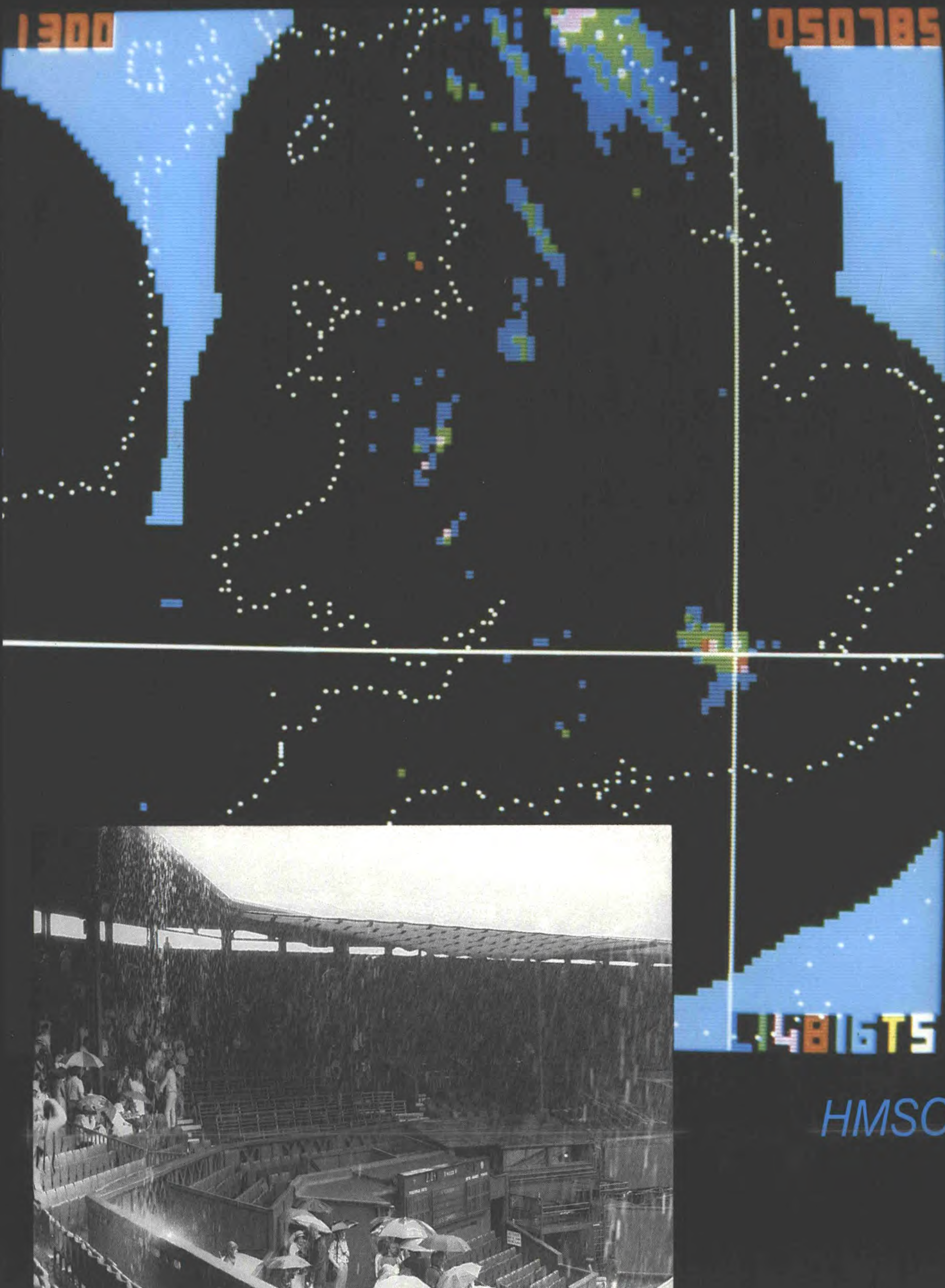
Annual Report 1985

Meteorological Office



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Annual Report 1985 Meteorological Office

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to the
Secretary of State for Defence

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LONDON HER MAJESTY'S STATIONERY OFFICE

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Contents

The front cover shows the rainfall radar display received at 1300 GMT on 5 July 1985—the day of the 'Wimbledon storm'—with cross wires centred on Wimbledon. With the help of these data, forecasters at London Weather Centre were able to alert officials at the Wimbledon Lawn Tennis Championships to the impending downpour (Photograph by courtesy of *The Times* Newspapers Ltd). The back cover shows Chenies radar, the latest addition to the Meteorological Office's weather radar network, which became operational on 1 January 1985.

	Page
Foreword by the Director-General	iii
Functions of the Meteorological Office	iv
Meteorological Committee	v
Meteorological Office organization	vi
Introduction	1
Observations and instrumentation	2
Introduction to the preparation of forecasts	8
Telecommunications	10
Computing and data processing	11
The forecast model and its performance	13
Services for Defence	16
Services for civil aviation	20
Services for the offshore industry	22
Services for shipping	23
Services for the general public, industry and commerce	24
Marketing services	27
Services for agriculture	28
Consultancy, advisory and data services	30
Introduction to the research program	31
Meteorological Research Flight (MRF)	33
Forecasting research	34
Mesoscale research	36
Satellite meteorology	37
Boundary-layer research	38
The middle atmosphere	39
Aviation research and development, and special investigations	40
Climate research	41
Atmospheric chemistry	46
Geophysical fluid dynamics	47
The National Meteorological Library and Technical Archives	48
Training	49
Personnel	50
International	51
Interaction with the national infrastructure	52
Finance	52

Appendices

I Books or papers by members of the staff	54
II A selection of lectures and broadcasts given by members of the staff	56
III Publications	58

Foreword by the Director-General

The Annual Report of 1984 in its new style has been very well received. This year's Report includes more detailed presentations of two areas of activity, namely 'Services for Defence' and 'Climate research'.

