of the USSR and was later detected in Japan and China. A second crossed over central Norway and out across the Norwegian Sea to be detected later in North America. The third moved south-westwards in response to a transient ridge of high pressure over the North Sea. A part of this plume crossed central Europe, moved over northern Italy and southern France, and then turned north-westwards as the ridge slipped away, entering Britain on Friday, 2 May. During this time, emissions were continuing and almost every direction from Chernobyl was affected. Nevertheless, most of the plume was moving rather slowly over central Europe and the western Balkans, with occasional 'fingers' being drawn off mainly to the north as active depressions and fronts crossed the United Kingdom and Scandinavia. Towards the end of the second week, when emissions had ceased, concentrations of radioactive material in the air were falling throughout Europe, and fewer measurements, together with increasing uncertainties associated with the air trajectories, meant that locating the plume became virtually impossible.

Loss processes

Concentrations in the air near the ground, within the so-called mixing layer, gradually fell not only because the plume mixed with previously uncontaminated air through turbulence, but also indirectly because some material must have escaped from the mixing layer through clouds. A third most important cause was the deposition of radioactive material to the ground. Deposition is thought of as happening through two processes: dry deposition and wet deposition. Dry deposition is the direct uptake of material in the air as it comes into contact with the surface. Sedimentation, absorption or impaction may be involved. It is a fairly continuous process as long as material is there to be deposited. Wet deposition, on the other hand, occurs much more sporadically, depending as it does on the occurrence of rain or snow, or on 'occult' deposition, i.e. the scavenging of wind-blown contaminated cloud droplets by vegetation which occurs whenever cloud or fog is at ground level. This latter process is quite common on hilltops.



Estimated path of the part of the plume which ultimately crossed the British Isles; 1200 GMT positions are shown.

Generally dry deposition is more effective for reactive gases like iodine-131 than for particulates or aerosols like caesium-137. For the latter, size is very important whether dry or wet deposition is being considered. Unfortunately, little information is available concerning the size distribution in the Chernobyl plume.

Wet deposition by rain will halve the mass of airborne material in less than 30 minutes in storms. Deep convective clouds which draw large volumes of contaminated air from the mixing layer through the cloud are particularly efficient in this respect. Large accumulated depositions of the material on the ground can result. In contrast, the highest *concentrations* in rain will often be associated with low rainfall rates or with occult deposition.

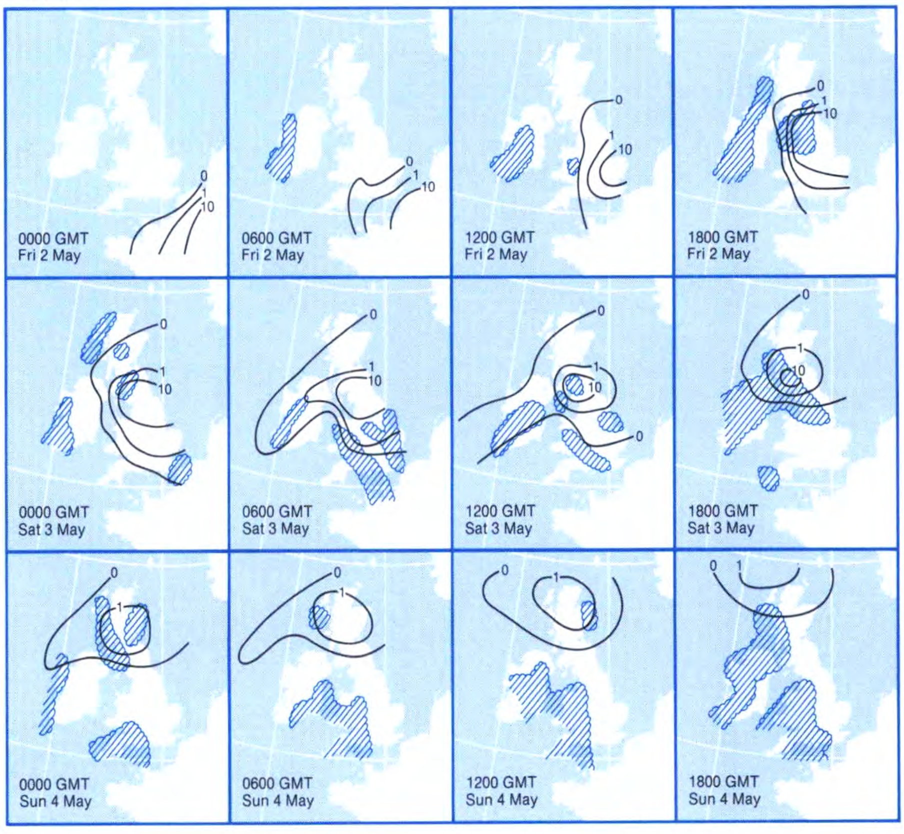
By far the largest depositions of activity away from Chernobyl itself occurred in areas affected by rain. These included Scandinavia, Austria, Germany, Poland, the United Kingdom and Ireland. Some of the highest measured depositions were in central Sweden and Norway with depositions of caesium-137 locally exceeding 100 000 Bq m^{-2} (over five times the highest measured values in the United Kingdom).

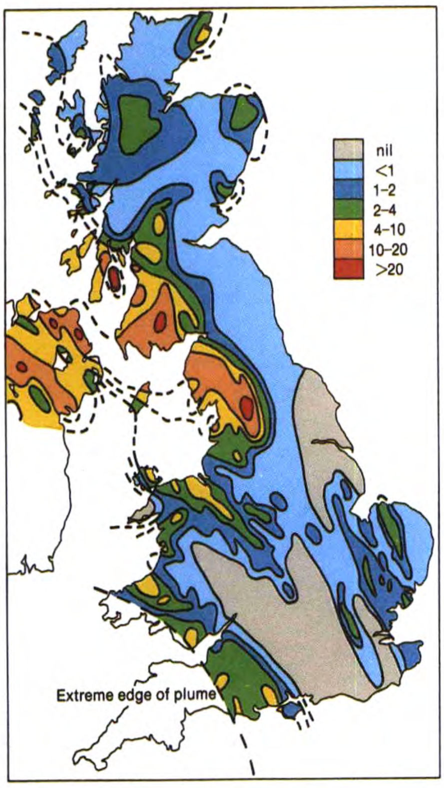
The plume over Britain

The radioactive plume crossed the English Channel into southern England in the early hours of Friday, 2 May, having experienced almost no rain on its 4100 km track from Chernobyl (see above centre). Measurements of related activity in the air were made by the Electricity Boards, by British Nuclear Fuels Ltd, by the UK Atomic Energy Authority and by the NRPB at various sites throughout Britain. These have been combined with trajectory analyses to define the subsequent movement of the plume and approximate levels of activity within it. Six-hourly sequences are shown below, covering the period from Friday to Sunday.

May 2 was a dry sunny day over most of Britain, although a weak cold front associated with a deepening slow-moving low, situated to the south-west of Britain, resulted in a shallow 'heat low' over France in the vicinity of which

The passage of the plume over the United Kingdom. Shading indicates areas of rainfall, contours are in Bq m^{-3}.





Rainfall totals (mm) that affected the plume.

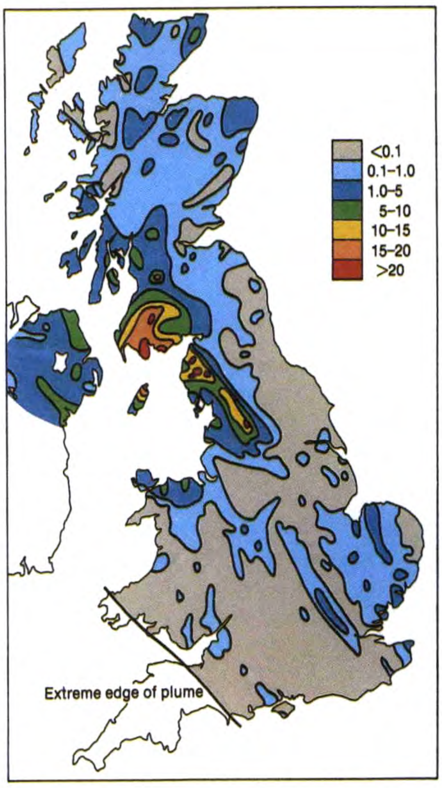
a few thunderstorms developed. The storms moved north to affect southern England by the early hours of Saturday, 3 May, although their strength ebbed and flowed. A few isolated storms became revitalized and some reached parts of North Wales by mid-morning. These storms produced the initial wet deposition of radioactivity over the United Kingdom; their tracks across south-east England can be deduced from the rainfall pattern shown above since they accounted for almost all the rainfall there during the period.

Some significant wet deposition of radioactivity occurred over Gloucestershire and parts of central and southern Wales in the early daylight hours of 3 May, when concentrations of activity in the surface air were relatively low. The rain fell in a rather narrow band parallel to the cold front but some 200 km behind its surface position. This curious observation has been explained by a three-dimensional analysis which showed the front to be 'rearward sloping'. This means that with increasing height the position of the frontal surface along which the contaminated air was ascending and in which the rain formed, lay increasingly behind its position at the ground. The rain band is seen later across central Wales and the Midlands on the radar picture (right) taken at 1430 GMT.

Most of the radioactive deposition occurred in renewed convective rain later on 3 May. The shallow heat low that had formed over France on the 2nd moved slowly north and later north-westwards to lie over northern England by 1200 GMT on the 3rd (see page 32). This heat low, together with locally high surface temperatures and hilly terrain, led to the formation of widespread thunderstorms over the Pennines. The network of weather radars monitored the location and movement of these storms which were embedded within a low-level jet well ahead of the cold front. The storms moved across Cumbria, Dumfries and Galloway, and later Northern Ireland, during the afternoon and evening, and gave very variable accumulations of rainfall and radioactive depositions. Mixing-layer air carrying radioactivity must have been swept up in vigorous updraughts into these storms. The radioactivity then either formed nuclei on which condensation took place or was captured by the falling precipitation. The convergence of contaminated air into the storms was evident from the shrinking outline of the plume during this period.

The plume did not remain as one coherent entity during the whole of its passage over the United Kingdom. Two fragments were drawn off; the first, on Saturday, moved rather rapidly south-westwards over western Ireland, and the second, on Sunday, travelled westwards across the Western Isles and was carried round the depression then over southern Ireland, recrossing Britain with much lower levels of activity on the following Wednesday and Thursday. The main part of the plume drifted slowly northwards across Scotland and the Shetland Isles and away into the Norwegian Sea area by the end of Sunday (see lower figure opposite).

Radar rainfall picture taken at 1430 GMT on 3 May 1986.



Total (wet + dry) depositions of caesium-137 on grass (Bq m^{-2}) from data supplied by the Institute of Terrestrial Ecology.

Depositions

Although dry deposition of iodine-131 and caesium-137 occurred over all parts of Britain crossed by the plume, it is only in those parts which experienced little or no rain that its rate can be assessed from measured depositions on grass, or less directly from concentrations found in milk. Elsewhere depositions are dominated by wet removal processes. The rate of dry deposition is generally expressed as the product of the concentration in air near the surface and a so-called deposition velocity. Measured and estimated values of deposition, concentration and plume-passage time have yielded mean deposition velocities, effectively averaged over the diurnal cycle, of 1.4 mm s^{-1} for caesium-137 and 4.2 mm s^{-1} for iodine-131.

It is interesting to note that in Somerset and Dorset iodine-131 levels in milk were later found to be higher than caesium-137 levels, compared with relative concentrations in other areas which experienced comparable rainfall, despite the fact that caesium appears to be more effectively removed by rain than does iodine. This result is believed to come about from the appreciable dry deposition of iodine-131 on the Friday, when concentrations in air were at their highest. This more than outweighed the caesium that came out in the rain which fell on Saturday morning when the plume had moved to the north.

The larger surface depositions over the country were a result of rainfall. Rainfall experienced within the passage of the Chernobyl plume varied geographically from over 20 mm in parts of north-west England and south-west Scotland to nil in parts of southern and eastern England. It has been estimated that with a caesium concentration in air of 1 Bq m^{-3}, the rain would contain about 5×10^5 Bq m^{-3}. This is largely confirmed by measurements: values ranged from 0.3 in Cheshire to 26 in Strathclyde (in units of 10^5 Bq m^{-3}), reflecting different concentrations in air at the time of the rain. These variations are also reflected in the depositions. The figure (top right) on page 31 shows depositions of caesium-137 interpolated from grass cropping measurements at a large number of sites by the Institute of Terrestrial Ecology. These measurements do not include material washed down into the soil; consequently total depositions may be several times higher. Nevertheless the concentrations in air combined with rainfall amount give a pattern over the country in good agreement with the interpolated pattern in the figure and in good quantitative agreement with those few total-soil depositions obtained by the Atomic Energy Research Establishment, Harwell. It is interesting that the removal rates in rain are in close accord with values found in the acid rain issue: namely, particulate caesium-137 has a rate comparable to that of particulate sulphate, and mainly gaseous iodine-131 has a rate similar to that of gaseous sulphur dioxide.

To put into perspective the relative magnitudes of wet and dry deposition rates, the contribution from the dry deposition of caesium-137 over a period of 24 hours is roughly a quarter of that deposited during a mere 1 mm fall of rain if the concentration in the air remains constant.

The relation between emission and deposition

It has been estimated that the radioactive plume which crossed the United Kingdom originated as a roughly 2-hour section of the emission on the day of the accident. This is broadly consistent with an inspection of the meandering trajectories, the dimensions of the plume over Britain and the magnitude of the concentration of radioactivity in the air. Further, assuming an almost constant emission rate on 26 April, the inferred total depositions on the United Kingdom, as a percentage of the appropriate emissions, are very roughly 40% for the caesium-137 and 2% for the iodine-131. In view of the number of assumptions involved, these estimates are clearly subject to large margins of uncertainty, but are nevertheless useful in emphasizing the roles of dry deposition and of precipitation in determining depositions at very long range.

The higher depositions of caesium-137 in areas of heavy rainfall within Britain exceeded 10 000 Bq m^{-2}. Localized peaks probably reached in excess of 20 000 Bq m^{-2}, especially on some mountain tops. Such depositions from the Chernobyl accident have greatly increased the pre-Chernobyl levels (less than 2000 Bq m^{-2}) remaining in the soil from cumulative fall-out associated with atmospheric testing of nuclear weapons in various parts of the world in the 1950s and 1960s. Monitoring of the latter depositions over the years indicates that post-Chernobyl concentration levels in soil will fall at a rate of about 50% per year as a result of leaching and decay.

Conclusions

The Chernobyl accident was the first major incident of its kind anywhere in the world. Areas well away from the source were affected to a very significant degree, especially where the plume was intercepted by rain. Depositions of caesium-137 and iodine-131 affected the food chain in many areas of Europe and restrictions on the sale of vegetables, milk and meat were variously imposed in many countries. In the United Kingdom restrictions on the slaughter and sale of lamb were imposed in some areas, creating considerable hardship to the farming community. However, levels of activity found in other food and in tap water in this country never exceeded the limits set by Government.

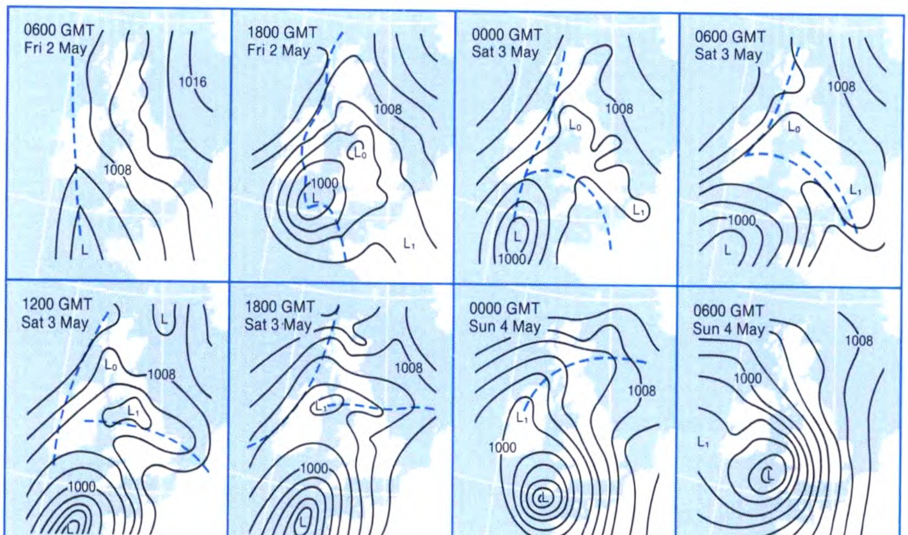
From an emergency planning point of view, the lessons to be learnt in retrospect are:

- Trajectory analyses provide a very useful and reasonably accurate guide to the movement of emitted material.

- A quick appreciation of where rain has affected the plume, even at very great distances, and hence where radioactivity may have entered the food chain to a significant degree, can be assessed from the co-ordinated output of a network of weather radars.

