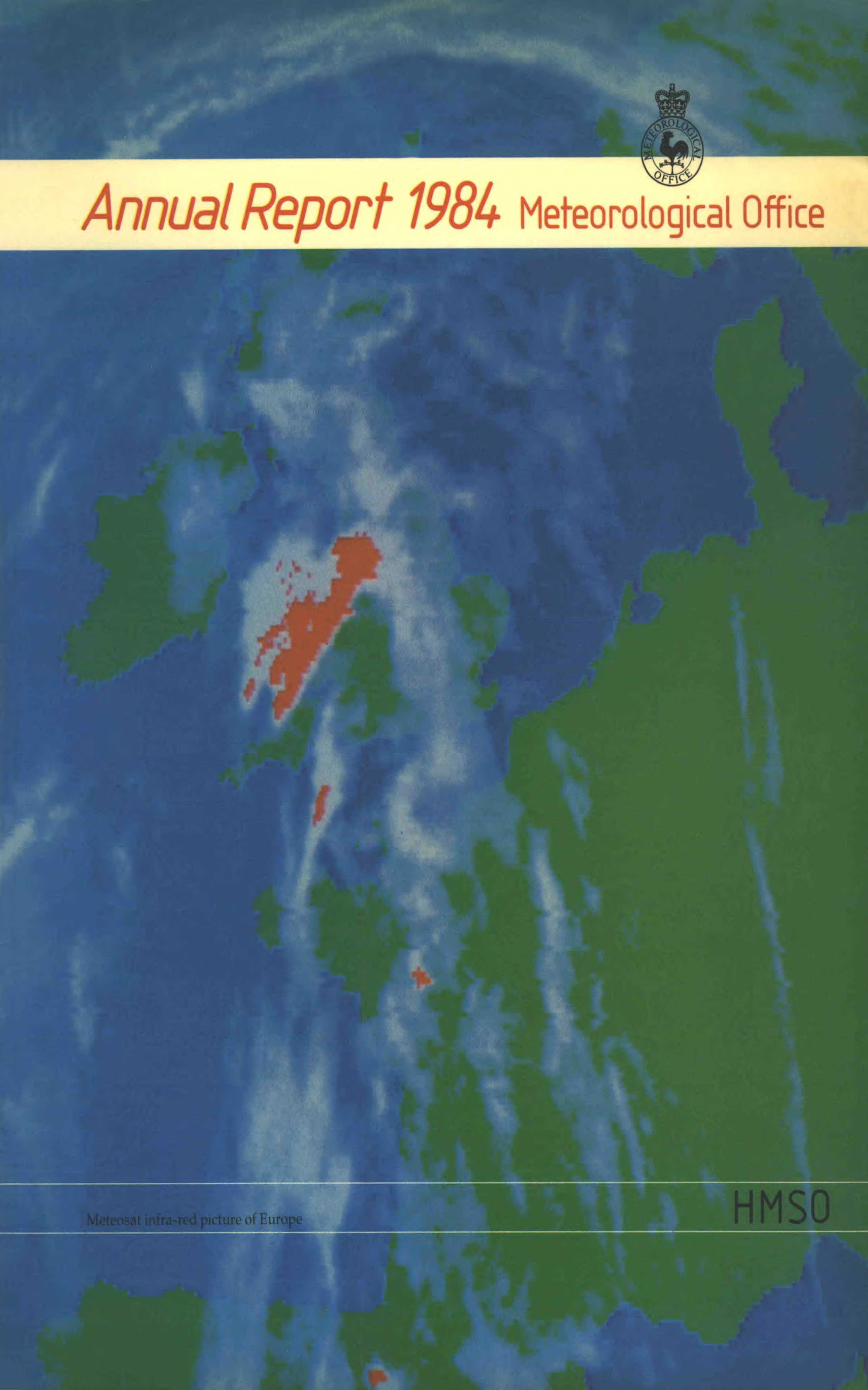
Annual Report 1984 Meteorological Office



Meteosat infra-red picture of Europe

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Annual Report 1984 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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Foreword by the Director-General

This year's Annual Report is presented in a new format. In this first issue with the new format, the opportunity has been taken to provide an overall review of the activities of the Meteorological Office. The practice of including detailed accounts of particular areas has therefore been discontinued for this year but will be reintroduced within the new format next year.

The new World Area Forecast System for civil aviation with Bracknell and Washington as World Centres came into operation during the year. Global products from the Bracknell 15-level model are increasingly in demand by civil air operators as the best source of forecast winds available for flight planning purposes.

The provision of meteorological services to UK forces in the South Atlantic has continued with the meteorological office at Port Stanley staffed by a group of volunteers who are temporarily in uniform. To improve the range of data and forecast material available to forecasters at RAF stations in the United Kingdom, computer equipment suitable for accessing and displaying meteorological data is being tried out at suitable outstations with a view to such equipment being installed at key stations within the next two years.

In continuation of the policy of concentrating our service to the public at a number of strategically located Weather Centres in major cities, Centres were opened during 1984 at Norwich and Leeds; staff for them being found by redeployment from Bawtry and Honington. An important part of the work of the Weather Centres is concerned with the presentation of forecasts on radio and television, both regional and national, and methods of improving these presentations are being discussed with the BBC and the IBA.

Much of the Research and Development work of the Office goes into improving the quality of the output from the models and the resulting forecasts, into improving the network of observations over the globe from which the forecasts are derived, and in developing better ways of presentation of the weather and climate information at our Weather Centres and outstations and ultimately to our customers. These developments are not only required in the interests of better quality and efficiency but also so that, despite an expansion in our activities, the Office can make a continued contribution to the rundown of manpower in the Civil Service.

Continued development of the 15-level model has resulted in a further improvement in the quality of the forecasts. Regular experimental runs of a newly developed mesoscale model with a 15 km grid size have been started with the aim, in due course, of improving local and short-term forecasting.

Regarding observations, the installation of a radar at Chenies, Bucks, that will cover the Greater London area is an important step towards the provision of a complete radar network for England and Wales. The Office has taken a lead in encouraging co-operation between European and North American meteorological services in the development of a better and more efficient observing system for the North Atlantic. As the Weather Ships are phased out, new more cost-effective systems are being introduced—upper-air ascents from merchant ships, automatic interrogation of aircraft from satellites, automatic observing buoys, as well as considerable effort being put into the interpretation of satellite data.

To assist with making more effective use of data from satellites which is an increasingly important component of the observational system, a small Meteorological Office research unit has been set up in Oxford University alongside the Department of Atmospheric Physics, one of the world's leading centres in satellite meteorology. A cell concerned with ocean modelling is also being set up within the Oxford unit in which the Natural Environment Research Council is also co-operating. The unit, which represents a significant step forward in the co-operation between the Office and universities, was formally opened in the presence of the Vice-Chancellor by Sir Peter Swinnerton Dyer, Chairman of the Meteorological Committee, on 14 November.

Meteorology is necessarily highly international in character; all nations of the world, without exception, co-operate in arrangements for the acquisition and free exchange of meteorological data. The United Kingdom is continuing to play a leading role in the World Meteorological Organization, the international body responsible for the international arrangements and links; members of the Office are involved in most of its committees and technical commissions. Close contact is also maintained with other leading meteorological services. In this regard, I paid a visit to the meteorological services in the United States where I was received most warmly and where there are many possibilities for continued and increased co-operation between us.

During the year the Office has continued to respond to the recommendations of the Resource Control Review. A number of these were concerned with commercial activities and with charging policy. To aid in the development of repayment services a new Marketing Branch has been set up within the Office. With the help of expert advice from commercial specialists it is beginning to generate a marketing strategy for the Office and, following the strong lead given in the Resource Control Review, is vigorously pursuing the possibilities of joining with appropriate companies in the setting up of joint ventures. With regard to charging policy, a report is expected soon from Sir Kenneth Sharp and Mr John Hansford who have been asked to adjudicate on the vexed question of the attribution of the costs of the Meteorological Office's central operation between our major customers.

J. T. Houghton

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 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 other Directors of the 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 1984:

Chairman:

Sir Peter Swinnerton-Dyer, Bt, FRS

Members:

Professor A. H. Bunting, CMG
Professor H. Charnock, FRS
Professor P. H. Fowler, DSc, FRS
Mr J. McHugh
Mr J. Miller, FIOB
Mr G. Williams
Mr J. Wilson
*Mr M. A. Gamester (Representative Civil Aviation Authority)
*Dr J. T. Houghton, CBE, FRS (Director-General, Meteorological Office)
*Mr D. C. Humphreys, CMG (Deputy Under-Secretary of State (Air))
*Air Vice-Marshal L. A. Jones, CB, AFC (Assistant Chief of the Air Staff (Operations)); alternate, Group Captain N. Bonnor
*Captain J. Marsh, RN (Director of Naval Oceanography and Meteorology)

Secretary:

*Mr F. R. Howell, MBE, FCIS (Secretary, Meteorological Office)

**ex officio*

The Committee met four times in 1984.

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)
*Dr D. Barber (Chief Scientist, Civil Aviation Authority)
*Group Captain N. Bonnor (Deputy Director of Operations (Navigation) (RAF))
*Dr B. S. Collins (Head of Physics Group, Royal Signals and Radar Establishment)
*Dr D. Everest (Representative Department of the Environment)
*Mr P. Goldsmith (Director of Research, Meteorological Office)
*Dr J. T. Houghton, CBE, FRS (Director-General, Meteorological Office)
*Captain J. Marsh, RN (Director of Naval Oceanography and Meteorology)

Secretary:

Mr R. J. Allam (Meteorological Office)

**ex officio*

The Committee met three times in 1984.

Meteorological Office Organization

- **DIRECTOR-GENERAL** — DG Met O — JT Houghton CBE D Phil FRS
  - **Director of Research** — DR Met O — P Goldsmith MA
    - **Deputy Director Physical Research** — DD Met O (P) — DE Miller BA
      - **Met O 14** Boundary Layer Research — **AD Met O (BL)** DJ Carson PhD — PJ Mason PhD *, FB Smith PhD *
      - **Met Research Flight** — **AD Met O (MRF)** REW Pettifer PhD
      - **Met O 15** Cloud Physics — **AD Met O (CP)** PR Jonas PhD DIC — AF Tuck PhD *
      - **Met O 19** Satellite Meteorology — **AD Met O (SM)** J Morgan BSc
      - **Met O 21** Geophysical Fluid Dynamics — **Head of Met O 21** R Hide ScD FRS *
      - **Radar Research Laboratory** — KA Browning * PhD DIC FRS
    - **Deputy Director Dynamical Research** — DD Met O (D) — A Gilchrist MA
      - **Met O 9** Special Investigations — **AD Met O (SI)** WT Roach PhD DIC
      - **Met O 11** Forecasting Research — **AD Met O (FR)** MJP Cullen PhD
      - **Met O 13** Synoptic Climatology — **AD Met O (SC)** DE Jones MSc DIC ARCS
      - **Met O 18** Library, Publishing, Cartographic, Archives — **Head of Met O 18** RPW Lewis MA MSc
      - **Met O 20** Dynamical Climatology — **AD Met O (DC)** PW White PhD — Climate Modelling PR Rowntree PhD
      - **Met O College** Professional Training — **AD Met O (PT)** CJ Readings PhD
  - **Secretary** — Sec Met O — FR Howell MBE FCIS
    - **Met O 4** Supply, Finance, Secretariat, Office Services — **Head of Met O 4** JE McNulty
    - **Met O 10** Personnel Management — **AD Met O (PM)** AI Johnson BSc ARCS
  - **Director of Services** — DS Met O — DN Axford PhD C Eng FIEE
    - **Deputy Director Observational Services** — DD Met O (O) — P Ryder PhD
      - **Met O 1** Observational Requirements and Practices — **AD Met O (OP)** JM Nicholls BSc
        - Marine Superintendent — Capt GV Mackie MRIN MNI
      - **Met O 3** Climatological Services — **AD Met O (CS)** F Singleton BSc DIC
      - **Met O 8** Agriculture and Hydrometeorology — **AD Met O (AH)** CV Smith MA BSc
      - **Met O 16** Operational Instrumentation — **AD Met O (OI)** CG Collier BSc ARCS
    - **Deputy Director Forecasting Services** — DD Met O (F) — DH Johnson MSc DIC ARCS
      - **Met O 2** Central Forecasting — **AD Met O (CF)** CR Flood MA — **Head of Met O 2b** AJ Gadd PhD; A Woodroffe BSc †
      - **Met O 6** Defence Services — **AD Met O (DS)** IJW Pothecary BSc — **C Met O HQSTC** D Forsdyke BSc
      - **Met O 7** Public Services — **AD Met O (PS)** RM Morris BSc — **C Met O LAP** SJ Caughey PhD
    - **Deputy Director Communications & Computing** — DD Met O (C) — MJ Blackwell MA
      - **Met O 5** Telecommunications — **AD Met O (TC)** RJ Sowden
      - **Met O 12** Data Processing — **AD Met O (DP)** RL Wiley PhD
      - **Met O 22** Systems Development — **AD Met O (SD)** WA McIlveen PhD
    - **Met O 17** International and Planning — **AD Met O (IP)** SG Cornford MSc
    - **Met O 23** Marketing Services — **AD Met O (MS)** DM Houghton MSc DIC

* Individual merit

† Special appointment

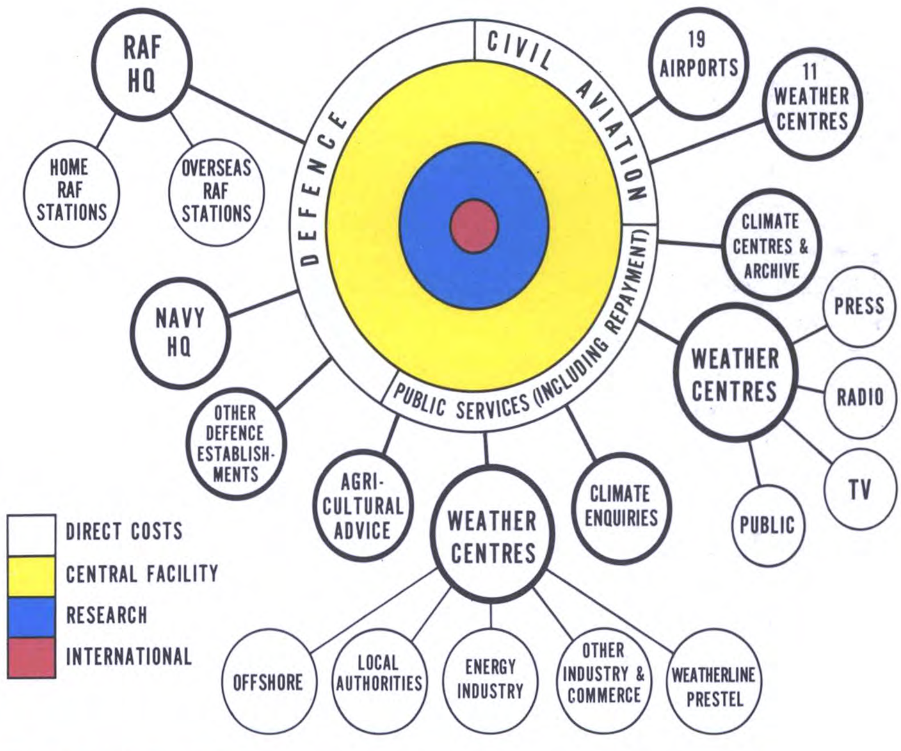
Introduction

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 15 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.



The Meteorological Office

Observations and instrumentation

Introduction

Regular, reliable and accurate measurements of many meteorological variables, both from the surface and in the atmosphere, are needed to support the wide range of forecasts produced by the Meteorological Office. Observations are also essential to its 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. In the maintenance and development of these networks, there is a continuing need to introduce modern automatic data-gathering systems to provide information from hostile, uninhabited regions and replace the observing capability lost to the Office as it, and other organizations which have historically provided it with regular observations, rationalizes and reduces its dependence on manpower. At present, technology is not available to enable all the necessary observational data to be obtained automatically. For example, human estimates and judgements of visibility, cloud type and structure, actual weather phenomena (especially those occurring adjacent to rather than at the station) and so forth cannot yet be adequately substituted by fully automatic, instrumental measurements. Nevertheless, a good deal of work is being done in this direction to reduce and keep to a minimum the dependence on human observers while at the same time maintaining, and in some cases improving, the observational data base.

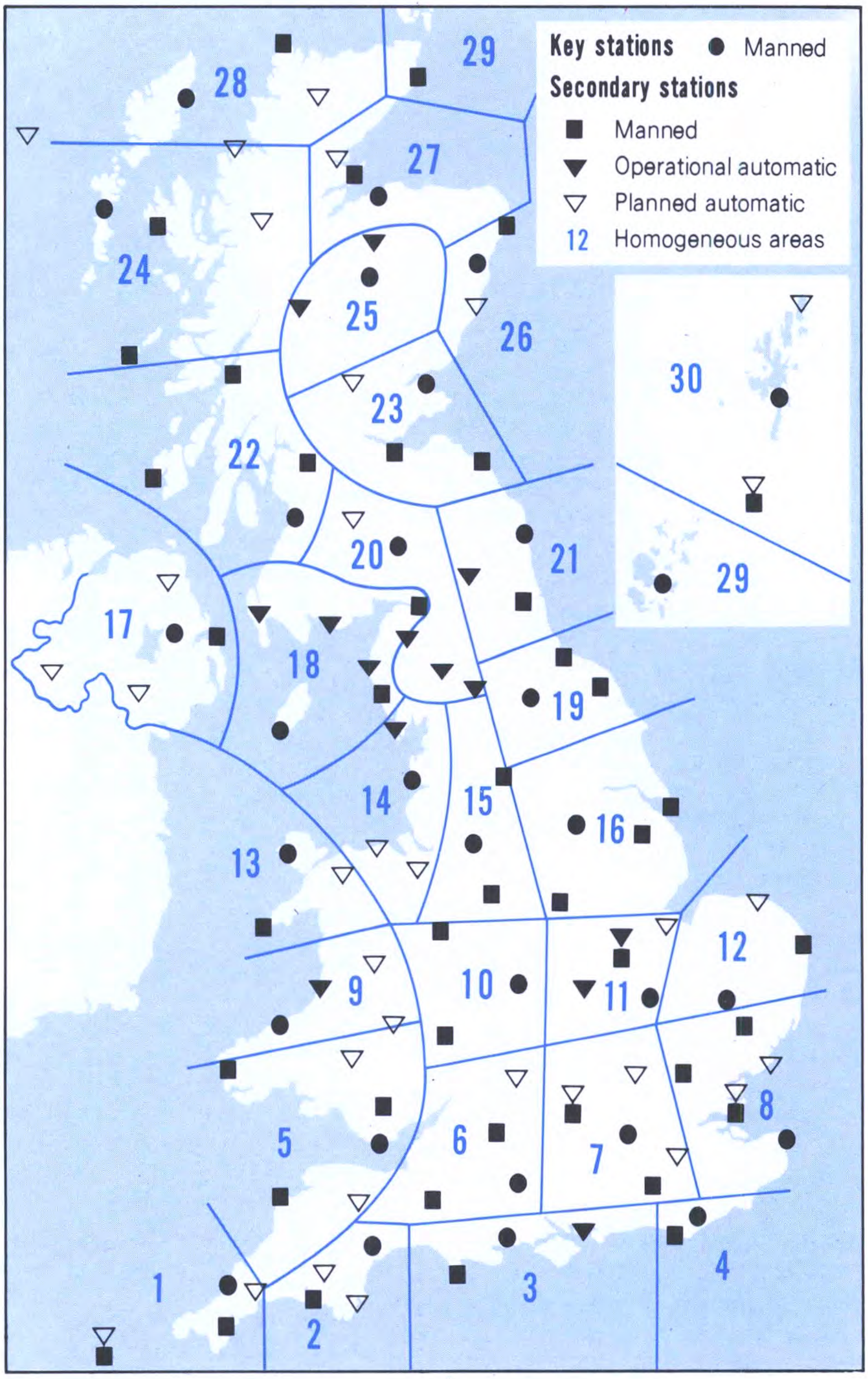
Surface observations

Key, secondary and supplementary observing networks on land

To define the existing state of the weather at or near the surface on space scales of around 1000 km (the 'synoptic' scale), a network of observing stations with a spacing of about 150 km over land is needed. To meet this requirement a 'key' station is established in each of 30 geographical areas (see right) which have approximately homogeneous meteorological characteristics on the broad scale. Key stations are professionally manned and accurate observations are made both by visual means and from instrumental sources (of pressure, temperature, humidity, wind and rainfall amount). Observations are generally made hourly, though at a few airfields they are made half-hourly.

To define the weather in greater detail over short periods and especially to take account of variations due to orography an additional network of 85 'secondary' stations is needed. Sixteen of these secondary stations are manned by Office staff and 23 by auxiliary observers who are individuals with a strong interest in the weather and who are trained by the Office as observers. The remaining 46 observing stations will be entirely automatic and will transmit instrumental measurements directly to collecting

The UK land-based network of key and secondary synoptic stations.



centres. Fourteen of these synoptic automatic weather stations (SAWS) have now been installed and commissioned into routine service and the overall data return from the systems and their reliability have been outstanding; data recovery has consistently exceeded 90 per cent of that possible. Auxiliary observers also man a network of some 165 very valuable supplementary stations which report on a limited range of elements for particular local-forecasting needs and other uses.

An extensive data base is required to support climatological services provided to customers such as those in the engineering industry, insurance companies and legal consultancies; about 500 stations report a range of elements once or twice a day. However, owing to the complex distribution of rainfall over the United Kingdom daily reports of rainfall are required from a network of around 6000 stations. Almost all of these observations are made by private individuals or other agencies, but a certain number of automatic instrumental systems are needed as well, especially for part of the rainfall measurement network.

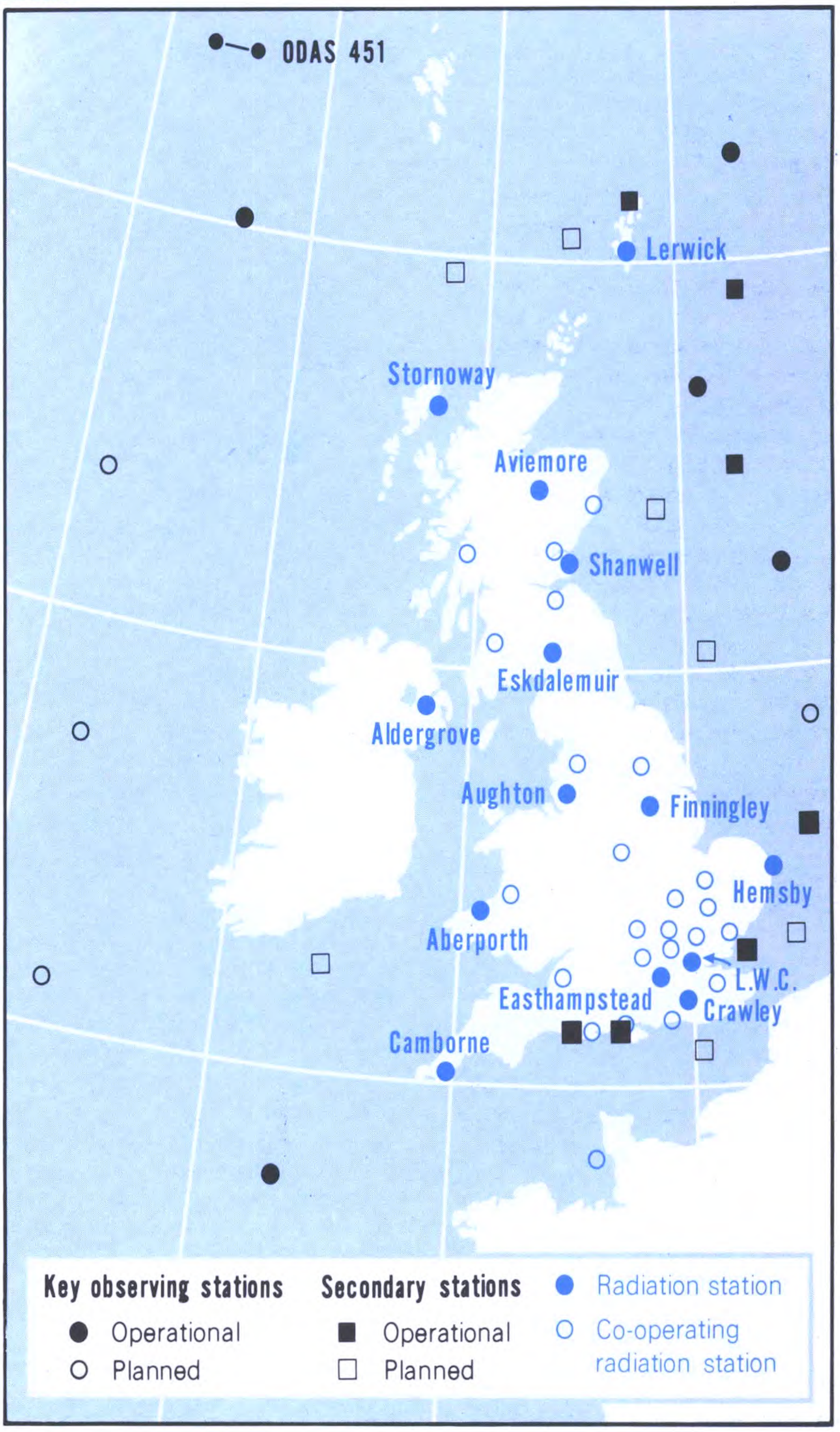
To meet these needs, and to provide modern instrumentation for the key and secondary observing networks, several re-equipment programs are under way. In particular, the final stage of development of the Automatic Climatological Recording Equipment (ACRE) was completed this year and procurement of the first batch of operational systems began. Procurement of new types of cloud-base recorders, transmissometers, digital wind-recording equipment and recording rain-gauges was continued or begun. Parts of the observational networks shown on page 2 entail the need for successful meteorological measurements to be made in mountain terrain. This presents severe technical difficulties associated with the accumulation of snow and, especially, rime ice on the surfaces of exposed instruments. These problems are being tackled by the development and testing of new prototype systems designed to overcome the problems of exposure. Systems capable of measuring wind speed and direction, temperature and humidity were installed for trials on the summit of Great Dun Fell in the Pennines and at the chair-lift station near the summit of Cairn Gorm. The system on Cairn Gorm functioned without significant fault for the entire winter and provided valuable local data during a period of very severe weather. Progress with this work was pleasing, but there remains some further work to do before an operational system is available.

The weather station at Great Dun Fell.

Marine observations

The figure below shows the network of existing and planned fixed, marine weather stations around the United Kingdom. Nine marine key stations that can report a comprehensive range of elements, preferably every three hours, are required. Ideally these stations should have permanent locations, a high standard of observational data and good telecommunications; they may be operated manually or be automatic. Fourteen secondary stations are also required in support of local forecasting requirements. In the autumn of 1983, as part of the program aimed at meeting these needs, a specially equipped buoy

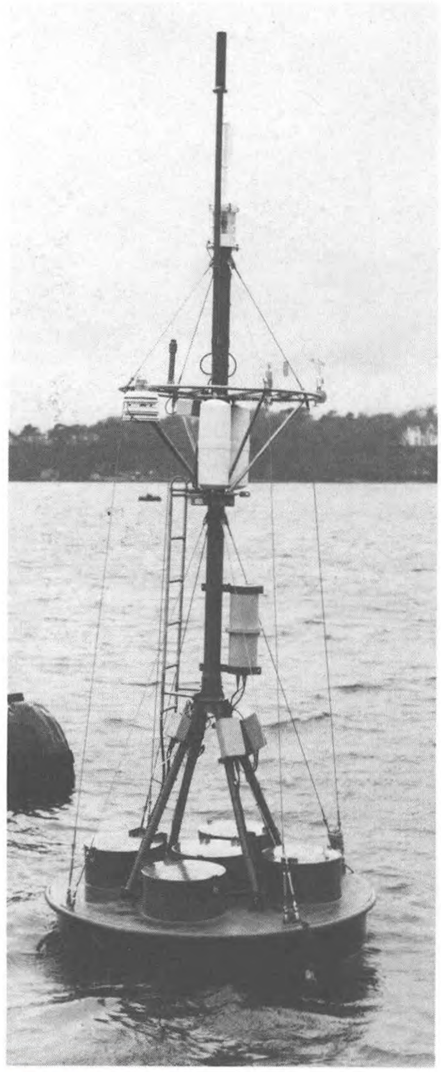
The network of key and secondary marine observing stations and the UK network of radiation stations.



(right) was moored about 150 miles south-west of Land's End and it provided regular, good quality data via the Meteosat communication channel until it broke adrift (or was cut free) during very severe gales in January. The facility on board the buoy to fix its position by satellite enabled it to be tracked as it drifted towards the north coast of Brittany. With the help of the French meteorological service, arranged through our membership of the COST-43 (European Co-operation in Science and Technology) Project, advantage was taken of a few hours of relatively quiet weather and the complete buoy was recovered when only one and a half miles from the rocks and certain destruction. Work has now begun on refurbishing the system ready for a further deployment at a different location in 1985.

Contractual obligations to the Shetland Islands Council were fulfilled when in June an unmanned marine automatic weather station (below) was installed and commissioned on the island of Foula, south-west of Shetland. This installation is similar to those already in service on Muckle Holm and Sule Skerry and is interrogated by VHF radio from a shore station at Lerwick. The station makes automatic measurements of pressure, temperature, humidity, wind direction and wind speed (including the highest gust in each hour).

The Foula automatic weather station.

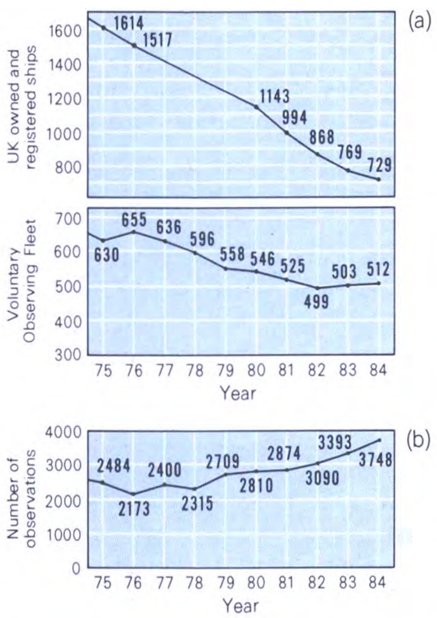


The ODAS 20 buoy.

To reduce the cost of obtaining observational data from remote, environmentally hostile regions, ways are continually sought to co-operate either nationally or internationally with others who have a need for similar data. This has led to co-operative projects in which automatic or semi-automatic observing systems are to be or have been set up at a variety of marine sites. Advice on instrumentation (especially sensors and their exposure) and on data processing and communication has been given to several major oil companies through the United Kingdom Offshore Operators' Association (UKOOA). This will result in these companies establishing well specified and properly installed automatic observing systems on four or five hydrocarbon recovery platforms in the North Sea from which the meteorological data will be made available to the Office in real time. Advice and guidance were given to EMIE Ltd on meteorological sensors and their exposure, and on general problems of making good meteorological measurements automatically from moored buoys, so enabling them to complete satisfactorily a contract with UKOOA to provide moored buoys at sites 150 miles south-west of Land's End and 70 miles north-west of Shetland. Both buoys were moored and commissioned in the second half of the year and the observational data are made available to the Office.

The requirement for observations from the oceans on the synoptic (about 1000 km) scale has been addressed by three projects during the year. The Office is participating in an international co-operative project to establish and maintain for at least three years two freely drifting observational buoys in an area of the North Atlantic bounded by 55°N, 63°N, 25°W and 45°W. The buoys will provide real-time measurements of surface pressure and sea surface temperature. The positions of the buoys will be determined by the location facility on the polar-orbiting satellites of the TIROS series and these satellites will also provide the data communication channel via a special radio receiving station in Oslo. This project has been set up under the auspices of the COST-43 Project and will be led by France with contributions from the United Kingdom, Norway, the Netherlands and Iceland. Ireland has expressed interest in joining later. In a separate venture, bilateral co-operation was arranged with the Institut für Meereskunde of the University of Kiel through which the Office was able to equip with barometers six drifting buoys owned and deployed by the Kiel group. This enabled the Office to obtain real-time observations of surface pressure and sea surface temperature (from sensors already on the buoys) as the buoys drifted eastwards from the deployment area in the Atlantic north of the Azores. To have obtained these valuable data without the co-operation of the Kiel group would have been prohibitively expensive. Thirdly, negotiations with Norway and Iceland are under way through COST-43 for the re-establishment of the jointly financed and operated, fixed observational buoy, ODAS 451, at a position about 280 nautical miles west of Faeroes (see page 3). It is hoped to redeploy the buoy in the summer of 1985.

A world total of approximately 7500 ships make and transmit meteorological reports to shore-based centres. The United Kingdom Voluntary Observing Fleet (VOF) consists of about 500 ships of various types, equipped with meteorological instruments, texts and record books, enabling ships' officers voluntarily to collect and transmit by radio meteorological data on a regular basis. The work is co-ordinated by the Marine Superintendent of the Meteorological Office who ensures that VOF numbers are maintained and that the ships are kept supplied through direct liaison with shipowners, by seven home-based Port Meteorological Officers (PMOs), and by the co-operation abroad of PMOs of other meteorological services. In addition to surface data, VOF ships collect information on ocean currents for use by the Admiralty in revising current charts, and on marine fauna, flora and other phenomena, all of which are communicated to interested parties.