Forecasting skill has continued to increase through improvements in the computer forecast model, through better input data, and through increased computer capacity. Regarding the computer model, significant benefit has resulted from a new description of the drag exerted by mountains on the atmospheric flow, which takes into account more properly the effect of gravity waves. Improvement from this has been particularly noticeable in the forecasts of upper-air winds for aviation which provide important information for route planning by airlines. So as to ensure rapid access to this information, a number of airlines including Pan American Airways and Japan Air Lines have arranged to receive Bracknell computer output either by direct connection or indirectly through agencies such as the Société Internationale de Télécommunications Aéronautiques.

With respect to the observing system, a radar station at Chenies some 40 miles north-west of London was officially opened in January by Mr Adam Butler, then Minister of State for Defence Procurement. Apart from its value to the local Water Authorities it is proving to be a powerful aid to local forecasting in the London area. A spectacular example of this was the warning given by the Meteorological Office to the All England Lawn Tennis Club at Wimbledon on 5 July that an intense storm was likely to break over the Club within the next half hour (the radar echo from this storm is illustrated on the front cover). The Wimbledon authorities were therefore able to cover the courts before the deluge arrived.

After a great deal of international negotiation it has proved possible to maintain ocean weather ships through 1986 at three of the four stations that were manned during 1985—but at about half the present cost. An agreement between the United Kingdom and the Netherlands, by which the United Kingdom will operate the Dutch vessel *Cumulus* at station 'L' (57°N, 20°W), has been a major factor in this. At a ceremony in Hull on 18 December the Netherlands Secretary of Transport and Public Works handed the ship over to Mr John Lee MP, the Parliamentary Under Secretary of State for Defence Procurement, in return for a nominal sum of one pound sterling.

Substantial enhancement of the central computing system has occurred during the year. An extra million words of main storage has been installed in the Cyber 205, and the IBM 370/158 has been replaced after some 11 years of life by an IBM 3081D, thus increasing both the efficiency and robustness of the whole computing system.

The part which the Office and the BBC have played in the design of a new computer graphics for the presentation of forecasts on television has been recognized by the grant of the Premier Award of the British Computer Society in the Applications Section. Many enquiries are made from home and abroad regarding the details of the techniques involved which result in presentations considered by the public and the media alike to be of a high standard.

Demand on all the services provided by the Office has continued to increase. The income from repayment services, other than the Civil Aviation Authority, has increased by 18 per cent (or 12 per cent in real terms). This has been achieved despite a significant reduction in the complement of personnel and no increase in resources in real terms. Advice regarding future commercial policy has been received under contract from firms specializing in marketing. Methods of improving customer awareness and of more appropriate presentation of Meteorological Office products to its customers are being stressed.

Through the co-operation of British Telecom and with the help of sponsors it has been possible to extend the automatic telephone service, Weatherline, to cover some of the less populated parts of the country. Mountainline has been set up in Scotland, and much of the coastline of England and Wales is now covered by Marineline which is proving invaluable to small commercial shipping and small-boat owners. The Office is also exploiting viewdata networks for the dissemination of more specialist information. One example of this, the supply of agriculturally related weather information and forecasts to Farmlink—a Prestel service to which the Office contributes—was extended to cover much of England during the year.

The Office continues to assist, with expertise and advice, in areas of substantial public interest related to weather and climate. Members of the Office have contributed to discussions on north African drought, the acid rain issue and to meetings both national and international on the likely effect on the climate of increasing carbon dioxide.

It is important for the health of meteorological science in the United Kingdom that there should be close collaboration between the Office and university departments engaged in meteorological education or research. A new venture in 1985 together with the University of Reading was a week's Summer School held at the Meteorological Office College, Shinfield Park. Under the general title of 'Mesoscale Meteorology', the school combined lectures with in-depth studies of two particular cases. The close interaction which took place between research scientists and bench forecasters proved particularly valuable. This is just one example of co-operation in research which occurs extensively: there are over eight joint projects with UK universities and many more with research institutes and government organizations. Meteorological Office staff supervise 14 CASE (Co-operative Awards in Sciences of the Environment) students. There is also a broad range of international collaboration.

In the international sphere the most notable event for the Office in 1985 was the conference of the heads of

Commonwealth Meteorological Services held at the College at Shinfield Park in June. Much of the meeting was concerned with the problems of Meteorological Services in developing countries. Members of the Office were also pleased to take part in the tenth anniversary celebrations of the European Centre for Medium Range Weather Forecasts in November.

An interim report on Meteorological Office charging policy by Sir Kenneth Sharp and Mr John Hansford, which became available early in the year, provided a temporary solution to the problem of how the cost of the Office's central facility should be distributed between different customers. Their final report has highlighted (as did the Resource Control Review) the need for the Office to bear more clear responsibility for its resources. Ways by which this might be achieved are being reviewed.

Functions of the Meteorological Office

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

The general functions of the Meteorological Office are:

(a) The provision of meteorological services for the Army, Royal Air Force, civil aviation, the merchant navy and fishing fleets; provision of basic meteorological information for use by the Royal Navy; and liaison with the Director of Naval Oceanography and Meteorology.

(b) The provision of meteorological services to other government departments, public corporations, local authorities, the Press, television, radio, industry and the general public.

(c) The organization of meteorological observations, including observations of radiation, atmospheric electricity and ozone, in the United Kingdom and at certain stations overseas.

(d) The collection, distribution and publication of meteorological information from all parts of the world.

(e) The maintenance of the observatory at Lerwick.

(f) The provision of professional training in meteorology.

(g) Research in meteorology and geophysics.

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

Meteorological Committee

Members of the Meteorological Committee.

Back row (left to right) Captain A.P. Moran RN, Mr J. Wilson, Dr D.N. Axford, Mr F.R. Howell, Mr M.A. Gamester, Group Captain N. Bonnor. Front row: Professor P.H. Fowler, Mr G.C. Band, Dr J.T. Houghton, Sir Peter Swinnerton-Dyer, Mr B.E. Robson, Professor A.H. Bunting, Professor H. Charnock.