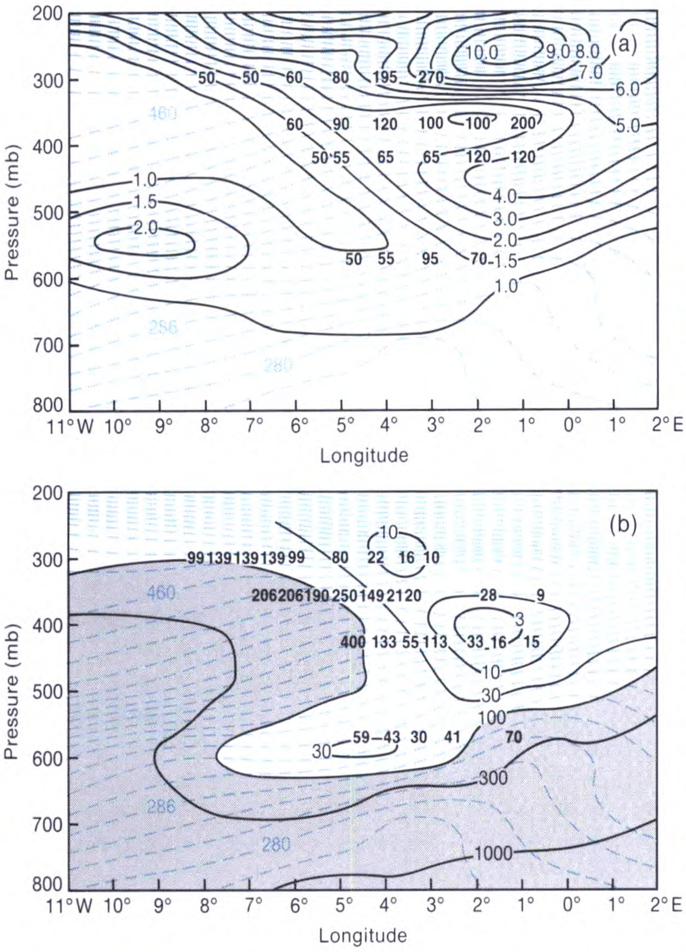
- Radioactivity-monitoring networks are invaluable, but details of their measuring programs and the speedy dissemination of their results need international co-ordination and regularization.

- An effective modelling centre is required to integrate these three sources of information, to produce analyses and predictions of concentrations in air and of depositions, and to issue appropriate warnings.



The synoptic situation from 0600 GMT on 2 May to 0600 GMT on 4 May showing the deepening depression L and the associated heat low L_1.

Atmospheric chemistry



Vertical cross-section in the neighbourhood of a tropopause fold with potential isotherms (dashed lines) at 2 K intervals. In (a) high values of potential vorticity (units $10^{-6}\ m^2\ s^{-1}\ K\ kg^{-1}$) corresponding to air of stratospheric origin are seen to extend down to 550 mb at 2°W. Superimposed aircraft spot measurements of ozone (ppbv) for the same event also show high values (stratospheric) in the fold. In (b) low values of water vapour mixing ratio (× 10^{-6}) corresponding to dry stratospheric air are seen in the fold. Aircraft spot measurements are superimposed. The shading identifies high (tropospheric) humidity mixing ratios.

Minor constitutents of the atmosphere play a major role in determining the environment at the earth's surface. Ozone in the stratosphere, a particularly important ingredient, protects the surface from harmful short-wave (280–320 nm) solar radiation. The aim of the Office's research is to gain a better understanding of the factors that determine the atmospheric distributions of ozone and other important trace species, and of the effects of possible anthropogenic changes.

Tropospheric chemistry

The chemical composition of the troposphere is important in such problems as local pollution events. Tropospheric air can move upwards into the stratosphere where it has the potential to influence the ozone balance. Research into individual meteorological events was conducted using the Hercules aircraft of the Meteorological Research Flight. Currently it carries gas chromatographs capable of in-flight detection of peroxyacetyl nitrate; this species is a long-lived reservoir of reactive oxides of nitrogen. Samples of air at different heights and locations are also obtained for subsequent analysis and ozone is measured in flight.

The hydroxyl radical (OH) is present in the troposphere, and it may react with other molecules reducing their residence time and preventing their passage into the stratosphere. There are too few reliable measurements of OH to test photochemical theories adequately. A feasibility study is under way, in collaboration with scientists at the University of Oxford, to develop a laser magnetic resonance device to measure OH and the hydro-proxy radical (HO_2) from the aircraft. A fast-response water vapour sensor and, in collaboration with scientists in the Federal Republic of Germany, instruments for total reactive nitrogen and carbon monoxide are also being developed.

Computer programs to calculate air parcel trajectories using velocity fields from numerical weather prediction models and the expected chemical evolution along the trajectory are being developed. The aim of this is to test rigorously the predictions of photochemical theories against observations.

An essential precursor of OH in the troposphere is ozone but there is uncertainty concerning the importance of local production of ozone, and exchanges of air with the ozone-rich stratosphere. In mid-latitudes, exchange takes place where the tropopause becomes 'folded' in the vicinity of jet streams. Although there have been local studies, it is difficult to estimate the net global exchange of mass. This might be done by using potential vorticity, derived from global numerical models, as a tracer. The extent to which such models reproduce the detailed observations was investigated and good agreement found between the observed and modelled water vapour mixing ratios.

Stratospheric chemistry

The Meteorological Office made measurements of total ozone in an atmospheric column, using Dobson spectrophotometers, at Bracknell, Lerwick and St Helena, in addition to providing assistance in connection with measurements at other sites forming part of a network of monitoring stations organized by the World Meteorological Organization.

From about 1979 observations made by the British Antarctic Survey have shown a dramatic downward trend from year to year of ozone concentrations within the antarctic polar vortex during September and October. Until this phenomenon is understood the global consequences will not be clear. Possible explanations range from a dynamical one, in which changes in the atmospheric circulation influence the transport of ozone to high latitudes, to a purely chemical one in which the decrease is related to anthropogenic changes in the atmospheric chlorine content. Essential components of the latter theory are the heterogeneous chemical reactions which take place on the surface of ice crystals found in the antarctic lower stratosphere. Isentropic trajectories calculated from data for antarctic latitudes obtained from Stratospheric Sounder Units on board polar-orbiting satellites have been used to calculate the length of time spent by air parcels in sunlight when photochemical processes are active.

Meteorological Research Flight (MRF)

View of the Hercules aircraft showing a pod under the starboard wing carrying cloud physics probes and the multi-channel radiometer.

The Hercules C-130 aircraft, based at the Royal Aircraft Establishment (RAE) Farnborough, is a major Meteorological Office facility for research. It is used by scientists from universities and research institutes as well as by the Office. It has also participated in an international project (HEXOS — Humidity Exchange Over the Sea) to study water vapour transfer from the sea in strong winds.

The aircraft can remain airborne for over 12 hours and operate up to 30 000 ft. It is flown by RAF aircrew and serviced by RAE ground crew. As well as using the aircraft for their own program, MRF scientists co-ordinate MRF services to other scientists. In August, the Hercules returned from a major overhaul to embark on a full flying program. During its overhaul further scientific equipment was fitted.

Instrumentation

The Hercules carries equipment to measure temperature, humidity, turbulence, and radiative fluxes. It also has a dropsonde release facility and chemical, aerosol and cloud sampling equipment, and an advanced navigation system.

A major project to replace the original data-recording system with a modern microprocessor-based device is nearly complete and the system is already in use. This includes a facility to provide the scientists on board with a real-time display of the data being recorded. A rapid replay device has also been built to enable scientists to take a 'quick look' at the data after a flight is complete.

A multi-channel radiometer is undergoing flight trials. This radiometer was adapted in collaboration with the Rutherford Appleton and Clarendon Laboratories from a prototype flown on the NIMBUS satellite. It measures radiative fluxes in selected wave bands in the visible and infra-red, and it complements broad-band solar and terrestrial radiation flux measurements made by other instruments.

A microwave radiometer is being installed. It will be used as a test system for a similar instrument to be flown on a US satellite in the early 1990s.

Radiation research

The Meteorological Office use of the MRF facilities is devoted primarily to studies of radiative transfer in clear air and cloud, and of the development of clouds and precipitation. A major objective is to improve the parametrization of the physical and dynamical processes involved in numerical forecasting and climate models.

MRF scientists are responsible for radiative transfer studies. A current problem is the representation of radiative transfer through broken (e.g. small cumulus) and semi-transparent (e.g. cirrus) cloud fields, and some progress has been achieved in the comparison of observations with theoretical models. In particular, an observed non-linear increase in albedo with cloud amount is of significance to general circulation models.

Another major problem is the effect of aerosol in cloud and clear air on radiative transfer. MRF scientists have observed that layer clouds absorb more solar radiation than is predicted by theory. In addition, a combined aircraft/satellite study of aerosol absorption during the 'straw burning' season has produced data of interest to studies of the nuclear winter scenario. An infra-red Advanced Very High Resolution Radiometer

Infra-red AVHRR image of south-east England on a day of widespread stubble burning. The blue dots indicate individual fires.

(AVHRR) satellite image of the distribution of straw-burning sites on the day of the flight is shown above. Observations of radiative fluxes are supplemented by post-flight analyses of the physical and optical properties of cloud water and aerosol (collected in clear air or cloud).

Cloud physics research

Because ice crystals can grow to precipitation size very rapidly in clouds containing supercooled water, it is important that the mechanisms responsible for their production and distribution within such clouds are understood. Maritime cumulus clouds, with temperatures above −10 °C, are frequently found to contain ice crystals in concentrations thousands of times higher than the number of ice-forming nuclei expected to be active at these temperatures. Previous aircraft investigations confirmed earlier ideas, based on laboratory work, that these crystals are produced by a multiplication mechanism in which ice splinters are formed during the riming of larger, pre-existing ice particles. The production and growth rates of these secondary ice crystals are highly dependent on temperature and on their subsequent motion within the cloud. Their eventual contribution to the formation of precipitation, therefore, probably depends on whether they are maintained in a favourable environment by the cloud dynamics.

Mesoscale research

There is great interest in predicting local variations in the weather over the British Isles for periods of up to 24 hours ahead. Several new systems designed to achieve this are now undergoing operational trials.

Satellite and radar data

Satellite visible and infra-red imagery enables weather systems to be identified in terms of clouds and moisture distributions. The characteristic patterns associated with middle latitude systems can be interpreted to determine the areas of rain. Information of this kind complements the guidance provided by numerical forecast models, and is especially useful in data-sparse areas.

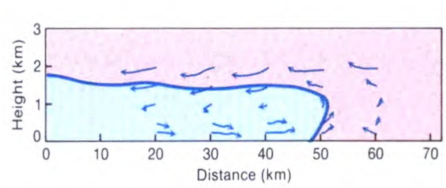
For the area within range of the UK radar network, more objective techniques can be applied to derive weather information from the combination of satellite and radar images. In the Office, this is done through the FRONTIERS computer and display system which can be used to produce detailed forecasts of rainfall for a few hours ahead. It operates on a 30-minute operational cycle and uses a specially designed work station. Radar data are quality controlled to remove spurious echoes, and satellite data from Meteosat from outside the area of radar coverage are used to infer the areas of precipitation which might affect the United Kingdom within a few hours. The radar and satellite rainfall fields are then combined, and forecasts produced by extrapolating the main areas of rainfall along tracks determined from their recently observed velocities. Trials of the operational system have been undertaken.

The satellite and radar data are also useful as input into a mesoscale numerical forecast model. The rainfall analysis is used to calculate the cloud thickness which is combined with surface observations of cloud base and satellite observations of cloud top. Layered structure can be deduced from the imagery and inserted to give a detailed three-dimensional cloud analysis.

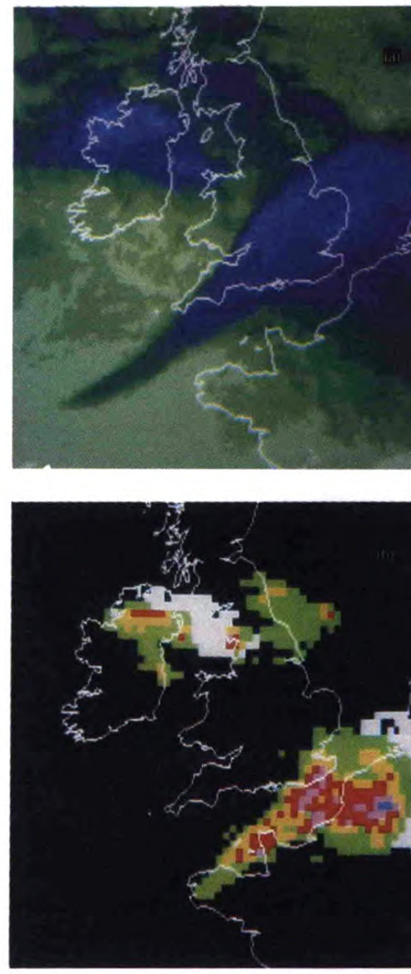
An example of Meteosat imagery illustrating a common feature, a frontal wave, is shown top right. Idealized models suggest that there should be areas of ascent along the tail of the cloud associated with the cold front giving widespread rain over southern England and another area, emerging from beneath the first, responsible for rain over northern England and Ireland. A 3-hour rainfall forecast, which showed good agreement with the observed rainfall distribution, was produced from this occasion using radar and Meteosat data; the major rainfall areas moved with different mean velocities.

Mesoscale Frontal Dynamics Project

The Office is playing a major role in the planning of the Mesoscale Frontal Dynamics Project which is intended to increase the understanding of complex processes associated with frontal systems. The Project, which involves other research groups in the United Kingdom, France and the Federal Republic of Germany, embraces both theoretical and modelling studies and an intensive program of observations. Preparations for the latter, which will take place over the English Channel during the autumn of 1987, include the development of a new aircraft drop-sonde to provide mesoscale soundings over the sea. On-going modelling activities related to the Project include the development of a three-dimensional convective-scale model. Unlike the mesoscale forecast model it attempts to simulate convection explicitly and therefore a high horizontal resolution is necessary. A grid length of 1 km is used. Simulations of an active cold front, initiated from mesoscale forecast model data, have demonstrated that there are complex circulations within both cold and warm air masses (see below).



Front-relative trajectories in a cross-section normal to the front for the first 50 minutes of simulated time. The blue area represents cold, dry air (low wet-bulb potential temperature) and the red area warmer, moister air.



(a) Meteosat infra-red cloud imagery where light blue denotes coldest (highest) cloud, and (b) FRONTIERS 3-hour forecast of rainfall distribution (heavy rain in blue) based on satellite and radar data for same time as (a).

Stratocumulus research

Extensive sheets of low-level stratiform cloud are common in many regions of the world, but forecasting their development has been hampered by an incomplete understanding of the processes involved. A series of detailed aircraft investigations has revealed many aspects of the structure of stratocumulus and, as a result, a model designed to reproduce them has been developed. The inclusion of a simple description of cloud microphysics enables proper account to be taken of radiative effects; it also allows diurnal variations to be studied and the effects of drizzle to be included. Unlike previous models two separate mixed layers may form and this is essential for the simulation of commonly observed features. As an example, in otherwise identical subtropical conditions, the formation of two mixed layers causes enhanced diurnal variation, with the thinnest cloud occurring during the afternoon. This feature and a corresponding seasonal modulation agree well with observations from geostationary satellites. The thinner cloud also enables more sunlight to reach the surface and this considerably alters the surface energy balance.

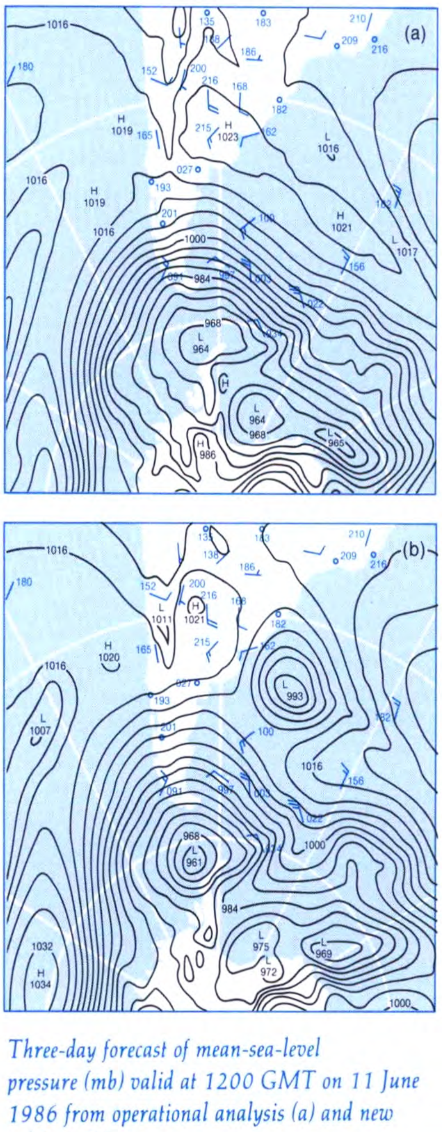
Forecasting research

The object of forecasting research in the Meteorological Office is to improve the forecasting system so that the needs of users for accurate and timely forecasts are met; and to make it as automated and efficient as possible. Complex computer models of the atmosphere are a central feature of the forecasting system. The present system was first implemented in September 1982. It incorporates a global model for forecasts up to several days ahead and a regional model, covering the North Atlantic and Europe, for predicting more detailed features of the weather over the British Isles up to 36 hours ahead. A very-high-resolution mesoscale model has been used experimentally (on a routine basis since October 1984) for forecasting local weather up to 18 hours ahead in the United Kingdom. Models of the latter kind open up the possibility of producing direct computer predictions of weather elements such as cloud amount and height, visibility, and surface temperatures that are of direct interest to many users. No forecasting system which treats meteorological phenomena in such detail has been used at any other weather prediction centre in the world.