The number of ships in the VOF compared to the British-owned and registered fleet (a) and the number of ships' messages received at Bracknell (b).

A previous decline in the VOF has been arrested (as illustrated above) despite continuing depletion of the British-owned and registered fleet of merchant ships. The figure also shows the increase in the number of weather messages received at Bracknell from these ships, a reflection of the greater time now spent at sea and of improved satellite communication. The main problem with the communication of meteorological observations from ships is to keep the time taken for the observation to reach the forecaster to a minimum. This problem has been tackled by operational trials of the new Meteorological Observing System for Ships which is a manual-entry data-formatting and transmission system which allows surface observations from merchant ships to be recovered to Bracknell within a few minutes of the observation time. The system uses automatically-timed broadcasts via the geostationary meteorological satellites (Meteosat, GOES-E and GOES-W). Eight ships were equipped during the year and the system has been enthusiastically received by the deck officers who use it. Data recovery, especially of the observations made at midnight and 0600 GMT, has been increased sharply and is now about 90 per cent of possible for these ships. Procurement action was begun to acquire, over a period of four years, sufficient systems to equip about sixty ships. Ocean Weather Ship (OWS) *Starella* a chartered, converted Hull trawler, fulfilled her obligations under the World Meteorological Organization (WMO) Agreement for the joint financing of the North Atlantic Ocean Stations (NAOS) by continuing to operate on station 'Lima' at position 57° 00′N 20° 00′W in the North Atlantic on alternate months in conjunction with the Netherlands' OWS *Cumulus*. The Agreement also covers the operation of three other stations by Norway, France and the USSR. Observers on board OWS *Starella* make hourly surface observations, which include sea state and swell, record sea temperature and salinity, and collect samples of plankton, rain and sea water for scientific analysis ashore.

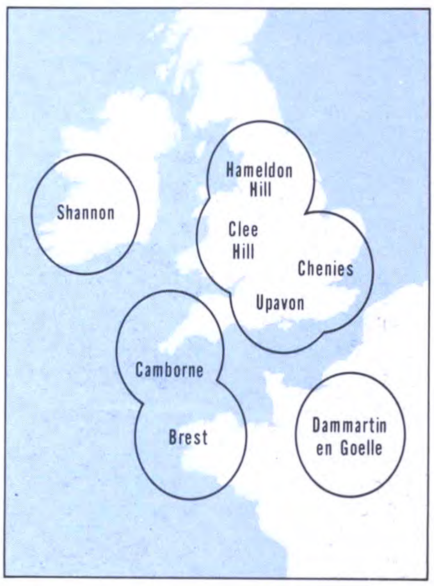
OWS Starella.

The weather radar network

Real-time knowledge of the geographical distribution and intensity of precipitation occurring over the United Kingdom and adjacent sea and continent is of very great value to forecasters who have to produce accurate short-period predictions for local areas. Moreover, such data have many other uses in the management of water supply and drainage. Work during the past few years at the Office's Radar Research Laboratory at Malvern, has led to the development of digital methods whereby precipitation measurements from several radars can be transmitted to a central location, and composited automatically to give a map of precipitation over a large area. The UK network of such weather radars currently consists of five radars (see below), and came into full operational service at the end of the year. Data from a sixth radar at Shannon in the Republic of Ireland are also included in the composite as part of an agreement reached within a European Economic Community (EEC) Project (COST-72, see below).

The radars in the UK network are of varying types and ages and have been established under a variety of arrangements. Those at Camborne

The weather-radar network. (The circles show the range of useful coverage (around 150 km). The maximum range is 210 km.)



(Cornwall) and Upavon (Wiltshire) are old units, originally acquired by the Office for other projects and now reaching the end of their useful lives; they give restricted coverage compared to the other radars in the network. The system at Hameldon Hill (Lancashire) is new and was procured as part of the North West Weather Radar Project, a co-operative venture between the Meteorological Office, the North West Water Authority, the Water Research Centre, the Central Water Planning Unit (now defunct) and the Ministry of Agriculture, Fisheries and Food. The radar at Clee Hill (Shropshire) is wholly owned by the Meteorological Office while that at Chenies (Buckinghamshire) has been established by a consortium which comprises the Meteorological Office, the Greater London Council, the Thames Water Authority and the Southern Water Authority. Each radar has its own on-site minicomputer which is used to accept the raw radar data, apply various corrections, and output the data in a number of formats to a variety of locations including a compositing centre presently at Malvern, but soon (mid-1985) to be relocated at the Meteorological Office Headquarters at Bracknell. The real-time processing at each radar site includes the calibration of the radar data using data from a few (3–5) telemetering rain-gauges, which are interrogated every 15 minutes. All the radars are capable of producing precipitation data at one-minute intervals with a minimum spatial resolution of about 1 km, although resolutions of 5 minutes and 2 or 5 km are used in the present system as a compromise to meet most user requirements at a reasonable cost.

A field of surface precipitation is transmitted from each radar site every 15 minutes. Data from individual radars are supplied, as images and as totals integrated over user-specified time periods and areas, usually river subcatchment areas, to an increasing number of Meteorological Office and Water Authority locations throughout England and Wales. An example of the composite images which are also distributed from Malvern is shown.

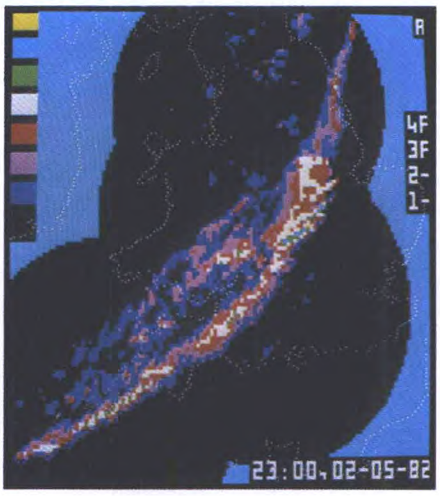
Data from the individual sites are also passed in near real time from the network computer to a further computer known as the FRONTIERS system, which is employed to quality control, reformat and display the radar data along with cloud imagery from the geostationary satellite Meteosat for use by a roster of forecasters. The quality-control function of the FRONTIERS computer is necessary so that any spurious ground returns or interference can be removed from the radar data. With this system it is also possible for the forecaster to use experience to combine radar information with conventional data (from rain-gauges and radiosondes) and thus improve the interpretation of the radar measurements, particularly at far ranges where the radar measurements are difficult. Work is in hand which will allow re-analysed precipitation fields based on radar and, later, precipitation fields over a larger area based on both radar and satellite data, to be distributed to users via the network computer. Eventually, forecasts for a few hours ahead obtained by extrapolation may also be produced by the FRONTIERS system. Further extensions to the radar network have been considered by a joint Meteorological Office/National Water Council working party. This group has proposed a cost-effective way of continuing to extend the network in England and Wales. Potential benefits to Scotland of radar are also being assessed.

The COST-72 Project aims at a wider exchange of radar data throughout western Europe. This Project, sponsored by the EEC, is currently considering how best to achieve this data exchange on an operational basis, and a Pilot Project has begun. The United Kingdom is acting as the centre for producing, on an experimental basis, a combined radar and satellite picture using radar data, obtained in real time using a British Telecom autodial system, from the United Kingdom, Switzerland, France, and later from the Netherlands.

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.

An example of the instantaneous distribution of rainfall over part of the United Kingdom observed by the weather-radar network.



The direction-finding equiment used for this work was originally designed before World War II and is now obsolete. For some years a project has been in progress to design, test, procure and commission an entirely new system based upon the concept of detecting the differences in the absolute times at which radio waves generated by a lightning flash are detected at a series of receivers geographically well separated. Very considerable progress was made this year on this project. Hardware and software for the control station were delivered in the autumn and the hardware for the first of the outstations arrived late in the year. Work then began on integrating these components into a complete, operational system.

Observations of radiation

The National Radiation Centre (NRC), based at Beaufort Park, oversees the measurement of solar radiation by a network of 38 stations (see page 3) within the United Kingdom. Fourteen stations belong to the Meteorological Office; the remainder belong to co-operating bodies, mainly in the agricultural and water supply industries, who exchange their data with the Office in return for an instrument calibration service.

At all the Meteorological Office stations in this network thermopile pyranometers are used to measure global and diffuse irradiances on a horizontal surface. Measurements are taken at one-minute intervals, and hourly averages are archived and supplied to customers in the fields of engineering, building and agriculture. Three stations also measure the intensity of the direct solar beam using pyrheliometers and two record data from instruments on vertical surfaces, a measurement of interest in solar energy and building design application. An important function of the NRC is the maintenance of the standard instruments used in calibration work, the primary reference for which is an absolute cavity radiometer. International consistency is ensured by periodic comparisons of standards, and in June the NRC instruments were present at the WMO pyrheliometer comparison held at Carpentras (France). A total of 11 European countries were represented with 8 absolute radiometers and 13 Ångström (non-absolute) instruments deployed in excellent weather conditions. Preliminary calculations indicate that the calibrations of the NRC instruments have changed by less than 0.1 per cent in the four years since the last comparison.

Upper-air observations

Vertical profiles of atmospheric temperature, humidity and wind to heights around 30 km are an essential data source for all types of weather forecasting. Temperature and humidity are obtained from instruments carried aloft on free-flying balloons tracked by radar to infer wind. Such radiosonde ascents are made operationally at eight land stations in the United Kingdom and by OWS *Starella* at 0000 and 1200 GMT. Wind-only ascents are also made at 0600 and 1800 GMT. Radiosonde stations are maintained overseas at Gibraltar and St Helena. Data from such ascents on a world-wide basis provide the basic input to numerical forecast models, while individual ascents enable forecasters at a regional or local level to assess in more detail such factors as local cloud formation and precipitation type and phase.

The performances of different types of radiosonde are not identical. To make the best use of world-wide radiosonde measurements in numerical forecast models it is important to define the relative performance of the different national radiosonde types. To this end, the first phase of an international radiosonde comparison on behalf of the Commission for Instruments and Methods of Observation (CIMO) of WMO was hosted for six weeks in June and July at the Office's Experimental Site at Beaufort Park, Bracknell. Participating nations were Finland, the Federal Republic of Germany, the USA, and the United Kingdom; in addition a radiosonde proposed for transoceanic measurements from merchant ships was also deployed. The five radiosondes were flown together and simultaneous measurements of all measured variables were compared. One hundred flights, mostly to a height of 35 km, were made. The results provide the most reliable link so far obtained between operational observations in North America and those in western Europe.

A recent concept in upper-air observing is the idea that environmental data acquired by aircraft in routine commercial transcontinental service could be coded and transmitted to meteorological operational centres. Aircraft to Satellite Data Relay (ASDAR) system is one of a family of data-retrieval devices which variously use satellite, HF, VHF or radar transponder communication systems to implement this idea. Seventeen experimental ASDAR systems developed in the USA were used during the Global Weather Experiment of 1979 and gave results which indicated that an operational ASDAR system would contribute usefully to the World Weather Watch. A consortium of nine meteorological services was formed to secure the development of an ASDAR unit suitable for quantity production and a contract due for completion in September 1985 was placed with GEC McMichael Ltd (Slough). Three units produced to production standard will be evaluated on UK-based aircraft early in 1985 and three more will be evaluated on US aircraft subsequently.

Every seven minutes ASDAR provides automatically measurements, based on one-second samples, of wind speed and direction, aircraft height and position, and air temperature and turbulence. Bulletins of measurements are transmitted every hour in level flight through geostationary meteorological satellites. During ascent and descent the mode of reporting is changed automatically and up to 30 observations are made between the ground and cruise level yielding atmospheric profiles which are a useful supplement to data obtained from balloon-borne equipment.

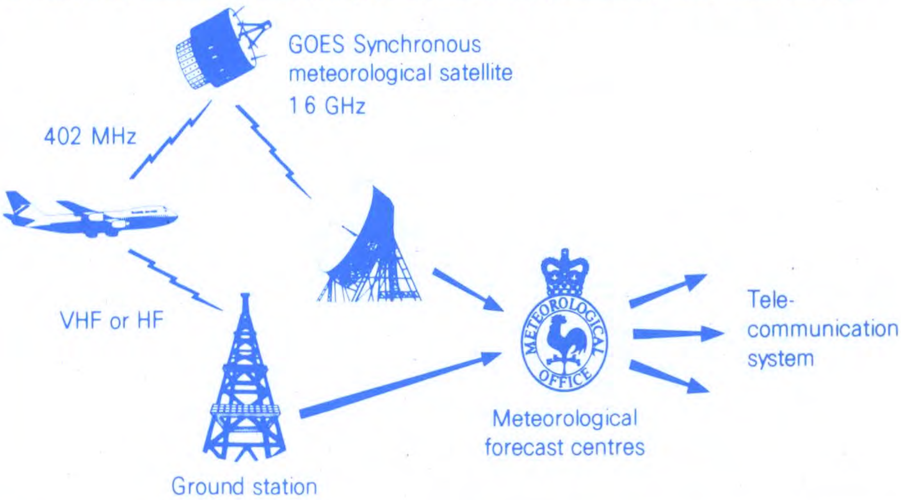
The ASDAR unit is capable of being interfaced with other external communication systems and efforts are being made to establish common ground with other systems which have been proposed but which are not in such an advanced stage of development. Suitable standardization of engineering specifications and of communication protocols would permit savings in weight and expenditure.

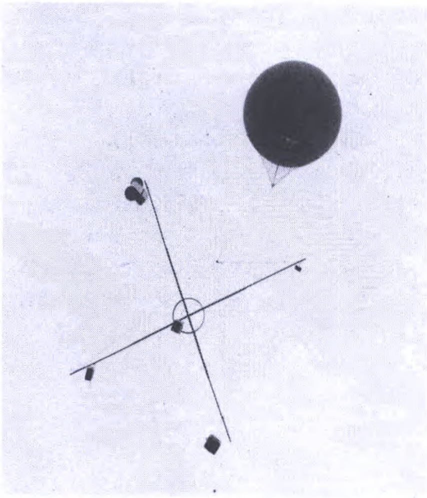
Observations from satellites

The Office continues to take an active role in the development of instruments for the observation from space of the earth and its atmosphere. Because of the high cost of systems intended for use in space most of the activities in this area are in co-operation with other establishments having common interests in the products of the systems or the necessary high technology.

In one such co-operative venture the Office is working with the Rutherford Appleton Laboratory on their project to fly the Along Track Scanning Radiometer (ATSR) on the European Space Agency's earth resources satellite, ERS-1, due for launch in 1989. The ATSR is an experimental instrument designed with the primary mission of measurement with high accuracy of sea surface temperatures. One of the problems of remote sensing of this variable is the effect of atmospheric absorption. This can introduce a bias of up to 10 °C in moist tropical atmospheres. Correction for it is difficult and residual errors in the atmospheric correction are a significant contribution to the error in the derived products. The ATSR introduces the idea of double sampling of the sea radiances by looking at the same sea pixel twice, from two different angles through different atmospheric paths. This will help in the retrieval process and permit the measurement of sea surface temperatures to an accuracy of 0.5 °C. The instrument will also be able to determine such a variable as cloud cover and, through use of the additional microwave package, measure total column water vapour.

The aircraft to satellite and aircraft to ground radio data acquisition and distribution concept.



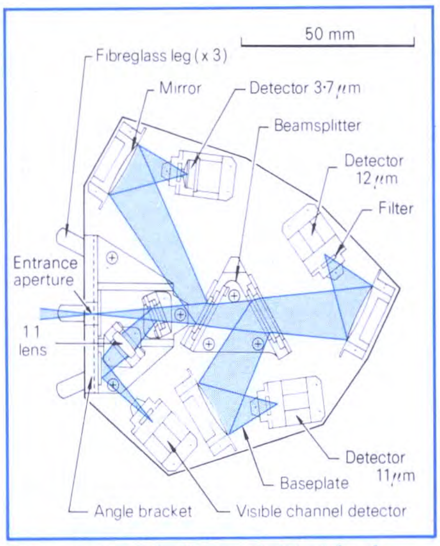


Five different radiosondes on a comparison flight.

The Office's main contribution to ATSR is to develop the focal plane assembly for the instrument. The assembly has provision for three infra-red sensors and one detector of visible light. It includes a high precision assembly of beam splitters, mirrors and a lens to enable all four of the detectors to view the earth through one telescope. In contrast with some previous focal plane assemblies the instantaneous views of earth from all four detectors will be accurately co-registered within the instrument. During 1984 the initial design report was written and a model of the assembly completed.

The development of instruments for flight on the US polar-orbiting satellites has been a longer-term activity since the early 1970s, as part of a co-operative program with the USA. The first phase of this program was the development of a series of Stratospheric Sounding Units (SSUs), built for the Meteorological Office by Marconi Space Defence Systems. The SSU complements two US radiometers on the same satellites forming part of the system of three instruments known as the TIROS Operational Vertical Sounder (TOVS). The SSU itself is a three-channel radiometer. Radiation from the atmosphere is transmitted through a pressure modulated gas-filled cell for each channel. The pressure in the cells is different for each channel such that the instrument measures the temperature of the upper part of the stratosphere at heights of between 20 and 50 km. Routine processing of these data yields the temperatures on a global basis at pressure levels around 1, 2, 5 and 20 millibars.

During 1984 SSU flight model F5 was integrated into the NOAA-F satellite in the USA, and launched on 12 December from the Western Test Range, California, into the planned polar orbit at an altitude of approximately 850 km. The instrument has been tested in orbit and found to perform as expected. This instrument was the sixth SSU to be provided by the Office and launched on the US polar orbiter satellites (Table I) in this successful co-operative program.



Components of the light path (blue) for the ATSR focal plane assembly.

The next phase in the co-operative agreement has been defined and concerns an entirely new instrument called the Advanced Microwave Sounding Unit (AMSU). Instruments of this type will be flown on the developments of the same series of satellites from about 1989 and will have two major components. AMSU-A will be provided by the USA and will be a fifteen-channel microwave radiometer to measure the temperature of the atmosphere from the surface up to about 50 km. The Office has agreed to provide a complementary instrument known as AMSU-B; a five-channel microwave radiometer which will measure humidity in the troposphere. AMSU-A will use microwave radiation in the range 23.8 to 89 GHz. AMSU-B will use higher frequencies ranging from 89 to 190 GHz. This will involve very demanding technology as components using this part of the electromagnetic spectrum have not yet been flown in space. During 1984 initial study contracts reported on various aspects of the proposed instrument and noted technology areas in which further development work is needed. The Office has initiated a major contract action for the development of critical high-frequency components, and has started work in conjunction with industry on the preparations for the development contract for the complete instrument. Further feasibility and design studies are under way on this project, and it is expected that the main industrial contract will be agreed in late 1985.

The Office has also agreed to make a limited financial contribution to the Microwave Limb Sounder (MLS), an instrument to be flown on the Upper Atmosphere Research Satellite of the National Aeronautics and Space Administration, USA, planned for launch in 1989. The Office's contribution will be to the Rutherford Appleton Laboratory, which is participating in the development of MLS with the Heriot-Watt University and with the Jet Propulsion Laboratory in the USA. Participation in this research program will provide the Office with essential access to developments in the technology needed for AMSU-B.

In addition to the above activities there have been investigations into other techniques for the remote sensing of the atmosphere, including the possible use of a limb sounder to estimate geopotential heights in the atmosphere, but these studies have not yet resulted in firm instrument proposals.

Activities in support of observing networks

The standards of observing sites and practices are maintained by regular inspections of stations in line with WMO recommendations. The accuracy of data obtained from the networks is ascertained by trials on the equipment before it is introduced into operational use, and by centralized automatic procedures which analyse the observations variable by variable and make sophisticated internal consistency checks upon the continuity of data in space and time. This is a comparatively newly developed process which this year has been adopted on a semi-operational basis. It is proving of value by alerting the Meteorological Office Maintenance Organization when automatic observing equipment develops faults.

Table I *Status and schedule for launch of the Office's Stratospheric Sounding Units (SSUs)*

SSU model	Satellite	Launch date	Satellite to be used until	Remarks
PF1	TIROS-N	Oct 78	Feb 81	Satellite failure
F2	NOAA-6	Jun 79	Jun 83	Reactivated July 84
F4	NOAA-B	May 80	—	Launch failure
F3	NOAA-7	Jun 81	Present	Two channels working
F6	NOAA-8	Mar 83	Jun 84	Satellite failure
F5	NOAA-9	Dec 84	Present	Latest launch
D2/3	NOAA-H	Mid 86		Plan
F7	NOAA-I	Mid 88		Plan
F8	NOAA-F	Mid 89		Plan

Introduction to the preparation of forecasts

Behind the scenes—getting the forecast right

In operational weather forecasting time is of the essence and a great deal of effort is required to provide the forecaster (and the customer) with the latest information. Keeping up to date with the current meteorological situation requires reliable observing systems, good international co-operation and fast telecommunications. Forecasts are then produced using a combination of the results of a numerical computer model and the skills and knowledge of the forecaster. The particular requirements of the individual customer also need to be considered to make sure the best service is provided.

How is all this done?

Knowing what is happening

This is a vital part of the forecasting process and the problem is by no means solved in spite of the technological advances in recent years. The weather picture is necessarily incomplete especially bearing in mind the very localized nature of some phenomena. Note that the area of data coverage has to be large; even forecasting a day ahead for the United Kingdom requires good knowledge of what is happening in the atmosphere over Europe and the North Atlantic while for longer-period forecasting a complete hemispherical or global data coverage is needed.

Within the United Kingdom, conventional surface observations from Meteorological Office and other observers form the mainstay of the network. Automatic weather stations fill in some awkward gaps though they do not provide the full range of elements, for example amount and type of cloud. Weather radars give very detailed information on precipitation areas and with frequent monitoring it is possible to follow changes very closely. Further afield, observations are received from other countries and from ships of all nations. Buoys both drifting and fixed are also used. Several thousand surface observations are received at the main observation times and a typical distribution is shown. Satellite pictures give much additional information and assist significantly in the location and

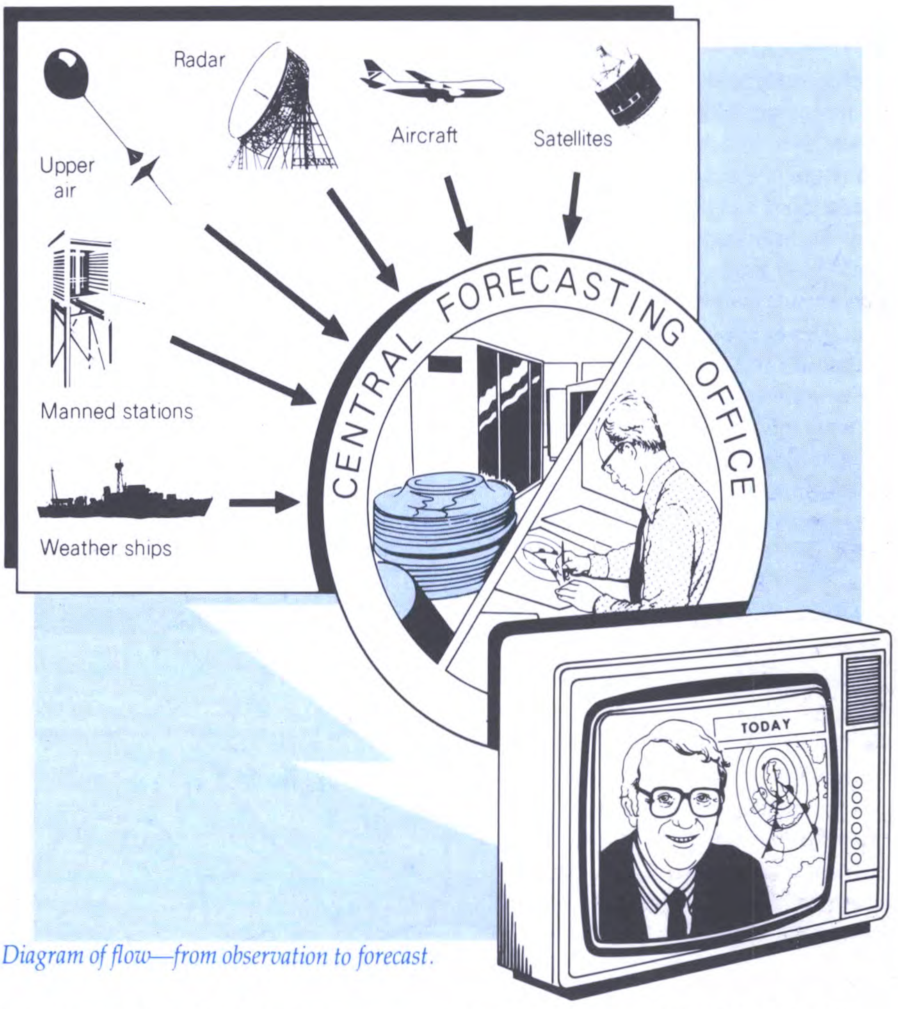


Diagram of flow—from observation to forecast.

assessment of weather features. However, even for the North Atlantic, the forecasters are often faced with uncertainty about the present weather situation, at least in detail.

Observations throughout the depth of the atmosphere are essential for weather forecasting. Developments at the earth's surface are strongly dependent on the atmospheric motions above, while the strong flows at about 10 km are important in themselves when it comes to forecasts for aviation. Detailed vertical temperature and humidity profiles are needed to understand the physical processes taking place and to assess the likelihood of thunderstorms, fog and so on. This upper-air information is gathered from a variety of sources. Regular vertical soundings of temperature, humidity and wind are obtained from radiosonde ascents made on a world-wide basis. Aircraft in flight report routinely on winds and temperatures experienced. Satellites provide temperature profiles inferred from radiation measurements and winds deduced from cloud movements.

All these observations, both surface and upper air, are transmitted rapidly around the world for meteorologists of all countries to use.

Producing the forecast

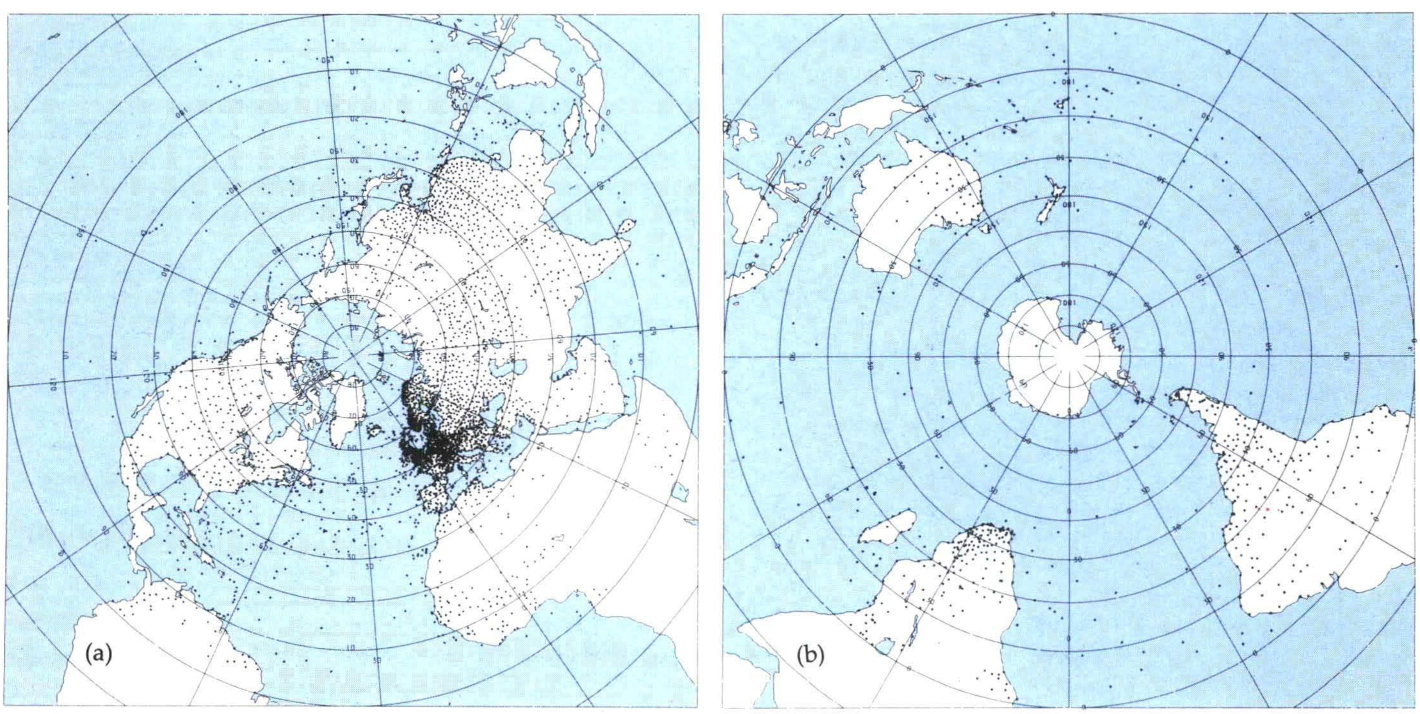
Even with perfect knowledge of the current and previous weather situations, it is by no means straightforward to produce a good forecast. Simple extrapolation can be used for short periods ahead but this quickly becomes unreliable. One of the main reasons for the improvement in weather forecasting in recent years has been the increasing accuracy of the numerical weather-prediction models, which take into account the dynamical and physical processes occurring in the atmosphere. Very fast computers are required to solve the differential equations involved, since this process is carried out numerically on a vast 3-dimensional array of points (about a third of a million in the current Meteorological Office global model). Results from these models are available to the forecasters twice a day within a few hours of the main observation times (0000 and 1200 GMT). This short delay includes time for the observations from around the world to reach Bracknell and to be monitored by a team of forecasters who ensure that the numerical model starts with the best analysis.

The forecasters use the numerical forecast as one source of information. For the general synoptic developments (the behaviour of the depressions, anticyclones and fronts) the model provides very useful guidance, both for the 24-hour forecast chart and for 2–5 days ahead. Even so it is necessary for the forecaster to use more traditional techniques and to make allowance for known problem areas with the model, for example the handling of very small-scale features. The evidence from more recent observations is also taken into account. This process leads to a forecast surface chart.

Following on from this to the forecasting of the actual weather is equally critical and taxing. Again the numerical model plays a part and there are numerical forecast fields which bear on all aspects of the weather including direct output of surface wind and precipitation. However, the skill, knowledge, experience and judgement of the forecaster, using more empirical techniques, remains very important. In forecasting the weather there is little doubt that the combination of the man and the computer (the 'man–machine mix') produces the best results and is superior to either working alone.

Forecaster's and visual displays in the Central Forecasting Office.

Surface observations received from the (a) northern and (b) southern hemispheres on a typical day.



Telecommunications

Efficient telecommunication systems are essential to provide the required facilities for the transmission of information in support of operational forecasting services. Large volumes of observational data must be collected with the minimum delay from many sources and the output from the forecast systems, whether provided directly from numerical forecast models or by forecasters, must be distributed quickly and accurately for the user to gain the greatest benefit.

To meet these requirements the Office maintains national data and facsimile networks for the collection of information and dissemination of forecasts. Telecommunication links to the USA and to a number of European centres enable data to be exchanged so that information from the whole of the globe is available not only at Headquarters but to other users as well.