Membership as at 31 December 1985:

Chairman:
Sir Peter Swinnerton-Dyer, Bt, FRS

Members:
Mr G.C. Band
Professor A.H. Bunting, CMG
Professor H.Charnock, FRS
Mr D.A. Davis
Professor P.H. Fowler, DSc, FRS
Mr J. Miller, FIOB
Mr J. Wilson
*Mr M.A. Gamester (Representative Civil Aviation Authority)
*Dr J.T. Houghton, CBE, FRS (Director-General, Meteorological Office)
*Captain J. Marsh, RN (Director of Naval Oceanography and Meteorology)
*Mr B.E. Robson, CB (Deputy Under-Secretary of State (Personnel and Logistics))
*Air Vice-Marshal A.G. Skingsley, CB, MA, RAF, Assistant Chief of the Air Staff; alternate, Group Captain A.M. Bowman

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

**ex officio*

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.

The Committee met four times in 1985.

Meteorological Committee—Research Subcommittee

Chairman:
Professor H. Charnock, FRS

Members:
Professor Sir Robert Boyd, FRS
Professor B. Hoskins
Professor J. Monteith, FRS
*Dr D.N. Axford (Director of Services, Meteorological Office)
*Mr D Barber (Chief Scientist, Civil Aviation Authority)
*Group Captain A.M. Bowman (Deputy Director Navigation)
*Dr B.S. Collins (Head of Physics Group, Royal Signals and Radar Establishment)
*Dr D. Everest (representing Department of the Environment)
*Mr A. Gilchrist (Director of Research, Meteorological Office)
*Dr J.T. Houghton, CBE, FRS (Director-General, Meteorological Office)
*Captain N. Marsh, RN, (Director of Naval Oceanography and Meteorology)

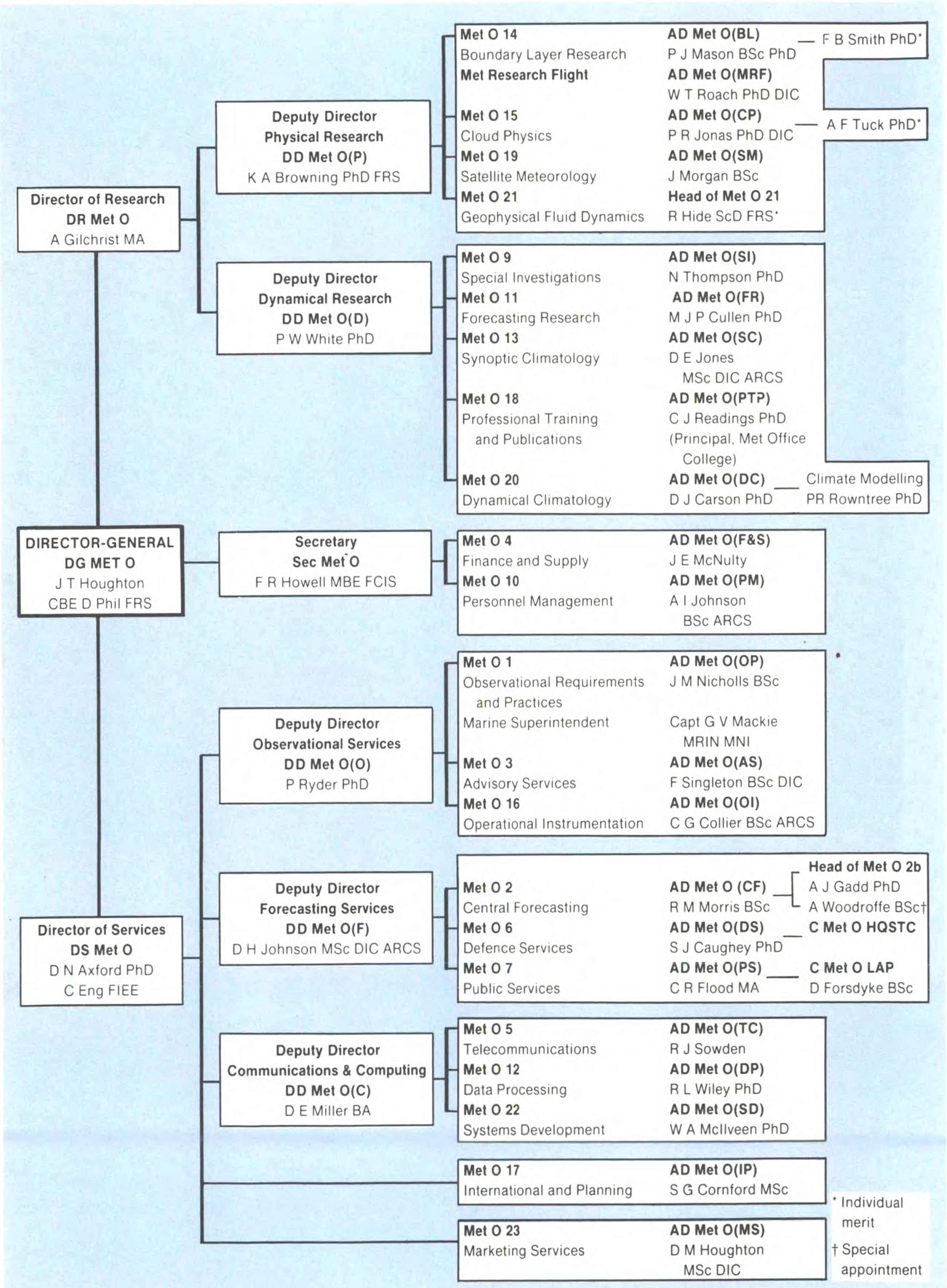
Secretary
Mr T.D.A. Fairlie

**ex officio*

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.

The Committee met three times in 1985.