Improvement of objective analysis of data

The global observing system which provides the basic data for forecasting is evolving continually. There is increasing dependence on observations that are not for the 'fixed synoptic hours', primarily 0000 and 1200 GMT, to which Meteorological Services were traditionally, and to a considerable degree still are, geared. The platforms for such observations are mainly satellites, or aircraft which can produce wind measurements automatically during flight. To ensure that new kinds of observation are used to best advantage within forecasting systems is a problem of formidable difficulty that will require continued attention by researchers.

The analysis system introduced in 1982 was designed to assimilate observations continuously. However, because of limitations in the available techniques, it was necessary to group data into 6-hour 'slots'. An analysis system has now been developed which allows observations to be inserted at their correct times. From the period from the last analysis up to the initial time for the next forecast, the computer forecast model estimates the detailed state of the atmosphere at 15-minute intervals. At each step an analysis of the data valid at that time is performed and a correction is applied to the estimate to bring it closer to reality. The correction allows for the expected errors in the observations and in the model predictions. At the end of the 'assimilation' all the new observations which are available have been used, and the forecast model is ready to produce a forecast. The greatest impact of this new technique can be seen over the oceans where the data are sparse. In the case shown here a developing low near Uruguay was missed by the operational system but correctly predicted by a forecast starting from the revised analysis.



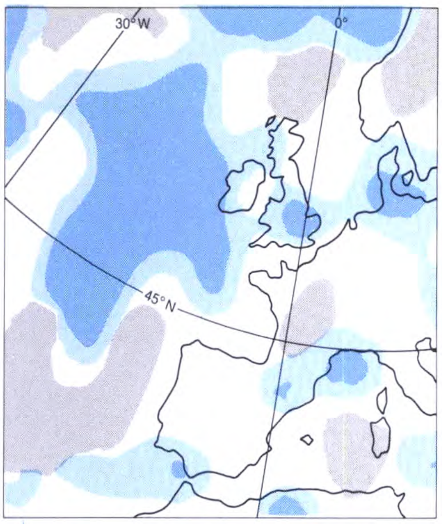
Three-day forecast of mean-sea-level pressure (mb) valid at 1200 GMT on 11 June 1986 from operational analysis (a) and new analysis (b).

Extensions to the representation of physical effects in the global model

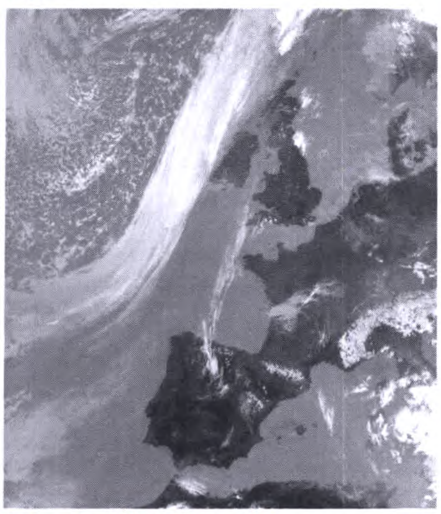
As is evident from everyday experience, cloud influences the amount of radiation reaching the earth's surface; therefore accurate cloud estimates are needed for predicting the surface temperature. The surface temperature is itself an important parameter for predicting other weather phenomena, for example the recurrence and intensity of convection. Methods of estimating cloud amount are investigated, primarily as part of the Office's program on climate, and successful techniques are then adapted for numerical forecast models. The regional fine-mesh model has incorporated a cloud prediction scheme for the last 2 years, but the requirements for a global model are more exacting and it is only recently that global cloud predictions have been produced. The figure opposite shows a typical layer-cloud forecast for comparison with the US NOAA-9 satellite photograph for the same time. The satellite picture shows cloud associated with a strong front to the north-west of the United Kingdom with shower clouds behind it; skies are clear over France and Spain. The model forecast delineates these main cloudy areas quite accurately although small regions of patchy cloud, corresponding to small-scale features, are not predicted well.

Communication between the main body of the atmosphere and the surface of the earth occurs through the 'planetary boundary layer' which is very variable but on average about 1 km in depth. Understanding of the processes by which heat, water vapour and momentum are transmitted through the layer is only partial, and therefore the 'parametrizations' of the processes in numerical prediction models are in a state of continuous evolution. A particular problem is that there is an inconsistency between the space and time-scales represented in the rest of the model and those that must be represented in the boundary layer. This can be overcome to some extent by calculating the integrated effect of boundary-layer processes over a model time step by mathematically implicit techniques. A method of doing this has been developed for operational use.

Over much of the world the atmospheric boundary layer is capped by a strong inversion which inhibits mixing between boundary-layer air and the free



Twelve-hour forecast of cloud for 1200 GMT on 1 May 1986. Grey shading indicates low cloud, light blue 5 and 6 oktas high and medium cloud, and dark blue 7 and 8 oktas high and medium cloud.



Infra-red satellite photograph from NOAA-9 at 1421 GMT on 1 May 1986. (Photograph by courtesy of University of Dundee)

atmosphere. When, however, there is cloud at the top of the boundary layer, air may be exchanged as a result of small-scale turbulent entrainment. This process is very important for transferring moisture into the middle troposphere. Since it is a small-scale effect, it cannot be represented explicitly by the numerical model and has to be calculated separately; a suitable method was developed for operational use.

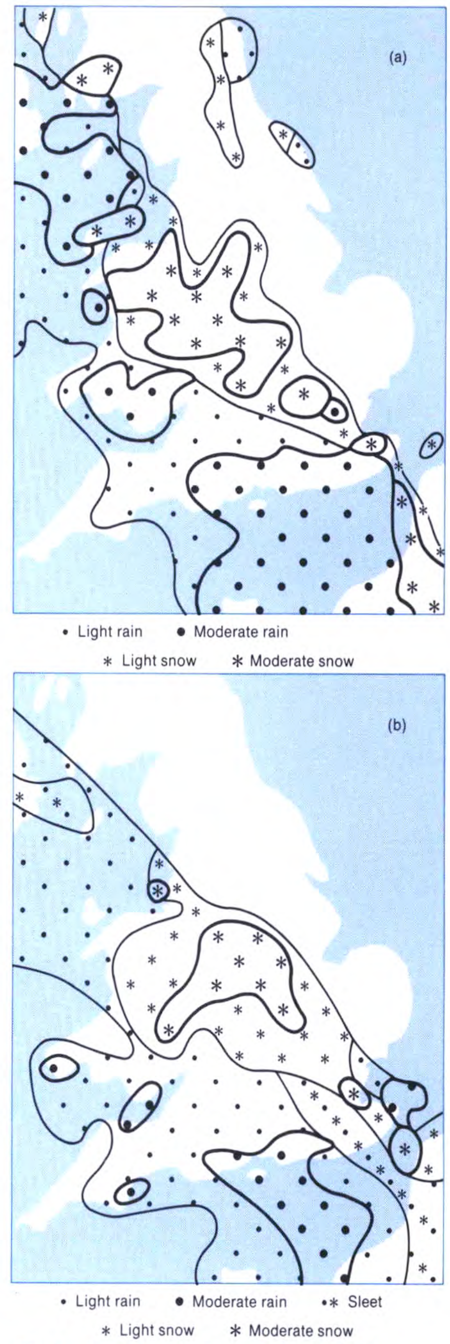
The combined effect of these improvements to the global model will improve the representation of the temperature and moisture structure and allow forecasts of variables such as surface temperature and sunshine duration to be produced routinely. Such forecasts have many applications, for instance for the travel industry.

Forecasts of weather over the British Isles using a mesoscale model

The daily trial of the very-high-resolution mesoscale forecasting system includes a 12-hour and an 18-hour forecast each day; one covers the daytime period 0600 to 1800 GMT and the other the overnight and morning period 1800 to 1200 GMT. The resolution of the model is 15 km in the horizontal and it has 16 levels in the vertical. The surface temperature, pressure, wind, humidity, cloud, visibility and rainfall are all quantities predicted by the model. Initial data are provided by merging the analysis prepared for the regional forecast model, which has a 75 km grid in the horizontal, with a previous forecast from the mesoscale model and with observations from the surface synoptic network, such as pressure, temperature, wind, humidity, and visibility, as well as the cloud type, amount and base and the rate of rainfall, from which the cloud distribution can be inferred. In the light of radar observations of rainfall rate and satellite observations of cloud top, the model rainfall and cloud fields are modified manually, using an interactive graphics system connected to the Office computer system.

One of the important applications of the model is the accurate prediction of the transition from snow to rain. This transition is very sensitive to the detailed structure of the air masses involved as well as to the local topography. As an example, on 7 January 1985 a warm front was moving north-eastwards over England and Wales. Over the land the precipitation was initially snow, but over the sea it started as rain, before turning to sleet temporarily as it became heavier. There were regions of moderate precipitation over the Midlands and south-east England. South-west of a line from Aberystwyth to Brighton the precipitation had turned to rain by the time illustrated, with some areas of moderate rain. The model forecast was slightly slow in moving the precipitation north-eastwards. The snow with regions of moderate snow was well predicted, given that there is as yet no explicit treatment of sleet in the model. The line of the transition to rain was forecast correctly, except for a small error near the south coast. Moderate precipitation was predicted in the correct regions, though it covered slightly too large an area. The reduction in the precipitation rate in the south-west peninsula was also correctly predicted.

The products from the mesoscale model are expected to be of use to outstations. One of the routine tasks they perform is



Twelve-hour forecast (a) and observed (b) precipitation for 1800 GMT on 7 January 1985.

the forecasting of screen temperatures for use by the Gas Boards in their estimates of likely gas consumption. Forecasts from the model for several stations were verified routinely with those made at the outstations themselves. An example of the results is shown in the table overleaf. Essentially the same information is available to the model and to the forecasters before making the forecasts for 1500 and 1700 GMT. However, the forecasters have access to several hours more information before making the forecast for 0900 GMT. Assuming that forecasts can be considered accurate if they have errors of less than 2 °C, predictions from the model have about the same level of accuracy as those made by forecasters, even when the forecasters have access to later information.

Percentages of forecasts for forecaster (a) and model (b) within specified limits at six locations in January 1986. Forecasts for 1500 and 1700 GMT are issued at 0700 GMT for both forecaster and model. Forecasts for 0900 GMT are issued at 0000 GMT for the forecaster and 1900 GMT for the model.

Time GMT	Tolerance °C	Southampton (a)	(b)	London (a)	(b)	Watnall (a)	(b)	Manchester (a)	(b)	Newcastle (a)	(b)	Glasgow (a)	(b)
1500	1	68	83	83	76	91	73	67	80	77	70	80	70
	2	96	100	90	97	100	97	97	93	93	90	100	93
	3	100		97	100		100	100	100	93	97		10
	4	100		100						100	100		
1700	1	74	70	70	68	83	83	74	84	77	77	68	65
	2	96	89	97	94	92	92	97	94	87	94	81	90
	3	96	96	100	100	96	100	100	100	97	100	97	100
	4	100	100			100				100		97	
	5									100		100	
0900	1	67	67			71	52	57	69	64	71	61	79
	2	96	92			95	81	82	85	79	86	82	89
	3	100	100			95	95	100	96	89	89	96	93
	4					100			100	100	96	100	96
	5						100				100		100

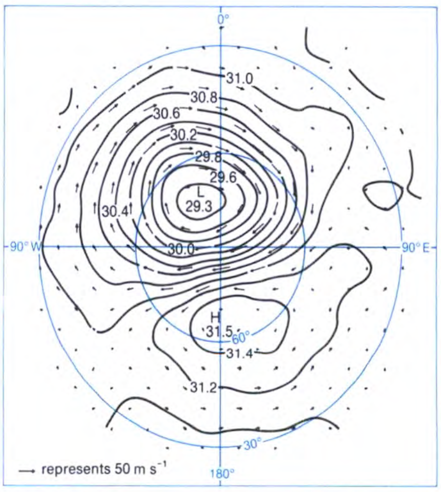
The middle atmosphere

The section of the atmosphere above the tropopause and below a height of about 85 km is usually referred to as the middle atmosphere. In the lower part, known as the stratosphere, the temperature generally increases with height while above, in the mesosphere, it decreases with height.

The stratosphere contains ozone which shields the earth's surface from the harmful effects of the sun's ultraviolet radiation. Its distribution is maintained by combined radiative, chemical and dynamical processes. Satellite measurements of temperature and chemical concentration and elaborate numerical models enable the complex processes at work to be studied.

A numerical model with high spatial resolution has been developed to simulate the middle atmosphere's circulation and investigate its coupling with the underlying troposphere. The work has been carried out in collaboration with the Department of Atmospheric Physics, University of Oxford, who have designed the model's representations of the effects of radiation and the high-level dissipation of gravity waves. A number of so-called sudden warmings, i.e. sporadic rapid increases in stratospheric temperatures sometimes exceeding 50 °C, were successfully reproduced by the model. The model is also being integrated through an annual cycle to ascertain what governs systematic changes in the circulation, such as the rapid shrinking of the westerly vortex in the northern hemisphere after midwinter.

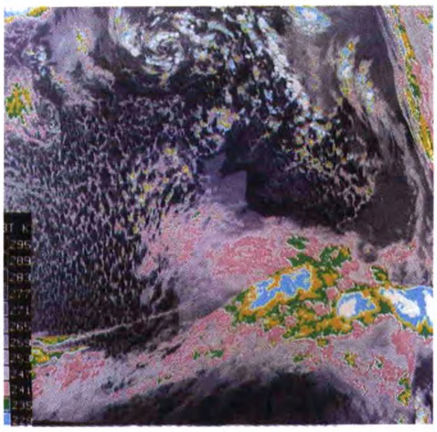
Observational studies complement the numerical experiments. Analysed data from Stratospheric Sounding Units (designed at the Meteorological Office and flown on the US NOAA series of satellites) now provide 8 years of daily global synoptic maps for various stratospheric levels which are made generally available to scientists for research purposes. Attention has been directed towards studies of the circulation of the southern hemisphere, where data were scarce before the advent of satellites. In contrast to the northern hemisphere, the stratosphere in the southern hemisphere is quiescent for most of the year. In the early spring, however, the flow becomes highly distorted as a prelude to a 'final warming', when warm air replaces cold air over the South Pole and winds reverse from westerly to easterly. The figure illustrates the onset of a final warming during November 1985. An anticyclone develops in approximately



Height (decageopotential metres) of the 10 mb pressure surface in the mid-stratosphere of the southern hemisphere on 1 November 1985. Arrows indicate the wind speed and direction. The big cyclonic vortex is displaced from the central position over the pole that it occupies for most of the winter. Note the strong jet stream over the polar cap.

the same place each year and subsequently moves over the pole. The troposphere is thought to induce these changes together with the evolving field of radiative heating. It is intriguing that the occurrence in the stratosphere of low concentrations of ozone (see Atmospheric chemistry) coincides with the development of the final warming.

Satellite meteorology



Infra-red brightness temperature field derived from the AVHRR instrument carried on the current NOAA polar-orbiting satellite. A rapidly developing depression is shown as it moves over the United Kingdom. Note the sharp edge to the cloud, which is close to the jet stream level, the eddies evident in the flow to the north of the United Kingdom, and the cellular convection which is widespread north of the frontal cloud band. Studies are under way to investigate the extent to which such images may aid forecasters in assessing how such systems will develop.

Development has continued in the area of satellite meteorology on a number of aspects. Work has been carried out to specify new ways of using soundings and images derived from polar-orbiting and geostationary satellites. The Office has contributed financially to EUMETSAT (EUropean METeorological SATellite organization) which in 1986 took over the running of the present European geostationary satellite, Meteosat II, and the development of future systems from the European Space Agency (ESA). The year was also notable for the founding of the British National Space Centre (BNSC). The Meteorological Office contributes to the BNSC program through some of the work being carried out on satellite meteorology. As in previous years the Office provided instruments for the US operational polar-orbiting satellites. Satellite instrument work is described elsewhere in the Report.

Local Area Sounding System (LASS)

The computer-based Local Area Sounding System enables meteorologists to analyse the temperature and humidity structure of the atmosphere from measurements made routinely from polar-orbiting satellites. During the year, about 1.5 million temperature profiles were supplied to the Central Forecasting Office and to the numerical prediction models.

A number of important developments that should lead to improvements in the quality of the retrieved soundings are being made. One involves a sophisticated method of minimizing the contaminating errors induced in the retrieved soundings by the presence of cloud. In another, forecast temperatures from numerical prediction models are used as the basis for a new method of improving the retrieval of the temperatures.

The AUTOSAT-2 computer system

With increasing demands for accuracy and detail in weather forecasts, more emphasis is being placed on the quality and presentation of satellite information. A computer system, known as AUTOSAT-2, for the extraction of as much information as possible from satellite data has been designed for operational use within the Office. Dedicated computers are required because a large amount of data is involved, and because satellite images are required for use by forecasters as soon as possible after they are obtained from the satellite instrument. Images from two types of satellite will be processed: from the TIROS-N series of polar-orbiting satellites, and from geostationary satellites including Meteosat.

As an example of the amounts of data involved, each time one of the TIROS-N satellites passes close enough to the United Kingdom for data to be received, which it does on average seven times a day, it broadcasts the equivalent in data of 75 copies of a medium-sized novel. The total amount of data from Meteosat and two polar orbiters in 1 day is equivalent to about 1700 novels — a fair-sized library.