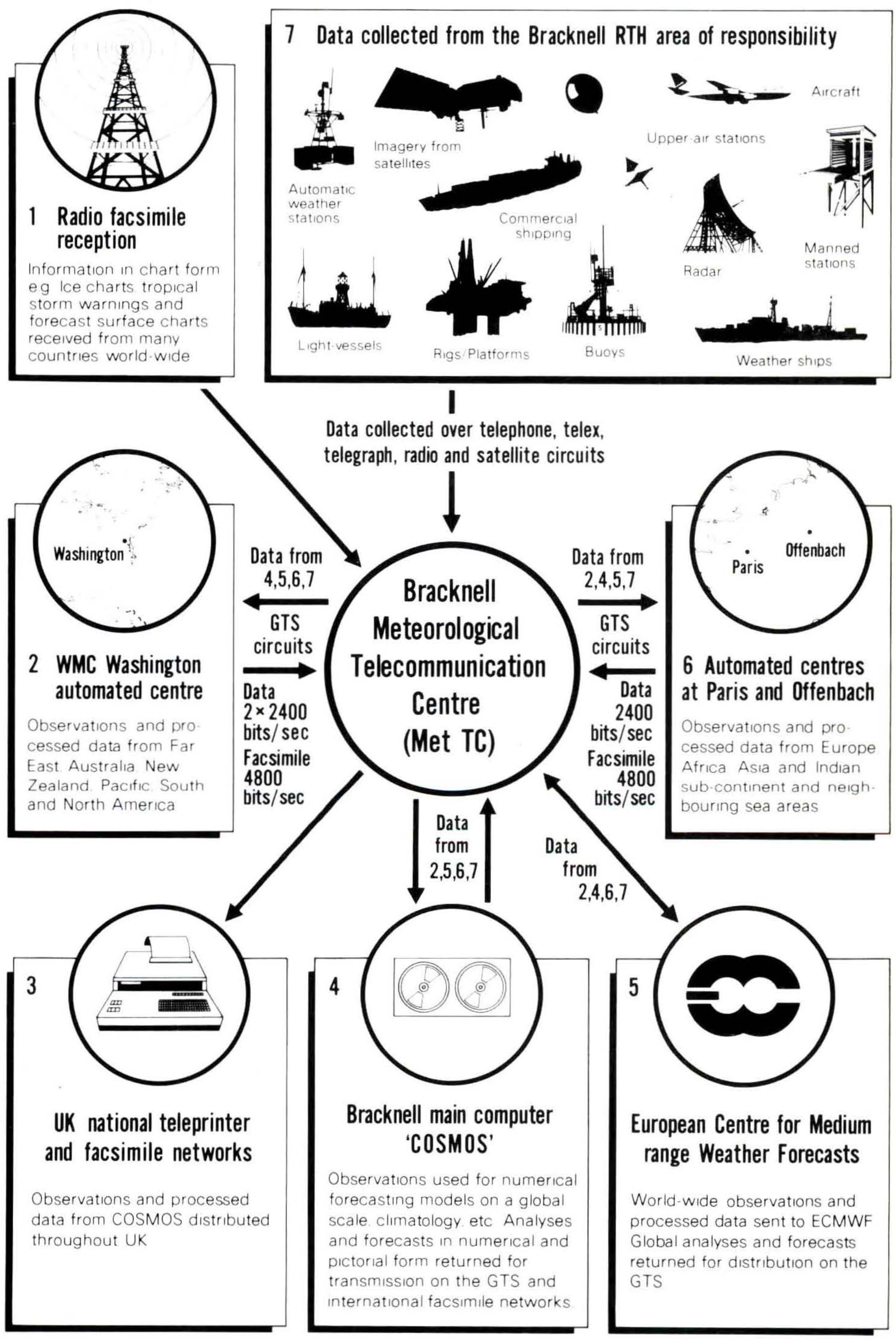
These international circuits are provided by means of a series of bilateral agreements and the network, which extends world-wide, is known as the Global Telecommunication System (GTS) (see page 12). The World Meteorological Organization arranges the co-ordination of methods of operation and transmission techniques to be used. Because of the continuing growth in the volume of traffic exchanged with neighbouring centres of the GTS, higher speeds of transmission are required and plans to upgrade many of the circuits are being developed. Arrangements for transmission control are to be improved by the gradual implementation of procedures in accordance with Recommendation X25 of the International Telegraph and Telephone Consultative Committee.

Nationally, an outline plan has been produced in which all existing communication circuits will be replaced by an integrated network of high-speed digital circuits. This network, together with the computer systems required to support it and to provide general-purpose displays for outstation forecasters, is to be known as the Weather Information System.

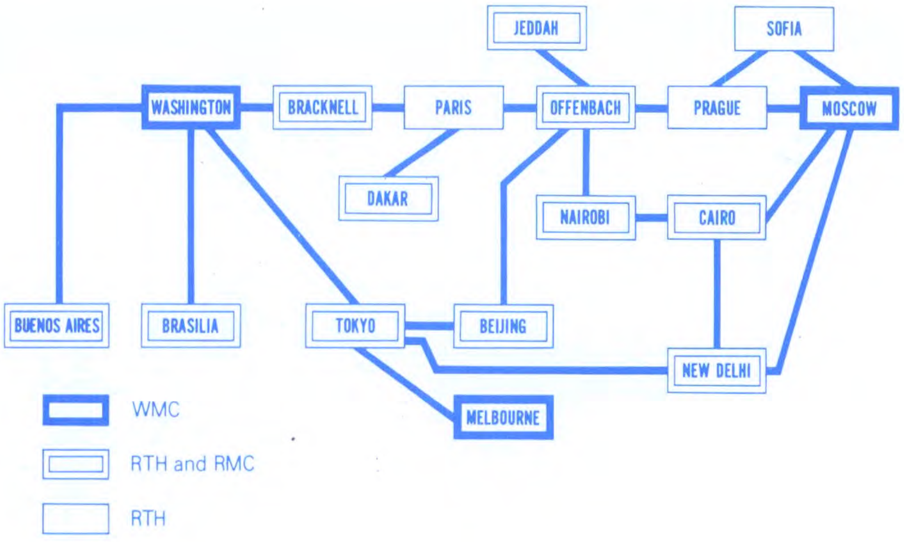
The Meteorological Telecommunication Centre

The Meteorological Telecommunication Centre at Bracknell plays a major role in the national and international collection and dissemination of meteorological information, and is a Regional Telecommunication Hub of the GTS. Observational data from the United Kingdom , the Republic of Ireland, Greenland, Iceland, the Netherlands, ships at sea and aircraft operating over the eastern North Atlantic, are collected and injected into the GTS. Automated switching systems, based on Ferranti Argus and Marconi Myriad computers, are used to receive, store and distribute data in a large variety of code forms. The principal links and the many sources and types of data handled are shown.

The principal types of data handled by Bracknell Meteorological Telecommunication Centre.



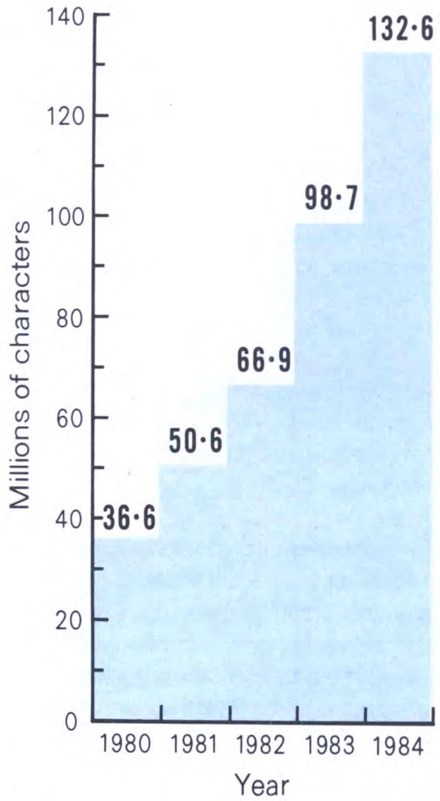
Routeing of the Main Telecommunication Network between the World Meteorological Centres (WMCs), Regional Telecommunication Hubs (RTHs) and Regional Meteorological Centres (RMCs) of the Global Telecommunication System.



The volume of traffic received and transmitted has continued to increase, see opposite, and now exceeds 100 million characters each day. This growth is mainly a result of the increased requirements for output products from numerical forecast models. The traffic on several of the major international links doubled when, in February, wind and temperature data for civil aviation began to be disseminated from the new World Area Forecast Centre based at the Central Forecasting Office, Bracknell. Word-processor systems connected to the Ferranti Telex Manager were installed there towards the end of the year to enable staff to prepare tailored forecasts and other products for distribution by automatic means.

The new message-switching system, known as Phase IV and based on five Tandem processors, was delivered at the end of July. However, initial testing of the system showed that some further development was required before parallel running with the existing systems could be undertaken in the second half of 1985. It is expected that by the end of 1985 the system will have replaced the present Marconi Myriad computers (Phase II) that have controlled the national teleprinter networks, and a few international data links, for the past ten years.

Development of a special digital-to-analogue conversion system has cleared the way for operational trials of an automated system for the handling of pictorial products by digital methods. The system, known as Autofax, is based on Ferranti Argus 700GX computers. Numerical forecast output charts in digital form are received from the central computer system and stored for subsequent transmission in pictorial form. Autofax provides output to the existing analogue facsimile network without modification of the existing recorders. Meanwhile a separate output channel, using digital transmission to a matrix printer, is under test and ultimately Autofax will control all transmissions of pictorial products.



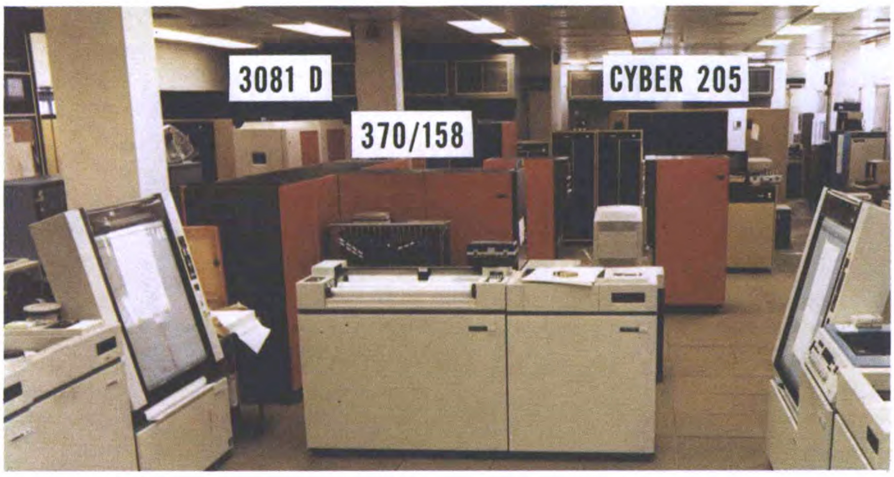
Number of characters handled in Bracknell Met TC on one (November) day.

Computing and data processing

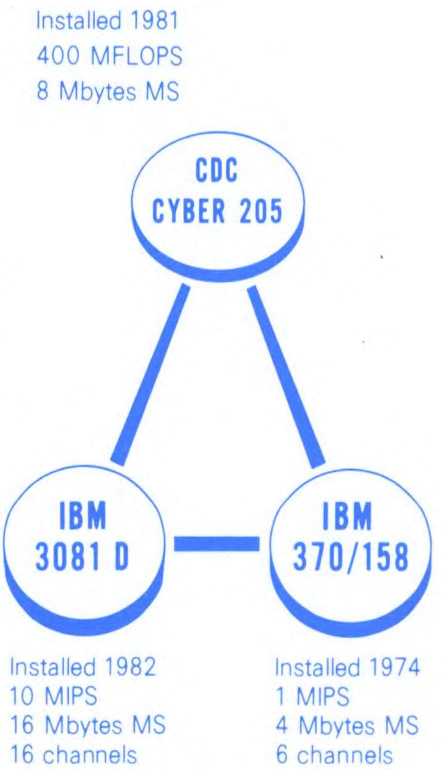
The central computer system in the Office is known as COSMOS. It provides the main computing service and is based on three computers: a Cyber 205, supplied by Control Data Corporation; and a 3081D and a 370/158, supplied by International Business Machines (UK) Ltd (IBM). All three processors are run 24 hours a day 365 days a year to support operational weather forecasting. The Cyber 205 is reserved for intensive numerical modelling in which role it can produce up to 400 million floating point results per second. The more notable numerical models are those that support the routine weather forecasts and research into climate and climatic change. Preliminary trials have recently started on a numerical model which provides high-resolution coverage of the British Isles. The Cyber 205 is also used to develop numerical models for ocean wave forecasting and physical research. The general computing service is provided by the 3081D which also acts as a front-end for the Cyber 205. The 370/158 is due to be replaced in 1985.

The COSMOS configuration contains a range of discs (17.8 gigabytes), tapes (12 drives) and printers. There is a particular emphasis on graphical output which is of great importance in meteorological work. Four Calcomp 960 plotters provide high-quality pen-and-ink charts at high speed and a fifth plotter is rather slower. For greater speed, but at some cost in quality, information is written to 35 mm film by two Calcomp 1581s and, following rapid development and enlargement, adequate working-scale charts can be made available. Use is also made of interactive graphic visual display units.

Dependence on COSMOS is increasing in both administrative and scientific work. As the range of users, and their abilities, expands, the provision of comprehensive support services is becoming correspondingly more important. More emphasis is now being placed on all aspects of support including enquiry services, advice on programming techniques and training. Computer-based training is being investigated as a means of providing more effective and flexible training both in computing and traditional meteorological work.



The COSMOS computer room. In the foreground two of the pen and ink plotters can be seen with the three computers further back.



The Cyber 205 takes four minutes to make a 24-hour forecast using a global numerical model with 150 km resolution and 15 levels through the depth of the atmosphere. The 3081D takes 6½ minutes for a 24-hour forecast using a much simpler model for a restricted area with a resolution of 300 km and for 10 levels—a performance ratio of 50 to 1. (MS—Main Storage, MIPS—Millions of Instructions Per Second, MFLOPS—Millions of Floating Point Instructions Per Second.)

For many years the computing service has been based on a batch service using punched cards. Terminals are now playing a significant role; over 50 have been installed, and several external customers are provided with an on-line service. During the year terminals have been obtained for use by several Headquarters Branches and for three sites remote from Bracknell—the Meteorological Office College at Shinfield Park, and the offices at Edinburgh and Belfast. A number of these terminals were personal computers, equipped to emulate IBM devices, thereby providing some limited local processing capabilities which complement access to COSMOS. A study of future terminal requirements is being undertaken, including planning for extending the necessary cabling in the Headquarters building at Bracknell. The trend towards use of terminals is expected to continue because it leads to higher productivity of programmers, and more on-line connections will lead to lower demands on computer support staff.

Weather forecasting depends on timely availability of accurate observational data. Raw data acquired via the automated telecommunications system (AUTOCOM) are passed to COSMOS with minimal delay and made available to users in a special-purpose data base. A limited number of quality-control checks are applied as data are inserted in the data base and suspect data are flagged. This data base is used to provide input for the analysis which is the first step in preparing the numerical weather forecast. In addition, the routine observations, which are received as groups of coded characters, are automatically plotted as weather symbols on maps for distribution to forecasters at Bracknell and outstations.

A separate climatological data base, for which much more stringent checks are made on the quality of data, is also prepared from the data base. The main users are now responsible for the day-to-day running of their own sections of the climatological data base.

Substantial amounts of data are still received in manuscript form. These data are converted to machine-readable form using a processor-controlled keying system. Experiments in the use of optical character recognition are also under way. Some data are received on non-standard media and these are transcribed on to magnetic tape compatible with COSMOS standards using a separate small computer.

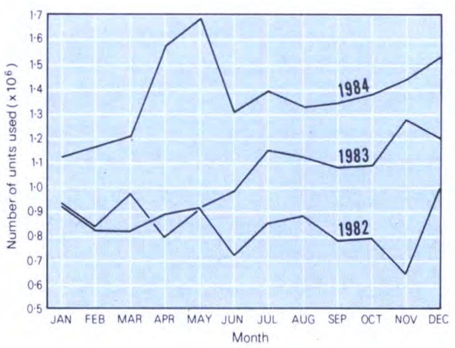
The main purpose of COSMOS is to support scientific work but some administrative work is now being undertaken. General purpose data-base management software (Integrated Database Management System (IDMS) supplied by Cullinet) is available. The Management Accounting and Information System has been implemented using IDMS as has the latest version of the Meteorological Office Library Accessions and Retrieval System.

Now that expertise has been acquired in the use of IDMS its extension into other appropriate projects, both scientific and administrative, is probable.

The pace of technological change in the area of computing is extremely rapid and it is essential to plan ahead if a reasonable balance is to be struck between cost and facilities. Plans are being made to formulate a consistent strategy for graphics in the Office to take advantage of recent technological improvements in both hard- and soft-copy facilities. At the same time a replacement for the 370/158 has been specified. The urgent need is for a machine that can perform the essential operational support work when the 3081D is unserviceable—a task beyond the capacity of the 370/158.

There are now a number of smaller computer systems at Bracknell which need to be interconnected, and also connected to COSMOS. In some cases operational links have been made, as between AUTOCOM and COSMOS, but the requirement for general interconnection is becoming more demanding as the number of computers increases. A preliminary study has been conducted but it is not yet clear whether the best solution is a local-area network or direct links. Looking much further ahead visits have been made to manufacturers who may be able to supply computers about thirty times more powerful than the Cyber 205 for meteorological modelling work early in the 1990s.

Jobs run monthly on the COSMOS computer, 1982–84. The inexorable rise reflects both the use of computers in new problem areas and the more intense activity on previously computerized tasks.



Units used monthly on the COSMOS computer, 1982–1984.

The National Meteorological Library

The National Meteorological Library at the London Road Headquarters acquires, catalogues and stores as much as possible of the available meteorological and climatological data, research papers and books that are of interest to the professional meteorologist or the serious amateur; coverage is world-wide.

Information in machinable (i.e. computer-readable) form is not included (apart from the Library's own catalogues) but increasing numbers of microfiche are now held. All holdings are classified by Universal Decimal Classification numbers, the indexing and classification going down to the level of individual papers within journals. About 200 000 books and pamphlets are held, as are runs of several hundred journals and over 25 000 slides and photographs.

The recording in machinable form of accessions to the Library began in 1972, and by 1978 much of the accession work had been automated by use of a dedicated minicomputer which also helped to produce the Library's long-standing Monthly Accessions List. This 'Meteorological Office Library Accessions and Retrieval System'—MOLARS for short—is being steadily extended to cover other aspects of the work of the Library, including information retrieval and loans control. The Office's mainframe computer complex (COSMOS) is now used via standard data-management software packages; the extended system will permit on-line bibliographic searches from any COSMOS terminal and will also make redundant much of the bulky card index which, physically, is becoming unacceptably large. The on-line service is now also available internationally for subscribers to the European Space Agency Information Retrieval Service based at Frascati in Italy.

Services for civil aviation

The provision of meteorological services for civil aviation in the United Kingdom follows closely the guidance provided by the Standards and Recommended Practices of the International Civil Aviation Organization (ICAO). In the terms of these 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 the CAA and to provide meteorological services on a repayment basis.

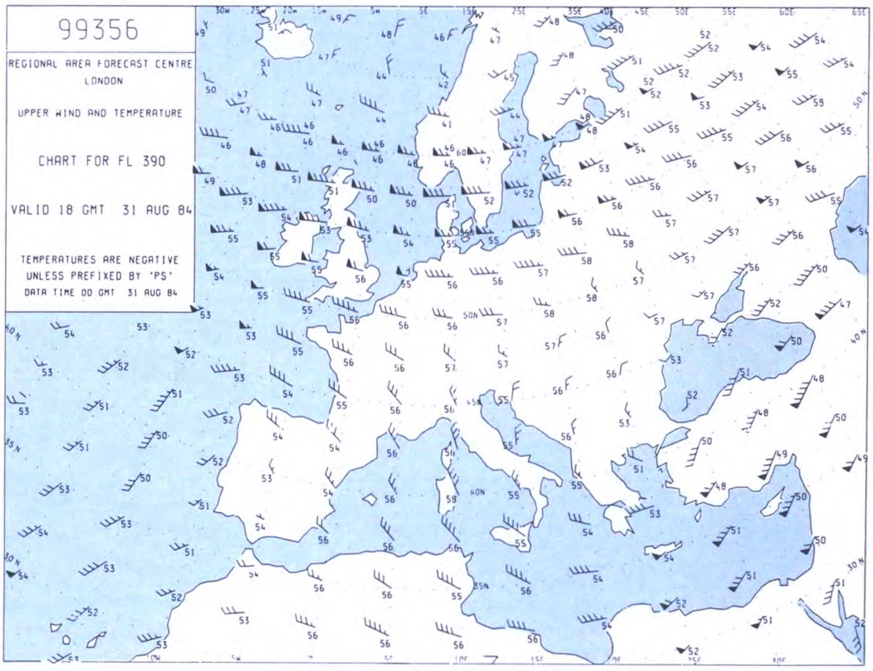
The organization of meteorological services for civil aviation is centred upon the new World Area Forecast System (WAFS), adopted by the ICAO Council in December 1982 and implemented from November 1984. The system consists of two World Area Forecast Centres, at Bracknell and Washington, each providing forecasts for the entire globe of grid-point data in digital form for a series of flight levels, twice per day for 12, 18, 24 and 30 hours after observation time. These data are sent to selected Regional Area Forecast Centres to be converted into chart format for distribution to other State meteorological services and aerodromes within the Region for flight documentation and also for onward transmission to airlines for flight planning by computer. Currently, British Airways, Scandinavian Airlines System and the Société Internationale de Télécommunications Aéronautiques are provided with the global forecasts of grid-point data directly from Bracknell. A number of other companies intending to introduce computerized flight planning have been provided with advice and background information.

In implementing the WAFS in the United Kingdom, the Central Forecasting Office (CFO) at Bracknell, one of the selected Regional Centres for Europe, has taken over from the Principal Forecasting Office (PFO) at Heathrow the task of preparing the North Atlantic significant weather charts and the role of Meteorological Watch Office (MWO) for the Shanwick Oceanic Control Area (OCA). In-flight warnings of certain significant weather phenomena (SIGMETS) are now prepared in the CFO for the Shanwick OCA. Heathrow and Prestwick retain responsibility for the London and Scottish Flight Information Regions respectively.

The centralized output is sufficient to satisfy the needs of most commercial air transport. For flights above Flight Level (FL) 100, that is above 10000 ft, within the European region, and above FL 250 elsewhere, significant weather and upper-wind and temperature charts are available. However, general aviation, which includes flying in private aircraft, gliding, hang-gliding, hot-air ballooning, micro-light flying, and some business activities such as crop spraying, aerial survey work and air taxiing, requires a different and more detailed service. For the many general aviation flights below about FL 150 within the United Kingdom, the Heathrow PFO provides a forecast chart of low-level weather together with an appropriate upper-wind and temperature chart. This chart documentation, supported by lists of weather observations and forecasts for the aerodromes as described below, is sufficient for most airlines and individual pilots operating from airfields equipped with the means of receiving them by teletype and facsimile. However, there are many airfields without these facilities and also a considerable number of flights are for destinations outside the United Kingdom not covered by the standard documentation. To meet the requirements for these, individual route forecasts are provided on request, principally from the Heathrow PFO and the Prestwick, Aldergrove and Manchester Main Meteorological Offices (MMOs). Local forecasts and advice are also provided on request from a number of smaller forecasting offices located at civil and military aerodromes.

Although face-to-face briefing is no longer an essential requirement for commercial air transport, the general aviation pilots make considerable use of the telephone in seeking information and advice from forecasters before commencing a flight. In an effort to reduce the volume of general aviation enquiries, an automatic telephone answering service, the General Aviation Visual Flight Forecast Service, GAVFFS, was introduced by the CAA some years ago but with only limited success. The Meteorological Office now provides a limited amount of information, comprising a selection of Terminal Aerodrome Forecasts (TAFs) and route forecasts on Prestel, the British Telecom Viewdata system. The Meteorological Office was called upon by the CAA again to help in the development of an expanded GAVFFS designed to meet general aviation needs comprehensively and cost effectively.

An example of an upper-level chart issued by Regional Area Forecast Centres.



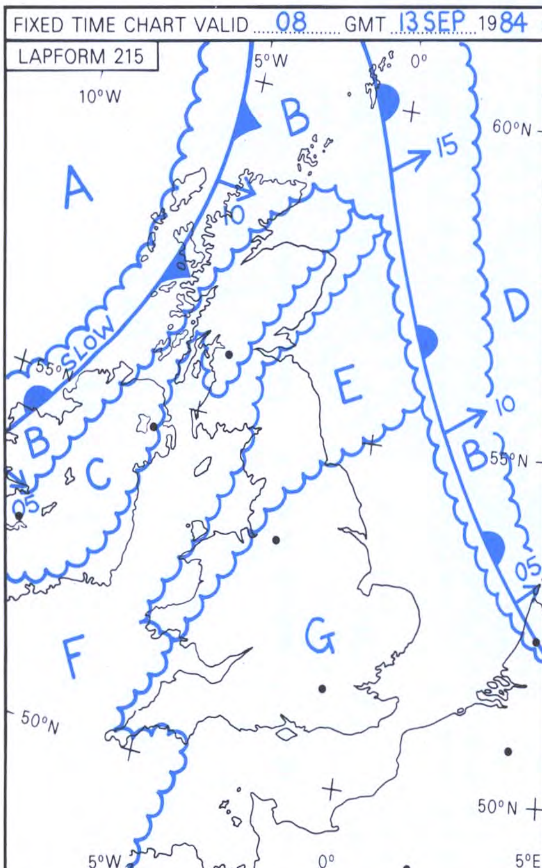
Weather observations at airfields are of great importance to forecasters and pilots, and Meteorological Aviation Reports (METARs) are made, usually half-hourly, at most civil airports when the airfield is open. Where no Meteorological Office staff are available, the observations are made and reported by Air Traffic Control staff who are specially trained for this purpose. In most cases the observations are transmitted by teleprinter on the Aeronautical Fixed Telecommunication Network (AFTN) to the CAA message switch at Heathrow whence they are disseminated nationally through the OPerational METeorological (OPMET) teleprinter circuits and internationally over the Meteorological Operational Teleprinter Network, Europe, (MOTNE). TAFs are also exchanged on the OPMET and MOTNE broadcasts to provide for aviation users information on future landing conditions. Copies of bulletins of METARs and TAFs are made locally at aerodromes to complete the forecast documentation provided by area forecast charts or lower-level route forecasts.

To assist with flight clearance over high ground and with vertical separation of aircraft, forecast minimum pressure values are prepared every hour in the CFO for each of 20 Altimeter Setting Regions over and around the United Kingdom. The forecast values are distributed by Meteorological Office teleprinter channels and by AFTN. These values are used primarily by aircraft in flight when outside controlled air space.

An example of a low-level weather chart prepared by London/Heathrow Airport.

FIXED TIME CHART VALID 08 GMT 13 SEP 1984 SUITABLE FOR INITIAL DEPARTURES AND FLIGHTS BETWEEN 13/06 AND 13/10 GMT

LAPFORM 215



VARIANT	VIS	WEATHER	CLOUD, TURBULENCE, ICING	0°C
AREA A	30	NIL	BKN CU SC 020\065 SCT/BKN AC 080\120 Ψ	060 NW 085 SE
OCNL	10	RAIN SH	BKN CU 015\090 Λ Ψ	
AREA B	10	NIL	BKN ST 008\020 OVC LYR 030\130 Λ Ψ } HILL FOG	090
OCNL	5000	RAIN	OVC ST SC 004\030	
AREA C	20	NIL	BKN SC 030\060 BKN AC 100\150 Λ Ψ } HILL FOG	095
OCNL	10	RAIN	BKN ST 010\015	
AREA D	40	NIL	SCT CU 025\045	070
AREA E	20	NIL	BKN SC 030\045 BKN AC 090\130 Λ Ψ	095
LOC	6	RAIN	BKN ST 015\020 HILL FOG	
AREA F	8	HAZE	SCT ST 010\015 BKN SC 030\045 } HILL FOG	090 NORTH 110 SOUTH
OCNL	4000	MIST	BKN ST 005\015	
LOC NORTH	—	RAIN	—— " —— BKN AC 100\140 Ψ	
AREA G	8	HAZE	SCT SC 035\045 SCT AC 130\xxx Ψ	100 NORTH 125 SOUTH
LOC	3000	MIST	SCT ST 005\008 HILL FOG	
ISOL	0800	FOG	BKN ST 003\008	

FORECAST WEATHER BELOW 15000 FT.

ISSUED BY LONDON (HEATHROW) AT 130412 GMT

WARNINGS AND/OR REMARKS

AREA B AND C: OVER NW SCOTLAND ICING MAY BE LOCALLY SEVERE IN EMBD CU 030\140

AREA G: FOG OVERLAND CLEARING 08-09Z. MIST CLEARING BY 10Z. VISIBILITY MAINLY OVER 10 KM BY 11Z

NOTES: 1. DECODE GIVEN IN LAPFORM 216
2. VIS IN M OR KM. HILL FOG IMPLIES 200M OR LESS
3. HEIGHT AMSL IN HUNDREDS OF FT. XXX = ABOVE 15000 FT.
4. TS AND CB IMPLY MOD/SEV ICING AND TURBULENCE

Sep 83

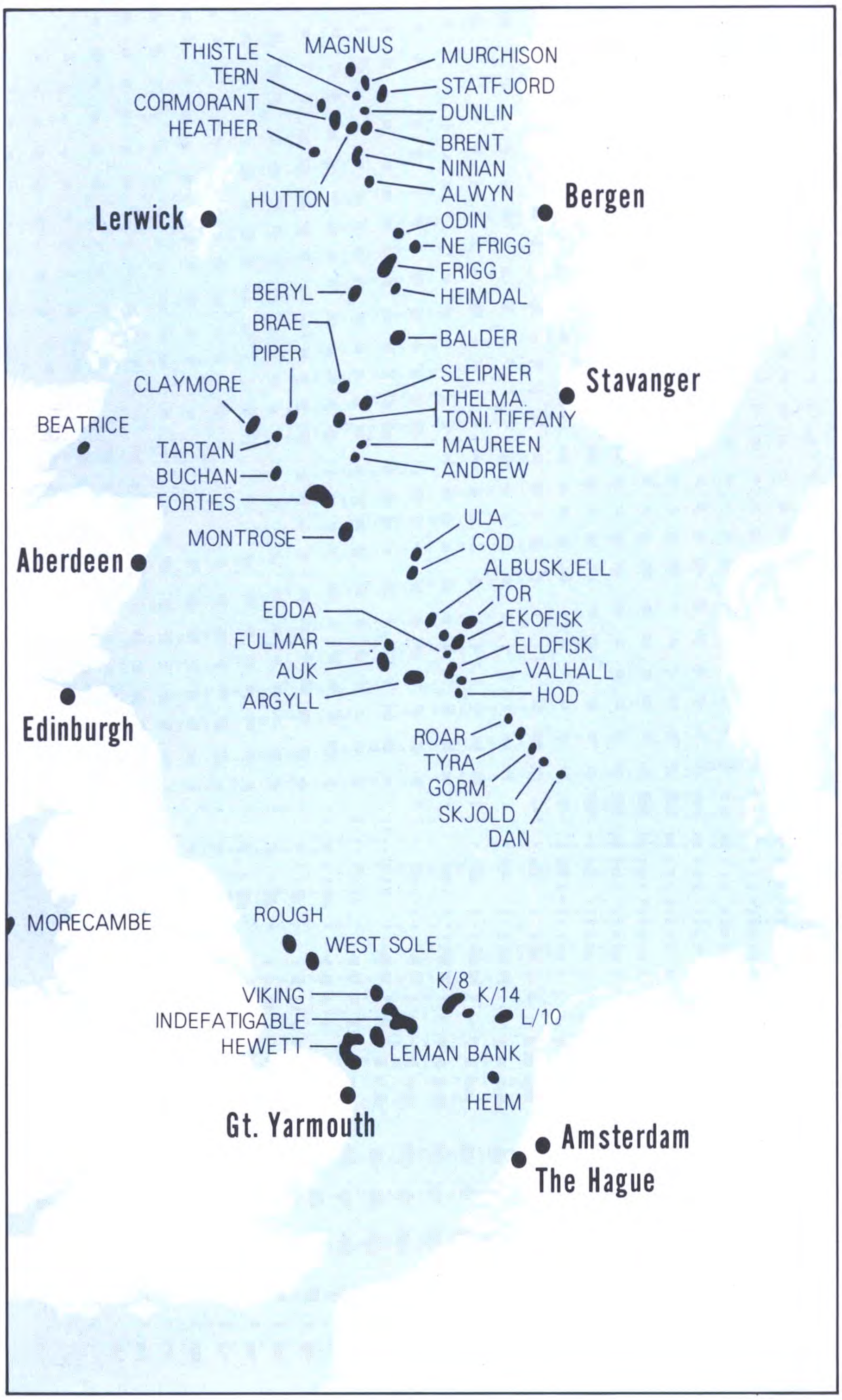
Services for the offshore industry

The Meteorological Office has been providing advice for the offshore industry since the early days of exploration in the North Sea. Now that most of the more accessible fields are fully developed, offshore operations are becoming more complex as the industry ventures further into deeper waters and has to withstand the hazards of more extreme weather. A high level of expertise has been developed within the Office to support the wide range of activities associated with offshore operations.

The Meteorological Office can be most effective when called in at the early planning stages so that the stresses and loads that the structure will have to bear and the conditions in which the personnel will have to operate can be taken properly into account. A bank of the relevant meteorological and oceanographic data has been assembled over the years and it is frequently used by commercial weather consultants and the like.