Meteorological Office organization



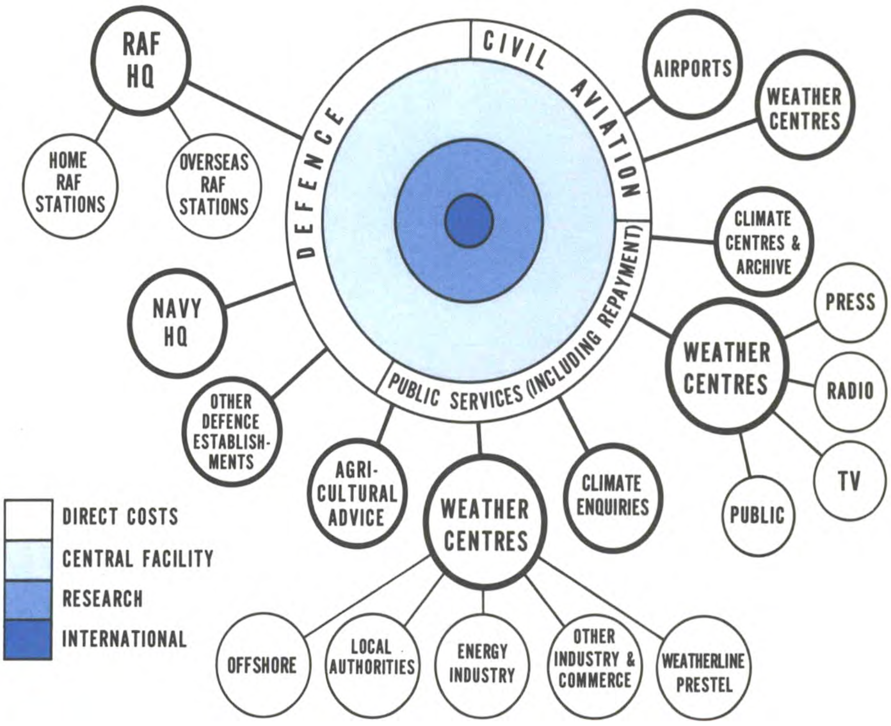
Introduction

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 12 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.



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 the provision of many consultancy, advisory, and information services.

To supply these data a series of observing networks of different types and using a variety of observing technologies has been established. In the maintenance and development of networks, modern automatic data-gathering systems are being introduced to provide information from uninhabited regions and to replace the observing capability which is lost as manpower is reduced. Technology is not yet available to enable all necessary observational data to be obtained automatically; for example, instrumental measurements of visibility, cloud type and structure, and precipitation type are not at present an adequate substitute for human estimates and judgements. Nevertheless a good deal of work is being done to reduce the dependence on human observers whilst maintaining and sometimes improving the observational data base.

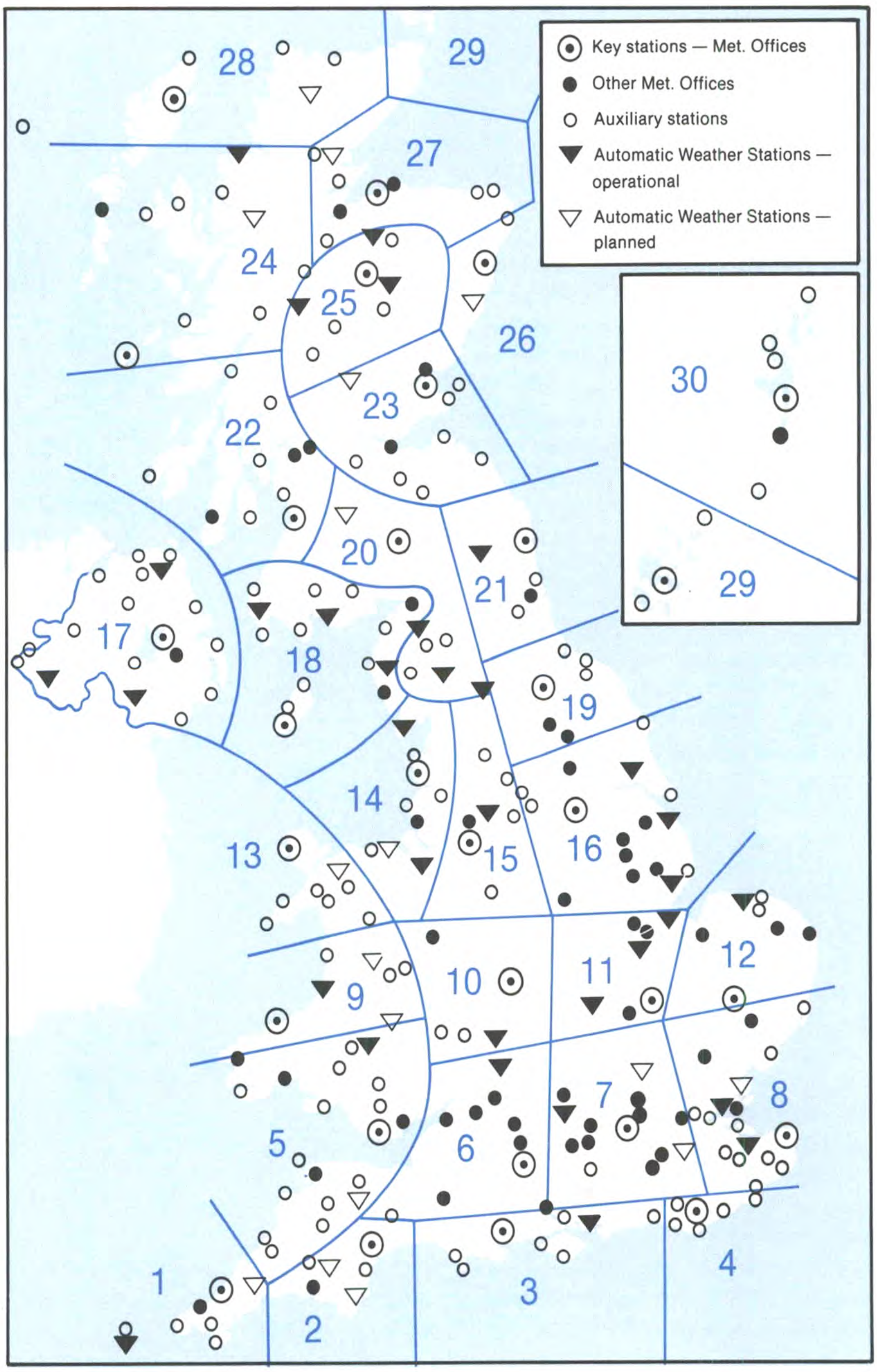
Measurements made from conventional surface networks are being increasingly complemented, and to a limited extent replaced, by those derived from remote-sensing systems such as weather radars and satellite instrumentation; complex processing techniques are being developed to exploit fully the application of raw data from such systems.