Definition of the AUTOSAT-2 system and the products to be made available on it are subject to continuing investigation.

Research on satellite imagery

Quantities which can be deduced from satellite images include the temperature of cloud tops and of the sea surface, and the location of areas of fog and low cloud. They will be among the products distributed on AUTOSAT-2.

A scheme for automatic quantitative analysis of high-resolution image data in terms of cloud and surface parameters has been developed for use in numerical models. Trials of the products have begun. The use of time sequences of images in understanding dynamical systems is being assessed. The photograph above is of a fast-moving depression. Information on the air motion and three-dimensional cloud structure can be extracted from such pictures. Methods have also been developed to find effective ways of using false colour in displaying satellite images.

Collaborative projects

The improved exploitation of satellite data, primarily in support of weather forecasting, continues to be a major part of the program of the Hooke Institute (Oxford) — a collaborative institute with the Natural Environment Research Council and the University of Oxford.

The Office has participated in the development of algorithms for the ESA wind scatterometer to be flown on the Earth Resources Satellite (ERS-1). Studies for the UK ERS-1 data centre at the Royal Aircraft Establishment, Farnborough were completed with initial specification of data sets, data flows and algorithms. A contract with ESA for a limited feasibility study of a near-real-time operational quality control and real-time validation scheme involving numerical model real-time data has been agreed.

The Office has responded to an invitation issued by ESA for proposals to use data to be produced from the ERS-1 satellite. The surface wind and wave data, which will become available in near real time when the satellite is launched at the end of the decade, are of particular interest for forecasting. Preparatory work is now beginning with a number of impact studies to assess the effect of these data on numerical weather prediction models.

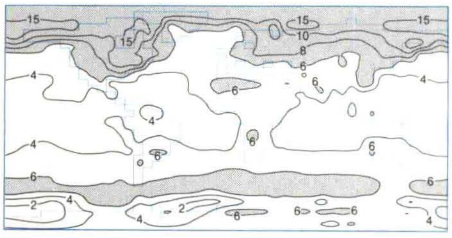
Climate research

improved in several respects — weaker westerlies over the northern continents in winter as expected from previous experiments with the gravity-wave drag, a more realistic contrast between wet and dry zones over the tropical oceans, and a reduction in annual and diurnal surface temperature ranges due to the new soil temperature parametrization. However, simulated cloud amounts were excessive over land and degraded some aspects of the simulation.

Climate modelling

A major objective of Meteorological Office research on climate is the development of a numerical model of the complete climate system, including the oceans, sea-ice and land surface, in addition to the atmosphere. During the year, a significant milestone was reached when the existing atmosphere model was coupled to a full ocean/sea-ice model and the coupled system was run for a simulated time of 18 months. Many oceanic features were reproduced or maintained correctly, but the main purpose of the integration was to highlight weaknesses, particularly of the ocean representation, which require further consideration. In this context, it was noted that better resolution of the near-surface layers of the ocean was needed and that the ocean description at the start of the integration was not entirely realistic.

Pending the use of the full climate model, investigations on the effect of doubled carbon dioxide (CO_2) concentrations on climate have been carried out using a model in which the oceans are represented as static bodies of water 50 m deep with uniform temperature in the vertical. The effects of ocean currents are allowed for, to some degree, by heating or cooling the oceans by amounts estimated, from climatology, to be transported within the oceans. Two integrations, with normal and with doubled CO_2 concentration but with the same estimate of ocean heat transport, were then compared. The results showed a global mean warming at the surface considerably greater than has been obtained in previous Meteorological Office integrations, though in conformity with recent results obtained in the USA. There are, of course, a number of major uncertainties and these latest results, which try to incorporate new physical processes, are not necessarily more reliable than earlier estimates from simpler models. Perhaps the major uncertainty is associated with the representation of cloud and cloud variations, which are recognized to be exceedingly difficult to simulate realistically because of the enormous disparity between cloud-scale processes and the large-scale processes that the models are designed to deal with. With enhanced CO_2 concentrations, the model results indicate reduced cloudiness, particularly over land areas, and this leads to a greater surface warming. It is, however, open to question whether the techniques, based on relative humidities only, for deriving cloud amounts are adequate. In reality, the amount of cloud, and its physical properties such as reflectivity and absorption, are the result of complex processes involving cloud microphysics and dynamics. Attempts to improve the representation of cloudiness are being given priority, as they have important applications in short-term weather forecasting as well as in climate research. A method which involves carrying the amount of liquid water and ice in clouds was developed during the year, and the first results indicate that it is capable of giving more realistic estimates of cloud amount for the present climate.

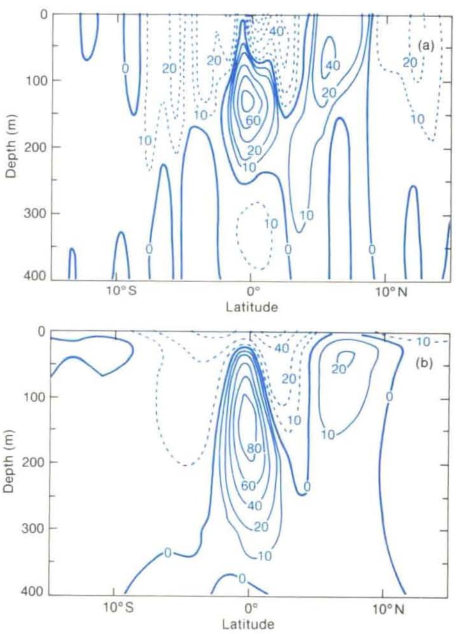


Average (15-year mean) changes in surface temperature (°C) for the period December–February due to a doubling of atmospheric CO_2 in a coupled slab ocean–atmosphere model.

For a model to be useful in studies of the response of climate to perturbations of the environment, as many as possible of the processes and interactions present in nature should be represented. The climate model therefore now uses model-determined cloud amounts and physically based representations of thermal and hydrological processes at the land surface which permit geographically varying soil and vegetation characteristics. The simulations must also be as realistic as possible, so a parametrization of gravity-wave drag and improved representations of convective and near-surface turbulent exchanges have been included. With these changes the model's simulation is

For the purpose of investigating El Niño events in the Pacific, the global ocean model has been adapted to create a model of the tropical Pacific with a much higher resolution near the equator. A comparison of the results of the original and the higher-resolution model has shown that, although large-scale features are similar in both, important smaller-scale circulations such as the eastward-flowing equatorial undercurrent are reasonably represented only in the latter. The process of coupling the tropical ocean model and the global atmosphere model, which is required to predict an El Niño event, is now well advanced. Research has shown that, although the El Niño event is a Pacific phenomenon, related changes also occur in the Atlantic.

A problem with experiments that simulate the effects of increasing the amount of CO_2 is the impossibility of verifying them *now*. There is only one



The speed (cm s⁻¹) of the Pacific equatorial undercurrent from observed data (a), and from the tropical Pacific model's simulation (b). Both figures show the annual mean latitude–depth cross-section of the east–west current component (solid lines) and the west–east current component (dashed lines) at 155 °W.

well-defined climate (the present) with which to verify the models and that has to some extent been used in developing them. One solution is to use past climates even though knowledge of these is limited. One of the best documented is that of about 9000 years ago when the earth's orbit differed from the present giving more heating of the northern hemisphere in summer; palaeoclimatic data (mainly of lake levels) imply a wetter climate over land in the northern hemisphere subtropics. An experiment was run with the coupled slab ocean–atmosphere model using the earth's orbital parameters for that time. The results show intensified summer monsoon rains over Asia and parts of north Africa, though over Africa the modelled increased wetness is not sufficiently extensive.

Other research activities this year included investigations through two co-operative studentships, one with the University of Southampton on the effect on the ocean circulation of variations in the water balance (i.e. precipitation less evaporation) at the ocean surface, and the other with the University of Liverpool on the impact on climate of higher reflectivity in snowy conditions resulting from a reduction in the extent of coniferous forest at middle and high latitudes.

Sahel drought

For the 19th year in succession the so-called wet season in the Sahel area of Africa (the belt stretching from Senegal to southern Sudan just south of the Sahara Desert) has brought below-average rainfall. An investigation revealed relationships between world-wide sea surface temperature (SST) anomaly patterns and Sahel rainfall, which normally falls between June and September. The statistical results are supported by general circulation model simulations which confirm that the SST patterns on a global scale are important, although the local distribution in the Atlantic Ocean has the greatest effect. Of course, other mechanisms, such as feedbacks involving land-surface albedo, soil moisture and vegetation, may also be instrumental in the persistence of the Sahel drought.

The study of the links between Sahel rainfall and mid-latitude atmospheric circulation in the northern hemisphere continued. In July and August during the periods of Sahel drought, rain-bearing Atlantic depressions tend to be deflected to the north of the British Isles, a characteristic feature that has relevance for long-range forecasting in middle latitudes.

Sea surface temperatures (SSTs)

Because SST anomalies are so closely related to variations in the atmospheric circulation, work continued on corrections to the historical data set. A significant improvement was possible following the completion of work on regionally and seasonally varying corrections to observations made before World War II when the use of uninsulated buckets, which were very prone to evaporative cooling, allowed the temperature of the water sample to fall before the thermometer had been read. These corrections have improved the consistency of the long-term climatic trends shown by each season especially before 1900; the inferred SST–Sahel rainfall relationship is also improved.

When simulations from different global atmospheric circulation models are to be compared it is important that the experimental details are as consistent as possible. In the past, even when the same or similar SST anomalies were used, inconsistencies were introduced by adding them to different climatological means. During the year a carefully constructed SST climatology was produced for each month of the year. These climatologies are based entirely on ship observations for 1951–80 and, where ship observations are inadequate, techniques have been used to blend in published climatological data. It is hoped that the new values will be used to ensure greater uniformity.

Long-range forecasting

Ensembles of seven individual integrations of a Meteorological Office general circulation model, starting from consecutive operational analyses 12 hours apart, are examined once a season at the Meteorological Office's internal long-range forecasting conferences. On average there is a small degree of skill out to 20 days for 5-day averaged fields. In the forecasts, SSTs are taken from analyses averaged over the 10 days before the first starting date. Other studies of the importance of SST anomalies for the skill of long-range numerical forecasts showed that, if the observed sequence of SSTs during the intense El Niño period in 1982–83 is used instead of climatology, the representation of the development of the monthly mean wind field at 200 mb in the tropics is improved substantially. In the extra-tropics the improvements are smaller and do not become evident until after the first 30 days.

Mean-sea-level pressure difference (mb) in the extra-tropical northern hemisphere in August, for the period 1968–84 (dry years in the Sahel) minus 1950–59 (wet years in the Sahel). Note higher pressure over the United Kingdom with increased westerlies to the north-west.

The long-range forecasts produced experimentally twice a month are based mainly on statistical methods. The higher level of skill in forecasting temperature and rainfall, attained after the introduction of major changes of method in 1980–82, has been maintained, and improvements in forecasting the surface pressure pattern have been observed. A revised technique for interpreting forecast patterns in terms of rainfall has improved the rainfall predictions. It involves matching the forecast pressure pattern to patterns observed in previous years and using the corresponding temperature and rainfall distributions as a guide. Account is also now taken of the effect on temperatures over the United Kingdom of SST anomalies in the nearby oceans.

The overall skill of the 30-day forecasts is low, but positive, and is correlated significantly with the confidence indicator that the forecasters attach to the forecasts. This confidence indicator depends on the consistency of the indications from all the techniques, both dynamical and statistical, that are used.

Other dynamical investigations

Investigations are proceeding into relationships between potential vorticity and the stream function associated with persistent atmospheric systems. The results may aid prediction as well as the understanding of the behaviour of monthly atmospheric anomalies.

A study is being undertaken of oscillations on a time-scale of 30–60 days in the atmospheric circulation. Such oscillations are clearly evident at 200 mb as an eastward-propagating disturbance in the divergent wind field with a wave-number-one structure. This feature has been found in data from operational analyses and also in multi-annual integrations with the 11-layer general circulation model.

Boundary-layer research

In most flows over solid surfaces the immediate effects of the surface are confined to a relatively thin layer adjacent to it. The earth's atmosphere is no exception and the planetary boundary layer is that region of the atmosphere, adjacent to the surface, where rapid vertical transfers of momentum, heat and moisture occur. The transfers occur through turbulent eddies whose dynamics and scale may vary considerably. In the daytime large-scale eddies may be driven by buoyant convection, while in strong winds the basic wind shear provides the source of eddies. At night the stable buoyancy stratification restricts the shear-driven eddies. The Meteorological Office's boundary-layer research is concerned with improving the representation of the boundary layer in a variety of applications.

The representation of the boundary layer in numerical weather prediction models is of particular concern. This application deals mostly with the gross transfer properties of the boundary layer whilst other applications focus on the human activities occurring within the boundary layer. An important part of the latter work is concerned with the transport of species within the boundary layer and is further discussed in the section describing the Chernobyl accident. Other aspects of the work deal with the structure of boundary-layer flows and their statistics; information on wind shears, gusts and temperature structure is required for such widely varying applications as forestry, building and aviation.

Boundary layers over the sea

The transfers of momentum, heat and moisture which occur over the sea provide a coupling between the atmosphere and the ocean, and are of particular importance to the formation of sea fog and low cloud. An analysis of measurements close to the sea surface obtained using the Hercules aircraft of the Meteorological Research Flight has been completed. The results provide an improvement in the specification of the relationship between the surface fluxes and the geostrophic wind above the boundary layer.

Towards the end of the year the main phase of HEXOS, an international experiment to study Humidity EXchange Over the Sea, took place. The experiment provided a rare opportunity to combine comprehensive surface-based measurements with data from the aircraft so that the whole of the boundary layer could be studied.

Dispersion in the atmosphere

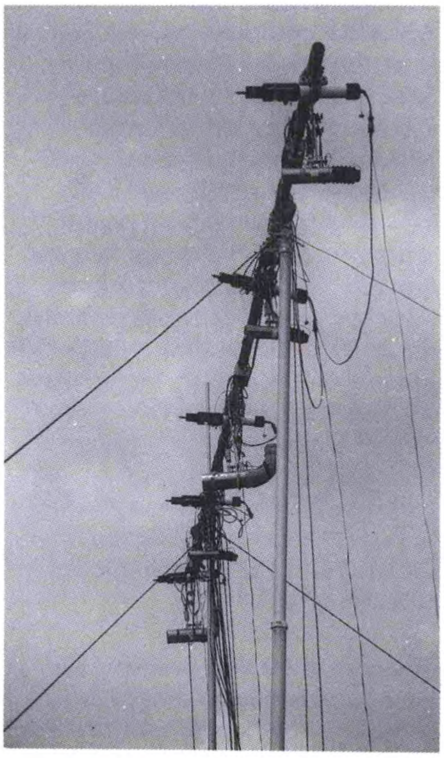
In view of the interest in long-range transport of pollutants and its relation to the acid rain problem, attention has been given to the errors arising in the calculation of trajectories in both forecast and observed wind fields. In both cases the results were found to be insensitive to the methods of interpolation: those calculated using a series of forecasts extending up to 3 days ahead, and those calculated using subsequent analysed synoptic fields. The separation in space between these trajectories is found to grow linearly with time at a rate of about 2.5 m s^{-1}. This rate of error growth is largely due to the inaccuracies of the forecast.

Although there is a substantial body of data on dispersion it is limited mainly to measurements of mean concentration in simple terrain. There is an urgent need to extend these measurements to complex terrain and to obtain information on fluctuations in concentration. For averaging times of some tens of minutes or longer the peak values of concentration within a plume may be ten times greater than the mean concentration, and of considerable practical consequence in determining the effect of toxic or inflammable gas. Current work is concerned with the establishment and evaluation of instrumentation necessary to conduct studies of dispersion on scales up to some hundreds of metres (see photograph).

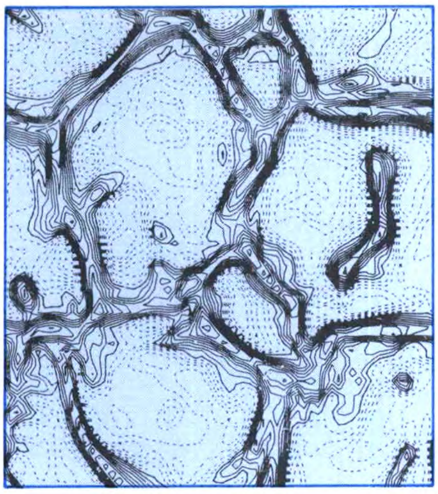
Investigation has continued into 'random walk' techniques of simulating pollution dispersion in the atmosphere, and a number of theoretical questions concerning the way in which such models should be formulated have been clarified. The correctly formulated models show consistently realistic behaviour and give encouragement for the further application of this technique.