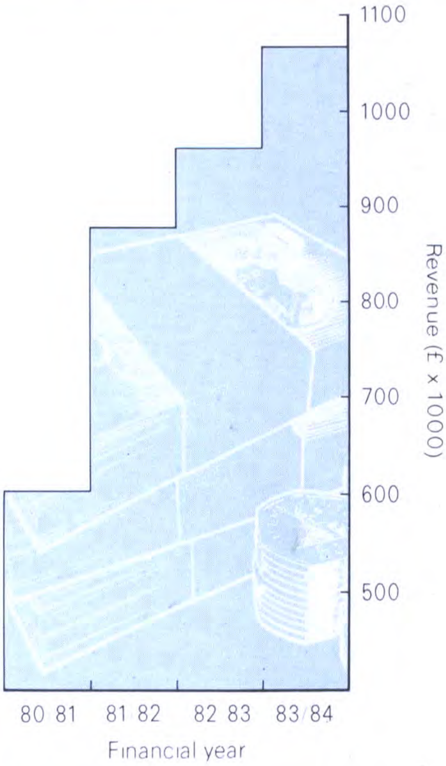
In the construction, exploration and production phases a forecast service is required which must be specially tailored to each operator's requirements. Most forecast advice is supplied in the form of telex messages which describe the expected weather conditions during specified periods of time. Offshore

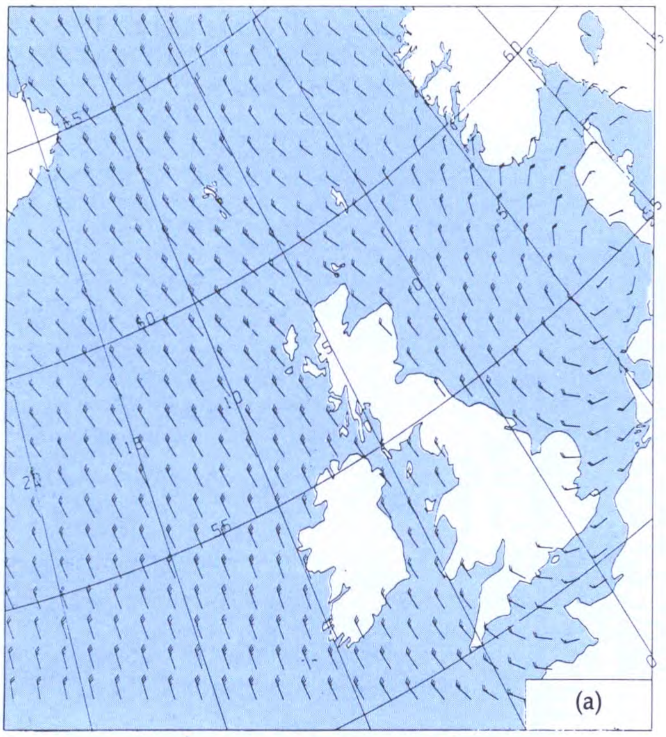
Offshore oilfields in the vicinity of the United Kingdom.

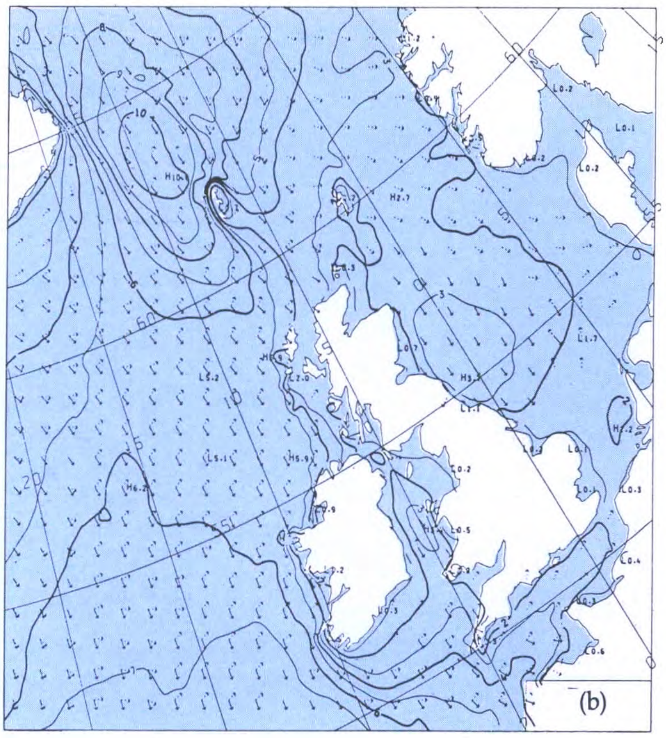


The Hutton Field Tension Leg Platform.

Revenue earned from the offshore industry.





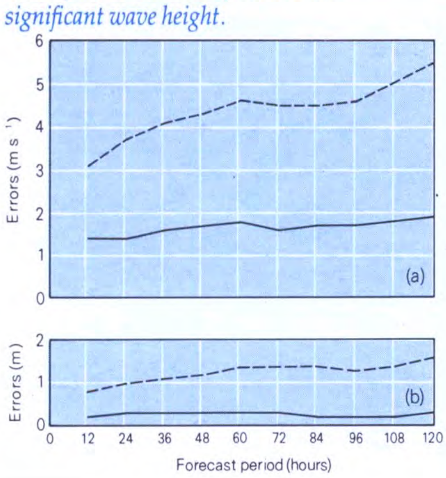


Examples of (a) a wind chart and (b) a sea-swell chart.

managers need to interpret these forecasts in relation to their operations and they are able to discuss the forecasts with the forecasters by telephone at any time of the day or night. When offshore operations are very complex and critically weather sensitive (in economic terms as well as in danger to human life) it is usually more cost effective and efficient to have a forecaster on site. This forecaster is able to give instant advice at any stage of the operation and is supported by the full resources of the Office for this purpose. The value of the on-site forecaster is now fully recognized by the industry and as many as five forecasters were simultaneously located offshore during the summer.

An illustration of the role played by the Office in critical operations is provided by its involvement with Conoco in the erection of their Tension Leg Platform (TLP). During the summer of 1983,

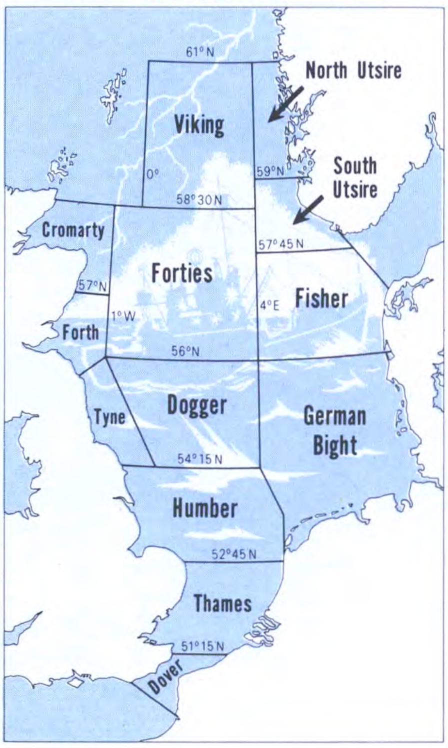
Root-mean-square errors (dashed lines) and mean errors (full lines) of forecasts for the Ninian Field issued by London Weather Centre during the period September 1983–July 1984 of (a) 10 m wind speed and (b) significant wave height.



forecasts were provided so that the sea-bed structures could be 'piled' in place safely. A forecaster was located on site: in March when the TLP deck had to be floated across the Moray Firth in quiet weather conditions, in May when the deck and hull were joined, and in July for the tow to the Hutton Field. The platform went into operation 22 days after mooring—an unprecedented achievement.

Once established, a production platform needs a continuing weather service for the safety of personnel and support vessels. When a platform has been in service for a few years, extensive repairs become necessary which can only be carried out in quiet weather.

The redefined shipping forecast areas.



Although central guidance is provided from the Office Headquarters at Bracknell in the form of dedicated forecasts of surface winds and waves for several days ahead, the specialized forecasts for individual sites are provided from London Weather Centre supported by subsidiary offices in Aberdeen, Kirkwall (Orkney) and Sella Ness (Shetland). All forecasts are checked for accuracy and there is a continual feedback between forecasters and researchers so that the modelling of sea state by mathematical techniques can be improved.

The Office enjoys a high reputation with the offshore industry for its technical excellence and well integrated services. This has enabled the Office to withstand competition from private organizations offering cheaper services based on more limited resources. It is worth recording that forecasters have been supplied offshore at only 12 hours' notice in response to emergency requests.

The gale warning cone.

Services for shipping

Mariners, shipowners and those concerned with the sea have always been weather-conscious; their particular concerns being wind, the state of the sea, and the effect of these on their lives and operations. In response to this interest the BBC and coastal radio stations of British Telecom International broadcast on a regular basis weather synopses, forecasts for the fishing and shipping industries and, when necessary, warnings of gale force winds. These warnings are also relayed directly to 35 port and other authorities. For the inshore mariner a strong-wind warning service that advises them of the possibility of winds of force 6 or more for up to five miles offshore is broadcast, throughout the year, by VHF radio from several HM Coastguard stations; a similar warning service is provided for a limited period, between Easter and October, by local radio stations.

On 1 June, almost 125 years after the introduction of the visual storm warning system for shipping, the display by HM Coastguard around the UK coasts of gale warning cones and lights was discontinued, mainly because all sea-going craft now carry radios which receive storm warnings.

Another change made during the year was the redefinition, with effect from 1 August, of the shipping forecast areas for the North Sea to include two new areas, North and South Utsire, off the west coast of Norway. This change was the result of an Agreement on a common designation of forecast areas for the North Sea by all those nations bordering it. Rescheduling of the BBC Radio 4 programs also meant that from 29 September two of the broadcasts of shipping forecasts were retimed, the 0015 to 0033 and the 0625 to 0555 clock time.

Navtex is a service which provides to shipping, by automatic print-out from dedicated on-board telex receivers, the latest urgent information on navigation and initial distress messages as well as weather forecasts and warnings. The service is at present confined to the northern European region, but it is expected that it will eventually have a world-wide coverage and that the carrying of Navtex will become mandatory for all ships over 300 tons gross. Meanwhile, the addition of Land's End Radio to the Navtex service already provided by Portpatrick and Cullercoats Radio stations completes the coverage by the service of the UK coastal waters.

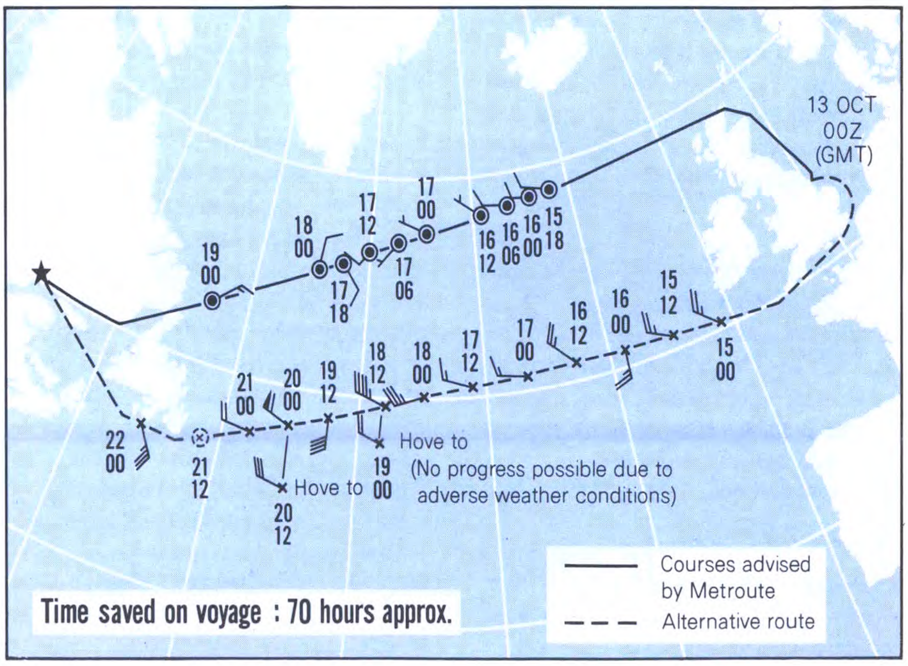
Wind and wave analyses are available so that assessments can be made of some of the risks likely to be incurred when vessels and structures are towed, and for other operations in the marine environment. Many marine consultants make use of these analyses to assist them in the determination of design characteristics and operating criteria. In general, the analyses are for particular projects or sites, but many have been prepared, and much work has been undertaken, for a major study of towing routes across the oceans of the world.

As a result of the severe northerly gales of January 1953, which caused disastrous flooding on England's east coast, a Storm Tide Warning Service has provided timely information on tide-level anomalies by monitoring 12 tidal gauges situated from Stornoway in the Hebrides, down the east coast of Britain, to Newhaven. The service now provides tidal forecasts for both the eastern and western Water Authorities and it co-operates closely with those responsible for the Thames Barrier at Woolwich. Also, and of more importance to shipping, alerts are issued when unusually low tides, caused by strong winds, are expected. The larger, deep-draught ships can be at risk of grounding in the shallower waters which occur under these conditions.

The Meteorological Office Ship Routeing Service, marketed under the title Metroute, provides a comprehensive range of services, on repayment, for practically all types of vessel and for structures under tow, of any nation, on all the seas of the globe. Advice is given to shipmasters by radio regarding the most advantageous routes to follow to make the passage in the least time, with the greatest economy or with the minimum prospect of heavy-weather damage to ship or cargo. The service includes provision for the latest information on areas of fog and ice in addition to other navigational hazards. A team of master mariners, all with experience of merchant ship command, operates the service in close collaboration with the Central Forecasting Office. On completion of the routed voyage 'hindcast' charts are available, on request, to the shipowner or operator so that the actual weather experienced and performance achieved can be compared with those conditions that would have existed and affected performance on an alternative (usually the shortest) route.

Sea ice charts for the North Atlantic Ocean; the Baltic, Barents and Greenland Seas; and Baffin and Hudson Bays are prepared from sea ice information obtained from many sources. Isotherms for 5-day sea temperature means, and isopleths for the present state of sea ice are included. In addition to the services provided free of charge in compliance with the International Convention for the Safety of Life at Sea (1974) commitments, forecasts of sea ice conditions are made to clients' specifications on repayment.

A Metroute 'hindcast' chart for the North Atlantic.



Services for the general public, industry and commerce

Introduction

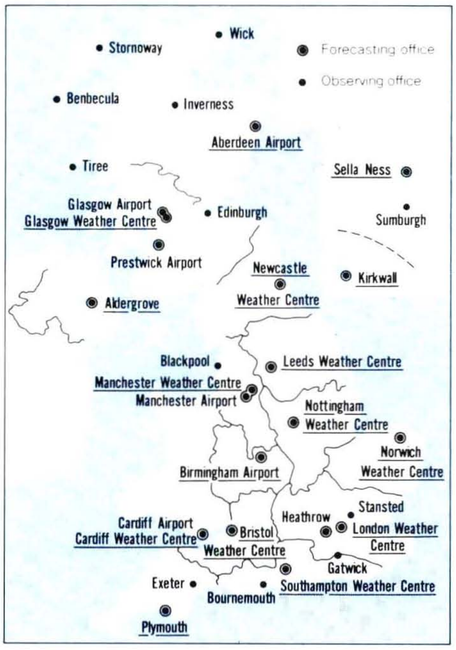
The Meteorological Office provides forecasting and other meteorological services to the media, industry, commerce and the general public mainly through a network of outstations, comprising ten Weather Centres, three offices attached to civil airfields and one based at a RAF station. In addition, a specialized unit operates from Sella Ness (Shetland) and further limited support comes from other stations mainly dedicated to Defence or civil aviation needs.

The organization of public service offices has been under continual review in recent years and the increasing pressure on staff resources coupled with changes in services supplied to civil aviation have led the Office to meet the needs of civil aviation, industry, commerce and the general public from multi-purpose forecasting offices. The rationalization of services in south-west Scotland was partially completed in 1984. During the year plans were completed and the work of fitting out a centralized Main Meteorological Office began in central Glasgow. This Office will be responsible for forecasting work previously carried out at meteorological offices at the Glasgow and Prestwick Airports and at the Glasgow Weather Centre. The move is planned to take place in spring 1985. In August, Weather Centres were opened in Leeds and Norwich to take over the civil forecasting work previously undertaken at RAF Bawtry and RAF Honington respectively. These offices are intended to provide to the public, better and more cost-effective services in their respective areas of responsibility than were possible before.

New technology has also played a part in the reorganization plans. Word processors and computerized telex facilities have been installed at a number of forecast offices to enable information to be sent to the users more efficiently and especially to those making use of viewdata systems.

Services for the general public

For many years members of the general public have been able to telephone the



Public service offices and areas of responsibility of those stations underlined.

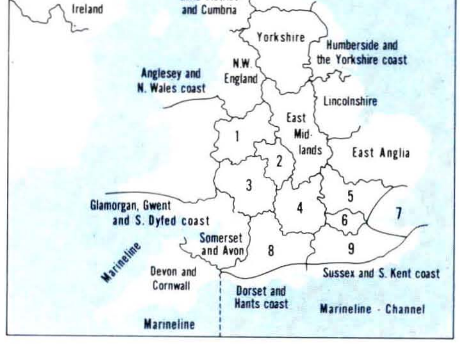
nearest meteorological office and speak directly to a forecaster. However, a progressive reduction in staffing levels and an increasing commitment to repayment services have made it very difficult to deal with public enquiries by telephone. Accordingly a good deal of effort has been put into expanding those sources of weather advice that can be readily accessed by members of the public at small cost to themselves as customers and taxpayers. These include Weatherline, the Press, radio and television and also the developing Videotex market for information.

Weatherline is a recorded telephone service operated by British Telecom; for the cost of a telephone call the public can hear a forecast for a specific area of the United Kingdom. Most regions now have a service and it is hoped to complete the national coverage during 1985. The forecasts are updated at least three times daily and cover the following 24 hours with a further outlook. The number of calls in 1984 to Weatherline totalled approximately 24 000 000. To serve the more specialized needs of yachtsmen and seafarers, a new service known as Marineline with forecasts for the English Channel and the Bristol Channel has been introduced. Extensions to Marineline are planned with the help of sponsorship from interested parties.

Weather reports and forecasts are supplied to the Press Association three times daily. The information provided is brief and rather general although some national and several local newspapers subscribe to more detailed services. Weather information is provided in more detail through national and local radio broadcasts. Routine live broadcasts are delivered by forecasters at London Weather Centre on BBC Radios 2, 3 and 4 several times daily although time constraints usually limit the amount of local detail that can be covered. The broadcasts are supplemented by a number of scripts prepared by the forecasters for delivery by BBC announcers. Some 40 local radio stations (IBA and BBC) now take forecasts from local Weather Centres and other public service offices. Again these are a mixture of live broadcasts and prepared scripts.

Services to television have increased substantially during the last two years. The national BBC TV Weatherman team consists of three or four forecasters based at the London Weather Centre. Forecasts and weather advice are supplied to both breakfast television channels and also to

Areas covered by the Weatherline and Marineline services.



Channel 4; the latter has displayed a sequence of forecast charts accompanied by an off-camera script read by an announcer following the mid-evening news. Most regional television companies, especially IBA, now include personal presentations of the weather. On some channels the presenters are local Weather Centre forecasters and in others the local presenters are briefed from the appropriate Weather Centre before the broadcasts. As with radio, scripts are provided to television companies either in lieu of personal presentations or as supplementary information.

Despite the growth of services to television it is recognized that the presentation of weather on television, which is the major source of information to most people, falls short of what could be shown. New technology has already been exploited by the breakfast channels in the presentation of animated weather-satellite pictures. Animation can be extended to forecast elements such as rainfall, temperature and wind. The BBC and the IBA are keenly interested in the animation of the sequences of weather displayed on television and the Meteorological Office has been working closely with both so that more comprehensive and more informative weather presentations will be seen in future.

Although the Office is anxious to extend the amount of weather advice available to the general public, the decision on how much time or space should be allocated for this purpose is normally taken by those who control the media. It may be unreasonable to expect television, for example, to devote large amounts of expensive air time to weather forecasts at the expense of other programs. For this reason the Office is taking a close interest in developments in information technology and in particular in the growing Videotex sector which offers considerable scope for expanding the range of weather services available to the general public.

Videotex services

National and regional forecasts for the United Kingdom are provided to ORACLE, the IBA teletext system. Rather less information is given in the BBC system CEEFAX. The number of teletext sets in the United Kingdom continues to grow at a rapid rate with around two million now in use. Thus weather forecasts are now available at the touch of a button to some ten per cent of the population.

The Meteorological Office was one of the first providers of information to Prestel, the public viewdata system operated by British Telecom, and it continues to be one of the major information suppliers. The Office Prestel data base has over 800 pages of information including comprehensive forecast services, actual weather reports from the United Kingdom and abroad, and weather statistics from around the world. The information is continuously monitored and frequently updated by a team of Office staff working around the clock, seven days a week.

Most of the information is available to all users of Prestel, but a facility on Prestel allows the access of specialized information to be restricted to members of a Closed User Group (CUG). This is an important development and the Meteorological Office already supplies data to two such CUGs, one for the home user in the West Midlands and the second for a specialized agricultural service (Farmlink), launched in the south-west of England. It is hoped that following the success of Farmlink in the south-west, the service will be extended to other parts of the United Kingdom in 1985/86.

Prestel is the public viewdata system but there are several private viewdata services, and discussions have taken place with a number of commercial organizations about the supply of meteorological information to them. During 1984 the Office started an agricultural service to one such system run by Imperial Chemical Industries.

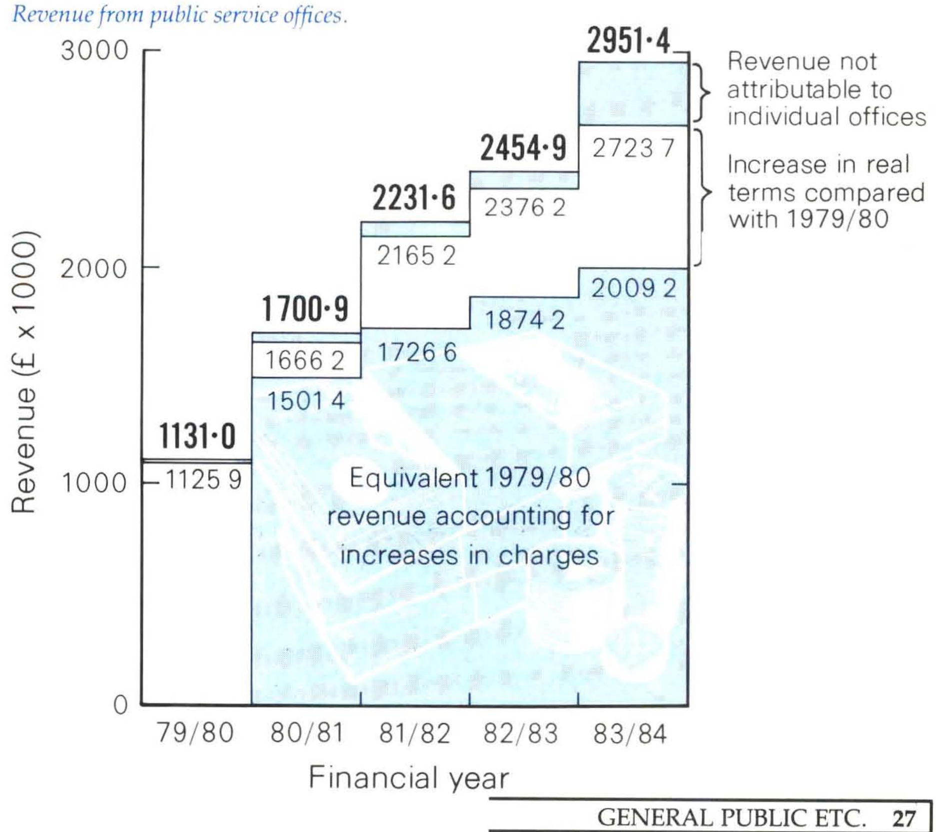
The information on Prestel is presently updated manually using a keyboard, but with the increasing need to serve CUGs and private systems, a high-priority task has been to develop the specification for an intelligent terminal that will allow automatic input of data to these systems. In addition, a group drawn from various sections of the Office has studied the feasibility and costs of transmitting images, via Prestel, of satellite and radar rainfall to users equipped with microcomputers.

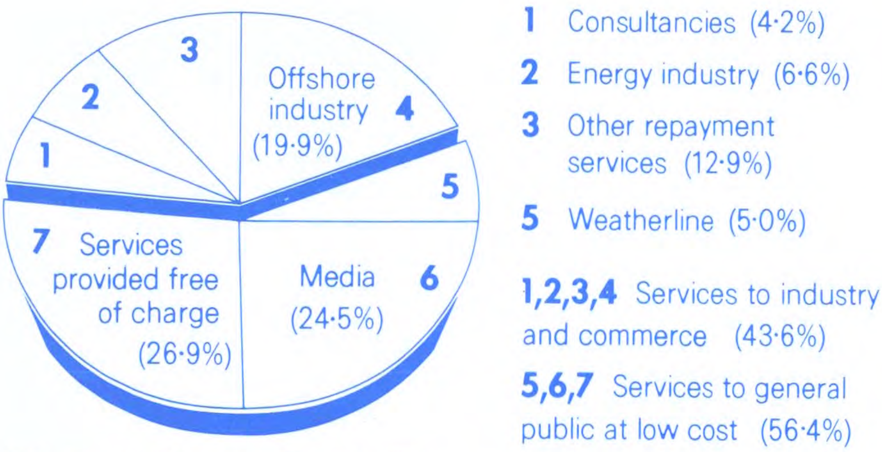
Summing up, the amount of weather advice available to the general public at little cost is increasing quickly and, as technology develops, there are prospects that more outlets for weather information will become available to be exploited.

Services for industry and commerce

Weather forecasts and advice are supplied to meet the specialized needs of industry and commerce on repayment terms. The offshore oil and gas industries are major customers for these services. Specialized forecasting services may meet nation-wide or site-specific requirements and are usually supplied daily as routine. Some customers require only warning services, e.g. frost, snow, heavy rain, etc. For those who are satisfied for the most part with the general forecasts issued on Weatherline and Prestel etc. and yet require further information on some occasions there is a consultancy service. This service can be very cost effective for

Revenue from public service offices.





Allocation of staff time for public service offices.

the user; it allows access to a forecaster through an ex-directory telephone at any time of the day or night.

Major commercial customers include the gas and electricity industries which require frequent detailed forecasts of temperature, wind and weather to help assess the demand for heating and lighting. Accurate forecasts allow British Gas to order the correct amount of natural gas from the offshore industry each evening and there are financial penalties if the order has to be revised.

Services for road transport are provided mainly through local authorities. During the winter season practically all authorities take a daily warning service for ice and snow. Advice given early in the afternoon determines whether or not the authorities should mobilize gritting lorries for the coming night. Although ice and snow occur relatively infrequently they can cause severe hazards to life and it is easy to see that accurate forecasts can be extremely cost effective in economic and human terms.

British Rail takes a winter service for ice and snow and the Southern Electric train network, in particular, is extremely vulnerable to deposits of ice on the conductor rails. Adequate warning of severe conditions allows preventive action to be taken through running earlier trains or by spraying de-icing fluid on the rails. Railway lines buckle in strong summer sunlight; and so a warning service is provided so that adjustments can be made to the gaps between rails to prevent the buckling.

Water authorities take a service which advises them on the likelihood of heavy rain in specific areas; this enables them to estimate the degree of run-off into rivers. Heavy rain is also a matter of concern to coal miners as are large changes in surface air pressure.

Agriculture is served in a number of ways. In the spring a service was introduced in south-west England warning of conditions likely to lead to severe wind chill in new-born lambs. The cost effectiveness of this service is illustrated by the fact that all the subscribers to the service in 1984 have registered for 1985. The most popular commercial service to farmers and growers, however, is the consultancy service. This personal service has the advantage that the specific needs of a client can be dealt with quickly and effectively. The consultancy service is not confined to agriculture—the building and construction industries make good use of the service too. All full commercial forecast services include provision for consultancy by telephone with the forecasters. Even pigeon racing enthusiasts take a weather forecasting service because the birds become easily disorientated if they have to fly through fog or low cloud.

A growth area for weather forecast services is the food retail market. A number of major retailers have recognized that with accurate forecasts for four or five days ahead they can better estimate the market demands for perishable food, especially at weekends. Weather advice of this sort is not confined to the United Kingdom; knowledge of specific weather conditions affecting crops, fruit and vegetables across Europe also allows retailers to anticipate fluctuations in the supply of these foods some days ahead.

Sport and leisure enthusiasts can make great use of weather advice. Professional long-distance cyclists will not attempt record runs if wind conditions are unfavourable over the course. Wimbledon tennis authorities are interested in short-period forecasts for rain during the summer championships. Even bookmakers lay odds on the weather. For several years punters have been able to bet on the likelihood of snow falling on the roof of the London Weather Centre on Christmas day. The bookmakers vary the odds on the basis of a special forecast service provided by the Weather Centre.

The revenue earned by the public service offices from commercial services has grown steadily in real terms in recent years in spite of a parallel increase in information supplied freely or at little cost to the general public. The Meteorological Office recognizes that there are wide areas of industry and commerce where activities are highly weather sensitive and where the full cost benefits of the available Meteorological Office services are not being realized. There is a need to develop greater awareness of the benefits in the interest of the national economy.

Marketing services

Following the recommendations of the Resource Control Review it was decided to adopt a more commercial approach in respect of the many and varied services provided by the Office to commerce and industry. A small specialist team was established to develop a more effective interface between the Office and the customer. Towards the end of the year marketing consultants were commissioned to research the market opportunities for the now much improved forecasts for 2–5 days ahead, and also to advise on the production of publicity material covering the very wide range of specialist services available.

Negotiations commenced with several companies and corporations for whom an intelligent use of meteorological advice could result in substantial operational benefits; for instance through aiding energy efficiency measures, providing better bases for the scheduling of outside contracts, and for the marketing and distribution of weather-sensitive consumables. Opportunities were pursued for the provision of weather forecasting services to UK companies operating overseas. Proposals for the establishment of a joint venture company reached an advanced stage.

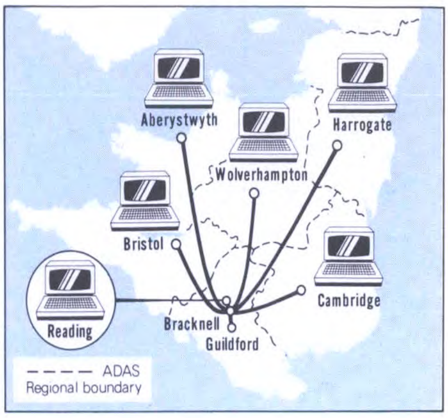
Services for agriculture

Agriculture is one of Britain 's largest industries, and clearly it is also one of those most sensitive to weather. Whilst a statement describing current weather may have straightforward implications for immediate fieldwork, the implications for crops, animals, pests and diseases are likely to be subtle. The relationships between local weather and the local environment in a crop canopy, or in the soil, are far from simple; it is necessary to consider the weather during the whole of the growing season to anticipate the rapid multiplication of pests to levels at which economic damage will occur. For reasons of this kind, a group of specialist agrometeorologists is available to provide services to agriculture, primarily through the Agricultural Development and Advisory Service (ADAS) of the Ministry of Agriculture, Fisheries and Food (MAFF). Staff are located at each of the six ADAS regional headquarters in England and Wales, where they contribute to the solution of weather-related problems that come from the field. In addition, the agrometeorologists undertake research and development work, either to close gaps in understanding or to improve existing services and facilities. A more limited response to the needs of agriculture in Scotland and Northern Ireland is provided by meteorologists at Edinburgh and Belfast, with specialist enquiries referred from there to Bracknell.

In UK agriculture, high input–high output systems are customary. The technical problems are therefore sophisticated and diverse and useful weather-related advice has to match the expertise of the industry. An adequate response by the agrometeorologist requires a sound understanding of environmental physics, together with a knowledge of general farming practices. Familiarity with the relationships between weather and crops, and weather and crop husbandry, is also essential. A wealth of such information is held in internal memoranda which document staff investigations over the past three decades; such memoranda now number more than one thousand.

The work by agrometeorologists in the field is helped by operational advice made available each day from Bracknell. For the most part, contrary to what one might expect, the advice gives greater emphasis to the weather actually observed at the network of stations across the country than to forecasts of the weather. When the weather observations are brought together and assessed, appropriate summaries can, for example, provide direct guidance on such matters as the timing of fertiliser applications, the availability of soil water for use by crops, and the development of plant and animal diseases. The long-period weather archives held at Bracknell are regularly accessed for case studies and for development work. Recent weather observations added to the archives may be used, for example, by staff, on standby all year round, to advise the State Veterinary Service on the potential for airborne spread and secondary infection in outbreaks of the animal virus diseases, foot-and-mouth disease and Newcastle disease. This service was fully activated on a number of occasions in 1984.

Wider customer access to the agrometeorological data base at Bracknell and some enhancement of the derived products available from it on an operational time-scale have been seen as desirable objectives for some time. Planning to these ends bore fruit in 1984 when procurement was begun of computer terminals with a built-in facility for data storage and manipulation and with links to the central computer at Bracknell for the offices of agrometeorologists at ADAS regional headquarters. At the same time a direct link was established from the Bracknell computer to the MAFF computer at Guildford to provide fast routine data-transfer and advisories throughout the ADAS network (see above right). Design work to expand the agrometeorological data base and its products has begun but implementation is not expected until 1986. The individual farmer with facilities to access Viewdata systems, either through open public systems such as Prestel or closed user groups such as Farmlink is a likely recipient of this information. The aim is to generate advice on fieldwork (irrigation, cultivation, spraying, field drying, etc.) and to make it site- and farm-specific.