Surface observations

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

To define the weather in greater detail and prepare forecasts for specific localities, regular observations are obtained from a denser network of stations. The Office mans a further 55 stations, mostly at airfields at which a forecast service is provided. At 142 auxiliary stations regular observations are made by observers who are employees (such as coastguards and lighthouse keepers) of other authorities, or private individuals. Auxiliary stations are a very valuable source of observations in mountainous and coastal areas where the topography has a

The UK land-based network of observing stations. Numbers indicate areas with homogeneous meteorological characteristics.

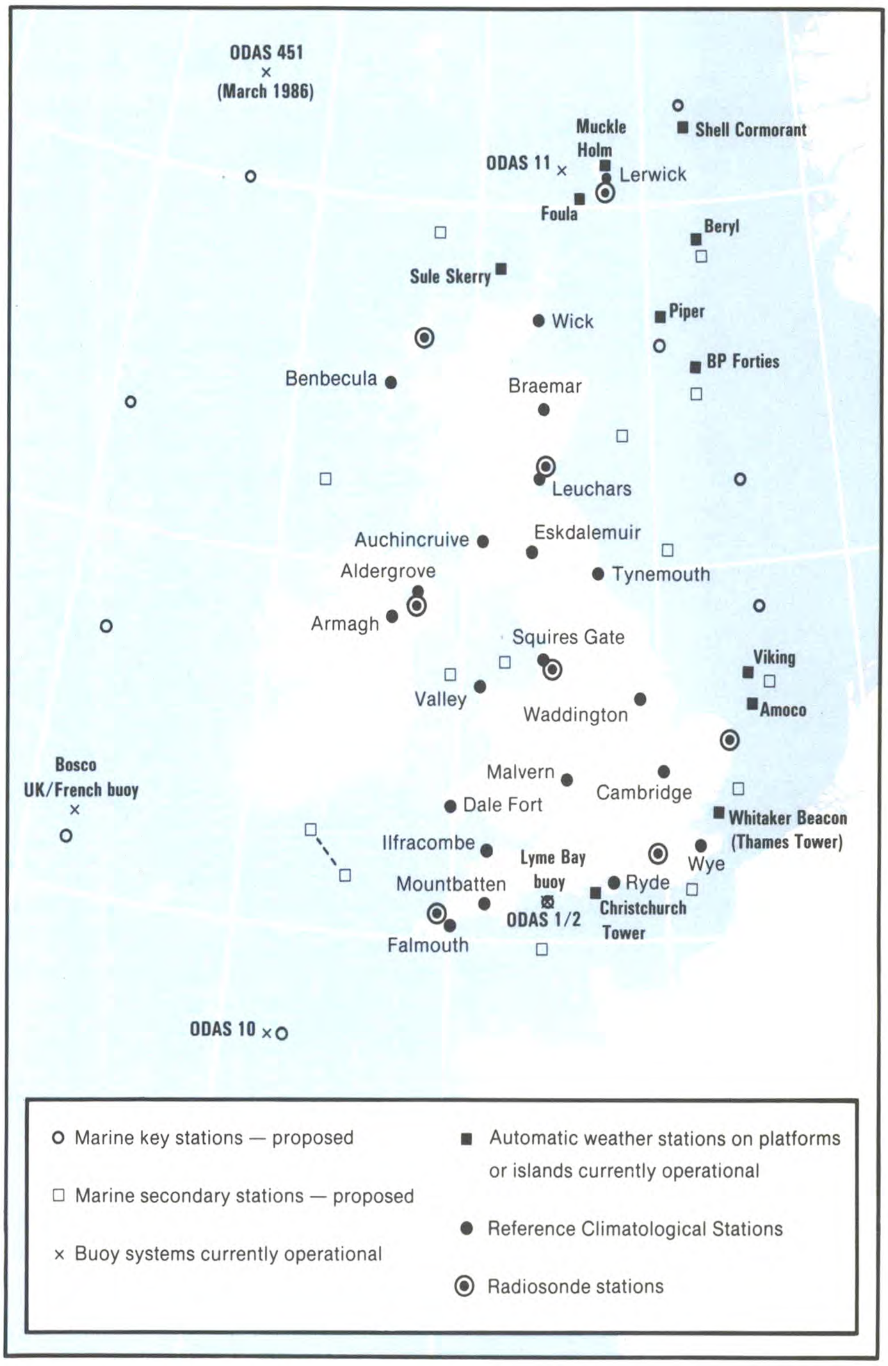


marked impact on the weather. Thirty-three automatic stations are installed in unpopulated areas and at locations where they are the most economic means of providing adequate, regular observations. The reliability of synoptic automatic weather stations (SAWS) is outstanding and further systems will be installed over the next few years.

An extensive data base is required to support climatological services provided to customers such as those in the engineering industries, insurance companies and legal consultancies. Some 450 stations (mostly voluntary) report at least temperatures and rainfall once daily; the rainfall network is supplemented by a further 4800 stations, mainly operated by Water Authorities and private individuals, to take account of the complex distribution of rainfall over the United Kingdom. A small network of 'Reference Climatological Stations', shown right, is maintained to help determine climatic trends; each of these has at least 30 years of homogeneous records. As part of the automation program a contract for ten Automatic Climatological Recording Equipments (ACREs) has been placed with projected delivery late in 1986.