Boundary layers over complex terrain

During the spring a major field experiment was conducted to allow an investigation of the structure of the boundary layer over complex terrain. This experiment involved the first detachment of the new Meteorological Office balloon facility from Cardington, and was located near the village of Llanthony in the Black Mountains of South Wales. The aim of the experiment was to determine the fluxes of heat, moisture and momentum over the mountains and thus to check the representation of these fluxes in theoretical models. The tethered balloon was flown to heights of up to 2 km above the surface, with measurements made simultaneously at six heights. The measurements were made with new turbulence probes. Each probe provides measurements of the wind components and temperature with a frequency response of 10 Hz. The probes are

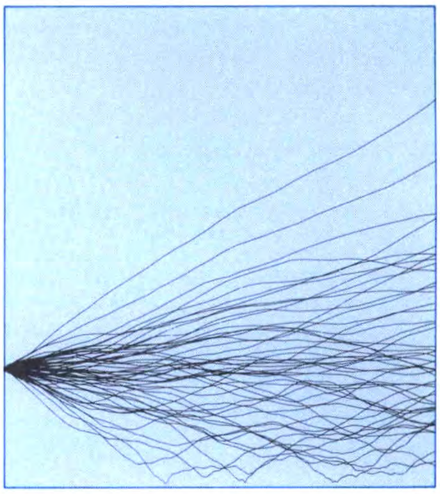


An array of fast-response concentration instruments for use in studies of short-range dispersion. The instruments are mounted 4 m above the ground. They are shown operating just above instruments used by the Chemical Defence Establishment, in an intercomparison experiment.



Results from a large-eddy simulation (left) of a daytime boundary layer with solar heating and a small mean wind speed. A horizontal section of the vertical velocity field 100 m above the ground. The solid contours denote upward motion and the dashed contours downward motion; the contour interval is 0.13 m s^{-1}. In agreement with field observations the rising motion is confined to narrow regions. This form of flow structure has a strong influence on the transport of pollutants.

A series of trajectories (right) starting at a point and showing a random walk simulation from an elevated source in a neutral boundary layer. In this example 50 trajectories are shown; to obtain accurate statistics several thousand would be needed.



attached at various heights to the balloon tether cable and the system of probes allows corrections for the velocity of the cable to be made. Despite gales and frequent heavy rain a considerable amount of data was collected in predominantly westerly winds over a range of stability conditions. Initial analysis of the data has shown promising results which should lead to a significant advance in knowledge.

Large-eddy simulation

Just as numerical weather prediction models try to describe explicitly the synoptic-scale eddies, a large-eddy model uses a three-dimensional numerical simulation to describe the large-scale boundary-layer motions. The objective is not to forecast the behaviour of particular eddies, but rather to obtain the statistics or, by analogy with the large-scale model, the 'climatology' of the boundary layer. Work has continued on the careful extension of the technique from simple to more complex flows.

An extensive series of simulations of a convectively heated (daytime) boundary layer with a capping inversion has been conducted. Differences in the parametrization of small-scale eddies and in the model domain size and resolution were considered. Although many features of the flow are insensitive to these details, others are not and a detailed analysis is proceeding. The results will be used for testing and development of other simpler models, whilst the improved understanding of the large-eddy simulation technique will lead to application in more complex flows.

Aviation research and development, and special investigations

Aviation studies

Safety and economy in aircraft operations largely determine the work undertaken in the field of aviation meteorology. As the aviation industry develops, new problems in aircraft design and in operations emerge requiring meteorological inputs for their solution. More accurate forecasts are also a continuing need. Some of the investigations which were carried out to meet these needs are described below:

Forecasting

The cost of meteorological services to airlines might be reduced if significant weather charts were produced by automatic techniques, and methods of doing this continued to be investigated. The results of a year-long trial in collaboration with three major airlines demonstrated an acceptable degree of skill in the probability forecasts of clear air turbulence over the North Atlantic and Europe. Automated forecasting of convection is also at an advanced stage of development, and methods of combining forecasts of clear air turbulence, deep convection, maximum wind speed and tropopause height in a simple pictorial form for operational use were developed.

The prediction of the extent and timing of the formation and clearance of fog and low cloud are major problems for the forecasters at many outstations. A program of observations of sea fog over the Moray Firth (Project 'Haar') by the Hercules aircraft of the Meteorological Research Flight was concluded and a report prepared. Understanding of the mature fogs typically found in the area has been greatly increased as a result. Following on from this program, a survey of very low cloud over the whole of the United Kingdom was started as a preliminary for developing methods for forecasting the formation and spread of low cloud over inland stations.

Operations

Better methods of using existing wind forecast information in advanced flight management systems are being sought so that the efficiency with which aircraft make use of the airspace and manage fuel in the approach and arrival phases of flight is improved. One possibility being explored is to obtain the correlation of forecast wind errors with height and, from a recent measurement made on board the aircraft, use the correlation to adjust a forecast wind profile.

Special investigations

Specialized studies over a range of non-aviation topics are carried out in response to specific requests for advice when current knowledge is inadequate. Some examples are provided below:

Radio duct forecasting

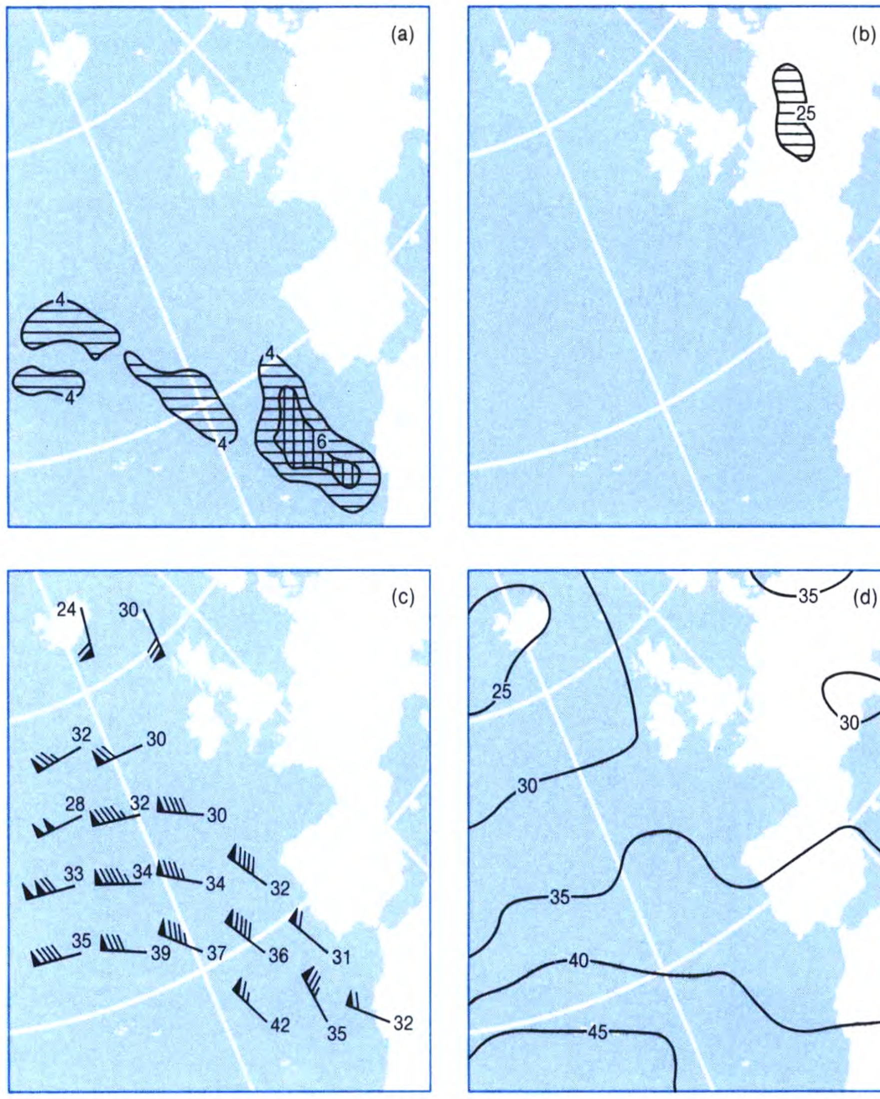
Radio ducts interfere with radio communication and a technique for forecasting them from the Office's operational forecast models would be valuable. The evaporation duct over the sea received particular attention; a physical model based on boundary-layer theory was developed and tested for sea areas surrounding the British Isles, and plans are in hand to verify forecasts based on the fine-mesh model for an area extending over the North Atlantic and the Mediterranean. The more difficult problem of identifying and forecasting elevated ducts from model output is now being studied.

Model output statistics (MOS)

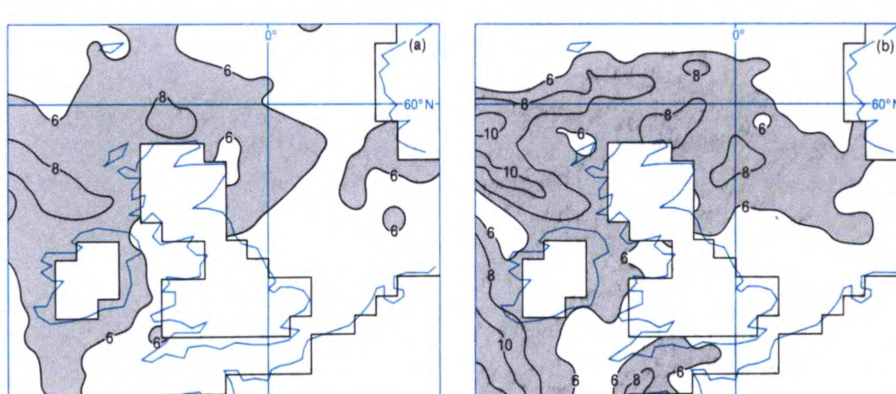
Output from the present operational forecast models represents averages over large areas. Statistical forecasting methods, which use correlations between model grid point values and observations at nearby sites, are being developed for deducing objective local forecasts from numerical forecasts. A novel feature is that the correlations are updated automatically each month in order that the consequences of changes in the numerical models are quickly incorporated. The operational use of maximum and minimum temperature forecasts up to 36 hours ahead, for 35 stations in the United Kingdom and Eire, began in the autumn. Work is in hand to extend the MOS forecasts to all UK stations and some overseas stations using the global model, and to increase the range of variables so that most of the content of a typical weather report is included.

Road surface temperatures

After a successful trial for a 3-month period in the winter of 1985/86, a model for predicting road surface temperature up to 24 hours ahead from standard forecast meteorological data was incorporated into the Meteorological Office 'Open Road' service to local highway authorities. It now runs on small Personal Computers installed at Weather Centres and is connected directly to the local authority network of road surface temperature sensors. It incorporates computer programs that make it particularly convenient for forecasters to use.

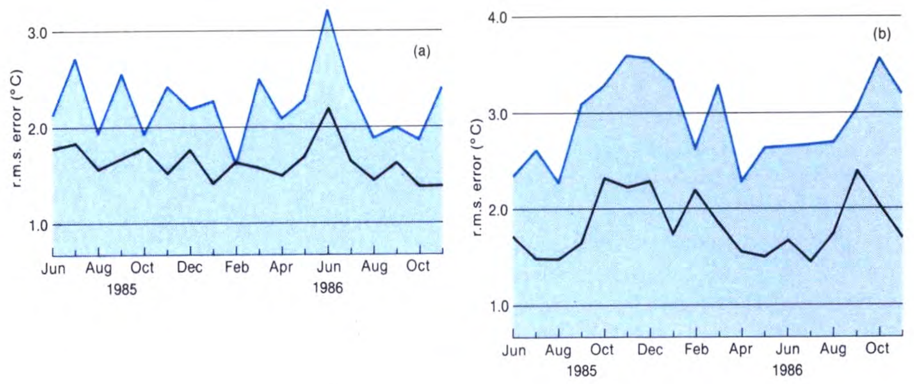


Forecast significant weather above 25 000 ft for part of the North Atlantic area produced objectively from computer model output (all heights are in thousands of feet): (a) Clear air turbulence probability (percentage per 100 km), (b) convective cloud tops with associated turbulence and icing, (c) maximum wind and height, and (d) tropopause height.



Evaporation duct height (metres) over the sea (only areas with duct height greater than 6 metres are shown): (a) analysis for 1200 GMT on 16 January 1985 and (b) 24-hour fine-mesh model forecast verifying at the same time.

Root-mean-square (r.m.s.) errors in temperature forecasts using MOS (black lines) and persistence (blue lines) for 35 UK and Eire stations. The midday model run provides the MOS-based maximum temperature forecast for the next day (a) and the midnight model run the minimum temperature forecast for the following night (b).

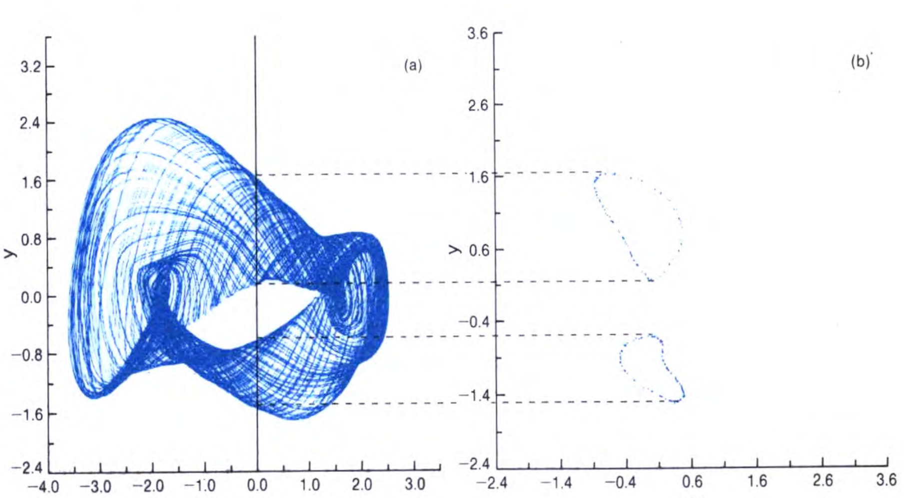


Geophysical fluid dynamics

In seeking solutions to many of the major problems of dynamical meteorology, it is necessary to adopt an approach which entails many diverse techniques, including the analysis and interpretation of observations, and the investigation of related systems such as numerical models, laboratory analogues and the atmospheres of other planets. Research into the basic hydrodynamical processes underlying a wide variety of phenomena in the atmospheres and hydrospheres of the earth and other planets is undertaken by the Office; the predictability of rotating fluid systems is a central theme. Current projects include: the investigation of angular momentum fluctuations in the earth's atmosphere; laboratory, numerical and analytical studies of thermally produced motions in rotating fluids; and the interpretation of highly persistent eddies which occur in the atmospheres of Jupiter and Saturn.

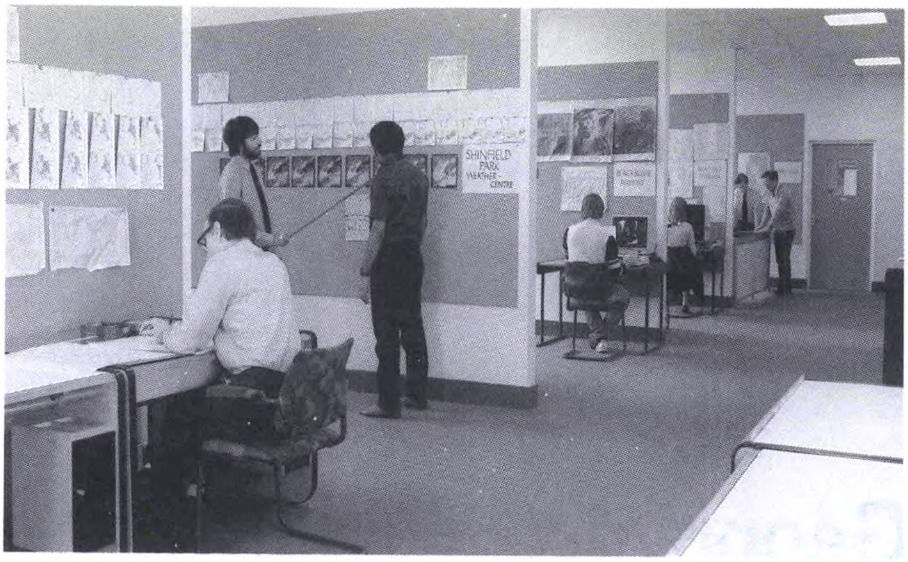
Atmospheric angular momentum fluctuations are of geophysical, astronomical and meteorological interest. Short-term changes in the length of the day have been shown to be due almost entirely to the transfer of angular momentum between the atmosphere and the solid earth. In principle, therefore, it should be possible to make useful forecasts of such changes with the aid of global atmospheric prediction models. Feasibility studies along these lines have made good progress, and routine forecasts should be forthcoming shortly. They will be of practical use in astronomy and spacecraft navigation. One of the principal findings so far as meteorology is concerned has been the discovery of a persistent, irregular and pronounced intra-seasonal fluctuation whose origin is not yet clear. This phenomenon has not yet been simulated satisfactorily in numerical models.

Also of relevance to predictability studies are some of the findings of a long-standing, extensive program of basic research on thermally driven flows in rotating laboratory systems and corresponding numerical models. New methods of data analysis, suggested recently by mathematical topologists, have proved of value in categorizing flows and the transitions between them, and for quantifying the intrinsic predictability of a flow. In such methods, the evolution of a flow is represented in geometrical terms (a 'phase portrait'), and the topological properties of the data in this representation are used to characterize the flow. An example of a perfectly predictable, doubly periodic flow (a steadily drifting wave with a periodic modulation, somewhat reminiscent of the index cycle in the terrestrial atmosphere), obtained in the laboratory, is shown in the figure. Geometrical methods of time-series analysis, which are now being used increasingly in many branches of physics, facilitate the formulation of simple theoretical models and the testing of more realistic models of complex phenomena.