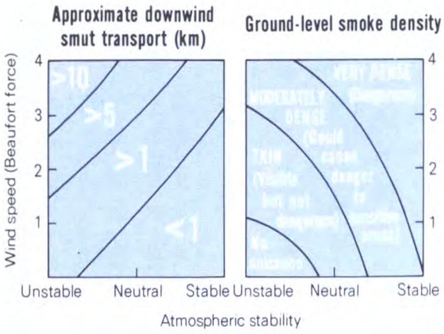


The ADAS regions and the links between the regional headquarters, Bracknell, and the MAFF/ADAS computer at Guildford.

A substantial amount of investigational work was again carried out during the year, some in response to particular enquiries, some more speculative though with an anticipated application in the longer term; examples are listed in Table IV. The topicality of the studies on grass production and conservation (see centre p.30) was heightened by the introduction of milk quotas in the dairying industry during the year (with the implied emphasis on the use of home produced fodder). Many enquiries were received from individual farmers who were concerned to obtain a variation in their allocated quota because of the unrepresentative nature of the weather they had experienced in the years on which the quota was assessed.

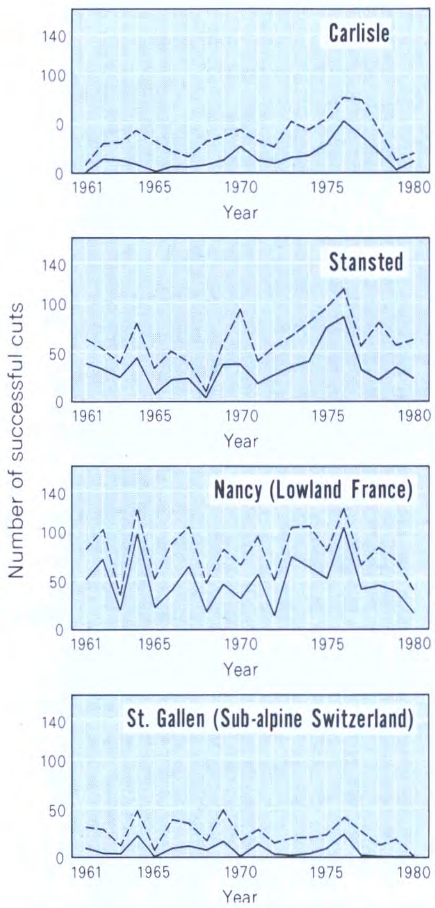
An issue of current concern to the public at large—straw burning—was investigated in some detail. The work included the development of computer models of the effects of weather on the downwind dispersion of smoke and smuts from straw fires (see left p.30) and collaboration in field burning experiments by Warren Spring Laboratory and Silsoe College of Agricultural Engineering. It would seem that some nuisance cannot be avoided but that by a suitable reference to recent and present weather and suggested firing techniques the operator has some control over its impact.

The pattern of farming in the United Kingdom (grassland versus arable) mirrors the climate and confirms the limitations to cropping set by temperature and rainfall. These weather elements are always of concern and are invariably reflected in some way in the investigational program, either directly, as when temperature or moisture thresholds are crossed, or through problems involving heat and moisture exchange and budgeting. The 1984 study program included applications to



The effects of the weather on the downwind dispersion of smuts and smoke.

Opportunities for field drying hay at different sites in north-west Europe, estimated using a micrometeorological simulation model: cuts of hay are assumed possible on any day of a 140-day season from May to September. The diagrams refer to hay dried to 25 per cent moisture content (ready for immediate long-term storage) within either five days, when losses of dry matter and quality would usually be small (full lines), or within 10 days (dashed lines).



Straw burning—in light winds smoke enables the entrainment of air into the rising plume to be seen. In the foreground the apparatus used to collect falling smuts can be seen.

orchards and poultry, cereal growth stages, and the irrigation scheduling of field crops.

The modelling of crop growth, and diseases such as potato blight, is sophisticated and detailed; daily weather observations are used to determine the daily growth rate of a crop or its pests and diseases. One can follow the progression through successive phases of the life cycle—towards harvest or towards disease levels that are of some economic importance. In such computer simulation studies, the observations from the synoptic weather observing networks provide the primary daily input. Such models, when adequately validated and accepted, give the basis for operational advice and also act as a management tool that can be used to explore options and consequences in a way that may reduce the dependence on long-running and costly field trials.

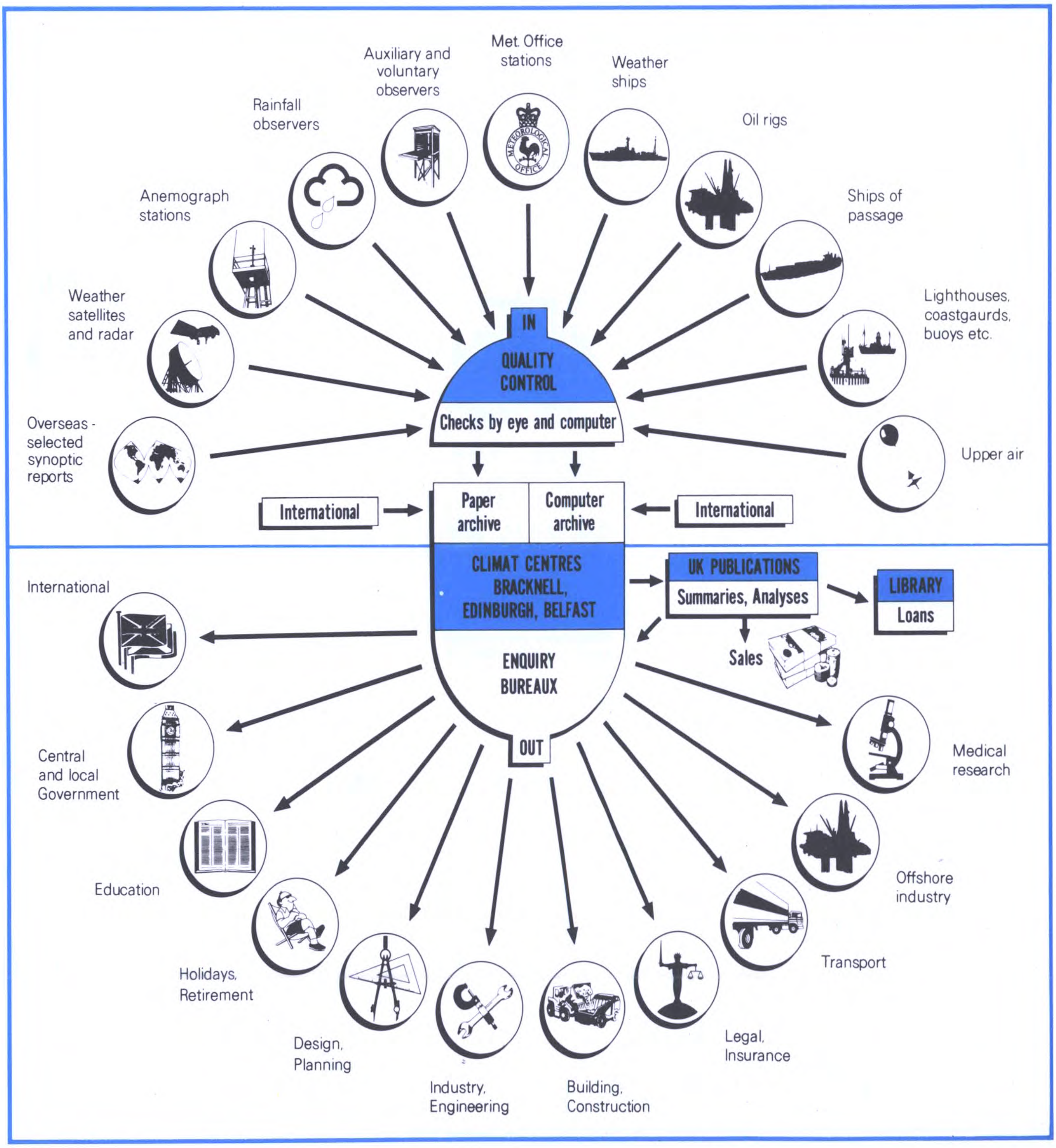
Table IV *Some investigations under way or completed during 1984*

Topic	Collaborating organizations	Notes
Effects of weather on the variability of grass production in north-west Europe	Grassland Research Institute	Mainly theoretical study: part funded by EEC
Effects of weather on field drying of hay in north-west Europe	—	Theoretical study: part funded by EEC
Opportunities for barn hay drying	—	—
Weather effects on straw burning	Warren Spring Laboratory, Silsoe College	Theoretical and experimental study
Influence of slope and aspect on air temperature	—	Theoretical and experimental study
Climate aspects of agricultural land capability classification	ADAS, Soil Survey	—
Cereal plant development in response to weather	Agricultural and Food Research Council	Experimental study
Frost protection to orchards by wind machines	—	Experimental study
Temperature stress in housed poultry	—	Theoretical study
Automatic monitoring of environment for plant disease development	ADAS	Experimental study
Relations between weather and water-soluble carbohydrate content of grass	—	—
Weather and 1967 outbreak of foot-and-mouth disease at Warwick	Animal Virus Research Institute	—
Development of improved criteria for potato blight prediction	—	—
On-farm estimation of irrigation needs using microcomputers	ADAS	Includes experimental verification of method

Consultancy, advisory and data services

In addition to daily weather prediction the Meteorological Office provides many varied data and advisory services valuable to industry, commerce, the professions, Government departments and the general public. These revenue-earning services are used at the design stages of engineering and other projects, in the planning and risk assessment of weather-sensitive activities, in the event of contractual disputes, for insurance or loss purposes and for litigation in both Crown and Civil Courts. Many enquiries are also received from the general public and students.

Such services depend upon the compilation and maintenance of comprehensive climatological data bases for the United Kingdom and for marine areas world-wide. The Meteorological Office marine data bank comprises well over 58 million observations occupying some 90 high-density magnetic tapes. This archive is organized and indexed to allow rapid and easy access for all foreseeable requirements. While keeping



Flow of climatological information.

the traditional document archives, all United Kingdom land data since 1958 have been transferred to the computer archive, with data from some stations going back to 1930 and, in a few cases, earlier.

Definitive publications of climatological data include the *Monthly Weather Report*, tables of *Monthly and Annual Totals of Rainfall for the United Kingdom* and the *Snow Survey of Great Britain*. Weekly, monthly and quarterly there is a print-out, in semi-plain language, of observations from the 50 stations that used to feature in the now defunct *Daily Weather Report*. For water budgeting purposes there is a routine weekly service providing estimates of rainfall and evaporation averaged over 40 km squares for the whole of Great Britain. Other publications are produced from time to time.

Specialized bureaux deal with rainfall and evaporation enquiries for England and Wales, marine and offshore enquiries anywhere in the world and meteorological aspects of building and construction. In addition, there are bureaux at Bracknell, Edinburgh and Belfast dealing with general enquiries for England and Wales, Scotland, and Northern Ireland respectively. Requests for details of actual weather for specific incidents in the past are often serviced by the straightforward supply of observational data in a certified statement, but sometimes require expert opinion on the interpretation and application of the available data. Staff can be called to court to explain a statement further or to give other expert evidence.

The Marine Bureau supplies data, analyses, summaries and consultancy services for offshore exploration or production work and, to a lesser extent, general shipping. Although largely concerned with British home waters, work can be, and is, undertaken for any ocean or sea in the world. Major projects and investigations included the collation and summarizing of meteorological data from offshore rigs and platforms, the assessment of the wind energy resource offshore and a study of ice and snow loading on offshore structures.

Routine hydrometeorological work includes the calculation of areally averaged monthly rainfalls for the 900 catchments of the Department of the Environment surface water archive. To meet individual requests, specific catchment rainfall and evaporation data have been calculated for past years enabling Water Authorities to extend recent and limited river flow data backwards in time. Such data are necessary for the assessment of risk of both drought and flooding, thus assisting the design of safe but cost-effective structures for water supply.

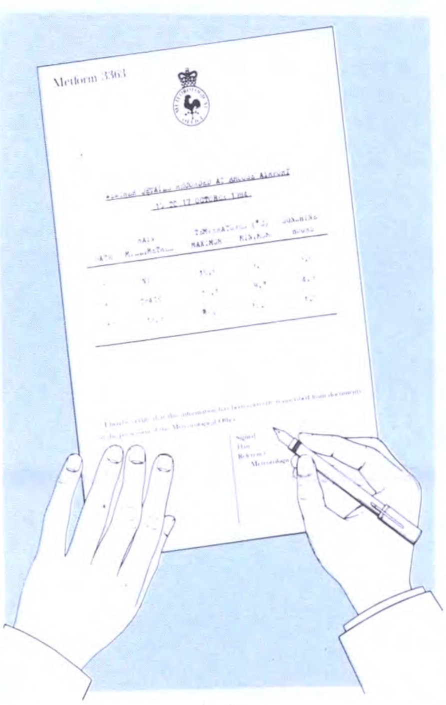
All the bureaux are becoming increasingly involved in the provision of advisory services and consultancies rather than the straightforward supply of data and analyses. The complex and rather imprecise nature of meteorology is such that many enquirers do not know what to ask and discussions with a meteorologist can indicate either the most appropriate data or analyses required or the need for a study tailored to the specific problem. Taking the initiative in such discussions resulted in the joint incomes of the general climatological and building enquiry bureaux for England and Wales more than doubling, in real terms, during the six years 1979–84.

Inevitably, many small enquiries are received for which charges cannot reasonably be made, but staff constraints are making this free service more difficult to maintain. Of particular concern are school children and students requiring data or advice for educational projects to be assessed for the various educational certificates. Steps have been taken towards the production of teaching packages by BBC CEEFAX and the Royal Meteorological Society and articles written publicizing readily available data. For general public and educational use a series of Regional Climatological Memoranda for England and Wales is in course of publication; one memorandum has been published for Northern Ireland and work is in hand to complete the series for Scotland.

Various investigations have been undertaken on repayment or in support of enquiry work. A study has been made of correction factors to anemometer exposures for a European wind energy project; adverse weather effects on construction activities have been studied and frequencies compiled of the incidence of driving rain (because of the effects on walls filled with foam or other insulating material).

Jointly with the Water Authorities a study has been made of the rainfall network. For England and Wales some areas were identified as needing more rain-gauges, and others had more gauges than necessary to describe the climatology and answer enquiries. Development continued on archiving areal rainfall measurements from weather radar which might provide an alternative source of climatological data to the traditional, limited information derived or implied from rain-gauges.

A certified statement.



Technical Archives

Original meteorological records, observation books, and forecasters' working charts are retained in a building at Eastern Road, Bracknell, which has been nominated as an 'approved place of deposit' under the Public Records Act (1958). Technical records for Scotland and Northern Ireland are similarly retained in archives in Edinburgh and Belfast respectively.

The records retained—inevitably only a proportion of the total generated—have been selected carefully so as to provide both an adequate 'public memory' of the weather affecting the United Kingdom and neighbouring sea areas and a continuing picture of the operations of the Office. These records are available for inspection by the public during normal working hours.

Introduction to the research program

Research aimed at improving the operational and advisory functions of the Office continues. At the centre of the program, work on improving the present generation of numerical weather forecast models, which were introduced operationally in 1982, continues at high priority. Experience with earlier generations of numerical models has demonstrated that a continuous program of assessment, amendment and adjustment is necessary to extract the best possible results and there is every reason to expect that the present models will be susceptible to a similar program of enhancement. In addition, the development of a very-fine-mesh model to be used for short-period weather forecasting has now advanced to the stage where the prototype model is run daily as part of an operational evaluation.

In parallel with these advances, the development of techniques that optimize the exploitation of radar and satellite information to provide high-density data for short-range forecasting continues in the so-called FRONTIERS project. The techniques for providing combined radar and satellite representations of the cloud distribution and precipitation rates on a high-resolution grid have already reached the stage at which they can be directly useful to forecasters.

Satellites provide not only visual and infra-red images as used in the FRONTIERS project, but also temperature and humidity soundings of the atmosphere and winds derived from cloud motions. Work is continuing and much remains to be done to derive the maximum benefit from the data used as input information for the numerical forecast models. Another major thrust now under-way is to develop the next generation of satellite instruments which by the increased exploitation of microwave techniques can be expected to overcome some of the limitations of the systems now in use. The setting up of a group within the Satellite Meteorology Branch at the Department of Atmospheric Physics, Oxford will enhance the co-operation between the Office and Oxford University on satellite matters which has been of much mutual benefit in the past.

A better understanding of the global climate system so as to provide the best possible advice on the degree to which man's activities, through changes in land use and in the composition of the atmosphere, may modify the climate is a major objective of the research program. The general circulation models needed for this work often require numerical techniques and physical parametrization schemes which have direct applications in the area of numerical weather forecast model development and provide a good illustration of the integrated nature of the Office's research program which ensures the timely interchange of knowledge and technology between projects. The need to represent more adequately the role of the oceans in the simulation of climate has led to an increased effort being devoted to some aspects of oceanography, particularly the interaction between ocean and atmosphere. This has been achieved partly by means of a joint University, Institute of Oceanographic Sciences/Natural Environment Research Council and Meteorological Office ocean modelling group located at Oxford University.

The instrumented Hercules aircraft of the Meteorological Research Flight is a major research facility used in many parts of the research program. It provides the means of carrying out field studies of, for instance, mesoscale meteorological phenomena, boundary-layer properties, atmospheric chemistry, cloud physics and the radiation budget of the atmosphere. The instrumentation available on the aircraft, which makes it one of the most advanced research aircraft in the world, has been maintained and improved to ensure that it continues to provide observations of the necessary quantity and quality. The aircraft plays a full part in improving our knowledge of physical meteorology. This is essential for a more realistic representation of the relevant physical processes in the various numerical models, and for the elucidation of various factors that are required to provide improved assessments of the meteorological aspects of such important environmental problem areas as the dispersion of pollutants, 'acid rain', and the possible reduction of atmospheric ozone by minor gases of an anthropogenic origin. In the latter case the numerical models of the stratosphere provide the means to integrate the dynamical and chemical aspects of the stratospheric changes.

The Office's research endeavour comprises complementary observational, theoretical and numerical studies combined and often interwoven to provide a program flexible enough to react in a timely fashion both to new discoveries and to demands for better meteorological services and advice.

Meteorological Research Flight (MRF)

One of the major facilities for atmospheric research operated by the Office is the instrumented Hercules aircraft of the MRF which is based at the Royal Aircraft Establishment (RAE) Farnborough and flown by RAF personnel under the direction of Office scientists. Most of the aircraft maintenance is carried out by RAE personnel.

The MRF is responsible for the scientific instrumentation in the aircraft which is extensively equipped to carry out studies of the lower levels of the atmosphere. It has, in addition to the more traditional sensors for measuring wind, temperature, humidity, etc., radiometers, equipment for studying cloud structure, a dropsonde system and an extensive chemical-sampling capability. The aircraft is used by several Branches of the Office often in collaboration with universities and other outside bodies. In addition, airborne studies of the radiative structure of the atmosphere are carried out by scientists based at Farnborough as part of the establishment of the MRF. Some of the work involves detaching the aircraft from Farnborough.

The Hercules instrumentation is subject to continual renewal. Also, new requirements generated by research interests have to be reconciled with the need to maintain existing instruments. Thus the past year has seen the installation of OMEGA navigation equipment and improvements to the chemical sampling equipment. Installation of a multi-channel radiometer and a new sensor for measuring temperatures inside clouds are well advanced. However, the bulk of the effort, over and above that needed for routine maintenance, has been devoted to the provision of a new data-recording system, based on microprocessors, within which data are stored on magnetic tape and information is displayed on television monitors. This replaces a system that was over ten years old and unable to meet requirements. In addition to gathering data, the new system has several novel features including an automatic test facility and a display of raw data.

Radiation research

Within the MRF itself, research effort is concentrated entirely on radiative studies. Basic to this study is the provision of radiometers. Part of this program is concerned with the radiative characteristics of broken cloud fields. This work has revealed a consistently non-linear relationship between solar albedo and cloud cover which may be contrasted with the linear assumption basic to most numerical models. Similar complexities are emerging from the study of long-wave emission.

Cirrus cloud sheets are also being studied and an attempt is being made to relate infra-red broad-band fluxes to cloud structure. Analyses show that emissivity is more closely related to total particle cross-sections than to total particle mass. Data gathered by the MRF Canberra (now withdrawn from service) have revealed that the actual shapes of the particles have to be modelled (i.e. they cannot be assumed to be spherical) if the scattering of solar radiation by such clouds is to be understood. Narrow-band observations of the reflectivity of stratocumulus sheets have clearly demonstrated the importance of inhomogeneities in cloud structure. It was not possible to model the observations without allowing for spatial variability in cloud-top height.

Measurements of broad-band fluxes of both visible and infra-red radiation in cloud-free conditions have also been made. These data are being used to assess radiative schemes such as that used in the Office's 11-level model. In addition, when the atmosphere is more polluted than normal, aerosol characteristics are recorded to see how radiative structure is related to the presence of aerosol. These studies have revealed heating rates as large as 5 °C per day sustained for several hours and single scattering albedos for the aerosol of about 0.7 (somewhat smaller than expected); they also detected an increase in the scattering of solar radiation in the stratosphere associated with the El Chichon eruption. The latter finding appears to have been confirmed from the surface by data from a network of radiometers at sites distributed throughout the United Kingdom; the presence of aerosol diminishes the intensity of the radiation reaching the surface. A measure of this diminution is the turbidity which increases as aerosol content increases. These data reveal an increase in this variable during the latter part of 1982 possibly because of the northwards extension of the dust veil created by the El Chichon eruption.

The prospect of deducing the cloud amount (and possibly type), using pyranometers placed on vertical surfaces of different azimuthal orientation, has been explored. Pyranometers measure the incident solar radiation from all unobscured directions—hence the different surfaces effectively sample different portions of the sky and the problem reduces to one of relating simultaneous pyranometric readings to the radiance distribution of the sky hemisphere in clear or cloudy conditions. Initial studies, concentrating on cloud-free days, indicate that considerable variability exists in the form of the radiance distribution, even without the effect of clouds.

The instrumented Hercules aircraft of the MRF.

Forecasting research

Most of the Office's forecasts are now either provided directly from computer models or are based on interpretation of computer products. The bulk of the forecasting research is therefore aimed at improving the models.

In September 1982 the Office implemented a new global forecasting system. It included a regional forecast model to predict detailed weather over the British Isles but since then a number of systematic faults have been identified; some have been eliminated—investigation of others continues. In addition, the requirement for more information from computer forecasts, for instance about the surface temperature, cloud, low-level winds and visibility, means that the operational system needs to be extended. This is being achieved by carrying out a higher-resolution data analysis for the regional model and by developing a new very-high-resolution model and analysis with a 10 km grid covering the British Isles. The latter system will make detailed forecasts of regional weather for use by the outstation network. Some examples of projects are described below.

Research into the model's forecasts of showers

It was noted that in summer the regional model forecast showers over land too frequently. Detailed investigations suggested two defects. The model predicted showers whenever any convective cloud formed whereas in reality, clouds have to reach a minimum depth before they can produce rain. Secondly, the land surface was assumed to be sufficiently moist to allow evaporation from it at the maximum rate permitted by its temperature. However, vegetation cannot supply moisture to the atmosphere as fast as this in dry summer conditions. These defects were removed by introducing a more detailed description of when convective clouds can produce rainfall and by allowing vegetation and soil moisture content to influence the evaporation rate.

The effect of these changes is illustrated below. The left figure shows the weather map for 1200 GMT on 16 May 1983. The British Isles lie in a south-easterly airstream with a front across southern districts associated with a thick band of cloud and continuous rainfall. Northern areas were dry. The forecast from the regional model valid at this time (centre) shows widespread shower activity. The revised forecast (right) replaces the showers by continuous rainfall near the front and predicts dry weather correctly over northern Britain and Ireland. In view of the results of this and other tests the revisions were introduced operationally in May 1984.

High-resolution analysis

This project was to improve the initial analysis used as the starting point for the regional-model forecast. Instead of interpolating the data from an analysis made for the global model, an independent analysis is carried out. Because this model has a shorter horizontal grid length it is necessary to insert observations in 3-hourly batches instead of the 6-hourly batches that are adequate for the global model.

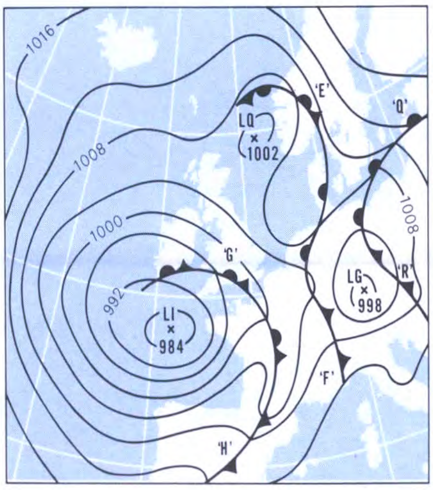
A typical case is shown on p.36, where top left is an analysis of a depression to the south-west of Ireland interpolated from the global analysis. The high-resolution analysis is shown top right where the depression is shown as more intense and in a slightly different position. The lines across which the wind changes direction are more sharply defined. Observations supported this new analysis. The computer forecast produced from the high-resolution analysis was significantly better than the one from the interpolated analysis. As a result of a number of similar successful tests, the high-resolution analysis was introduced operationally in the autumn.

A problem with the technique used to merge observations into the model is to ensure consistency between the pressure analysis and the wind analysis. (In the atmosphere in middle latitudes the wind and pressure are closely related, away from the earth's surface, with the wind blowing almost parallel to constant pressure surfaces.) The two qualities are analysed separately, and the data are then merged with the model forecast gradually over a period of several hours so that the model itself can enforce the required consistency. In the example shown the wind is blowing across the isobars to the south of the depression. Though some cross-isobar flow is realistic, the amount shown may not be and could have contributed to errors in the subsequent forecast. Further work is being carried out to see if the techniques used to merge the data into the model require improvement.

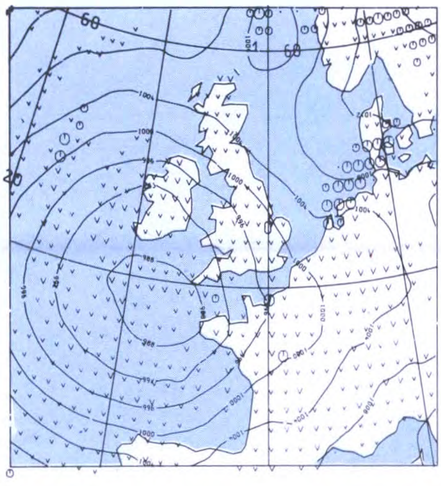
Model winter climatology

A fault noted in the global-model forecasts over the first two winters of operation was a tendency to produce predominantly westerly winds near 50°N after the first few days of a forecast. The problem is associated with a systematic tendency for pressures to become too low over northern Europe. The effect is particularly noticeable when the model is

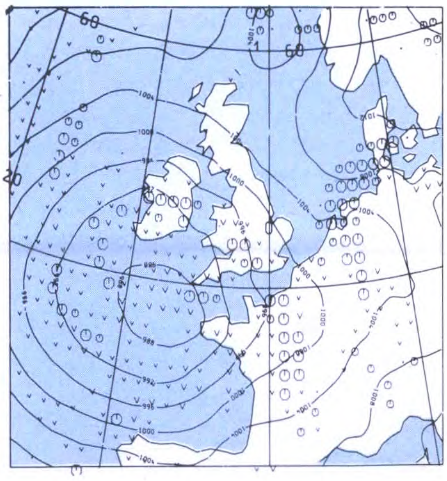
Surface analysis for 1200 GMT, 16 May 1983.

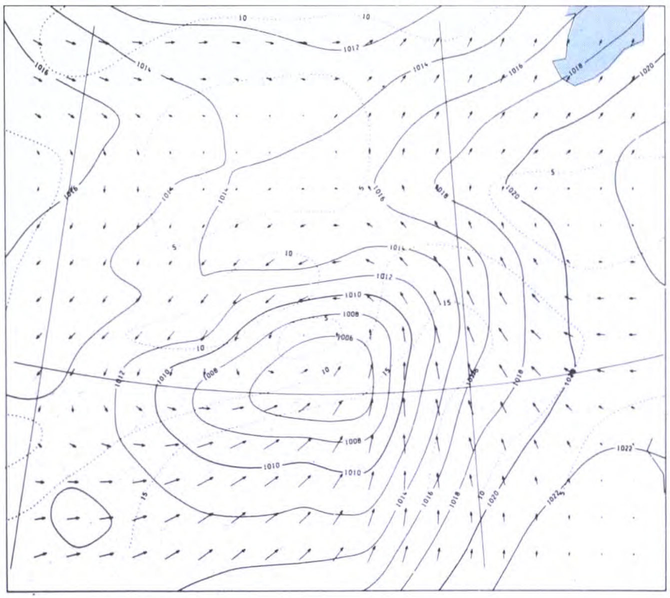


Regional model forecast for 1200 GMT, 16 May 1983. (Frontal rain—Ⓘ, showers—v)

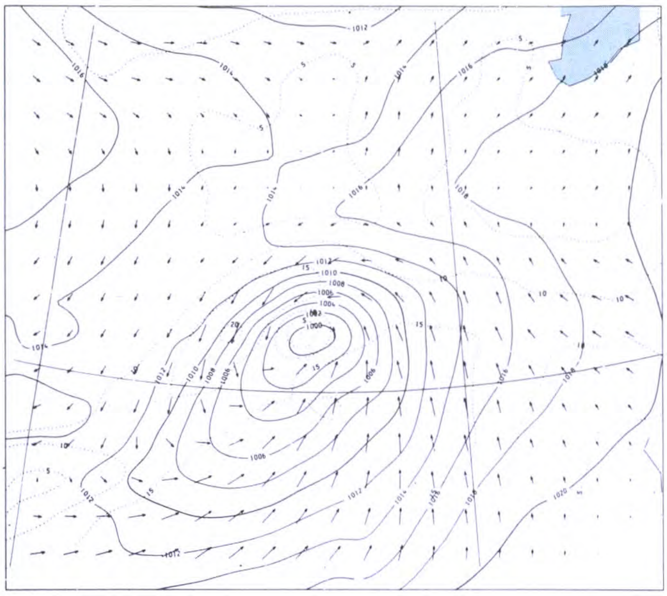


Revised model forecast for 1200 GMT, 16 May 1983.





Interpolated analysis of 1000 mb wind (m s^{-1}) and mean-sea-level pressure (mb) for 1200 GMT, 20 September 1983.



High-resolution analysis of 1000 mb wind (m s^{-1}) and mean-sea-level pressure (mb) for 1200 GMT, 20 September 1983.

used for extended range forecasts up to 50 days or climate integrations.

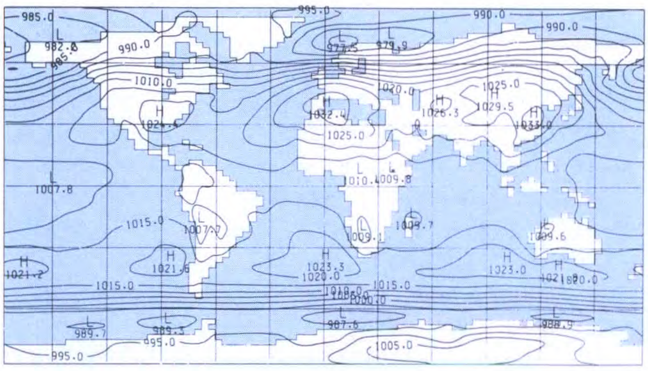
By examining long-term climatological statistics it can be shown that the mean westerly flow in the atmosphere is weaker than would be expected because there is a large residual drag from small-scale disturbances. It is most likely that these disturbances are associated with mountains. Attempts have been made to include this drag explicitly. A different representation of the mountains has also been tested in which, instead of using the mean topographic height over a grid square, a value closer to the maximum height is used. The effects of the latter changes on the mean-sea-level pressure field in an extended integration of a model are shown opposite. The flow is now more realistic.

Numerical forecasting of mesoscale phenomena

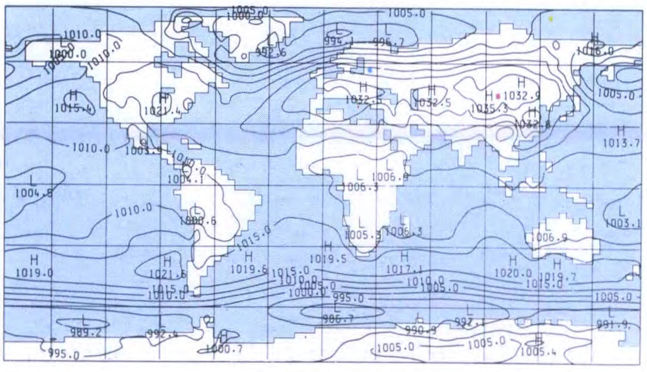
The development of a numerical forecast model with a very fine mesh that will give guidance to local forecasters for periods up to 18 hours ahead has continued. At the beginning of the year a prototype system, which included not only the numerical model but the computer programs necessary to prepare the initial conditions and display the results, was assembled. The model currently operates with a 15 km mesh covering the British Isles although it is hoped eventually to reduce this to 10 km. Models of this kind present numerous problems that do not arise in dealing with more conventional numerical weather predictions; for example showers, considered as a minor correction to the larger-scale flow, may be significant locally. Attempts to incorporate such detail have resulted in a model that requires extensive computer resources, and it has been necessary to ensure that it can be run with high computational efficiency. It has been possible to improve the representation of small-scale processes, especially low cloud and showers, while reducing the time taken to complete a 12-hour forecast from 45 to 30 minutes.