New automated sensors are being introduced into service:

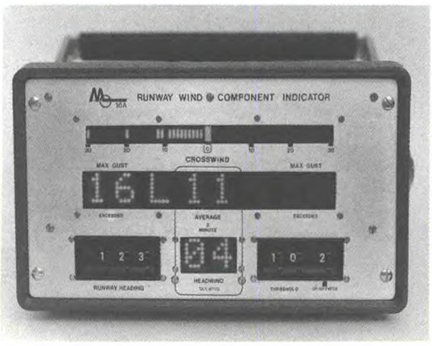
- A batch of five laser cloud base recorders (LCBRs) has been purchased and evaluated at the Office's experimental site, Beaufort Park. Although the tests have revealed some shortcomings, the devices provide useful information and one was deployed operationally at RAF Coningsby in August. Commercially available LCBRs can give unreliable information in precipitation and in fog, and work to improve the processing and interpretation of output from these machines is continuing.
- Eleven Marconi short baseline visibility sensors were delivered, and deployed initially at Beaufort Park for acceptance and evaluation trials. Consideration is being given by the Department of Transport to the deployment of a number of visibility sensors on motorways as an aid to forecasting hazardous road conditions.
- To meet an urgent requirement of military aviation, a runway cross-wind resolver has been developed, see right. It replaces an earlier, now obsolete, design and has been enhanced to accept inputs from wind-measuring systems now in operational service. Production devices will become available in 1986. Progress has also been made with the development of a prototype replacement



The UK network of marine observing stations, land-based Reference Climatological Stations and radiosonde stations.

Digital Anemograph Logging Equipment (DALE) the major electronic components of which will be identical to those of the new cross-wind resolver. The new improved Mk 5B wind systems have been deployed at Belfast Airport, RAFs Odiham, Cranwell and Coningsby and at Wildenrath, Laarbruch and Gütersloh in the Federal Republic of Germany.

Prototype runway cross-wind resolver.



Marine observations

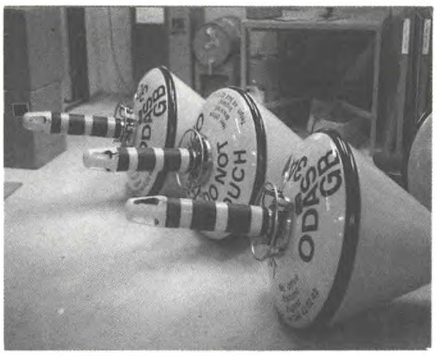
The figure also shows the network of existing and planned fixed, marine weather stations around the United Kingdom. Nine key stations which report a comprehensive range of elements every three hours are required. At least 14 secondary stations are also needed to support the preparation of local forecasts, particularly for the offshore oil and gas industries in the North Sea. To satisfy this requirement, work has continued on the development of marine automatic weather stations on both drifting and moored buoys, and for both oil and gas platforms in co-operation with the platform owners. During the year a new system, based on a Meteorological Office design, became operational on the BP Forties platform. The current deployment of these types of system, together with the present locations of buoy systems, is shown on page 3. The COST-43 (European Co-operation in Science and Technology) System of Operational Buoys in the Atlantic (SOBA) drifting buoy Project ran successfully throughout the year. The Meteorological Office contribution of five buoys, of the type shown on right, for the year was completed in September. Agreement was also reached for a COST-43 drifting buoy program for the Azores region.

Two international co-operative moored buoy programs, organized under COST-43, were carried out. The UK/France 'Bosco' buoy project to moor a buoy of French manufacture at about 50°N, 14°W was completed successfully. The buoy was launched during July by a French naval vessel. Moorings, some sensors and batteries were supplied by the United Kingdom, who have agreed to provide the bulk of the maintenance resources over the next two years. Data of good quality were routinely received via Système Argos. The UK/Iceland/Norway project to redeploy the Ocean Data Acquisition System, ODAS 451 buoy near 67°N, 13°W made steady progress, but delays in placing some of the contracts to refurbish and replace equipment have postponed the expected deployment until January 1986.

The ODAS 20 buoy, recovered from the south-west approaches in January 1984 was refurbished and under test by late autumn with deployment in the southern North Sea now expected in January 1986. A prototype, commercially produced, data buoy manufactured by Thorn-EMI Ltd was deployed in Lyme Bay for comparison tests against the ODAS 1/2 buoy which has remained operational throughout the year. The experience gained with this new data buoy, as well as that learned from the other deep-ocean buoy programs will be used to prepare the specification for an operational buoy system to implement the complete deep-ocean buoy network shown on page 3. Procurement of the first systems will commence in 1986.

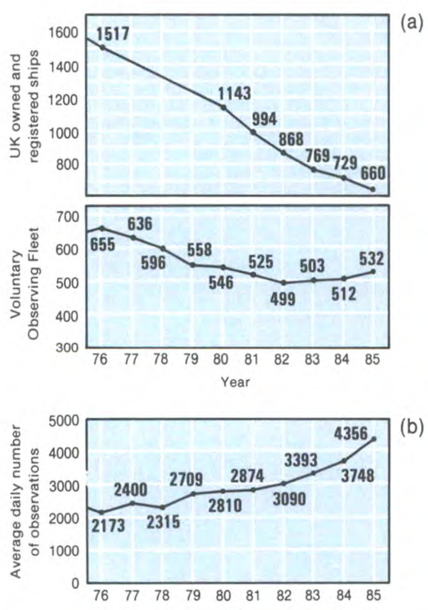
A program to equip seven automatic (unmanned) light-vessels with automatic weather stations has begun.