Temperature, $T(t)$, in a periodically modulated wave at a single fixed point in a laboratory flow. Using a fixed time delay, τ, an m-dimensional trajectory $[T(t), T(t+\tau), \ldots T(t+(m-1)\tau)]$ was constructed from the time series and reprojected in three dimensions using empirical orthogonal vectors (EOVs); x is the coefficient of the first EOV, y that of the second and z that of the third.

Training



Simulated forecasting office bays.

The Meteorological Office College, which is situated at Shinfield Park, near Reading, provides the facilities and is the centre for most of the in-house professional training. Meteorological Office staff are taught new skills and kept up to date with new developments at various stages in their careers. The residential accommodation at the College allows students to remain on the campus throughout their course so fostering the sharing of experience and knowledge between students and teaching staff; courses can be more intense, occupy less time and be more effective.

Courses* are designed to teach the essential skills that staff will need to perform their jobs, but it is recognized that an important element in the training process must be provided by on-the-job experience. Good honours graduates who have recently joined the Meteorological Office attend a 5-month course which gives a broad introduction to the theory and practice of meteorology, while those who are recent school leavers with GCE O- and A-levels are given instruction in just the basic elements. The length of their course depends on whether the student is due to work at an observing/forecasting office or within another part of the Office. Students with appropriate qualifications who are training to be forecasters not only learn about meteorology and its applications but are also given practical experience in verbal and written communication and in decision making. Potential research scientists are encouraged both to work as part of a team and to solve problems independently.

Staff attend courses, often linked to particular milestones such as promotion or a move to a different area of responsibility, at regular intervals. For example, newly promoted Scientific Officers embarking on careers as forecasters start by taking the Initial Forecasting Course followed, about 2 years later, by the Advanced Forecasting Course. Training is also given on specialized topics such as computer programming, statistics and telecommunications and on staff and resource management within the context of the Office.

On the basis of a detailed reappraisal of the training of Assistant Scientific Officers, it was decided to alter radically their basic training so that, instead of attending two 4-week courses separated by an interval of 2 years or so, new entrants now attend either a 4-week course or one which lasts 7 weeks (on which both theory and observing skills are taught) depending on the requirements of their jobs.

The College also keeps under review the needs for training in new technology within the Office. Thus steps are taken to install new types of equipment at the College as early as possible and to provide instruction in their use. During the year acquisitions included a digital facsimile machine, word processors and a video projector. Additional equipment was installed within the computer laboratory and the facilities and equipment within the School of Technical Training (also housed at Shinfield) were brought up to date.

Training of staff on topics not covered by the College syllabus takes place elsewhere when suitable courses are available. Staff attend courses on the principles of management at the Civil Service College and training in basic electronics at the Reading College of Technology. With encouragement from the Office, staff may attend outside courses to improve their academic qualifications, especially in mathematics and physics. Where possible, concessions are made available for external study; during the year about 100 staff took advantage of this facility.

One-week courses were held for auxiliary and co-operating observers — people who are not professional meteorologists but who assist the Office by making weather observations. Those who work in aviation continued their training with a week at an airfield meteorological office. Also during the year, instruction in the use of data from the weather radar network was given to members of some Water Authorities.

* Details are available from: The Principal, Meteorological Office College, Shinfield Park, Reading RG12 9AU.

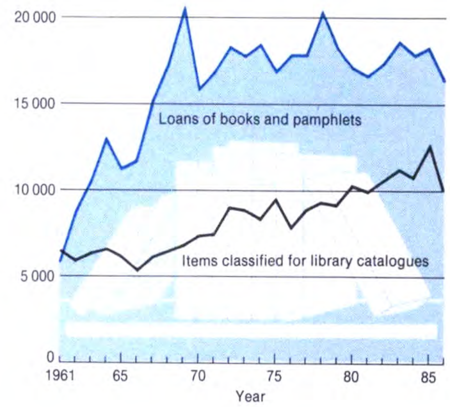
Students using the new soldering bays.

The National Meteorological Library and Technical Archives

The National Meteorological Library was started more than 120 years ago with monographs and reports donated by pioneers of atmospheric science, and over the years a major part of the collection has been received from institutes throughout the world under international exchange agreements. However, many items (especially journals) are purchased and, as a national library, it is essential that the holdings should be as comprehensive as possible. The combined holdings of the National Library and Technical Archives at Bracknell offer a source of historic and scientific meteorological information that is probably unsurpassed in the world. They now total about 200 000 books and pamphlets, many thousands of weather reports and some 25 000 slides and pictures. Also available, and catalogued, is a collection of rare and historical books and pamphlets owned by the Royal Meteorological Society. All this information is available to the general public, either on loan or for reference.

A bibliographic data base (MOLARS — the Meteorological Office Library Accessions and Retrieval System) helps customers access these holdings. It is available on line in the Library or else more publicly via the European Space Agency Information Retrieval Service. It has already been used by many organizations in some 20 countries around the world. Library automation has made a major contribution to the increased productivity of the accessions team who now process about 1000 entries a month — nearly double the number 25 years ago.

The Technical Archives are specifically included in the list of approved 'places of deposit' within the meaning of the Public Records Act (1958). Original weather records from Scotland are held at Edinburgh and those from Northern Ireland at Belfast. The Archives at Bracknell hold the observation records from England, Wales, overseas posts and the mercantile marine (some 1 million ships' weather logs), as well as nearly



Statistics of the National Meteorological Library for the past 25 years.

2 million working weather charts — at least one for every day since 23 May 1867. All these records are available for public inspection. During the year new shelving was installed at Bracknell and some 45 000 observation registers from England and Wales were re-housed and catalogued on a computer data base.

Publications and exhibitions

Within the Office small specialist groups are responsible for all official publications. Some staff deal with the text through all the stages of editing, sub-editing and proof reading. Others concern themselves with the artwork and design layout while others look after the distribution of the final product.

An increasing number of publications are prepared internally as 'camera-ready' copy using a phototypesetter and then printed externally from facilities provided by the Ministry of Defence and Her Majesty's Stationery Office (HMSO). This procedure reduces time-scales by removing the galley-proof stage from the printing process. The changeover to this method of production for the monthly *Meteorological Magazine* took place in January and has proved to be a very flexible and efficient method of preparing the magazine. The production by this means of the quarterly *Marine Observer* is well under way and this very Report is for the first time being produced camera-ready. At present all the text has to be rekeyed into the phototypesetter but work is well in hand to link it to the word-processor system to eliminate duplication.

Most published material reaches the public either through the Weather Centres or by post from Headquarters at Bracknell. However, major works and those intended primarily for sale, such as the *Annual Report*, handbooks and the periodicals mentioned above, are sold through HMSO outlets.

The Office also participates in exhibitions, and the Meteorological Office Travelling Exhibition was used at several major agricultural shows. Displays were put on at the Royal Navy Show at Portland and at several RAF open days and career drives. Exhibitions of this general nature were also displayed at various places including the University of Reading and Jersey; others of a more specific nature, either business or technical, were mounted using exhibition boards made especially to suit the occasion. The purchase of additional lightweight equipment for the Offshore Technology Conference at Houston in the USA has extended the range and scope of the exhibitions in which the Office can participate.

International

Experience shows that to forecast for Britain for 1 day ahead the Office needs observations from an area extending well into Europe to the east, across the Atlantic to the west, to Iceland and Norway to the north and to Gibraltar to the south. To make forecasts for 3 days ahead, observations are needed from the northern hemisphere and for a week or so, from the whole globe. A prime aim of international meteorology is to ensure that National Meteorological Services (NMSs) receive the observations they need, when they need them. For over a century NMSs have exchanged observations free of any charge. This is highly beneficial for each country: in return for the observations put into the Global Telecommunication System (GTS) of the World Meteorological Organization (WMO), it can receive many times more. This exchange is arranged under the World Weather Watch (WWW) of the WMO's Commission for Basic Systems.

Because the United Kingdom needs data to operate a global forecast model and issue forecasts for more than a day or two ahead, it gains more than most countries from this exchange. It needs the data to be reliable and to arrive in a timely fashion. The United Kingdom thus has an interest in helping NMSs of less-developed countries to be efficient by world standards. It does so in several ways: it makes numerical weather prediction products freely available to overseas NMSs in real time using the GTS or other means; it provides equipment, training and services through the Voluntary Cooperation Programme (VCP) of WMO; and its staff take part in activities where the primary beneficiaries are in the developing world.

Through VCP, wind-finding radars at Athalassa (Cyprus), Dar es Salaam (Tanzania) and Kasama (Zambia) were replaced with a more modern type, the Plessey WF33. In addition, observing equipment and spares were provided to eight African countries and telecommunication equipment to four. Fellowships were provided to NMSs to enable their staff to follow courses at the Meteorological Office College and elsewhere (frequently the University of Reading and the Colleges of Technology at Reading and Farnborough). Under the WMO CLICOM Project, a microcomputer-based system for providing answers to detailed enquiries on aspects of climate was provided to Sri Lanka. In Vanuatu, observing and telecommunication equipment was kept working by one of the Office's technicians.

UK delegations attended sessions of the WMO Commissions for Agricultural Meteorology, Aeronautical Meteorology and Atmospheric Sciences. The Director-General, Dr J.T. Houghton, took part in the annual session of the Executive Council of WMO and, after the fire in the nuclear power station at Chernobyl, the Council's Working Group on the transport of hazardous materials across national boundaries. He was represented at the Council's Working Groups on the VCP, Antarctic Meteorology and the WMO Second Long Term Plan. Delegations attended sessions of the WMO Regional Associations for Europe, Africa and the Southwest Pacific. The United Kingdom joined the Association for the Southwest Pacific during the year to support WWW in this data-sparse area.

A trend towards increased multinational co-operation on particular projects continued. Senior staff of the Office took part in the international mangement of the North Atlantic Ocean Stations and of the Operational WWW System Evaluation for the North Atlantic. The Aircraft to Satellite Data Relay System (ASDAR) ran into difficulties early in the year when the British firm responsible for developing it ceased trading. Another firm in the same group is now working on the project. The first units will probably be flown late in 1988, provided states that are members of the Consortium for ASDAR Development can solve the financial problems set by the change of contractor. Britain has played a leading part in the planning and development of ASDAR: recent obloquy can yet turn into kudos.

Throughout the year there has been close co-operation with other NMSs and the Foreign and Commonwealth Office on matters of common interest. In conjunction with the Overseas Development Administration (ODA), WMO and the Directors of representative African NMSs, a particular focus of interest has been on the proposed African Centre of Meteorological Applications for Development (ACMAD). ACMAD was proposed by Ministers of the Economic Commission for Africa and is intended to be a centre of excellence for meteorology and its applications, especially agriculture. The United Nations Development Programme, ODA and the Office have all expressed interest in helping to foster the development of ACMAD but there is no commitment to funding yet. ACMAD is a good example of international efforts to ensure that meteorology and NMSs play a full role in the social and economic development of nations.

The Director-General is Chairman of the Earth Observation Programme Board of the European Space Agency and other members of staff attend meetings and workshops. The Office continued to provide the UK representatives on the Council of the European Centre for Medium Range Weather Forecasts and on the Council's Technical Advisory and Finance Committees. A member of the Office also served on the Centre's Scientific Advisory Committee. The Centre continued to make steady progress towards its objective of issuing useful forecasts of weather 4 to 10 days ahead for its 17 Member States.

In June, the Director-General was the UK delegate at a meeting in Paris which agreed that the Convention of the EUropean METeorological SATellite organization (EUMETSAT) should come into force. The first session of the EUMETSAT Council followed. It decided to locate the Headquarters of EUMETSAT in Darmstadt, Federal Republic of Germany, and to appoint Mr J. Morgan, then Assistant Director (Satellite Meteorology) in the Office, as the first Director. Mr Morgan has since taken up the post.

Interaction with the national infrastructure

The Meteorological Office interacts with the national infrastructure in many ways. In connection with its forecasting and advisory services it works closely with the Building Research Eastablishment of the Department of the Environment, the Agricultural Development and Advisory Service of the Ministry of Agriculture, Fisheries and Food, and there is liaison with the Departments of Transport, Energy, Health and Social Security, Trade and Industry, the Home Office, the Health and Safety Executive, Central Office of Information, British Nuclear Fuels, Civil Aviation Authority and the British Standards Institution. Staff also serve on government interdepartmental committees and other bodies. Examples are the Physical Sciences Committee of the Chemical and Biological Defence Board, the Working Group on Atmospheric Dispersion Modelling of the National Radiological Protection Board, the Civil Aviation Research and Development Board, the Department of Energy Environmental Data Collection Committee, the Central Electricity Research Laboratory Advisory Panel on Environmental Research, the Interdepartmental Committee on International Hydrology, the Working Group on Acid Rain of the Watt Committee, the United Kingdom Review Group on Acid Rain, the Department of Environment/Meteorological Office Committee on Ozone, and the Flood Protection Committee of the Joint Consultative Organization for Research and Development in Agriculture and Food.

WWW in operation — Funafuti, Tuvalu, Pacific Ocean. A balloon carrying a radar target is being followed visually just after launch to allow the Plessey WF3 radar (white sphere) to follow it automatically. Winds to stratospheric heights are measured twice daily. Replacement of the radar with the more modern WF33 is in hand.

The Office is closely involved in the promotion of the science of meteorology through the Royal Meteorological Society: the outgoing President, a Vice-President, a Secretary, and the Editor of the Society's Quarterly Journal are members of the staff.

The Office also interacts with other scientific communities through the Royal Society and its committees, the research councils, and through contacts with the universities. Dr A.E. Gill was elected Fellow of the Royal Society just before his untimely death in April. Three other members of the staff (Drs J.T. Houghton, R. Hide and K.A. Browning) are Fellows of the Royal Society and several members serve on its committees; Dr Browning is Deputy Chairman of the British National Committee for Geodesy and Geophysics and Chairman of its subcommittee on Meteorology and Atmospheric Physics. Other staff serve on the British National Committees on Problems of the Environment, Solar Terrestrial Physics, Space Research and the World Climate Research Programme. The Director of Research is Chairman of the Meteorological Office/Research Councils' Committee on Climate.

Meteorological Office representatives serve on the Natural Environment Research Council, its Marine Science Committee, Services and Facilities Committee, Polar Science Committee, and its Aquatic and Atmospheric Physical Sciences Grants Committee. Staff also serve on the United Kingdom Coordination Committee for the World Ocean Circulation Experiment, the Steering Committee on Hydrological Applications of Weather Radar and the Liaison Committee with the Department of the Environment on the Surface and Ground Water Archive. A member of the Office serves on the Science and Research Engineering Council's Solar System Committee.

Some of the Office's work forms part of the program of the newly created British National Space Centre. Dr J.T. Houghton is a member of the Management Board of the Centre and Chairman of its Earth Observation Programme Board. The Office is also formally represented on this latter Board and also on the Core Group determining the UK position on the proposed European Polar Platform.

A member of staff has taken part in the work of the Distributed Advanced Computer Study Group set up by the Computer Board for the University and Research Councils.

Personnel

The number of staff on the strength of the Meteorological Office as at 31 December 1986 was 2546. This figure excludes staff on secondment to other organizations, but includes employees engaged locally at certain stations overseas. It is 41 lower than the previous end-of-year figure. This reflects the continuing Government drive for reduced public expenditure and greater efficiency in the Civil Service. Increasing use of new technology and communication facilities has helped to make this possible, but some services have had to be either reduced or abandoned to comply with permitted manpower ceilings.

This increased reliance on modern technology to bridge the manpower gap, however, introduces other problems, notably the difficulty of retaining highly qualified staff in computer-related fields. Since most of the Office's demand for these skills is at its Bracknell Headquarters, there are significant problems in retaining staff because of the proximity of many vigorous high-technology companies competing for computer programming expertise in the area.

Although the number of resignations from the Meteorological Office is as high as last year and therefore higher than would be wished, the Office enjoys a conspicuous level of loyalty on the part of its staff, which it strives to maintain. However, an organization like the Office, which has outstations widely spread across the United Kingdom and overseas, also has the need to relocate staff in response to both work and career development requirements. This gives rise to further difficulties when staff are asked to move from the west or north of the United Kingdom to the much higher-cost housing area of the Thames Valley where the bulk of staff are employed.

Notwithstanding these difficulties, the ability of the Office to recruit high-quality new entrants continues to keep pace with losses. The Office's reputation for advanced research in a number of scientific fields continues to attract the high-calibre graduate recruits on which its progress in meteorology ultimately depends. Careful attention to training and career development is required both to meet the needs of the Office and to retain the services of individual members of the staff, despite the competition by local high-technology industries for their highly valued computer-based skills, by satisfying their aspirations.