The initial analyses from which the forecasts start are very important when making short-period forecasts. They are based on values interpolated from the operational regional model to which are added near-surface observations and cloud information. Objective analysis of clouds is difficult and an interactive technique including objective methods and manual intervention has been developed. For output purposes visual display units are used extensively, and general facilities are available to overlay maps of forecast elements in various formats to create an easily assimilated picture. The mesoscale forecast suite of programs includes a range of verification and archiving routines.

The results of runs of the mesoscale forecast model carried out once each week have been assessed by skilled forecasters and have demonstrated advantages over what could have been deduced from the larger-scale operational forecast products. From October a daily run of the forecast model was implemented with detailed objective and subjective verification for about 25 regions in the United Kingdom.



Model's average climatological surface forecast obtained using mean topographic height.



Adjusted forecast obtained using near maximum topographic heights.

Boundary-layer research

Turbulence probe mounted on the tethering cable of a kite balloon.

The atmospheric boundary layer

The boundary layer is that part of the atmosphere influenced directly by the underlying surface. It has a very variable character, particularly over land where its depth ranges from only a few tens of metres in weakly turbulent conditions at night to often a few kilometres on hot summer days. The turbulent nature of boundary-layer flows is necessary for the effective exchange of heat, moisture and momentum betwen the earth's surface below and the 'free' atmosphere above and also determines the dispersion, transport and ultimate deposition of many airborne pollutants.

The current research program comprises complementary observational, theoretical and numerical studies which incorporate investigations of the mean and turbulent characteristics of wind, temperature and humidity in the boundary layer, the 'boundary conditions' at the underlying surface, and atmospheric dispersion.

Boundary layers over the sea

In some ways the boundary layer over the sea is simpler to deal with than that over the land; there are generally, for example, suppressed diurnal variations and a more extensive uniform surface with no orographic influences. There are, however, also some complications including the variation with wind speed of the surface roughness characteristics, the possible breaking of waves on the surface, and the increased importance of evaporation. Further, because of the difficulty and expense of making measurements at sea, such studies often require international co-operation and a pooling of resources.

The analysis of data collected during one such recent collaborative exercise, the KONTUR (KONvektion und TURbulenz) experiment, has been completed. The KONTUR field phase took place in generally convective conditions over the German Bight in autumn 1981. Fast-response measurements of temperature, humidity and the three wind components were made throughout the boundary layer using two instrumented aircraft, the Hercules of the Meteorological Research Flight (MRF) and a German-operated Falcon 20 jet. The two aircraft flew a number of joint missions in a variety of meteorological conditions and some very useful results were obtained on the mean and turbulent characteristics of weakly convective, inversion-capped, marine atmospheric boundary layers. On some occasions when cloud streets were observed there is evidence in the data obtained of two-dimensional circulations in the form of roll vortices parallel to the streets and with their longitudinal axes aligned approximately along the mean wind direction.

HEXOS (Humidity EXchange Over the Sea), another international boundary-layer program, has been set up and is aimed at studies of turbulent humidity exchange over the sea for moderate to high wind speeds. Because of the increasing contribution of sea-spray and water droplets produced by whitecaps, the humidity exchange between sea and air is expected to vary considerably with wind speed. A preliminary field trial was conducted for three weeks in November to test and compare various airborne and surface-based measuring systems in preparation for the proposed main observational period in 1986. Measurements throughout the boundary layer were made from the MRF Hercules aircraft in the vicinity of the research platform, Meetpost Noordwijk, situated 9 km off the Dutch coast, where near-surface measurements, particularly of the humidity flux, were made by Dutch, American and Canadian scientists.

Boundary layers over complex terrain

Information on the mean and turbulent properties of boundary layers over hilly terrain is required for applications such as: dispersal of airborne pollutants; wind-power studies; safety of aircraft; assessment of forest damage; siting and construction of factories, other buildings and tall structures; and development of numerical weather forecast and climate models. Despite these diverse needs such knowledge is limited, and extensive observational and theoretical work remains to be done.

Results from an experiment carried out in 1982 on the small, isolated hill, Blashaval, on North Uist indicated a need to obtain more detailed measurements of the turbulent stresses within the lowest 8 m of the boundary layer over the summit region. Surface irregularities on Blashaval prevented such useful data being collected. An appropriate site was found at Nyland Hill, a similar, small, isolated, rounded hill near Cheddar, and a five-week experiment was conducted there during September–October. After a slow start in unsuitable meteorological conditions the weather changed to allow a sufficient quantity of the required high-quality summit turbulence data to be recorded. A secondary aim, also achieved, was to observe the mean flow over such a hill in stably stratified conditions.

Atmospheric dispersion

The Office has continued to support studies related to the 'acid-rain' problem; fundamental theoretical and observational research programs having been initiated in 1971. In particular, close collaboration has continued with the Central Electricity Research Laboratories, Leatherhead, in using the instrumented MRF Hercules aircraft to provide data for the study of many dynamical, physical and chemical facets of this complex issue. One meteorological aspect of the current work is an assessment of the ability to forecast up to three days ahead the long-range trajectory of a polluted plume. The recent introduction of the current, improved operational forecast model may mean that occasions when significant pollution is likely to be transported from UK sources to a particularly sensitive target area, such as southern Scandinavia, can be identified and predicted correctly a few days ahead.

Since the first Sirhowy Valley Experiment in 1980, short-range dispersion experiments have been an important component of the Office's study of the influences of the physical relief on the boundary layer's dispersive properties. Experiments conducted in the Sirhowy

Valley in 1983 confirmed that the sampling technique being used, namely the charcoal-cloth 'badge' samplers developed by the Chemical Defence Establishment, Porton Down, was adequate for sampling ambient concentrations of a gaseous tracer for up to a kilometre or so from its source. Worthwhile scientific results are now emerging from these and previous short-range dispersion trials (e.g. those conducted on Blashaval in 1982).

Further valuable experience was gained in 1984 during nine dual-tracer experiments at Nyland Hill where near-surface dosages of tracer were measured at an array of the 'badges' distributed over the hill. Two different tracers were released simultaneously upwind of the hill, one at 14 m and the other at 28 m above the ground. The measurements will be used to verify theoretical predictions and also for comparison with the corresponding predictions for similar releases over flat, uniform terrain.

Numerical modelling

The boundary-layer structural and dispersion experimental programs mentioned above have again been supported by considerable theoretical investigation and the development and application of a wide variety of numerical models. Of particular note has been the continuing development of a three-dimensional model explicitly for studying large-eddy motions in the boundary layer. This has simulated successfully laboratory channel-flow and is currently being applied to the study of the homogeneous, neutral, atmospheric boundary layer. In co-operation with the Department of Applied Mathematics and Theoretical Physics, Cambridge University, through the CASE Studentship scheme (Co-operative Awards in Sciences of the Environment), an existing two-dimensional model has been extended to include higher-order stress terms and is being used in detailed studies of turbulent structures in flows over hills, as revealed by the measurements made at Blashaval and at Nyland Hill.

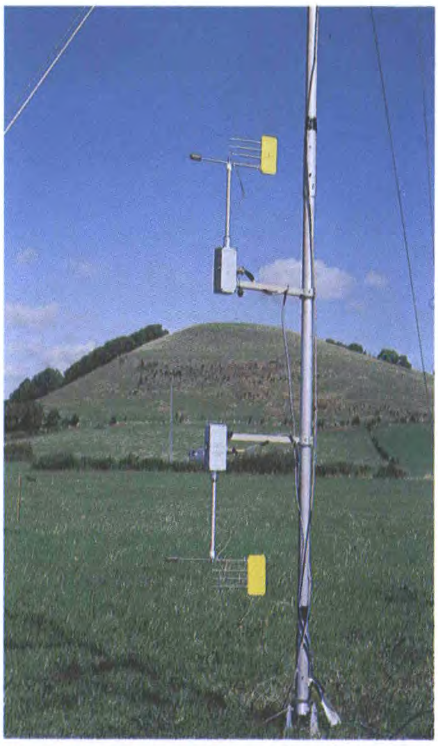
Investigation has continued into the use of so-called 'random-walk' and 'integral-equation' approaches to modelling pollution dispersion. A three-dimensional random-walk model has been used to simulate dispersion over complex terrain, with an encouraging degree of agreement with results from the Sirhowy Valley Experiments of 1981 and 1983. The method gives substantially better dispersion estimates than those obtained from the more traditional Gaussian-plume models. The integral-equation method has been used to simulate simple chemical reactions, such as when the primary chemical species in a plume interacts with an ambient atmospheric species to produce a secondary pollutant. The resulting distribution of secondary pollutant across the plume is markedly different from, and more realistic than, that obtained from the 'well-mixed box' approach commonly used in atmospheric chemistry.

A version of a three-dimensional, mesoscale numerical forecast model continues to be adapted and tested for eventual application in support of planned medium- and long-range dispersion studies.

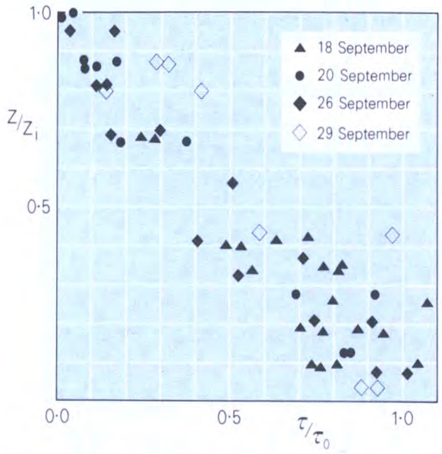
Boundary-layer instrumentation

A big task has been to test and evaluate a new balloon-borne package to measure the high-frequency turbulent properties of the boundary layer. Prototype probes have been on trial both at Cardington (in test 'flights' and in observational studies of inversion-capped boundary layers) and under the more exacting conditions experienced in 1983 in the more rugged terrain of the Sirhowy Valley. Ten 'operational' probes are now under construction.

Preparations are well advanced for the Meteorological Office to operate its own, reduced, tethered kite-balloon facility at the Meteorological Research Unit, Cardington, following the withdrawal of the Royal Aircraft Establishment from the site early in 1985.



Rapid response, mast-borne, turbulence instruments used at Nyland Hill near Cheddar.



Values of the turbulent shearing stress τ (normalized by the surface value τ_0) as a function of height Z (normalized by the depth of the boundary layer Z_i) obtained from aircraft data collected over the German Bight during the KONTOUR experiment.

The middle atmosphere

The region of the atmosphere above the troposphere and below a height of 85 km is usually referred to as the middle atmosphere. It comprises two layers: a lower layer called the stratosphere where the temperature generally increases with height, and an upper layer called the mesosphere where the temperature decreases with height. There is much interest in the middle atmosphere, partly in response to concern about the effects of pollutants on the ozone layer which lies within it and acts as a screen to harmful ultraviolet solar radiation. The complex photochemical reactions involved must be considered in conjunction with the wind systems which transport the minor chemical species. The advent of remote sensing from satellites has transformed our ability to monitor the circulation of the middle atmosphere while numerical models of increasing sophistication are being used to simulate the main features of this circulation and to investigate interactions with the troposphere.

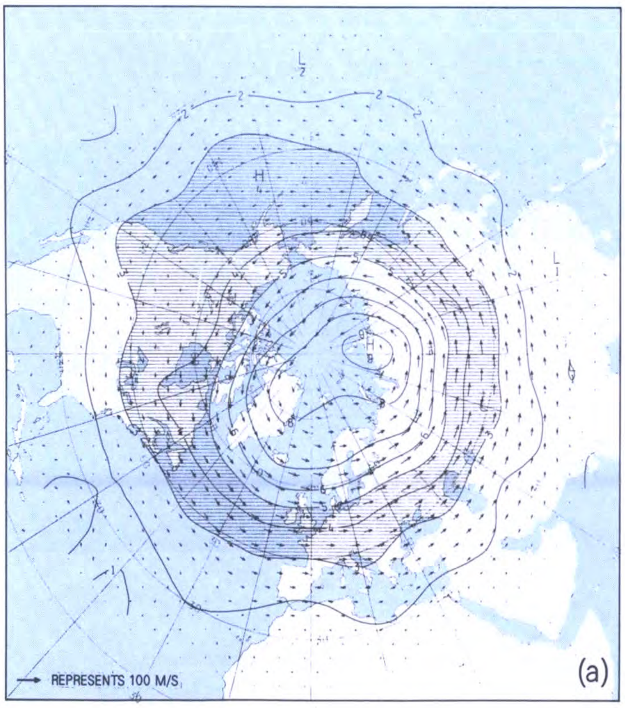
Observational data from Stratospheric Sounding Units (SSUs) (designed at the Meteorological Office and flown on the US NOAA series of satellites) have been analysed to produce daily global synoptic maps at various levels in the stratosphere for the last six years. Studies using them include the seasonal evolution of the stratosphere and the causes of inter-hemispheric differences, and of rapid events called sudden warmings. Stratospheric warmings are believed to be triggered by changes in the large-scale flow in the troposphere. They involve a disruption of the predominantly west to east flow in the winter stratosphere and, at the same levels, a rise in temperature which in some places may be more than 50 °C in a few days. During these events chemical species are transported from low latitudes towards the Pole. Data from SSUs are distributed to over 20 research centres to support observational and theoretical research projects.

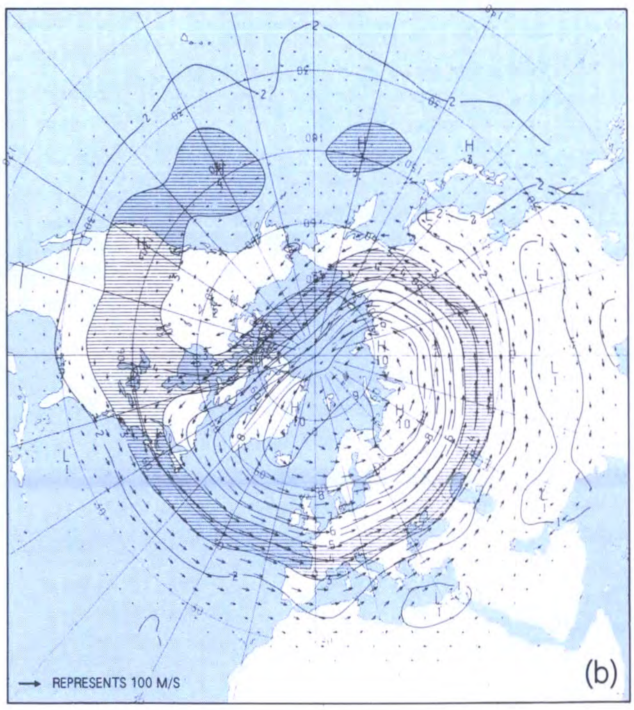
The Office participates in the international Middle Atmosphere Program one of whose activities has been a comprehensive intercomparison of data received from different satellites and analysed by different methods. Often there is good agreement between derived meteorological fields, but serious discrepancies have been noted, particularly during periods when the circulation is strongly disturbed. One difficulty is that satellite instruments measure averages over a volume of the atmosphere rather than local values. Differences in the derived fields inevitably arise because of differences in the resolving power of the instruments. Such comparisons of data alert users to the limitations of the observations and may suggest ways of improving the methods of analysis.

A numerical model of the stratosphere and mesosphere is used to interpret the observations and test theoretical ideas about the dynamics of the middle atmosphere. The model has been formulated to investigate the way that large-scale circulations in the troposphere affect higher levels. The main features of a number of observed sudden warmings are successfully simulated when the model's atmosphere is disturbed from below by appropriate patterns of pressure. To simulate events of longer duration, such as the seasonal reversal of wind direction in the middle atmosphere, work has recently begun, in collaboration with the University of Oxford, to improve the representation of radiative effects and of dissipation by gravity waves.

A quantity of fundamental interest in both observational and modelling studies is the potential vorticity, a measure of the local spin of the atmosphere that is approximately conserved for air parcels. When displayed on surfaces of constant potential temperature the property of conservation allows the movement of air to be followed. An illustration from SSU data is given below where the maps refer to a surface in the middle of the stratosphere at a height of about 30 km. A relatively undisturbed flow in November becomes highly distorted in a few days as equatorial air of low potential vorticity displaces air of high potential vorticity from polar regions. This phenomenon is a characteristic of sudden warmings. The extreme buckling of isopleths of potential vorticity is reminiscent of the shape adopted by ocean waves breaking on a beach, and as a consequence is often referred to as planetary wave breaking. There are striking similarities between this evolution and the formation of blocking anticyclones in the troposphere, encouraging a unified approach to dynamical investigations of large-scale flows in both the troposphere and the middle atmosphere.

Potential vorticity at about 30 km from SSU data for (a) 9 November 1984 and (b) 21 November 1984.





Aviation research and development

Meteorological factors enter into many aspects of the safe and economic operation of aircraft. Requests are received for meteorological advice and information relating to problems of aircraft operation or design, while improvements in techniques of forecasting for aviation are continually sought. Both aspects often lead to special investigations, some of which are described below.

Forecasting

Significant weather charts

There is an International Civil Aviation Organization requirement to generate forecast significant weather charts as numerical model output for aviation world-wide. These charts indicate areas of expected clear air turbulence, deep convection and icing.

Clear-air-turbulence charts are now being produced in the Central Forecasting Office on a trial basis, and an example of a 24-hour forecast is shown opposite. The reaction from pilots to a trial issue of these charts to British Airways has been encouraging, and a more extensive verification trial is planned.

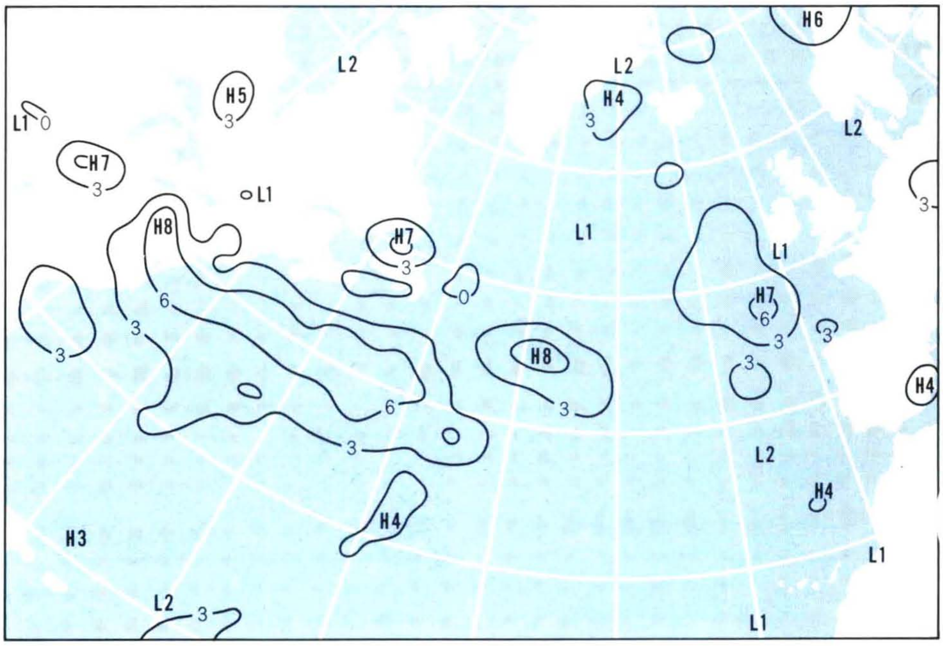
Forecast charts of areas of deep convection have commenced, and a special study for the United Kingdom of occasions when deep convection is likely to be particularly hazardous to aviation is well advanced.

Local forecasting for aviation

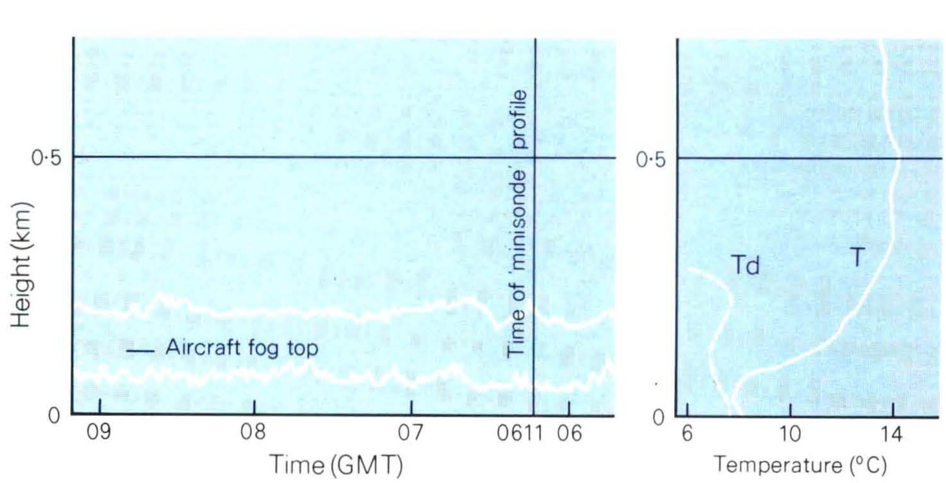
The development of outstation forecasting techniques and the testing of additional local observations which give more information about fog and low cloud are being pursued in collaboration with outstation forecasters.

(a) *Inland stations* At the Royal Aircraft Establishment, Bedford, observations of the lower atmosphere have been made using a minisonde and an acoustic sounder to assess their potential for improving the forecasting of fog.

The right-hand figure shows an acoustic sounder record (upper and lower echo boundaries are indicated) linked to a minisonde temperature profile and fog



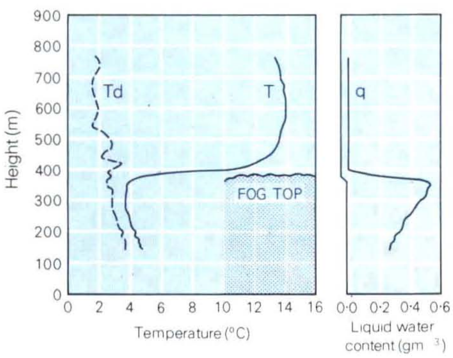
Example of a clear air turbulence probability forecast (per cent).



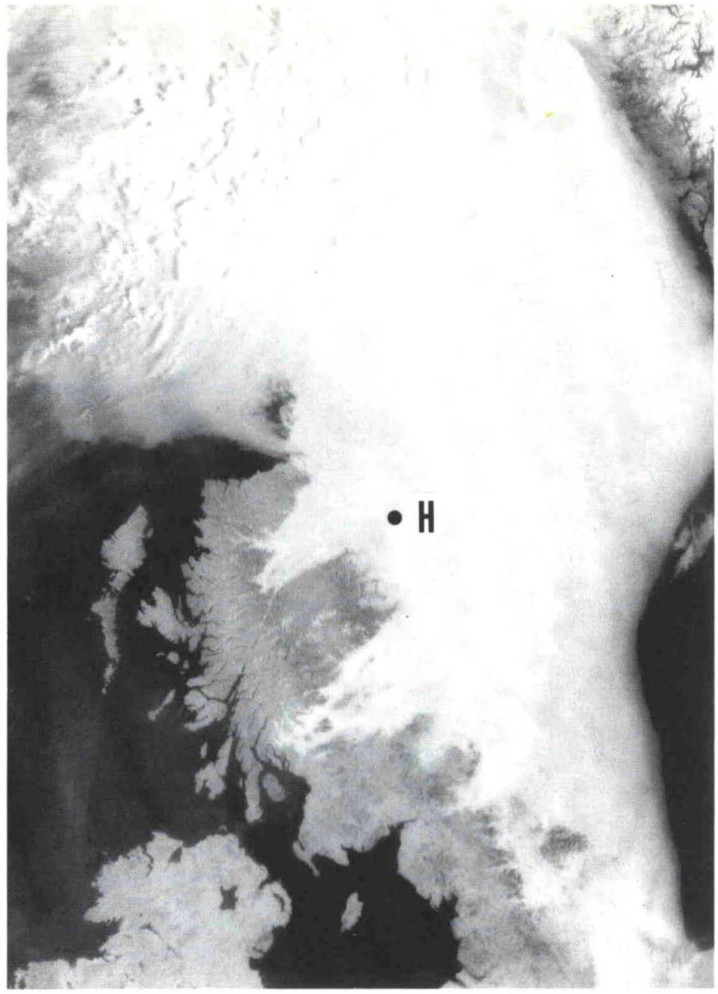
Upper and lower boundaries of an acoustic sounder record together with a minisonde temperature (T) and dew-point (T_d) profile and an aircraft report on the fog top height.

top reported by an aircraft at the same site. The base of the acoustic echo corresponds closely to the base of the temperature inversion (just below 100 m), while the fog top (see aircraft report) is characteristically about 50 m above this level.

(b) *Coastal stations* Sea fog frequently affects coastal stations, but the processes which influence the formation and movement of areas of sea fog are poorly understood. Observations of the distribution and vertical structure of sea fog over the Moray Firth were made on 27 April from the Hercules aircraft of the Meteorological Research Flight. Minisondes were also released from Lossiemouth at intervals during the flight. The figure (right) shows the extensive sea fog recorded by satellite NOAA-8 at 0836 GMT, while the figure below exhibits the vertical structure of the fog obtained by the aircraft at 1152 GMT near H on the figure (right). Of interest is the high liquid water content near the fog top, and the large temperature increase (but with little change in dew-point) above it. These and other features are now being studied.



Vertical profiles at H (see satellite picture) of temperature (T), dew-point (T_d) and liquid water content (q) obtained through the sea fog.



Photograph by courtesy of Dundee University.

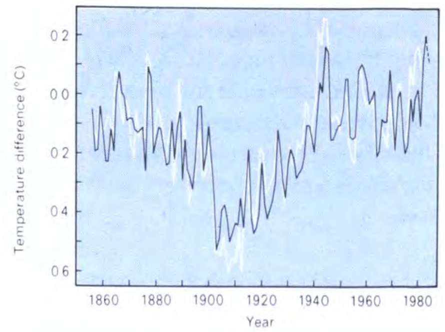
Satellite visual photograph for 0836 GMT, 27 April 1984 (H indicates position of aircraft at 1152 GMT).

Operations

Table V *Aviation requirements, associated meteorological requirements and actions taken in 1984*

Aviation requirement	Meteorological requirement	Action in 1984
To set design criteria for icing protection systems for helicopters.	To describe atmospheric parameters relevant to icing.	An icing climatology for helicopters was completed and issued.
To operate twin-engined aircraft on transatlantic flights—aircraft must reach diversion airfields if an engine fails.	To assess forecast reliability and frequency of closure of diversion airfields because of bad weather.	An investigation of frequency of adverse weather at airfields in Iceland and Greenland for September 1984–May 1985 has begun.
To use real-time meteorological data from aircraft for flight management and air traffic control purposes.	To assess the value of inputting aircraft meteorological data to operational numerical forecasts.	A feasibility study by a Joint Meteorological Office/Civil Aviation Authority Working Party was submitted.
To save fuel by a reduction in height separation between mandatory cruise levels.	To provide pressure/height calibrations from radiosonde data for a Civil Aviation Authority/Eurocontrol radar study of aircraft height-keeping performance.	The provision of radiosonde data for height-keeping trials over the period June 1984–May 1985 has commenced.
To provide equivalent headwind forecasts for Britannia Airways of route sectors over Europe and the Near East.	To arrange for the operational numerical forecast suite to output and transmit equivalent headwind forecasts to Britannia Airways.	A six-month trial was successful, and a routine service has commenced.

Climate research



Annual global night marine air temperature, white, for 1856–1981 and annual global sea surface temperature, black, for 1856–1984 both relative to the normal for 1951–60.

It has become evident that man's activities could cause climate to change on a global scale, and there is now greater sensitivity to the consequences of climatic variations. A greater understanding of the global climate system has become a major goal of research, and the World Meteorological Organization and the International Council of Scientific Unions, in collaboration with other international agencies have planned a World Climate Research Programme to which the Meteorological Office is making a considerable contribution.

Observational studies of climatic change

Much of the Office's observationally based research into climatic change and climatic variability makes use of the Meteorological Office Historical Sea Surface Temperature and Marine Air Temperature data sets. These are syntheses of over 50 million ship observations that have been quality controlled and analysed to provide, for each month since 1854, world-wide fields of sea surface temperature (SST) and marine air temperature (MAT).

Some authors have held that changes in climate cannot be detected in SST observations because of changes in the systematic errors caused by changes in the methods of measurement. Before World War II uninsulated buckets were used to obtain samples of the water, during the war engine water-intake temperatures were measured, whereas more recently some of the observations have been of water-intake temperature and others of water sampled in insulated buckets. However, a comparison of SST, night-time MAT and daytime MAT has enabled global corrections to be estimated. The figure (top right) shows the corrected series of SST and night-time MAT averaged over the globe.

A long-period fluctuation of about 0.5 °C with the coldest period around 1910 and the warmest near 1950 can be seen. For the period since about 1900, the fluctuation is similar to that documented for average surface air temperature over the land masses of the northern hemisphere. The similarity between the SST, MAT and land air temperature series supports the reality of the long-period fluctuation and also of others of shorter period. However, between 1860 and 1890 the series show SSTs and MATs higher than the land air temperatures and in the 1860s the former were almost as high as they are now. The reason for this difference between land and sea temperatures is not clear; observations in the earlier period were few, but the SST values are likely to be more representative than the land air temperatures. This long-period fluctuation, which is as large as the rise in global temperature that could be expected in the period from the observed increase in atmospheric carbon dioxide (CO_2), indicates that other important mechanisms are operating to cause climatic variations. It is also possible to deduce from these results and from measurements of other variables that because of the natural variability of the atmosphere it is likely to be at least 25 years before it can be confirmed that the progressive increase in CO_2 has had an effect on atmospheric temperatures.

Since about 1960 the oceans of the southern hemisphere have warmed relative to those of the northern hemisphere. This type of variation in SST between the northern and southern halves of the ocean basins may be linked with the drought in the Sahel region of northern Africa and this is being investigated.

An important aim of the SST studies is to find out whether variations that have occurred over the North Atlantic in the past 100 years in large-scale SST patterns, and long-term variations in atmospheric circulation, are related. These circulation variations have sometimes, in specific seasons, led to large fluctuations in mean temperature and rainfall for the United Kingdom—for example the decline in summer rainfall that is evident from observations since about 1960.

Simulation of climate and climatic change

Man's activities may affect the climate through changes to the land surface (caused by deforestation, irrigation, etc.) or to the composition of the atmosphere (through increases in CO_2 and other trace gases). To provide estimates of these effects it is necessary to develop numerical models of the combined atmosphere, ocean, sea-ice and land system capable of simulating the climate realistically.

The atmospheric component of such climate models is similar to that used in numerical forecasting although more attention has to be given to those physical processes which operate on particularly long time-scales. For example, small imbalances between incoming and outgoing radiation may become important in time; as the effects of increasing CO_2 in the atmosphere depend on its radiative properties, an accurate representation of the properties is important and the model has been improved by making the emissivity of CO_2 dependent on temperature. Similarly the impact of deforestation can only be assessed if the model contains a proper representation of the effects of vegetation on the energy and moisture budgets at the earth's surface; work is in progress, partly supported by European Economic Community (EEC) funds, to represent land-surface processes more accurately.

Simulations of the atmospheric circulation have been made over several annual cycles with two models. One has a mesh size in middle latitudes of about 280 km and the other 560 km. With the finer-mesh model many features of the time-averaged flow are realistic but mid-latitude westerlies are too strong in the northern winter. This error is less serious with the coarser-mesh model but at the cost of realism in several other features.

Mathematically, the ocean model that has been developed is similar to the atmospheric model with which it is linked, though there are complications due to the formation and decay of sea-ice.

Coupling of the ocean and atmosphere models has been the focus of this year's research. The ocean model has been changed to allow it to use diagnostic packages originally designed for the atmosphere model, the sea-ice model's time-step has been given special treatment to allow for the different time-scales of sea-ice interactions with atmosphere and ocean, and coupling techniques have been designed to allow for long integrations in which it is desirable to run the ocean and atmosphere models asynchronously because the latter requires more computer time. Study of this coupling problem has used simple one-parameter models prior to embarking on coupled runs of the full models.

The first coupled experiments use models of the ocean with only sufficient thermal capacity to represent the seasonal cycle, so that they can be run synchronously with the atmosphere model. It is important for the subsequent use of the model in assessing CO_2 impacts that possible variations in cloudiness should be treated explicitly, so allowing a more complete representation of relevant feedback processes and providing better estimates of the radiation balance at the ocean surface than are possible with the prescribed, zonally averaged cloud amounts used previously.

Analysis has continued of earlier experiments on the effects of increased CO_2 in an atmosphere model with changes in sea surface temperature and ice extent prescribed so as to balance approximately the radiative consequences of the CO_2 changes. In this analysis, partly funded by the EEC, there has been particular emphasis on the effects of increased CO_2 on European climate. Reruns of some of these earlier experiments using a different model have given results which, though similar in many respects, confirm the expectation that where the control experiment simulations differ, so does the response to a CO_2 increase.