Meteorological observations are collected regularly on board manned surface craft, and transmitted by radio, sometimes through a satellite link, to shore-based centres. The United Kingdom contributes some 500 vessels to the 8000 vessels in the world-wide Voluntary Observing Fleet, and includes passenger liners, container ships and tankers, as well as short-haul ferries, coasters and



Buoys of the type contributed by the Office to the COST-43 SOBA drifting buoy Project.

supply ships. Despite a continued decline in the number of ships sailing under the British flag, the number of observing vessels has increased in recent times and the total is at its highest for five years (see below). The increasing number of weather messages reflects both the size of the fleet and the greater time ships now spend on the high seas. The recruitment and training of volunteer observers, together with the provisioning of suitable meteorological instruments and code books, is carried out by Port Meteorological Officers (PMOs) based at seven major UK ports. PMOs in many overseas countries contribute much willing assistance in servicing ships, showing the value of international co-operation in this field.



The number of ships in the Voluntary Observing Fleet compared to the British-owned and registered fleet (a), and the average daily number of ships' observations received at Bracknell (b).

The Meteorological Observing System for Ships (MOSS), a minicomputer-based system which automatically formats manually entered surface observations into the correct code and then broadcasts them via geostationary satellites, is installed on eight vessels. The system enables ships' reports to be received at Bracknell within a few minutes of observation time. A contract for a further ten updated MOSS equipments with improved ability to withstand severe environmental conditions has been placed.

Ocean Weather Ship (OWS) *Starella* continued to operate at station 'L' (57°N, 20°W) in the North Atlantic to fulfil UK obligations under the WMO Agreement for the joint financing of the North Atlantic Ocean Stations (NAOS). Observers, besides making hourly surface and six-hourly upper-air observations, also recorded sea temperatures and salinity, and collected samples of plankton and rain- and sea water for scientific analysis ashore. The withdrawal at the end of the year of some countries from the NAOS Agreement has led to a reorganization of the observing stations; agreement was reached with the remaining participants to operate a three-station network until the end of 1988. *Starella* will be replaced at the beginning of 1986 by the Dutch OWS *Cumulus* which was transferred to UK ownership under beneficial financial arrangements.

To supplement the observations from the weather ships, a system has been developed, mainly by the Atmospheric Environment Service (AES) Canada and the National Weather Service (NWS) USA, for launching radiosondes from merchant ships. This system known as ASAP—Automated Shipboard Aerological Programme—has undergone trials on ships crossing both the North Pacific and North Atlantic oceans. The United Kingdom collaborated in the North Atlantic trial during 1984. A report on the six-month trial was prepared and presented at a one-week ASAP conference convened by AES Canada and hosted by the Meteorological Office at Bracknell in February.

The weather radar network

The UK weather radar network continues to provide composite precipitation data at 15-minute intervals to a number of Meteorological Office users. The same data are also provided, on a repayment basis, to Devon County Council and a number of Water Authorities.

The weather radar network, including the London weather radar installed at Chenies in Buckinghamshire, was converted to operational status from 1 January with servicing cover over 24 hours a day.

A contract has been placed with Plessey Radar Ltd for additional weather radars to be installed in Northern Ireland, north

Mr J. Scherpenhuizen, the Netherlands Secretary of State for Transport and Public Works (left) and Mr John Lee MP, Under Secretary of State for Defence Procurement display the suitably mounted pound coin symbolizing the sale on 18 December 1985 at Hull of OWS Cumulus *by KNMI to the Meteorological Office. (Photograph by courtesy of Walter Fussey and Son, Industrial and Marine Photographers)*

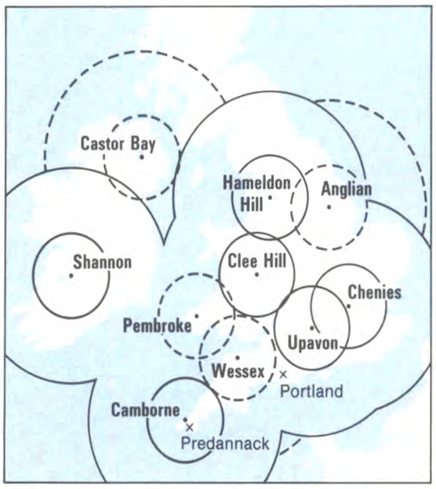
Devon and Dyfed. In addition the Directorate of Naval Oceanography and Meteorology (DNOM) is procuring two similar radars on the same contract for installation at Predannack (Cornwall) and Portland (Dorset). These will replace the old S-band radars at Camborne and Upavon and existing old DNOM radars. These additional radars will produce a significant improvement in the quality of the data provided to users in Northern Ireland and southern England.

Early discussions have taken place between the Meteorological Office, the River Purification Boards in Scotland, which now have responsibility for flood warning and control, the Highways Departments and other interested parties with a view to extending the network to Scotland. This has resulted in a number of benefit studies being commissioned to determine whether the network could be financially supported. A network of three radars in Scotland has been proposed and a minimum cost–benefit ratio of 3.3:1 is expected. The radar network as currently installed and planned is shown right.

The move of the weather radar network computer operation from Malvern to Bracknell was completed at the end of the year. This involved the procurement of a new DEC PDP 11/44 computer and an upgrade of the existing network computer to PDP 11/44; both computers will operate from Bracknell with terminals at Beaufort Park.

A total of 25 additional electronic display systems for use in receiving weather radar data were delivered at the beginning of the year, eight of which replaced ageing Mk I/Mk II systems. Three prototype weather radar display systems manufactured by Software Sciences Ltd of Farnborough were located in the Central Forecasting Office, at Malvern and at Beaufort Park for assessment. This assessment resulted in the need for a number of enhancements that will make the new display systems more useful and 'user-friendly'. The new display systems include facilities to store and display radar network and combined radar–satellite pictures and eventually other images including forecasts from radar data. To enable Jasmin users to derive greater benefit from their displays a vacation student spent six months programming a BBC microcomputer to display 128 × 128 pixel and 256 × 256 pixel images using the microcomputer as a 'front end' to a Jasmin display.

Location of existing and proposed weather radars. Inner circles (75 km radius) indicate quantitative coverage and outer circles (200 km radius) extreme theoretical range. Solid lines indicate range of existing stations, dashed lines that of proposed stations. X indicates proposed DNOM radars.