Staff numbers

Deputy Secretary (Grade 2)	1
Under Secretary (Grade 3)	1
Science Group	
Chief Scientific Officer (Grade 4)	2
Deputy Chief Scientific Officer (Grade 5)	5
Senior Principal Scientific Officer (Grade 6)	26
Principal Scientific Officer (Grade 7)	110
Senior Scientific Officer	302
Higher Scientific Officer	415
Scientific Officer	460
Assistant Scientific Officer	623
Administrative Group	
Assistant Secretary (Grade 5)	1
Senior Principal (Grade 6)	1
Senior Executive Officer	2
Senior Executive Officer Management Accountant	1
Higher Executive Officer	7
Higher Executive Officer Management Accountant	2
Executive Officer	19
Clerical Officer	56
Clerical Assistant	49
Professional and Engineering Group (including Marine Superintendent staff)	
Superintending Engineer (Grade 6)	1
Principal Professional and Technology Officer (Grade 7)	3
Senior Professional and Technology Officer	5
Higher Professional and Technology Officer	16
Professional and Technology Officer	7
Telecommunications staff	
Telecommunications Technical Officer Grade A	1
Telecommunications Technical Officer Grade I	9
Telecommunications Technical Officer Grade II	28
Telecommunications Technical Officer Grade III	60
Radio (Meteorological) Technician	39
Electronics Officer (OWS)	1
Signals grades	31
Teleprinter grades	40
Typing and miscellaneous non-industrial grades	116
Security officers	10
Industrial employees	44
Locally entered staff overseas	52

Staff honours and awards

The Imperial Service Order was awarded to Mr J. Findlater (now retired) in the New Year's Honours.

The Imperial Service Medal was awarded to Mr R.G. Fry and Mr J.W. Alcock (both now retired). The medals were presented to them by the Director-General.

The Royal Society Esso Energy Award was awarded to Dr M.J.P. Cullen, Mr C.R. Flood, Dr A.J. Gadd, Dr T.N.Palmer, Mr K.Pollard, Dr G.J. Shutts and Dr P.W. White.

The Professor Dr Vilho Väisälä Award was awarded to Mr C.G. Collier.

The Hugh Robert Mill Medal and Prize was awarded to Mr C.K. Folland.

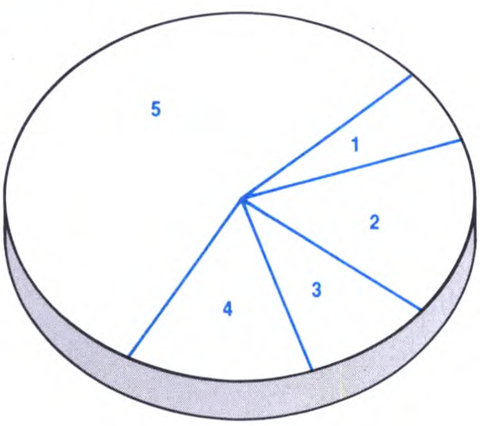
The L.G. Groves Memorial Prize for Meteorology was awarded to Mr J. Findlater.

Finance

On a fully cost-accounted basis, the total cost of the Office in 1985/86 was £73.7 million compared with £68.4 million in 1984/85. The net cost after earnings from services was £51.9 million compared with £47.5 million in 1984/85. Charges for repayment services were increased by between 5 and 8 per cent on 1 April 1986.

The Office's voted expenditure is borne on the Defence Budget to which all receipts from repayment services are credited. Details are shown in the *Annual Statement of Defence Estimates*. However, for costing purposes, a fully cost-accounted Memorandum Operating and Trading Account (MTA) is also maintained and the charts below summarize the costs and receipts involved. These figures include non-Voted costs that are not shown in Defence Votes in Parliamentary Estimates, such as pension contributions, notional insurance provision, interest on capital and depreciation. By the same token, the cost of major items of equipment, which appears in Defence Votes for the year of acquisition, is excluded from the table, being covered by annual interest and depreciation charges in the usual commercial accounting manner.

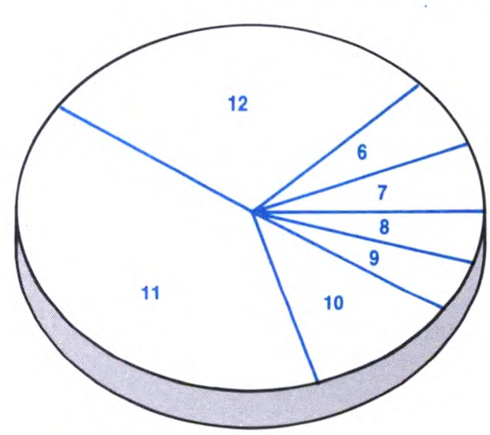
Input of resources



1 Depreciation of interest on capital (6.3%)
2 Grants and subscriptions to international bodies (17.0%)
3 Office support, telecommunications and accommodation (8.9%)
4 Materials and miscellaneous (12.9%)
5 Staff costs (54.9%)

Allocation of resources

6 Technical support and maintenance (6.5%)
7 Miscellaneous overheads including MOD costs (8.2%)
8 Training (3.2%)
9 Administration (4.0%)
10 Research and development (10.8%)
11 Observations, telecommunications, computing and central forecasting (40.5%)
12 Meteorological services for customer activities (26.8%)



Statement of the cost of meteorological services for the year ended 31 March 1986

	1985/86		1984/85	
	£000	£000	£000	£000
Total meteorological services (cost accounted)		73 658		68 415
Receipts		21 755		20 918
Net expenditure:				
Defence and other Exchequer departments	29 903		27 818	
General public services and international	22 000		19 679	
		51 903		47 497

Appendices

APPENDIX I

BOOKS OR PAPERS BY MEMBERS OF THE STAFF

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WHITE, P.A.; The offshore wind-energy resource around the United Kingdom. *Wind Eng*, **9**, 1986, 221–233.

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WILSON, C.A. and MITCHELL, J.F.B.; Diurnal variation and cloud in a general circulation model. *Q J R Meteorol Soc*, **112**, 1986, 347–369.

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APPENDIX II
A SELECTION OF LECTURES AND BROADCASTS GIVEN BY MEMBERS OF THE STAFF

ALLARDICE, J.G.
Weather for highway road maintenance. *Highway and Traffic Technicians Association 1986 Annual Symposium, Glasgow.* 20 June.

ANDREWS, D.G.
Review of transport mechanisms in the middle atmosphere. *NATO Workshop on Transport Processes in the Middle Atmosphere, Erice, Sicily.* 26 November.
The Influence of atmospheric waves on the general circulation of the middle atmosphere. *Discussion Meeting on Studies of the Middle Atmosphere, sponsored by the Royal Society, London.* 5 December.

BALLARD, S.P.
Operational trials with a mesoscale forecast system. *Royal Meteorological Society Summer Meeting, Dublin.* 9–11 July.

BARRIE, I.A.
Weather during the cereals '85 crop. *Royal Agricultural Society of England, National Agriculture Centre, Stoneleigh.* February.

BELL, R.S.
Real time data processing at the Meteorological Office. *Columbus Ocean Workshop, Southampton.* 14–15 July.

BROWN, R.
Progress with the FRONTIERS system for nowcasting rain. *Joint meeting of Royal Meteorological Society and Irish Meteorological Society, Dublin.* 9–11 July.

BROWNING, K.A.
Use of radars and satellite imagery in short-term prediction and estimation of precipitation. *Lectures at NATO Postgraduate Summer School on Remote Sensing Applications in Meteorology and Climatology, Dundee.* 28–29 August.
Opportunities within the UK for validation of satellite-derived rainfall estimates. *COSPAR International Workshop on the Validation of Satellite-derived Precipitation Measurements for the Global Precipitation Climatology Project, Washington DC.* 17 November.
Applications of Meteosat imagery in nowcasting and synoptic practice. *Keynote lecture at the Meteosat Users' Conference, Amsterdam.* 26 November.

BROWNSCOMBE, J.L.
Weather and horticulture. *Lindfield Horticultural Society, Lindfield.* 12 February.
Long term and day to day irrigation planning. *ADAS, Oxford Division, Irrigation Day, Frilford.* 3 June.

BUTCHART, N.
Evidence for planetary wave breaking from observational data. The relative roles of diabatic effects and irreversible mixing. NATO *Advanced Workshop on Transport Processes in the Middle Atmosphere, Erice, Sicily.* 23–27 November.

CALLANDER, B.A.
Agrometeorological services in Scotland. *Department of Agriculture and Fisheries for Scotland, Edinburgh.* 17 September.
Surface energy budgets. *Series of ten lectures and five practicals, Department of Meteorology, University of Reading.* Spring and summer.

CARSON, D.J.
An introduction to the parametrization of land-surface processes. *Centre National d'Etudes Spatiales (CNES) Summer School of Space Physics, Climatology and Space Observations, Roscoff, France.* 21 July.

CATTLE, H.
Sea ice models for climate research. *Royal Meteorological Society Meeting on Polar Meteorology and Climate, London.* 16 April.
The impact of parametrization of orographic gravity wave drag on modelled atmospheric variability. *Royal Meteorological Society and American Meteorological Society Conference on the Variability of the Atmosphere and Oceans on Timescales of a Month to Several Years, Royal Society, London.* 8–12 September.

CHYNOWETH, S.
Semi-geostrophic solutions to flow over steep orography using a Lagrangian model. *European Geophysical Society 1986 General Assembly, Kiel, Federal Republic of Germany.* 27 August.

COLLIER, C.G.
The use of radar and satellite data for weather forecasting. *Institute of Civil Engineers (N Ireland), Belfast.* 10 November.

CRABTREE, J.
From Windscale to Chernobyl. *Central Electricity Research Laboratories, Leatherhead.* 25 July.

CULLEN, M.J.P.
Two lectures: (1) Forecasting of weather over the UK using a mesoscale forecasting system, (2) Representation of mesoscale phenomena in a Lagrangian semi-geostrophic model. *WMO/IUGG Symposium on Short and Medium Range Weather Prediction, Tokyo.* 4–8 August.
Barrier effects in fine mesh models. *ECMWF, Reading.* 16 September.

DAVEY, M.K.
Kelvin waves in a moist tropical atmosphere model. *University of Reading.* 28 April.
A moist tropical atmosphere model driven by Pacific sea surface temperature. *NATO Advanced Study Institute, Erice, Sicily.* 14 May.

DAVIES, T.
Modern methods of weather prediction. *Institution of Electrical Engineers, Dundee, Glasgow and Norwich.* 21, 22 January and 16 April.
Limited area modelling in the UK. *European Working Group on Limited Area Modelling, Madrid.* 11–16 October.

DIXON, J.C.
Meteorology and highway design. *Highway Maintenance Course, The City University, London.* 16 October.

DONOPHY, E.H.C.
Use of modern technology in Weather Centres. *Royal Television Society, BBC Llandaff.* 26 March.

EASTWOOD, P.J.
On the work of Belfast Weather Office. *To Scientific Advisers, Northern Ireland Office.* 10 July.

ELLIS, R.J.
The use of computer graphics in producing BBC weather reports. *EUROGRAPHICS UK Conference, Glasgow.* 25–26 March.
Cartographic presentations by electronic means. *British Cartographic Society, Brighton.* 21 September.

EYRE, J.R.
Radiative transfer modelling for satellite temperature sounding. *Royal Meteorological Society, London.* 15 January.
TOVS retrievals in the UK: progress and plans. *Third International TOVS Study Conference, Madison, Wisconsin.* 14 August.

FAIRLIE, T.D.A.
Observational studies of stratospheric sudden warmings. *European Geophysical Society 1986 General Assembly, Kiel, Federal Republic of Germany.* 28 August.

FARMER, S.F.G.
Forecasting radio ducts. *RAF Wyton.* 19 September.

FISH, M.J.
Behind the scenes of your TV Weatherman. *University of Reading.* 27 February.

FOLLAND, C.K.
Sahel rainfall and worldwide sea temperatures. *BBC Radio 4 'Science now'.* 28 April.
Scotland's summer deluge of 1985. *Meteorological Office Annual Special Topic Lecture, Heriot-Watt University, Edinburgh.* 22 May.
Sahel rainfall, N. Hemisphere circulation anomalies and worldwide sea temperature changes. *Pontifical Academy of Sciences, Vatican.* 25 September.
Experimental monthly forecasts for the United Kingdom: a review of recent developments. *WMO Conference, Sofia, Bulgaria.* 29 September.

FOOT, J.S.
Meteorological research from aircraft. *East Midlands Centre, Royal Meteorological Society, University of Nottingham.* 27 February.

FOREMAN, A.M.
The computing aspects of weather forecasting. *The British Computer Society (West Yorkshire Branch).* 4 November.

FORRESTER, D.A.
Where and when helicopter icing occurs. *Symposium on Helicopter Rotor Icing, Royal Aeronautical Society, London.* 14 January.

FRANCIS, P.E.F.
Numerical wave models as a source of data for marine climatology. *Oceanology International 86, Brighton.* 5 March.
Two presentations: (1) The Meteorological Office Operational Sea State Forecasting System, (2) The North European Storm Study (NESS). *International Workshop on Wave Hindcasting and Forecasting, Halifax, Nova Scotia, Canada.* 23–26 September.
The Meteorological Office wave forecasting system. *Institute of Oceanographic Services, Bidston.* 26 November.

FULLWOOD, J.
MORECS climatological data set: preliminary results. *Association of British Climatologists/British Hydrological Society Meeting on Water: Management and Measurement, Swansea.* 17–19 September.

GADD, A.J.
Modern developments in weather forecasting. *University of Wales Institute of Science and Technology, Cardiff.* 5 March.
Operational performance in the southern hemisphere of a finite-difference global model. *Second International Conference on Southern Hemisphere Meteorology, Wellington, New Zealand.* 1 December.

GEORGE, D.J.
Understanding mountain weather. *Series of lectures to Royal Meteorological Society Field Courses, National Centre for Mountain Activities, Plas y Brenin, Gwynedd.* 3–4 May and 24–26 October.

GIBBS, J.I.
Meteorology and climatology. *To Scientific Advisers, Department of Agriculture, Belfast.* 19 February.

GILCHRIST, A.
Designing global observing systems. *Royal Meteorological Society Presidential Address, London.* 18 June.
Long-range forecasting. *WMO Conference, Sofia, Bulgaria.* 1 October.

GILES, W.G.
Broadcasting for the general public. *Royal Meteorological Society/Irish Meteorological Society Summer Conference, Dublin.* 9–12 July.

GOLDING, B.W.
Uses of satellite imagery in mesoscale models. *Royal Meteorological Society Meeting on Satellite Meteorology, London.* 19 November.

GORDON, C.
The performance of the atmospheric and the oceanic GCMs at the Met Office. *Workshop on Simulation of Climate Variations on Time Scales of Months to a Few Years, Hamburg.* 17 November.

HARDY, R.N.
Weather for 'Outlook'. *BBC Overseas Service 'Outlook'.* 13 February.

HIDE, R.
Planetary magnetic fields, *Yorkshire Branch of the Institute of Physics, York.* 20 January.
The Earth's differential rotation. *California Institute of Technology, Pasadena.* 17 February.
Institute of Geophysics, Prague. 23 September.
Frozen vector fields and inverse boundary value problems in geophysics. *Culham Laboratory.* 12 March.

HILL, A.H.A.
Weather for winter road maintenance. *Highway and Traffic Technicians Association 1986 Annual Symposium, Glasgow.* 20 June.

HOUGHTON, J.T.

Problems in the retrieval of useful atmospheric information from satellite remote sensing observations. *Institute of Mathematics and its Applications, Southend.* 28 May.

Predictability of weather and climate. *Department of Physics, University of Oxford.* 30 May.

Remote sensing from space — a new view of planet earth. *Royal Society Evening Lecture, London.* 28 October.

Problems in the predictability of weather and climate. *Department of Chemical Engineering, University of Cambridge.* 5 November.

HUME, C.J.

The influence of climate on forage production in Dorset. *ADAS/ICI/Midland Bank Conference, Dorset College of Agriculture.* 5 February.

HUNT, G.S.F.

Forecasting the weather using modern technology. *Cardiff Branch Welsh Scientific Society.* 20 January.

JONAS, P.R.

The physics of precipitation. *Gaskell Lecture, Royal Meteorological Society, Manchester Centre.* 23 January.

Examples of the operational utility of radar observations of cold air vortices. *International Conference on Polar Lows, Oslo.* 21–23 May.

JONES, D.E.

The practical use of 30 day forecasts. *WMO Conference, Sofia, Bulgaria.* 3 October.

JONES, R.L.

Studies of stratospheric O_3 in polar regions in a trajectory coordinate system. *European Geophysical Society 1986 General Assembly, Kiel, Federal Republic of Germany.* 25–30 August.

KEERS, J.F.

Weather and farming. *ADAS Farmers Group Meeting, Droitwich.* 21 January.

KERSHAW, R.

Numerical experiments on the Asian monsoon onset. *Royal Meteorological Society Meeting on Tropical Meteorology, Imperial College, London.* 19 March.

KILSBY, C.J.

Radiative fluxes and aerosol properties measured from an aircraft during a straw-burning episode. *Sixth Conference on Atmospheric Radiation, Williamsburg, Virginia.* 12–16 May.

KITE, A.

The short-wave albedo of broken cloud fields. *Royal Meteorological Society, London.* 15 January.

LEE, M.J.

Meteorological aspects of strawburning. *Oxfordshire Farmers, Kidlington.* 8 January.

LUNNON, R.W.

3-dimensional modelling of cold front convection. *Royal Meteorological Society, London.* 15 October.

MACKIE, G.V.

The return of the Met. Office weathership to the Clyde at Greenock. *BBC TV, Scotland.* 11 February.

MACVEAN, M.K.

The effect of model resolution on the simulated circulation and dynamics of the tropical Pacific Ocean. *Joint Meeting of European Geophysical Society and European Seismological Commission, Kiel, Federal Republic of Germany.* 21–30 August.

Royal Meteorological Society and American Meteorological Society Conference on the Variability of the Atmosphere and Oceans on Timescales of a Month to Several Years, Royal Society, London. 8–12 September.