The development of the land surface model and work on the ocean model have benefited from the co-operation with Liverpool, Cambridge and Southampton Universities. Past co-operation in ocean modelling with Cambridge and Oxford Universities has culminated in the formation of a new group at Oxford, funded jointly by the Meteorological Office, Oxford University and the Natural Environment Research Council.

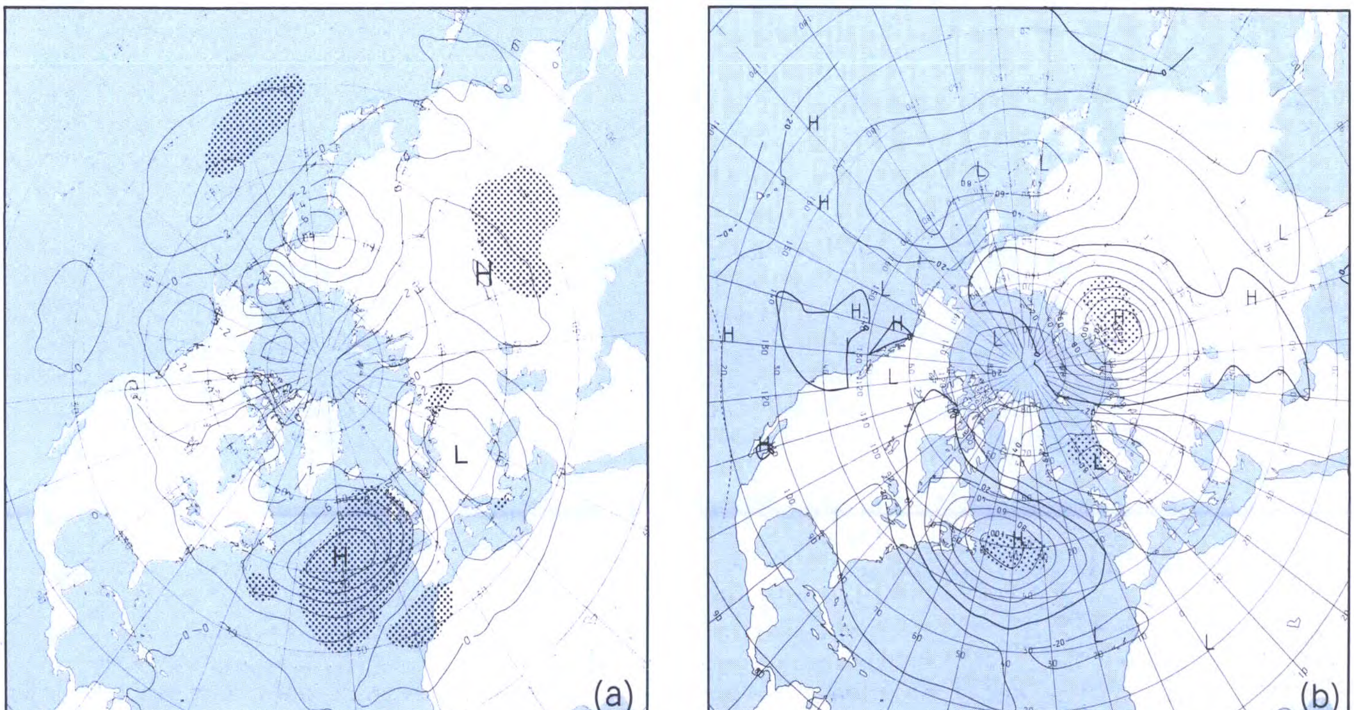
Numerical general circulation models are powerful tools for the study of the effects of SST anomalies on the large-scale atmospheric flow that affect the variability of seasons from year to year. For example, from observational studies it is known that a rise in temperature of the ocean surface which occurs irregularly every few years in the eastern equatorial Pacific (El Niño) has a profound effect on atmospheric circulation over an area from eastern Asia to the American continent and southwards to Australasia. However, away from the tropical Pacific, the effects are not always consistent. Experiments with Meteorological Office numerical models have indicated that a small SST anomaly in the west equatorial Pacific may produce a stronger atmospheric response than a similar sized anomaly in the east Pacific, and this may modify the response of the atmosphere to the El Niño event, especially over North America. Similar experiments have been started using typical SST anomalies in the tropical and the north-west Atlantic; observational studies have shown that anomalies in these areas can influence the flow over a large area which includes the British Isles.

The figure below illustrates an experiment carried out during the year in which four pairs of 50-day winter-time integrations were run on the 5-level general circulation model. Each pair comprised an integration with a warm SST anomaly (about 3 K) to the south of Newfoundland, and an integration with a cold anomaly of equal magnitude. The mean difference in 500 mb geopotential height field between the warm and cold integrations is illustrated. Note the positive difference over the mid-Atlantic. These differences are statistically significant in shaded regions (at the 1 per cent level).

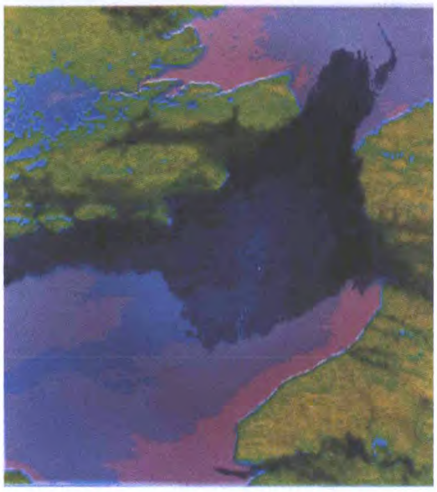
The observed 500 mb geopotential height for those months between November and February in the period 1951–80, when SST anomalies to the south of Newfoundland were unusually warm, were composited together. A similar composite was formed for the winter months when SST anomalies were unusually cold. The mean 500 mb geopotential height difference field between the two composites is shown. Positive height centres over the Atlantic and Siberia, and a negative centre over Europe, are strongly significant.

Over the Atlantic the model results agree well with these observational results. The lack of agreement further to the east probably arises from the excessive westerly flow generated by the numerical model. The work indicates that SST anomalies of sufficient size can affect the atmospheric circulation patterns in a systematic way; this is already well established for tropical SST anomalies, but not for those in middle latitudes.

Model forecast of mean difference in 500 mb geopotential height field (decametres) (a) and (b) observed mean 500 mb geopotential height difference field (metres).



Satellite meteorology



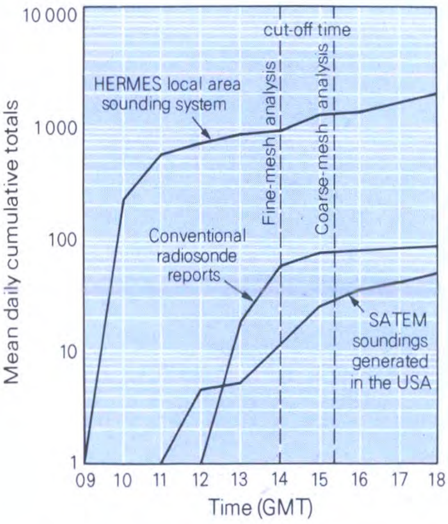
Composite night-time image of south-east England derived from two spectral channels. The grey-shaded areas indicate fog or low cloud and other colours show temperature variations. The London 'heat island' and the variations in sea surface temperatures are clearly apparent.

The most obvious use of satellites for meteorology is through the provision of cloud images. However, quantitative use of satellite data is becoming more and more important and dominates the research effort.

Local area atmospheric soundings

A system was established in 1983 using the new HERMES (High-resolution Evaluation of Radiances from Meteorological Satellites) computer to process data from satellite soundings of the atmosphere over Europe and the North Atlantic. During 1984 the main objectives were to increase the performance of the system, to improve understanding of the characteristics of the retrievals and to develop improved algorithms. Progress was achieved in all three objectives. The system converts the raw radiances measured by the satellites into temperatures and humidities at 15 levels in the atmosphere ranging from near the surface to more than 20 km above the earth. These profiles are then transferred automatically to the main Office computer system (COSMOS) where they are used for forecasting applications. The quantity of data and speed of delivery are far in excess of that available from other sources.

Time of arrival and quantity of atmospheric sounding data from three sources. (Note the logarithmic vertical scale.) The operational numerical analyses are run at 1400 and 1520 GMT by which time the HERMES system has provided more than ten times the quantity of conventional sounding data and nearly 50 times the quantity of SATEMs. (Daily means, period 1–5 June 1984 for European/North Atlantic area.)



The Oxford unit

Apart from the satellite instrument work referred to elsewhere, the development with potentially the greatest implications was the transfer of four meteorologists from Bracknell to Oxford. They now work alongside members of the University Department of Atmospheric Physics in the expectation that this will lead to increased and mutually beneficial interaction between the Meteorological Office and the University.

Imagery research

There has been an increase in research into the more effective use and display of satellite imagery data, using the new image-processing hardware systems. This includes work on imagery from the US polar-orbiting satellites and Europe's Meteosat. For the former, research is under way on the extraction of surface temperatures and other variables to a mesoscale resolution. The picture above shows an image formed from the combination of two spectral channels which reveals fog even during the night.

Research into the use of Meteosat data continues, notably in the FRONTIERS system, in which the satellite imagery is merged with ground-based radar data to help generate rainfall maps and forecasts.

Operational aspects

The Office continues to expand its operational use of satellite data, a process given fresh impetus when the Office assumed responsibility as a World Forecast Centre for Civil Aviation. The global satellite sounding data and the winds derived from cloud movement, received over the meteorological Global Telecommunication System (GTS), are used in operational numerical weather prediction models and have proved vital for use in the new global numerical model, particularly for the southern hemisphere.

Satellite imagery is now used routinely at over 40 operational locations. A few sites make use of direct reception facilities, but most are served by an image-processing computer known as AUTOSAT which receives satellite data from the Royal Aircraft Establishment ground station at Lasham. AUTOSAT serves an extensive network of users through the distribution system known as SATFAX. A new, very-high-speed data link between Lasham and Bracknell is under development to improve the availability and timeliness of satellite data. A link is being developed between AUTOSAT and COSMOS to enable satellite imagery to be combined with other data, so that an improved service can be offered to television companies.

Future satellites

Work started in preparation for the European Space Agency's ERS-1 satellite expected to be launched in 1989. ERS-1 will be Europe's first earth resource satellite and will have the primary aim of observing the oceans. Its payload will include a high-resolution Synthetic Aperture Radar incorporating wind and wave scatterometers, as well as a high-precision altimeter and the Along Track Scanning Radiometer for high-precision measurements of sea surface temperature.

The wind scatterometer will be able to measure surface winds over the oceans using an active microwave technique. The first research project for this system has been a search for an efficient way to remove the directional ambiguities that are expected in the results from the scatterometer.

Atmospheric chemistry

The radiative transfer properties of a cloudless atmosphere are largely determined by the distribution of water vapour, carbon dioxide and ozone. Carbon dioxide and ozone distributions may be affected by human activities—carbon dioxide directly by fossil fuel burning and ozone indirectly through photochemical reactions following the interaction of anthropogenic gases with sunlight. Interest in factors affecting the distributions of these species results from the fact that changes in the radiative properties can affect the general atmospheric circulation and hence the global temperature patterns. An additional area of concern, however, is the possibility that any reductions in total ozone amounts resulting from human activities and arising largely in the stratosphere, can change the amount of ultraviolet light in the 280–320 nm wavelength range reaching the surface with potentially harmful effects. Recent studies have shown that ozone has an important dual role in determining the effects of human activities in the atmosphere. It is probably an important influence on the chemical reactions by which sulphur dioxide and oxides of nitrogen in exhaust plume gases are oxidized to produce sulphuric and nitric acids (the 'acid rain' problem). Atmospheric ozone is also an important absorber of solar radiation. To understand these problems and to provide information on possible harmful effects atmospheric monitoring is being carried out as well as research. The research includes both observational studies and numerical modelling in collaboration with other interested groups especially the Atomic Energy Research Establishment and Central Electricity Research Laboratories.

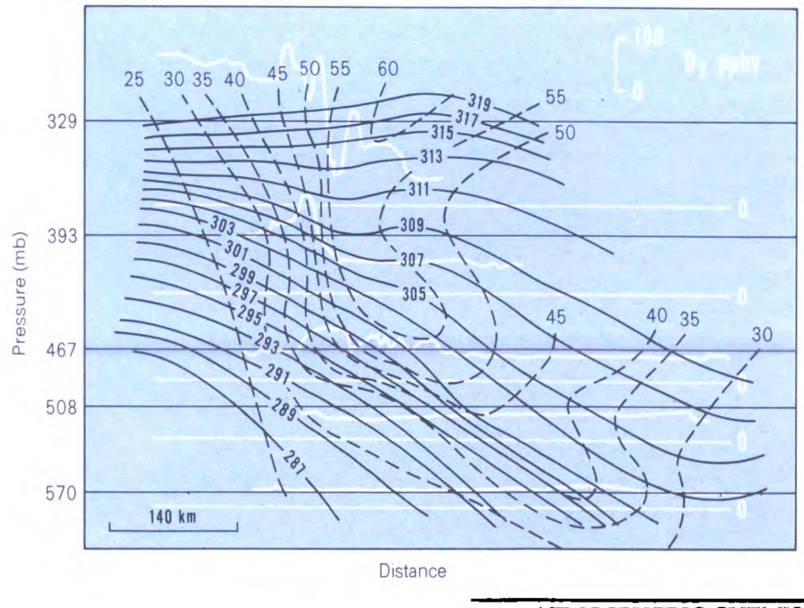
Even the most powerful computers do not permit inclusion of highly detailed chemical calculations in numerical models of the atmospheric circulation. A detailed photochemical model has therefore been developed by means of which the chemical changes are calculated along predetermined trajectories of stratospheric air parcels. The trajectories are derived from simulations of stratospheric flows from an atmospheric general circulation model. They can be followed for six to ten days and a comparison of the predictions of chemical concentrations with satellite observations provides a test of the completeness of knowledge of important chemical reactions. Such a model has been used successfully to explain the observed large diurnal variation of nitrogen dioxide in the stratosphere as well as the 10–20 per cent diurnal changes in ozone concentration at 35–40 km above the surface.

An important factor which influences the effects of species in the stratosphere with anthropogenic sources is the rate of transport of material through the tropopause from the stratosphere, where removal processes are slow, to the troposphere, where removal may be more rapid so that the average residence time for these species is reduced. A series of measurements made using the instrumented Hercules aircraft of the Meteorological Research Flight shows that stratospheric air is folded into the troposphere in the vicinity of jet streams although, locally, mixing and dispersive processes may play a significant role in determining the total cross-tropopause transport. The aircraft measurements of both the chemical composition of the air and the dynamical properties enable the origins of the air to be traced. The local tropospheric chemical reactions are accelerated because of enhanced hydroxyl concentrations near tropopause folds. Lightweight instruments with low power requirements are being developed for mounting on a manned balloon that is to circumnavigate the earth in the vicinity of the subtropical jet stream. The balloon will be piloted by Dr Julian Nott who will make measurements of the concentration profiles of ozone and water vapour in the vicinity of the jet. These observations will further clarify the exchange processes.

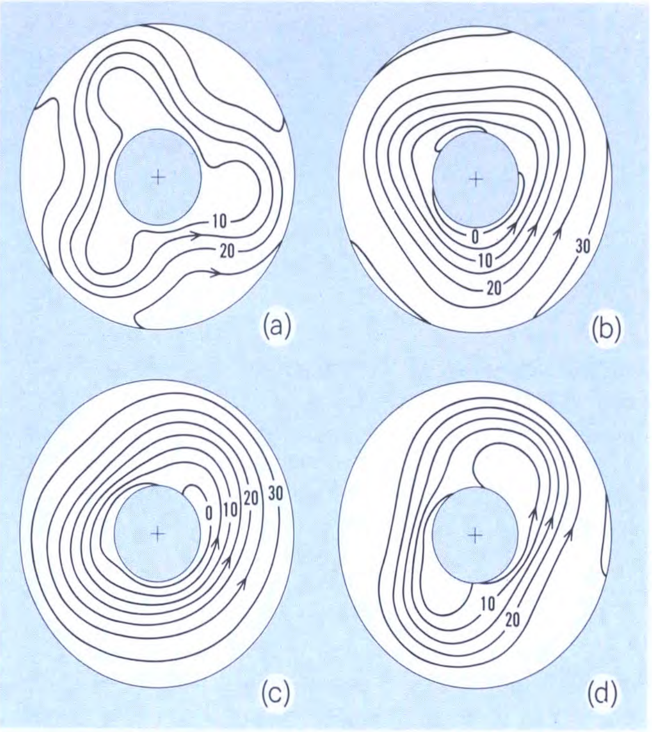
The correlation between the concentrations of various chemical species in the troposphere depends on a range of mechanisms involving non-linear chemical interactions which may involve both the gaseous phase and aqueous solution phase as cloud droplets. Analysis of aircraft observations has demonstrated the sensitivity to the presence of other species, such as ammonia and ozone, of the rate of oxidation of sulphur dioxide to sulphate. This sensitivity complicates the estimation of the removal of pollutants from, for example, power station plumes. A series of measurements made on successive days in the centre of an anticyclone has enabled estimates to be made of the rate of photochemical loss of light hydrocarbons when trapped in stagnant air. These measurements demonstrate the importance of both dynamical and chemical factors in determining the contribution of different species to the loss of hydrocarbons.

The research outlined above is intended to clarify the importance of different atmospheric chemical processes but it does not give warning of long-term trends. Routine monitoring of the chemical composition of rain-water has therefore been continued at three sites forming part of the UK network. In addition to these local measurements related to pollution monitoring in the troposphere, assistance has been given in the monitoring of ozone that is undertaken at many sites which form part of a World Monitoring Programme.

Cross-section through a jet stream showing isotachs ($m\ s^{-1}$, dashed lines) and isotherms (K, full lines) derived from aircraft measurements. Measurements of ozone concentrations (ppbv, parts per billion by volume) at five levels are also shown. These measurements demonstrate stratospheric air of high ozone concentration being brought down on the cold side of the jet. The structure of the ozone concentration profiles can also be seen.



Geophysical fluid dynamics



Numerical simulation of a wave number transition occurring in the rotating annulus flow system. Patterns (a), (b), (c) and (d) correspond to times 650, 850, 950 and 1050 seconds after a rotation rate reduction. Quantity plotted is a deviation pressure measure at an upper level in the model fluid. Direction of geostrophic flow is indicated by arrows.

Many of the major problems of dynamical meteorology—including that of establishing a reliable theoretical framework for assessing atmospheric predictability—require for their full appreciation and solution a combined attack involving the analysis and physical interpretation of observations, and the investigation of related systems such as numerical models, laboratory analogues and the atmospheres of other planets. Research on the basic hydrodynamical processes which underlie 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 of this research, and laboratory, theoretical and computational studies each play an important role. Current projects include: the investigation of angular momentum fluctuations of the earth's atmosphere; laboratory, numerical and analytical studies of thermally produced motions in rotating fluids; and interpretation of the long-lived eddies which occur in the atmospheres of Jupiter and Saturn.

Atmospheric angular momentum fluctuations, day-length changes and polar motion

Possibly the most striking large-scale dynamical features of the earth's atmosphere are its average 'super-rotation' relative to the solid earth and the concentration of much of the motion into jet streams. Studies of the mechanisms which produce and maintain these features are important in any attempt to predict large-scale atmospheric motions.

In recent work both observational and theoretical studies of angular momentum exchange between the atmosphere and solid earth have been carried out. Daily values of the three components of atmospheric angular momentum have been calculated from several years of meteorological data and compared with the corresponding astronomically observed changes in day-length and polar motion. The changes in day-length can be accounted for almost entirely by angular momentum exchange between atmosphere and solid earth, and the existence of a persistent fluctuation in the exchange, with a time-scale of about seven weeks, is confirmed. The successful elucidation of this seven-week fluctuation will constitute a major advance in the understanding of large-scale features in the atmosphere, and their time variation. It has also been demonstrated that meteorological phenomena provide an important contribution to the excitation of the earth's polar motion. This work, and its theoretical basis, offer guidelines for future routine determinations of atmospheric angular momentum fluctuations for the purposes of research in meteorology, oceanography and solid earth geophysics.

Thermally driven motions in rotating fluids

Many features of the large-scale atmospheric circulation can be reproduced in a liquid filling a cylindrical annulus rotating about a vertical axis, when the inner and outer walls of the annulus are maintained at different temperatures. Laboratory studies of such systems over wide ranges of impressed conditions have revealed several possible flow regimes: axisymmetric flow at low rotation rates, regular non-axisymmetric flow at intermediate rotation rates, and irregular non-axisymmetric flow at high rotation rates. Travelling waves and associated meandering jet streams are characteristic features of non-axisymmetric flows. The regular wave flows may be in the form of either steady or vacillating waves (in which periodic changes of amplitude or shape occur).

Studies based on the joint use of laboratory systems and their counterparts in numerical models make it possible, amongst other things, to 'verify' the basic dynamical structure of numerical models of rotating baroclinic flow in a way that is virtually impossible for atmospheric numerical models—in which important small-scale processes are represented by comparatively crude and uncertain parametrizations. A numerical model based on the Navier–Stokes equations is at present being used in work of this type. The model reproduces most of the different flow types and phenomena seen in the laboratory system (see above). Detailed quantitative comparisons between laboratory measurements of steady waves and corresponding numerical simulations have also been carried out—with encouraging results.

Sloping convection in the laboratory and in the atmospheres of Jupiter and Saturn

The very existence of long-lived prominent markings on the visible surfaces of dense clouds on Jupiter and Saturn has clear and important implications for theories of atmospheric predictability. Such long-lived features include the Jovian Great Red Spot and three White Ovals. Investigations have continued of the hypothesis that these robust anticyclonic eddies are manifestations of the fully developed 'sloping' or 'slantwise' quasi-steady convection which occurs in a rapidly rotating fluid when internal heating is applied. Theory predicts (and numerical experiments confirm) that stable eddies having *cyclonic* upper-level circulations would be characteristic of fully developed slantwise convection in a rapidly rotating fluid subject to internal *cooling*; thus suggesting that the cyclonic 'barges' of Jupiter and Saturn might also be manifestations of steady slantwise convection.

Training

The focus for professional training is the Office's residential college sited at Shinfield Park near Reading, where the teaching staff are all highly experienced practitioners. Residence fosters the sharing of experience and allows all courses to be shorter, more intense and therefore economical. Students come from both home and overseas.

At all levels, courses* concentrate on the skills staff will need to perform their duties, supplemented by training on the job. Those for new entrants range from a five months' introduction to professional meteorology for good Honours graduates to a four-week course in basic meteorology for school leavers with O- and A-levels. The latter vary according to whether the entrant is going initially to an observing/forecasting office or to another part of the Office. Suitably qualified students training to be forecasters not only learn meteorology and its application, they also practise the arts of communication and of decision making; those going into research are encouraged to think independently whilst working as one of a team.

In-service courses, lasting three or four weeks at about five-yearly intervals, keep staff updated and professionally extended. Each has an objective matched to a stage in a career. The Extension Course for Higher Scientific Officers, for example, fosters an investigative spirit, whilst the Senior Meteorologists' Course fits Senior Scientific Officers to take a broad view of developments within the Office. Some courses concentrate on management skills peculiar to the Office (courses at the Civil Service College or elsewhere are used for general management principles). There are also courses for specific tasks (e.g. computer programming, statistics, telecommunications).

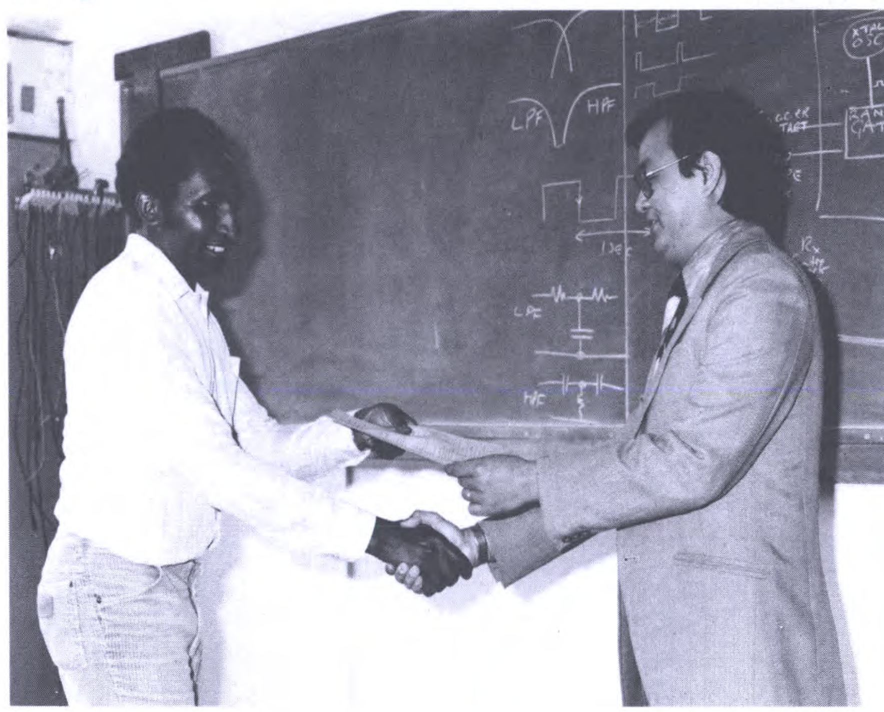
The Office's technicians mostly rise from amongst its own Assistant Scientific Officers. They learn basic electronics at the Reading College of Technology and train on specifically meteorological equipment in-house either at the College or at the School of Technical Training at Beaufort Park.

Many observations of the weather are made by people outside the Office—some follow a one-week course at the College. Those who will work in aviation undergo a second week of training at an aerodrome.

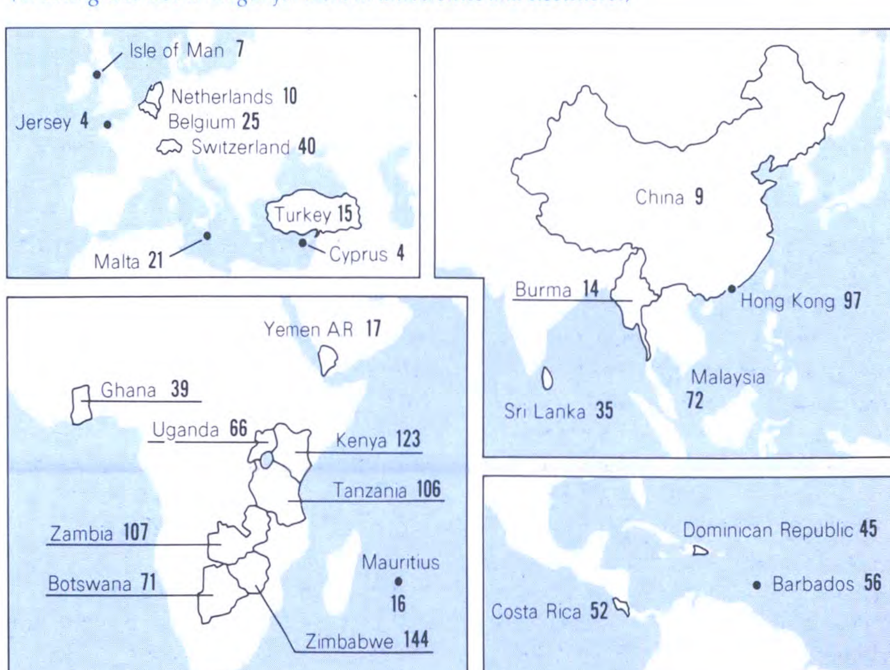
The Office strongly encourages staff to improve their academic qualifications, especially in mathematics and physics, so that they may progress in their careers to the mutual benefit of the Office and the individual.

During the year there was a major review of the requirements for training and the means of meeting them. The report is currently being considered but shows that the College compares very favourably with other institutions both here and abroad.

On completion of his 5-term course in electronics at Reading College of Technology, Mr P. Kanni of Kenya receives his Technical Education Council certificate from Dr R. de Guzma of the WMO at an informal ceremony during a specialist course at the Office's School of Technical Training.



Training (student weeks) given to meteorologists from overseas. (Training was also arranged for them in universities and elsewhere.)



*Details are available from: The Principal, Meteorological Office College, Shinfield Park, Near Reading RG2 9AU.

International

The preparation of meteorological forecasts and warnings depends on observations being received from areas beyond national boundaries. In the United Kingdom forecasts are based on a mathematical model of the atmosphere that uses data from the whole globe. A timely flow of good information is achieved only through a very high level of international co-operation. This is arranged through the World Meteorological Organization (WMO), which is a specialized agency of the United Nations based in Geneva and has more than 150 member countries.

The senior management body of the WMO is the Executive Council, of which Dr J. T. Houghton, Director-General of the Meteorological Office, is one of 26 elected members. The Council met from 6–22 June and authorized a budget of US $19480000 from 1985. It also considered some important Programmes for acquiring observations from non-sovereign areas. These systems include the Aircraft to Satellite Data Relay (ASDAR), launchers for radiosondes from merchant ships, and observing systems on fixed and drifting buoys.

Ocean Weather Ships on four fixed stations in the North Atlantic are maintained by a group of nations under the North Atlantic Ocean Stations (NAOS) Agreement. The United Kingdom operates one of the ships. The costs of operating the ships have been rising; in June 1984 the NAOS Board met in Geneva to consider what should be done when the Agreement ends in 1985. The Board considered a reduced network that could be operated at a much lower cost for a few years and at an extra session held in Geneva in December it proposed to its member Governments that the Agreement should be extended to cover a reduced scale of operation until 1988.

The need for an operational system in the North Atlantic to replace the Ocean Weather Ships has greatly concerned the directors of western European meteorological services. On their behalf the United Kingdom convened a meeting at the European Centre for Medium Range Weather Forecasts (ECMWF) in Reading on 8–10 October to plan for a Combined Observing System on the North Atlantic (COSNA). This will include ASDAR, buoys, and systems on merchant vessels. In particular it will provide a useful basis on which to design the optimized Combined Observing System in data-sparse areas (both over oceans and over land) needed in the late 1980s and 90s. Observations from the new system will be received in increasing numbers by 1986 so that they may be tested against those from fixed Ocean Weather Ship stations whilst they are still operating.

The WMO operates a Voluntary Co-operation Programme to assist less developed countries to improve their meteorological services. The United Kingdom is a major participant and directs most of its attention to Africa where help is most needed. In order to discover where assistance may be most effective, liaison visits are made from time to time; during March and April a member of the Office visited the meteorological services in Malawi, Zimbabwe, Botswana and Lesotho. The visits confirmed that a great deal remains to be done to improve the meteorological services in less developed countries to the benefit of their peoples and also to the world in general. Both funds and people for this work are woefully inadequate and dedicated effort is required to use them well. One important initiative is a project, begun during the year, to refurbish wind-finding radar equipment which has been supplied to eight countries in the past. Modern microcomputer-based systems will be incorporated. By this means, effectively new and much improved facilities will be provided relatively cheaply.

Research on medium-range weather forecasting in western Europe is mostly carried out at the ECMWF at Shinfield Park near Reading. The ECMWF is funded by 17 countries and its task is to develop methods for forecasting up to 12 days ahead. It is accommodated in premises provided by the United Kingdom. A supplement to the Agreement which specifies the responsibilities of Her Majesty's Government and the Centre in regard to the land and premises was finally signed during September after several years of negotiations in which the Meteorological Office played a constructive part.

The Meteorological Office is represented on 75 Committees, Panels, Technical Commissions and Working Groups of various International Organizations, Councils and Committees. The Director-General is the Permanent Representative of the United Kingdom with the WMO. He also represents the United Kingdom on the Council of the ECMWF. During the year Dr R. E. W. Pettifer resigned as Vice-President of the WMO Commission for Instruments and Methods of Observation whilst Mr R. J. Shearman was elected Vice-President of the WMO Commission for Marine Meteorology. Also under the umbrella of the WMO, the Office provided the President of the NAOS Board and the Chairman of the Consortium which is developing the ASDAR system. Membership of European bodies ranges from European Economic Community Co-operation in Science and Technology (COST) Committees on Meteorological Radar and Ocean Buoys to the Meteorological Satellite Programme Board of the European Space Agency.

On the military side, the Office is represented on the Meteorological Committee of the Supreme Headquarters Allied Powers Europe as well as on NATO's Meteorology Panel and eight of its specialist groups.

Overall, meteorology has been an internationally interdependent operation for well over 100 years but modern, technologically based, ways of observing, information handling and distribution of forecasts and other products are making these international activities ever more essential.

Personnel

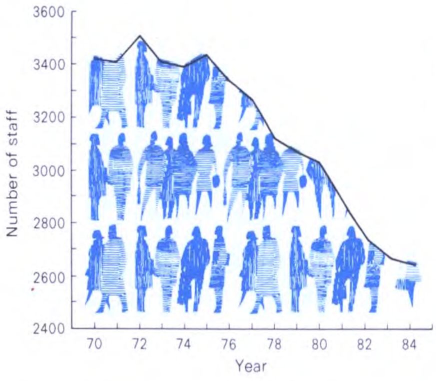
Strengths

The Office's staff strength continued to decrease during 1984 to meet its share of the Government's Civil Service ceiling targets. At 31 December the total (including staff engaged locally overseas) stood at 2714, a decrease of 42 over the year. The accompanying graph shows the year-by-year variation since 1970. During the last decade the staff strength has fallen by over a quarter, mainly because of an extensive program of centralization and automation that was planned in the early 1970s.

This year retirements continued at a high level and resignations from certain key areas, notably computing and electronics, also became significant. Consequently the number of staff promoted and moved to keep posts filled was greater than usual and substantial recruitment at graduate and school-leaver level was needed to meet operational commitments. Many of these changes required appropriate courses of training or retraining.

The situation demanded considerable attention to career development both to meet the future needs of the Office and to satisfy the longer-term aspirations of the staff. Several short courses in staff appraisal for line managers were also organized.

At the end of the year 10 staff were on secondment to international bodies and commercial organizations overseas. This is a valuable scheme which not only broadens the individuals' experience in the public and private sectors but adds to the United Kingdom's influence in international meteorology.



Staff numbers

Deputy Secretary	1
Under Secretary	1
Science Group	
Chief Scientific Officer	2
Deputy Chief Scientific Officer	6
Senior Principal Scientific Officer	30
Principal Scientific Officer	103
Senior Scientific Officer	291
Higher Scientific Officer	465
Scientific Officer	464
Assistant Scientific Officer	710
Administrative Group	
Assistant Secretary	1
Principal	1
Senior Executive Officer	3
Higher Executive Officer	8
Executive Officer	18
Clerical Officer	43
Clerical Assistant	62
Professional and Engineering Group (including Marine Superintendent staff)	
Superintending Engineer	1
Principal Professional and Technology Officer	3
Professional and Technology Officer Grade I	6
Professional and Technology Officer Grade II	16
Professional and Technology Officer Grade III	4
Professional and Technology Officer Grade IV	4
Telecommunications Staff	
Telecommunications Technical Officer Grade A	1
Telecommunications Technical Officer Grade I	9
Telecommunications Technical Officer Grade II	26
Telecommunications Technical Officer Grade III	60
Radio (Meteorological) Technician	40
Signals grades	45
Teleprinter grades	57
Typing and miscellaneous non-industrial grades	125
Security officers	11
Ocean Weather Service	2
Industrial employees	43
Locally entered staff and employees overseas	52

Staff honours and awards

Mr K. Bryant (now retired) was awarded the Imperial Service Order in the Queen's Birthday Honours.

Mr J. B. Lawson was awarded the Air Officer Commanding-in-Chief's commendation in the Queen's Birthday Honours.

Mr M. C. Cotton (now retired) and Mr M. Trespaderne were each awarded the Imperial Service Medal. The medals were presented to them by the Director-General.

The L. G. Groves Memorial Prize for Meteorology was awarded to Mr C. G. Collier.

Number of Meteorological Office staff 1970–84. (From 1981 figures are for 1 April, earlier years are for 1 January.)

Finance

On a fully cost-accounted basis, the total cost of the Office in 1983/84 was £63 million compared with £55.7 million in 1982/83. The net cost after earnings from services was £44 million compared with £38.3 million in 1982/83. This increase was due to the United Kingdom's participation in the European Eumetsat which is to replace the Meteosat series of geostationary meteorological satellites. In all other areas the cost of the Office decreased in real terms.

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 is also maintained and the details shown in the accompanying chart and tables are drawn from this. These figures include non-Voted costs that are not shown in the Defence Votes in Parliamentary Estimates, such as pensions, notional insurance, 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 tables, being covered by annual interest and depreciation charges in the usual commercial accounting manner.

Following the 1982 Resource Control Review, accounting and procurement procedures have been streamlined in the process of automation. Work on the computer-based Management Accounting and Information System (MAIS) has been continued and subsystems implemented include one for storage of data on the use of COSMOS and another for processing invoices. As well as recording details of amounts paid and due, the latter incorporates a classification scheme for customers and services which will aid analysis of income for marketing purposes. Considerable progress has been made with the subsystem to support equipment supply and management, including the setting up of an equipment stores vocabulary within MAIS.

Meteorological Office Receipts 1983/84 (Cash recoverable)

	1983/84 £000	1982/83 £000
Services to:		
Ministry of Agriculture, Fisheries and Food	728	656
Other Exchequer departments (Department of Environment etc.)	131	137
Civil Aviation Authority	14 264	13 304
Natural Environment Research Council	0	1
Other non-Exchequer departments	29	79
European Economic Community	117	222
Public Authorities etc.	209	202
Meteorological Office College (training of meteorologists)	187	209
Secondments to outside bodies	43	65
Comprehensive forecasting for the offshore oil industry	1 314	1 077
Forecasting and climatological services tailored to meet users' special needs:		
Ship Routeing Service	81	106
Gas Boards	185	152
Central Electricity Generating Board	170	174
British Rail	26	23
Independent Broadcasting Authority	293	127
British Broadcasting Corporation	275	105
Press	70	54
Other customers' special services	568	494
Automatic Telephone Weather Services (British Telecom)	239	233
	18 929	17 420

Statement of the cost of meteorological services for the year ended 31 March 1984

	1983/84		1982/83	
	£000	£000	£000	£000
Total meteorological services (cost accounted)		63 021		55 684
Receipts:				
Training and secondments	230		274	
Exchequer departments	859		817	
Non-Exchequer bodies	15 641		14 566	
Industry and commerce	2 159		1 680	
General public	40		83	
		18 929		17 420
Net expenditure:				
Defence	28 419		19 887	
Civil (general public services)	13 063		17 048	
International	1 410		921	
Exchequer departments (Home Defence and emergency services)	1 200		408	
		44 092		38 264

The accompanying tables include for comparison figures for the previous year, 1982/83, shown on the same basis as the current year figures. Charges for repayment services were increased by 8 per cent on 1 April 1984.

The increase in the proportion of costs attributed to Defence is primarily due to the cessation of public services previously undertaken by meteorological staff at RAF stations and other Defence offices. Since these services were performed in the margins of staff time that had to be available for operational purposes, all of that time is now booked to Defence.

Input of resources

Allocation of resources

Statement of operating expenses for the Meteorological Office for the year ended 31 March 1984

(1) Expenditure	(2) Defence services £000	(3) Exchequer departments non-repayment £000	(4) Public services £000	(5) Inter-national £000	(6) CAA £000	(7) 1983/84 Total £000	(8) 1982/83 Total £000
Customer activity costs:							
Direct labour	3 439	180	2 543	388	2 421	8 971	8 093
Other direct costs	125	1	132	153	117	528	423
Indirect costs:							
Labour	3 734	85	1 804	78	1 806	7 507	8 188
Others	1 459	40	938	1 370	379	4 186	4 117
North Atlantic Ocean Stations (NAOS) receipts				(1 162)		(1 162)	(1 192)
Depreciation	159	3	67	106	63	398	331
General Meteorological Office costs:							
Research	4 377	135	1 723	124	1 690	8 049	8 182
Observations						14 041	9 382
Telecommunications	7 778	505	6 531		4 932	5 193	4 903
Computing						512	1 341
General services:							
Central Forecasting Office						2 346	1 342
Technical support						3 877	2 648
Maintenance	6 617	230	3 578	225	2 430	1 216	1 680
Training						1 540	1 137
Administration and personnel						3 188	2 479
Others						913	1 071
Total Meteorological Office management costs:	27 688	1 179	17 316	1 282	13 838	61 303	54 125
Full cost items:							
Share of MOD HQ costs						508	466
Insurance						74	69
Interest on capital:	731	21	412	128	426		
Fixed						917	830
Working						219	194
Total Meteorological Office full costs	28 419	1 200	17 728	1 410	14 264	63 021	55 684

Appendices

APPENDIX I

BOOKS OR PAPERS BY MEMBERS OF THE STAFF

ALLAM, R. J. and TUCK, A. F.; Transport of water vapour in a troposphere–stratosphere general circulation model. I: Fluxes. *Q J R Meteorol Soc*, **110**, 1984, 321–356. II: Trajectories. *Ibid.*, 357–392.

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AUSTIN, J. and PALMER, T. N.; The importance of nonlinear wave processes in a quiescent winter stratosphere. *Q J R Meteorol Soc*, **110**, 1984, 289–301.

BADER, M. J. and BROWN, R.; Comparison of the observations from a dual-polarisation radar with simultaneous airborne measurements. International Association of Meteorology and Atmospheric Physics, International Commission on Cloud Physics. Proceedings of the 9th International Cloud Physics Conference, Tallinn, Estonian SSR, USSR, 21–28 August 1984, 1984, 761–764.

BAMBER, D. J., HEALEY, P. G. W., TUCK, A. F., VAUGHAN, G. *et al.*; Vertical profiles of tropospheric gases: chemical consequences of stratospheric intrusions. *Atmos Environ*, **18**, 1984, 1759–1766.

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APPENDIX II

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

ATKINS, M. J.
Quality control, selection and processing of observations in the UK Meteorological Office operational forecasting system. *ECMWF Workshop on The Use and Quality Control of Meteorological Observations*. 6–9 November.

BANNISTER, J. E.
Weather forecasting in the Midlands. *Royal Meteorological Society East Midland Branch, Birmingham University*. March.

BLACKHALL, R. M.
The FRONTIERS system. *Department of Geography, University of Bristol*. 27 February.
Talks at field course on weather in the hills. *Draper's Field Studies Centre, Betws-y-Coed*. 4–10 August.

BROMLEY, R. A.
Observing system experiments using the Meteorological Office's 15-level model. *ECMWF Seminar, Shinfield*. 6 September.
Modern methods of weather prediction. *Institution of Electrical Engineers, South-Western Centre, Yeovil*. 16 October.

BROWN, P. R. A.
Aircraft observations of mountain waves over the UK. *Royal Meteorological Society, London*. 18 April.

BROWNING, K. A.
Nowcasting using satellite data. *Royal Meteorological Society Summer Meeting, University of Oxford*. 5 July.
FRONTIERS—progress with a system for nowcasting rain. *International Nowcasting II Conference, Norrköping, Sweden*. 6 September.

BUTLER, A. P.
Recent developments in hydrometeorological services provided by the Meteorological Office. *Institution of Civil Engineers, Strathclyde University*. 5 October.

CARPENTER, K. M.
Real-time use of Meteosat imagery and weather radar data for precipitation forecasting. *Remote Sensing Society, Imperial College, London*. 28 March.

CAUGHEY, S. J.
Some mathematical relationships in meteorology. *Institute of Mathematics and its Applications, Queens University, Belfast*. 7 February.

CULLEN, M. J. P.
The mathematical theory of atmospheric fronts. *Oxford University Mathematical Institute*. 14 May.
Interior layers in the atmosphere—computational and theoretical aspects. *BAIL III Conference, Dublin*. 20 June.
Developments in global modelling at the UK Meteorological Office. *WGNE Scientific Seminar on Numerical Modelling, Sigtuna, Sweden*. 2 October.
Current problems with large-scale forecast models, in particular the forecasting of tropospheric westerlies. *Royal Meteorological Society*. 17 October.
Theory and numerical modelling of some atmospheric discontinuities. *University of Nottingham*. 5 December.

DEVRELL, C. J.
Recent developments in operational fine mesh modelling at Bracknell. *6th Meeting of European Working Group on Limited Area Modelling*. 23–26 October.

DYSON, J. F.
Experiments with a low resolution atmospheric general circulation model. *European Geophysical Society 10th Annual Meeting, Louvain-la-Neuve, Belgium*. 31 July.

EASTWOOD, P. J.
The Meteorological Office in Northern Ireland. *Lurgan College Geographical Society*. 8 May.

EPHRAUMS, J. J.
Operational wave models in the Meteorological Office. *Japanese Meteorological Agency, Tokyo*. 27 July.

EYRE, J. R.
Applications of remote sensing in weather forecasting. *MSc Course in Remote Sensing, University College, London*. 20 March.
Detection of fog at night using AVHRR imagery. *Workshop on Digital Image Processing, Imperial College, London*. 28 March.
Atmospheric temperature profiling from satellites. *Colloquium on Inverse Methods in Geophysics, Institution of Electrical Engineers, London*. 30 May.
Two presentations: (1) User requirements for imagery from second generation Meteosat: a discussion paper, (2) User requirements for soundings from second generation Meteosat and implications for an infra-red sounding radiometer. *Workshop on Second Generation Meteosat, Avignon, France*. 5–6 June.
Tropospheric sounding for forecasting in the UK. *Royal Meteorological Society Summer Meeting, Oxford*. 5 July.

FAIRLIE, T. D. A.
A strong stratospheric sudden warming during January, 1982. *Clyne Castle, Wales*. 27 September.

FLOOD, C. R.
Applications of numerical models, satellite and radar data in forecasting. *Indonesian Meteorological Service, Jakarta*. 29 February.

FOLLAND, C. K.
Statistical aspects of assessing long-range forecasts. *Statistical Department, University of Kent*. 23 February.
Multivariate statistical methods in meteorology. *Department of Environmental Sciences, University of Lancaster*. 4 June.
Worldwide marine temperature variations on the season to century time scale. *Massachusetts Institute of Technology*. 19 October.
9th Climate Diagnostics Workshop, Corvallis. 22–26 October.
Worldwide marine temperature variations 1856–1981. *BBC 'Science Now'*. 5 November.

FOOT, J. S.
Observations of broad band solar albedo and reflectivity at discrete wavelengths in the near infra-red over a stratocumulus cloud. *International Radiation Symposium, Perugia, Italy*. 23 August.
The measurement of diffuse solar radiation from an aircraft. *International Radiation Symposium, Perugia, Italy*. 27 August.

FRANCIS, P. E.
Operational models at the Meteorological Office. *Royal Observatory, Hong Kong*. 22 March.

FUGARD, T. B.
Initialisation by forced adjustment in the UK Meteorological Office regional assimilation system. *NMC and GLAS, Washington, USA*. 9 April.
Mathematical modelling of the atmosphere. *Queens University, Belfast*. 4 May.
The UK Meteorological Office fine mesh data assimilation scheme. *6th Meeting of EWGLAM, Oslo, Norway*. 26 October.

GADD, A. J.
The Meteorological Office global numerical weather prediction model. *Bureau of Meteorology, Melbourne, Australia*. 13 February.
The use of numerical models for weather forecasting. *Department of Environmental Sciences, University of Lancaster*. 23 May.

GILCHRIST, A.
Observing system experiments—review and outlook. *ECMWF Seminar on Observing System Experiments*. September.

GILL, A. E.
An overview of the dynamics of the tropical oceans and global atmosphere. *JSC/CCCO Conference on the TOGA Scientific Programme, Paris*. 17 September.
Stream 2 interactions between ocean and atmosphere in the tropics. *Royal Meteorological Society, London*. 19 December.

GOLDING, B. W.
Development of an operational mesoscale forecast system for the British Isles. *International Conference on Mesoscale Meteorology, Melbourne, Australia.* 10 February.
The Meteorological Office wave forecasting model. *Royal Meteorological Society.* 21 March.

GORDON, C.
The Meteorological Office coupled ocean–atmospheric model. *NERC Ocean Modelling Group, Bangor.* 21 September.
On the parametrization of the upper ocean mixed layer in the coupled atmosphere–ocean models. *16th International Liege Colloquium on Ocean Hydrodynamics: Coupled Atmosphere–Ocean Models.* 7 May.

HIDE, R.
Giant planets: Galileo Galilei to Project Galileo. *Presidential Address to Royal Astronomical Society, London.* 10 February.
Earth, Jupiter and Saturn: Magnetii deformable gyroscopes. *Scott Lectures, Cavendish Laboratory, Cambridge.* 27 April, 2 May, 4 May.
Predictability of atmospheric flows. *Andrew Thompson Lecture, University of Toronto.* 22 November.

HOUGHTON, J. T.
The mathematics of weather forecasting. *Oxford Invariant Society.* 14 February.
Observing the climate from space. *Edinburgh University Physical Society Appleton Lecture.* 25 April.
Ozone, weather and space. *Cherwell-Simon Lecture, Oxford University.* 18 May.
Remote sensing applications of the future. *Institution of Electrical Engineers, London.* 22 May.
Satellite meteorology in the UK. *Washington Chapter of American Meteorological Society.* 16 October.
Remote sensing of the oceans. *British Interplanetary Society 50th Anniversary, Brighton.* 17 November.
The predictability of weather and climate. *Rutherford Appleton Lecture.* 6 December.
The world climate research programme. *Royal Meteorological Society.* 19 December.

JOHNSON, D. W.
Some effects of varying the aspect ratio on thermal convection in rotating annulus experiments. *European Geophysical Society 10th Annual Meeting, Louvain-la-Neuve, Belgium.* 1 August.

JONAS, P. R.
Cumulonimbus modelling. *DFVLR, Oberpfaffenhofen, West Germany.* 24 January.
Microphysics of cumulus clouds. *University of Mainz, West Germany.* 26 January.
Effects of clouds on tropospheric chemistry. *9th International Cloud Physics Conference, Tallinn, Estonian SSR, USSR.* 22 August.
The physics of weather. *University of Glasgow.* 28 November.

JONES, D. E.
Interview on drought in the western UK. *BBC TV 9 O'Clock News.* 24 July.
Contribution to discussion on nuclear winters. *BBC World Service.* 15 October.

KERSHAW, R.
Numerical experimentation for the tropics at the UK Meteorological Office. *FGGE Seminar, Tallahassee, Florida, USA.* 10 October.
The simulation of the Asian summer monsoon in a seasonally varying integration of a general circulation model. *Goddard Laboratory of Atmospheric Science, NASA, Goddard Space Flight Centre, Greenbelt, Maryland, USA.* 17 October.

KNIGHT, K. A.
Mixing in small maritime cumulus clouds. *9th International Cloud Physics Conference, Tallinn, Estonian SSR, USSR.* 24 August.

LAWSON, J. B.
Basic meteorology and effects of weather on nuclear fallout. *UKWMO Scientific Advisers' Conference, Home Office Defence College, Easingwold.* 21 January.

LEY, A. J.
Aircraft observations of the radiative properties of broken cloud fields. *International Radiation Symposium, Perugia, Italy.* 24 August.

LORENC, A.
Response of NWP systems to FGGE data. *FGGE Workshop, US National Academy of Sciences Study Centre, Woods Hole, Massachusetts, USA.* 10 July.
Data assimilation by repeated insertion into a forecast model—principles, practice, problems and plans. *ECMWF Seminar on Data Assimilation, Shinfield.* 4 September.
Analysis methods for the quality control of observations. *US Department of the Navy, NEPRF, Monterey.* 15 October.

McCALLUM, E.
Four lectures on meteorology for yachtsmen. *Hurst Further Education Centre, Tadley.* February.

MACHIN, N. A.
The UK Meteorological Office mesoscale forecasting system. *Nowcasting II Conference, Norrköping, Sweden.* 5 September.

McILVEEN, W. A.
The Cyber 205 at the Meteorological Office. *Seminar on Super-computers, Control Data Ltd, London.* 21 September.

MANSFIELD, D. A.
Response of GCMs to tropical Pacific SST anomalies. *European Geophysical Society, Louvain-la-Neuve, Belgium.* 30 July–3 August.

MASON, P. J.
Numerical simulation of buoyant convection. *Monash University, Clayton, Victoria, Australia.* 24 January.
Observation of turbulence structure in flow over hills. *CSIRO Division of Environmental Mechanics, Black Mountain, Canberra, ACT, Australia.* 2 February.
A numerical study of cloud streets in the planetary boundary layer. *International Conference on Mesoscale Meteorology, Melbourne, Australia.* 8 February.
Two lectures: (1) Three-dimensional numerical integration of the Navier–Stokes equations for flow over surface mounted obstacles, (2) Trailing vortices induced by surface mounted obstacles. *Von Karman Institute for Fluid Dynamics, Belgium.* 24 April.

MILLER, D. E.
Weather satellites. *Short Course on Perspectives on Spaceflight, Cranfield Institute of Technology.* 5 June.
Weather satellites. *Manchester Association of Engineers, Manchester.* 23 November.

MINHINICK, J. H.
GCE O-Level Meteorology Course, series of lectures. *Frogmore Further Education College.* Commenced 19 September.

MITCHELL, J. F. B.
Carbon dioxide and climate. *British Association for the Advancement of Science, Norwich.* 11 September.
Modelling the effects of CO_2 on climate. *European Commission Climatology Programme Symposium, Sophia Antipolis, France.* 2 October.
Numerical modelling of climate. *Atmospheric CO_2 Convention, Sophia Antipolis, France.* 6 December.

MORGAN, J.
Operational satellite meteorology, current status and prospects. *Remote Sensing Society 10th Anniversary Conference, Reading.* 18 September.
The accuracy of SATOB cloud motion vectors. *Workshop on the Use and Quality Control of Meteorological Observations, ECMWF.* 6 November.

MORRIS, R. M.
Specialised weather services for industry and commerce. *Executives Association of Great Britain, Savoy Hotel.* 26 April.

MOSS, H.
Interview about recent rainfall. *Granada Reports.* 4 September.

MURPHY, J. M.
The use of ensembles of integrations in extended-range numerical weather prediction. *European Geophysical Society, Louvain-la-Neuve, Belgium.* 30 July–3 August.

NICHOLLS, S.
The structure of clear and cloudy boundary layers. *Royal Meteorological Society, London.* 18 April.
The dynamics of stratocumulus: comparison between aircraft observations and a mixed layer model. *9th International Cloud Physics Conference, Tallinn, Estonian SSR, USSR.* 23 August.

OFFILER, D.
Measurements of near surface wind vectors from satellites. *University of Southampton, Department of Oceanography.* 10 February.

O'NEILL, A.
Observational and modelling studies of the middle atmosphere. *Department of Applied Mathematics and Theoretical Physics, University of Cambridge.* 24 February.
Potential vorticity in the stratosphere derived using satellite data. *XXV COSPAR Meeting, Graz, Austria.* 27 June.
The structure of planetary waves in the stratosphere: observations, modelling and theory. *Kristineberg, Sweden.* 22 August.
Recent studies of the stratosphere. *British Association for the Advancement of Science, Norwich.* 14 September.
Two lectures: (1) The effect on the middle atmosphere of local disturbances in the troposphere, (2) The evolution of Ertel's potential vorticity during stratospheric sudden warmings. *Kyoto, Japan.* 27 November.

PALLISTER, R. C.
Photochemical model comparisons with satellite observations in a trajectory coordinate system. *Quadrennial Ozone Symposium, Halkidiki, Greece.* 3 September.

PALMER, T. N.
The response of an atmospheric general circulation model to sea surface temperature anomalies in the tropical Pacific Ocean. *International Colloquium on coupled ocean–atmosphere models, Liège, Belgium.* 11 May.
Breaking planetary waves in the stratosphere. *Mason Conference, British Association for the Advancement of Science, University of East Anglia.* 14 September.
The dynamics of the troposphere, stratosphere and mesosphere. *International Centre for Theoretical Physics, Trieste, Italy.* 24–28 September.
Response of GCMs to SST anomalies. *Royal Meteorological Society Meeting on the World Climate Research Programme,* 19 December.
Long range forecasting. *Radio 1 'Newsbeat'.* 2 August.
Droughts and the global climate *Radio 4 'International Assignment'.* 9 August.

PARKER, D. E.
Tropospheric effects of El Chichon. *Royal Meteorological Society.* 18 January.

PARKER, G. H.
North Sea floods. *Look East TV.* September.

PARKER, J.
The hazards of Scotland's climate. *Royal Scottish Geographical Society/Royal Meteorological Society Symposium on Climatic Hazards in Scotland, University of Stirling.* 1 June.

PARRY, M.
Drought in Wales. *Recording for S4C sponsored by HTV for 'y byd ar bedwar'.* 3 July.

PETTIFER, R. E. W.
New meteorological observing systems for the North Atlantic. *Christian Michelsen Institute, Bogen, Norway.* 17 August.

PICK, D. R.
Microwave instruments. *Royal Meteorological Society Summer Meeting.* 5 July.

PRIOR, M. J.
The development of new wind-driven rain maps for DD 93. *British Standards Society Building Seminar, 'Exposure to wind-driven rain', London.* 5 April.

READ, P. L.
Long-lived eddies on Jupiter and Saturn: laboratory and analytical models. *Space Science and Engineering Center and Department of Meteorology, University of Wisconsin, Madison, USA.* 27 February.
The circulation of planetary atmospheres. *Department of External Studies, University of Oxford.* 20 May.
Axisymmetric diffusion of angular momentum in a rotating fluid: a resolution of Hide's theorem for equatorial jets. *European Geophysical Society, 10th Annual Meeting, Louvain-la-Neuve, Belgium.* 30 July.
Long-lived eddies in the atmospheres of Jupiter and Saturn. *British Association for the Advancement of Science, Mason Conference, University of East Anglia, Norwich.* 14 September.
The circulation of planetary atmospheres. *British Astronomical Society, Department of Physics, University of Bristol.* 2 November.
An azimuthally localised baroclinic eddy in a rotating fluid. *Department of Mathematics, University College, London.* 16 November.

ROACH, W. T.
Physical causes of temperature extremes in the UK. *Royal Meteorological Society, Aston University, Birmingham.* 12 May.

ROWNTREE, P. R.
Review of general circulation models as a basis for predicting the effects of vegetation changes on the climate. *United Nations University Workshop on Forests, Climate and Hydrology–Regional Impacts,* Oxford. 29 March.
Aspects of the effects of vegetation on climate. *European Geophysical Society 10th Annual Meeting, Louvain-la-Neuve, Belgium.* 31 July.
UK activities relevant to TOGA. *JSC/CCCO Conference on the TOGA Scientific Programme, Paris.* 20 September.
Hydrology in climate modelling. *Royal Meteorological Society/British Hydrological Society Meeting on Climatic Change and Water Resources.* 29 October.

ROY, M. G.
The Ben Nevis Observatory 1883 to 1904. *Institute of British Geographers Annual Conference, Durham.* 7 January.

SARGENT, G. P.
The use and interpretation of radar data. *Wessex Water Authority.* 6 November.

SAUNDERS, R. W.
Removal of cloud-contamination from infra-red radiances. *EARSeL Workshop on Sea Surface Temperature Measurements, Valbonne, France.* 9 October.

SHAW, D. B.
Parametrization of moist convection. 9 October.
Analysis and initialisation in the tropics. 12 October.
Numerical weather products in the tropics. 12 October.
International School of Meteorology of the Mediterranean—Workshop on Limited-Area NWP Models for Computers of Limited Power, Erice, Sicily.

SHAWYER, M. S.
Meteorological aspects of drainage design. *Planning and Transport Research and Co-operation, Education and Research Services Ltd, Course on Flood Estimation for Drainage Design, City University, London.* 11 December.

SHEARMAN, R. J.
Marine meteorological services. *WMO Commission for Maritime Meteorology, Geneva.* 1–12 October.

SHUTTS, G.
Isentropic analyses of Ertel potential vorticity and blocking. *Department of Applied Mathematics and Theoretical Physics, Cambridge University.* 3 February.
A case study of eddy forcing during an Atlantic blocking episode. *Workshop on Global Scale Anomalous Circulation in the Atmosphere and Blocking, Rome.* 27–30 August.
Theories of blocking. *Royal Meteorological Society meeting entitled 'Is current dynamical theory relevant to forecasting?'* 17 October.

SLINGO, A.
Climate modelling in the UK Meteorological Office. *Max Planck Institut für Meteorologie, Hamburg, West Germany.* 28 March.
Simulation of European climate with an atmospheric general circulation model. *CERAM, Sophia Antipolis, France.* 2 October.

SMITH, F. B.
Airborne pollution. *A series of lectures to MSc course in Radiation and Environmental Protection, Department of Physics, University of Surrey, Guildford.* 2, 9, 16 February.
Acid rain. *Sixth Form Lectures, ILEA, GLC London.* 10 November, 7 December.
Solution of the integral equation of diffusion for continuous plumes and instantaneous puffs in the atmospheric boundary layer. *29th OHOLO Conference on Boundary-layer Structure-modelling and Application to Air Pollution and Wind Energy, Zichron Ya'acov, Israel.* 27 March.
Estimates of uncertainty in dispersion modelling. *Commission of European Communities Seminar on The Results of the Indirect Action Programme, Safety of Thermal Water Reactors (1979–83), Brussels.* 2 October.

SPALDING, T. R.
Weather on the hills. *Royal Meteorological Society Field Study Course, Betws-y-Coed, Gwynedd.* 4–10 August.

STEPHENS, R. J.
The use of the Cyber 205 at the Meteorological Office. *European Control Data Users Group, Montreux, Switzerland.* 12 April.

STOBBS, R. J.
Mountain weather. *Lake District National Park Day Centre, Brockhole.* 28 April.

SWINBANK, R.
Two lectures: (1) A comparison of results from the Meteorological Office level IIIa FGGE analysis and the ECMWF IIIb analysis, (2) The global atmospheric angular momentum balance during the FGGE. *Scientific Seminar on Global Diagnostic Studies based on data collected during the Global Weather Experiment, Helsinki.* 28–31 August.

TUCK, A. F.
Aircraft studies of atmospheric oxidation of SO_2. *Royal Society of Chemistry, University of Reading.* 21 February.
Aircraft studies of atmospheric chemistry near lows and jet streams. *NASA Langley Research Center, Hampton, Virginia, USA.* 21 May.
Towards a stratospheric strategy: the example of hydrogen. *NASA Meeting on Stratospheric Ozone, Feldafing, West Germany.* 16 June.
Atmospheric chemistry and meteorological dynamics. *Natural Environment Research Council Symposium, Oxford University.* 11 July.
Transport of water vapour in a stratosphere–troposphere general circulation model. *Royal Meteorological Society.* 21 November.
The origin of acid deposition—transport and transformation. *IES/CES Seminar on Acid Rain, Baden Powell House, Queen's Gate, London.* 22 November.

WHITE, A. A.
Finite amplitude baroclinic waves in a rotating fluid system: numerical and analytical models. *Department of Mathematics, Imperial College, London.* 18 January.
Numerical and analytical modelling of finite amplitude baroclinic waves. *Department of Applied Mathematics and Theoretical Physics, Cambridge.* 27 January.
Numerical and laboratory studies of baroclinic waves. *Royal Astronomical Society, Mason Conference on Topics in Geophysical and Astrophysical Fluid Dynamics, University of East Anglia, Norwich.* 14 September.

WHITE, P. W.
Vectorization of weather and climate models for the Cyber 205. *Super-computer Applications Seminar, West Lafeyette, USA.* 2 November.

WICKHAM, P. G.
Five lectures on forecasting methods. *Course for MSc Students, Department of Meteorology, University of Reading.* February–March.

WILDERSPIN, R. C.
Development of an improved GCM radiation scheme. *International Radiation Symposium, Perugia, Italy.* 24 August.

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 1984; 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.

Periodical

Annual
Annual Report on the Meteorological Office 1983 (0 11 400347 5)*
Marine climatological summaries for the Atlantic Ocean E of 50°W, N of 20°N (microfiche), 1971 (0 86180 168 7), 1972 (0 86180 169 5), 1973 (0 86180 176 8), 1974 (0 86180 182 2), 1975 (0 86180 186 5), 1961–1970 (0 86180 151 2)
Meteorological Office Almanack 1985 (Leaflet No. 11) (0 86180 150 4)
Monthly and annual totals of rainfall for the United Kingdom 1979 (0 86180 146 6), 1980 (0 86180 174 1)
Monthly ice charts 1983 (0 86180 127 X)
Snow survey of Great Britain 1982/3 (0 86180 167 9)
Meteorological Office Calendar 1985 (0 86180 177 6)

Quarterly
*Marine Observer**
Stratospheric charts for the northern hemisphere (microfiche), 1982 2nd quarter (0 86180 147 4)

Monthly
*Meteorological Magazine**
*Monthly Weather Report**

Fortnightly
Meteorological Office Rainfall and Evaporation Calculation System (MORECS)

Weekly
Ice charts (scale 1:10 million), North Atlantic (Wednesdays only)

Note: Many Weather Centres produce meteorological summaries and statistics on a variety of time scales. Details are given in Leaflet No. 12 obtainable free from the Meteorological Office on request.

Serial

Climatological Memorandum No. 133, *The climate of Great Britain: East Anglia and Lincolnshire* (0 86180 145 3)
Climatological Memorandum No. 136, *The climate of Great Britain: South-east England* (0 86180 111 3)
Climatological Memorandum No. 137, *The climate of Great Britain: South England* (0 86180 142 3)
Climatological Memorandum No. 139, *The climate of Great Britain: South-west peninsula and Channel Islands* (0 86180 110 5)
Climatological Memorandum No. 140, *The climate of Great Britain: Wales* (0 86180 141 5)
Climatological Memorandum No. 144, *Frequencies of snow depths and days with snow lying at stations in Scotland for periods ending winter 1981/82* (0 86180 140 7)

Occasional

Special Investigations Memorandum No. 112, *An icing climatology for helicopters* (0 86180 173 3)
Global forecast products from Bracknell (leaflet) (0 86180 178 4)
Leaflet No. 3: *Weather bulletins, gale warnings and services for the shipping and fishing industries* (0 86180 148 2)
Climatological services (0 86180 149 0)
Radar Research Laboratory (0 86180 114 8)

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