MANSFIELD, D.A.

Practical extended-range dynamical forecasting.*Royal Meteorological Society/American Meteorological Society Conference, Royal Society, London.* 12 October.

MARYON, R.H.

A study of the effects of grid resolution upon the representation of the inversion and entrainment at the top of a convective boundary layer. *European Geophysical Society 1986 General Assembly, Kiel, Federal Republic of Germany.* 28 August.

MASON, P.J.

Frictional effects of an irregular surface. *ECMWF Seminar on Observations, Theory and Modelling of Orographic Effects, Reading.* 18 September.

Studies of the planetary boundary layer. *Royal Meteorological Society Meeting on Large-eddy Simulations of the Planetary Boundary Layer, London.* 15 October.

MAY, B.R.

The present and future Meteorological Office processing and archiving of rainfall and climate data. *British Hydrological Society Meeting on Hydrological Data Management in the United Kingdom, London.* 17 February.

Radar rainfall data: processing and archiving. *Association of British Climatologists/British Hydrological Society Meeting on Water: Management and Measurement, Swansea.* 17–19 September.

McNEILL, J.B.

Meteorology and climatology. *To Scientific Advisers, Department of Agriculture, Belfast.* 19 February.

Basic meteorology and work of Belfast Weather Office. *Queens University Teacher Centre.* 30 September.

MINHINICK, J.H.

The influence of weather on soil. *ADAS Soil Examination and Management Course, Loughborough.* April.

MITCHELL, J.F.B.

On CO_2 and climate. *Mullard Institute for Space Studies, Holmbury St Mary.* 6 March.

The greenhouse effect, CO_2, trace gases and climate. *Royal Geographical Society, London.* 15 April.

Simulation of climatic change due to increased atmospheric CO_2. *NATO Advanced Study Institute, Physically Based Climate Modelling and Simulation of Climate and Climatic Change, Erice, Sicily.* 11–23 May.

The greenhouse effect; past, present and future. *British Association for the Advancement of Science, Bristol.* 8 September.

Simulation of climate change due to increased CO_2. *CEC Symposium on CO_2 and other Greenhouse Gases: Climatic and Associate Impacts, Brussels.* 3–5 November.

CO_2 and climate, some recent Meteorological Office experiments. *Department of Meteorology, University of Reading.* 5 December.

MORRIS, R.M.

Meteorological support for marine operations. *Royal Institute of Naval Architects and RINA Offshore Engineering Group, London.* 15 May.

Using the Meteorological Office 15 level operational model in global and limited area forecasts. *WMO Workshop on Rain Producing Systems, Costa Rica.* 21–25 July.

MURPHY, J.M.

The use of ensembles of integrations in extended-range dynamical forecasting. *WMO Conference, Sofia, Bulgaria.* 3 October.

Practical extended-range dynamical forecasting. *Royal Meteorological Society/American Meteorological Society Conference, Royal Society, London.* 12 October.

MURRAY, R.A.

The meteorologist in nuclear and chemical emergencies. *West Yorks County Scientific Advisers.* 24 September.

NASH, J.

Errors in radiosonde measurements — Results of the WMO International Radiosonde Comparison. *ECMWF, Reading.* 13 June.

Long term monitoring of stratospheric temperature trends using radiance measurements obtained by the TIROS-N series of NOAA spacecraft. *Workshop on Detection of Climate Change by Stratospheric Monitoring from Space, COSPAR XXVI, Toulouse, France.* 7 July.

NICHOLLS, J.R.

Requirements for observations in support of weather forecasting. *Royal Meteorological Society One Day Discussion Meeting, ECMWF, Reading.* 28 November.

NICHOLLS, S.

The structure of the cloud topped boundary layer. *KNMI, De Bilt, Netherlands.* 10 April.

O'NEILL, A.

Recent advances in modelling and analysis of the middle atmosphere. *European Geophysical Society 1986 General Assembly, Kiel, Federal Republic of Germany.* 28 August.

Material exchange during large-amplitude wave events, and systematic changes in the stratospheric circulation. *NATO Workshop on Transport Processes in the Middle Atmosphere, Erice, Sicily.* 25 November.

Dynamics of the middle atmosphere inferred from satellite data and numerical models. *Discussion Meeting on Studies of the Middle Atmosphere sponsored by the Royal Society, London.* 5 December.

PAINTING, D.J.

Meteorological data acquisition for weather forecasting. *Institution of Electronic and Radio Engineers, Southern Section, Crawley.* 9 September.

PALEY, J.

Meteorology and the prediction on radioactive fallout. *UKWMO Senior Officers' Residential Course.* 21 September.

PARKER, D.E.

Detection of upper-troposphere and lower-stratosphere temperature changes induced by increasing atmospheric carbon dioxide. *Royal Meteorological Society, London.* 19 February.

Strategy for early detection of climate change. *COSPAR XXVI, Toulouse, France.* 7 July.

PARTINGTON, S.J.G.

Hurricane Charlie — effects over Northern Ireland. *Ulster TV.* 26 August.

Introduction to Open Road weather services. *Department of the Environment, Northern Ireland.* 30 September.

PICK, D.R.

Humidity sounding. *Humidity Sounding Workshop, USAF, Boston, Mass.* April.

The operational sounding of the lower atmosphere from satellites using millimetre waves. *16th European Microwave Conference, Dublin.* September.

READ, P.L.

Diagnostic methods for weakly-forced 'free modes' in atmospheres, oceans and laboratory systems. *ICDM/DMG Conference on Verification of Theories in Large/Medium Scale Atmospheric Dynamics, Burghausen, Federal Republic of Germany.* 24 June.

Phase-space analyses of rotating, thermally driven baroclinic flows. *28th British Theoretical Mechanisms Colloquium, University of Bristol.* 9 April.

Super-rotation and planetary atmospheres. *Royal Astronomical Society, London.* 10 October.

On the scale of baroclinic instability in deep, compressible atmospheres. *Division of Planetary Sciences of the American Astronomical Society, Paris.* 4 November.

RIDDAWAY, R.W.

Numerical methods for weather prediction. *ECMWF Meteorological Training Course, ECMWF, Reading.* 22 April–2 May.

ROWNTREE, P.R.

A survey of ocean surface temperature anomaly experiments for the northern hemisphere winter and their relevance to the climatic effects of a CO_2 increase. *Working Group on Interchange of Pollutants between Atmosphere and Ocean, Paris.* 6 January.

Numerical model experiments on the role of land-surface processes relating to semi-arid tropics. *Royal Meteorological Society Meeting on Tropical Meteorology, London.* 19 March.

Modelling the impact of land-surface changes on Sahel rainfall — possible interactions between land, atmosphere and oceans. *Royal Meteorological Society and American Meteorological Society Conference on the Variability of the Atmosphere and Oceans on Timescales of a Month to Several Years, Royal Society London.* 12 September.

Natural surface changes and climatic variations. *Conference on the Mechanism of Interannual and Longer Term Climatic Variations, Melbourne.* 8–12 December.

ROY, M.G.
Scotland's summer deluge of 1985. *Meteorological Office Annual Special Topic Lecture, Heriot-Watt University, Edinburgh.* 22 May.
Climate on Scottish mountains. *NATO Advanced Research Workshop on Acid Deposition Processes at Elevated Sites, Edinburgh.* 8 September.

RUMNEY, R.P.
Shelter for horticultural crops. *Cornish Nurseryman's Association, Truro.* 12 February.

SAUNDERS, R.W.
Retrieval of surface and cloud parameters from AVHRR/2 data. *American Meteorological Society Sixth Conference on Atmospheric Radiation, Williamsburg, Virginia.* 15 May.
The impact of clouds on remote sensing of surface atmsopheric variables. *International Meeting on Atmospheric Transparency, Capri, Italy.* 16 September.
Detection of cloud-free and cloud-filled AVHRR/2 fields of view. *First Australian AVHRR Conference, Perth, Western Australia.* 24 October.

SHAWYER, M.S.
Meteorological aspects of drainage design. *Planning, Transport Research and Computation Co. Ltd, course on Flood Estimation for Drainage Design, Charing Cross Hotel.* 21 April.

SHUTTS, G.J.
Parametrization of gravity wave drag in numerical weather prediction models. *WMO/IUGG Symposium on Short and Medium Range Weather Prediction, Tokyo.* 4–8 August.
Geometric modelling of semi-geostrophic flows. *Department of Atmospheric Physics, Imperial College, London.* 30 October.

SINGLETON, F.
The present and future Meteorological Office processing and archiving of rainfall and climate data. *British Hydrological Society Meeting on Hydrological Data Management in the United Kingdom, London.* 17 February.

SLINGO, A.
Stratocumulus and climate. *GFDL/NOAA, Princeton University, Princeton, New Jersey.* 9 May.
Treatment of solar radiation in climate models. *Summer Course on Radiation as it Relates to Climate, NCAR, Boulder, Colorado.* 14–19 July.
Studies of the effect of cloud radiative forcing on the GCM. *Department of Meteorology, University of Utah.* 17 October.

SMITH, F.B.
The long range transport of air pollution and the significance of non-linearity within oxidation–deposition processes. *EURASAP Symposium on Interregional Air Pollutant Transport, Budapest, Hungary.* 21–25 April.
Under the cloud. *Acid rain interview, Radio 4.* May.
Two lectures: (1) Atmospheric turbulent transport, (2) Proportionality problems in the formation of acid depositions. *JRC Course on Regional and Long Range Transport of Air Pollution, Ispra, Italy.* 15–16 September.
Long range transport modelling. *HM Industrial Air Pollution Inspectorate Annual Meeting, Windermere.* 12 November.

SMYTH, E.A.
Case study on split fronts. *Irish Meteorological Society, Trinity College Dublin.* 22 November.

SPACKMAN, E.A.
Weather and the grower. *Talk to a group of growers, Swineshead.* 6 October.
Spray occasions, July 1985 to June 1986. *BCPC Herbicide Review.* 21 October.

STARR, J.R.
Weather on the hill farm. *Pwllpeiran EHF, Cymdeithasyr Hafod (Hill Sheep Group).* 6 January.
Weather advice for grassland management. *Glamorgan Grassland Society.* 24 March.
Meteorology and agriculture. *Third World Course, University College of Wales, Aberystwyth.* 30 September.
Weather and animal health and production. *IXth Session of C.Ag.M., WMO, Madrid.* 25 November.

STEVENS, P.J.
Weather for Virgin Atlantic Challenger II. *Thames TV 'Splash'.* 19 June.

STUBBS, M.W.
Meteorological applications of satellite data. *Earth Observation Systems and their Usefulness for Agrometeorology and Water Resources, Nairobi, Kenya.* 23–30 October.

TABONY, R.C.
The wet summer of 1985. *BBC Radio Scotland inteview.* 22 May.

THOMAS, J.P.
Data assimilation studies with the Met. Office wave model. *4th WAM Meeting, Venice.* 12–14 May.

THOMPSON, N.
Meteorology and herbicide application. *Imperial College, Silwood Park.* 7 January.

THOMSON, D.J.
Random walk modelling of dispersion in inhomogeneous turbulence. *Fluid Mechanics Seminar, Department of Applied Mathematics and Theoretical Physics, Cambridge.* 31 January.
The neutral static stability planetary boundary layer. *Royal Meteorological Society Meeting on Large-eddy Simulations of the Planetary Boundary Layer, London.* 15 October.

TOWNSEND, J.
Operation of the Storm Tide Warning Service. *Institution of Water Engineers and Scientists, London.* 24 January.
Tidal surge forecasting in Great Britain. *Symposium on Physics of Shallow Bays, Estuaries and Continental Shelves, Qingdao, China.* 3–5 November.

WARD, M.N.
Space time dispersal patterns of low cloud and fog: analysis and prediction. *Association of British Climatologists, University of Birmingham.* 15 March.

WATTS, P.D.
Preliminary AMSU retrieval simulations. *Workshop on Microwave Sounding AFGL, USAF Hanscom, Mass.* 9 April.
Validating a TOVS cloud-clearing scheme using AVHRR data. *Third International TOVS Study Conference, Madison, Wisconsin.* 14 August.

WHITE, A.A.
Large amplitude flow structures in rotating systems: their existence, stability and predictability. *Hooke Institute, University of Oxford.* 17 February.
Two lectures: (1) Diagnostic methods for weakly-forced 'free modes' in atmospheres, oceans and laboratory systems, (2) Laboratory experiments on rotating baroclinic flow: their use in verifying numerical models and in testing predictions of quasi-geostrophic theory. *ICDM/DMG Conference on Verification of Theories in Large/Medium Scale Atmospheric Dynamics, Burghausen, Federal Republic of Germany.* 24–25 June.
Vacillations in the atmosphere and in the annulus. *Royal Meteorological Society and American Meteorological Society Conference on the Variability of the Atmosphere and the Oceans on Timescales of a Month to Several Years, Royal Society, London.* 8 September.
Instabilities: vacillations and blocking. *IAMAP Conference on Mechanisms of Interannual and Longer Term Climatic Variations, Melbourne.* 12 December.

WHITE, P.W.
Aviation forecasting in the Meteorological Office. *National Meteorological Center, Washington.* 9 October.
Advances in numerical weather prediction for aviation forecasting. *Royal Society Esso Energy Award Lecture, London.* 13 October.

WILSON, C.A.
A $2 \times CO_2$ climate sensitivity experiment using a global climate model including a simple ocean. *European Geophysical Society 1986 General Assembly, Kiel, Federal Republic of Germany.* 26 August.

WILSON, M.F.
Application and evaluation of radar data in rainfall archives. *British Hydrological Society Meeting on Hydrological Data Management in the United Kingdom.* 17 May.

APPENDIX III
PUBLICATIONS

Publications prepared by the Meteorological Office are either published and sold by Her Majesty's Stationery Office or are produced as departmental publications and sold directly by the Meteorological Office. A catalogue containing all current titles (Leaflet No. 12) is available on request. More extensive details of HMSO publications (only) are contained in HMSO Sectional List 37.

The titles that follow are those completed during 1986; those handled by HMSO are marked with an asterisk (*). The final numbers, within brackets, are International Standard Book Numbers (ISBN), which provide positive identification of items that bear them.

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Monthly Weather Report, annual summary 1984 (0 11 727554 9)
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Climatological Memorandum No. 137, *The climate of Great Britain: South England* (rev) (0 86180 218 7)
Climatological Memorandum No. 139, *The climate of Great Britain: The South-West Peninsula and The Channel Islands* (rev) (0 86180 217 9)

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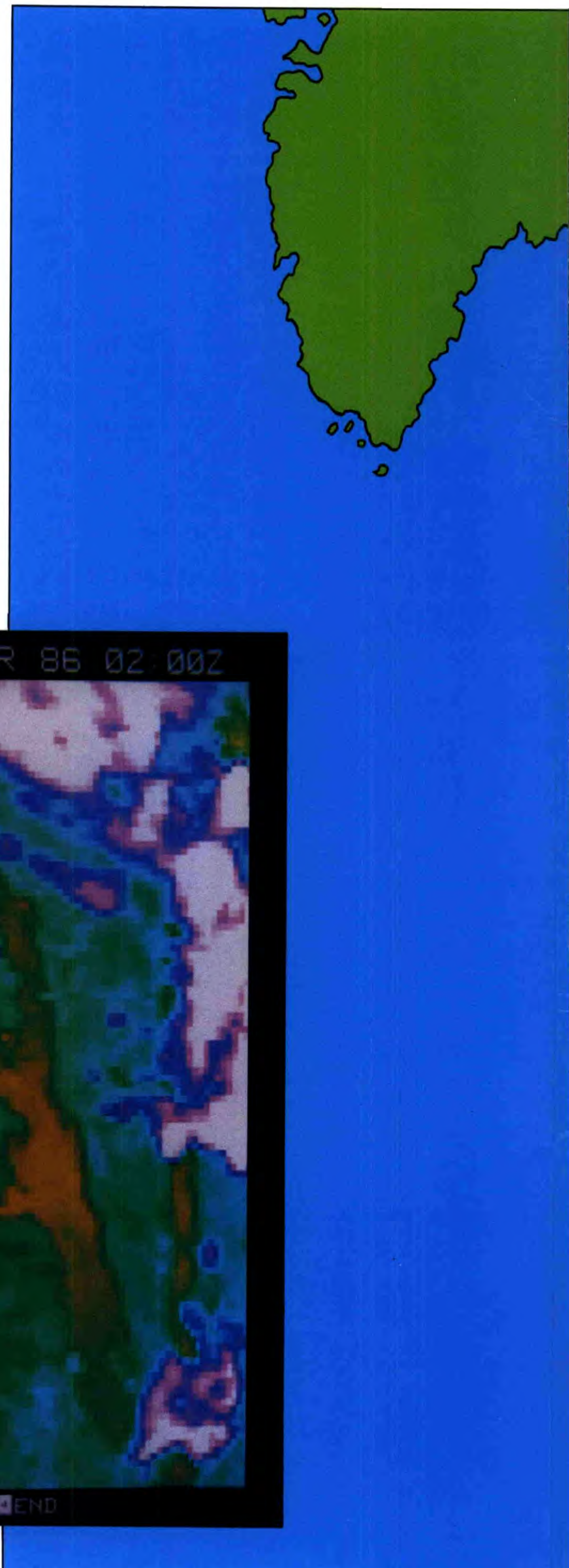

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