The COST-72 Project sponsored by the EEC was brought to a conclusion at the end of the year. Over six years this project has assessed the benefits of radar data to users, produced an outline radar system specification, studied the accuracy of radar data, and demonstrated the feasibility of exchanging radar data throughout western Europe. The Meteorological Office acted as a compositing centre, receiving data in real time from the Republic of Ireland, France and Switzerland. These data were combined with UK data and infra-red satellite data from the European satellite Meteosat II. The composite images were disseminated to London/Heathrow Airport for assessment of their utility to forecasting for civil aviation. Dissemination via the WMO Global Telecommunication System has also taken place in real time to the Republic of Ireland, Belgium, Sweden and Finland, and via a dial-up system, to Switzerland and Austria.

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.

Work continued on the development of the new arrival time difference system. The first two units were delivered to Bracknell, and installation was completed at Camborne during October and at Hemsby by the end of the year. The other outstations will be delivered at regular intervals such that it is hoped to begin full system trials by mid-1986.

Observations of radiation

The National Radiation Centre (NRC) based at Beaufort Park oversees the measurement of solar radiation by a network of 38 stations, 14 of which belong to the Meteorological Office and the others to co-operating bodies with agricultural and water management functions. The Office stations use thermopile radiometers to measure both global and diffuse solar radiation on a horizontal surface, with a small number also measuring other components (such as the direct solar beam). Data are recorded at one-minute intervals on magnetic tape. All network pyranometers and pyrheliometers are calibrated at NRC, which provides traceability to the World Radiometric References through a transfer standard radiometer. NRC also undertakes a range of experimental work. Investigations were completed of the performance of integrators which enable real-time reports to be made of daily irradiance, and of corrections to be made for the effects of a shade ring on diffuse radiation measurements when the radiance distribution is not isotropic.

Upper-air observations

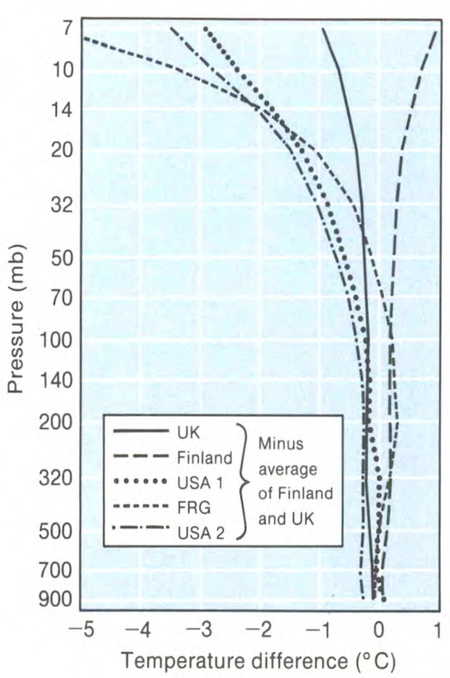
Measurements of temperature, humidity and wind to heights of around 30 km are an essential data source for weather forecasting. The temperature and humidity measurements are made at 0000 and 1200 GMT daily by radiosondes carried by freely ascending balloons from eight stations in the United Kingdom (see page 3). Winds are also obtained at these times by tracking a radar reflector attached to the balloon. Further measurements of wind-only are made at 0600 and 1800 GMT. Data from such ascents on a world-wide basis provide basic input to numerical forecast models, and also give forecasters at local level information on such factors as regional cloud and fog formation. Radiosonde stations are maintained overseas by the United Kingdom at Gibraltar and St Helena.

Field investigations of the performance of systems which make and process upper-air measurements continued. The Office participated in both phases of an International Intercomparison of radiosondes (at Beaufort Park in 1984 and at Wallops Island, Virginia in 1985). The processed data are being used to analyse sensor deficiencies, improve the performance of the sensors, and to provide guidance on corrections that should be included in numerical forecast models. The figure on right shows the mean differences, as a function of height, between simultaneous temperature measurements from five radiosondes launched at 0000 GMT on 26 days during phase 1. The divergence at about 50 mb is related to the radiation corrections for the sensors and their application.

The intercomparisons also provided an extensive data set from which the accuracies of a variety of methods of measuring wind have been determined. These methods included wind finding by primary radar, radio-theodolite and Omega navigational aid systems. This data set has now been augmented by the results of separate field investigations of winds measured using Loran C navigational aids. For some local forecasting purposes winds in the lower atmosphere have to be measured frequently (sometimes hourly) and with a vertical resolution of about 50 metres. The ability of an acoustic Doppler radar to meet such requirements was examined in a successful collaborative project with the Central Electricity Research Laboratories, Leatherhead.

Upper-air data will remain sparse over oceanic areas in spite of the improvements which will be achieved by observations from the ASAP systems mentioned earlier, and an avionics system is being developed to retrieve and process meteorological data from sensors on board commercial aircraft which overfly such data-sparse areas, and to transmit these data automatically via satellite links to the surface telecommunication networks. The system, known as ASDAR (Aircraft to Satellite Data Relay), collects measurements of wind, temperature and turbulence, and aircraft height and position every seven minutes and transmits a bulletin of measurements every hour when the aircraft is at cruise level. During climb and descent measurements are made more frequently to give a 30-point atmospheric profile between the ground and cruise level. An international consortium was set up during 1985 to oversee the operational ASDAR program including its implementation and funding,

Comparison of five radiosonde systems.



maintenance and procurement matters, and the establishment of an operating centre.

Observations from satellites

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

The primary Office involvement with satellites is through contributions to the European Meteosat satellite system. The half-hourly images available day and night from this satellite provide a dramatic view of the evolution of weather systems over nearly one fifth of the globe. The satellite is at an altitude of 36 000 km over the equator, but the image can be enlarged to show a considerable amount of cloud detail over the United Kingdom and provide an important analysis tool. Quantitative products can be derived from the imagery data and the Office uses cloud track winds and sea surface temperatures provided by the central ground station. The image data are also used in conjunction with ground-based radars in experiments to derive rainfall estimates.

The Office is collaborating with the Rutherford Appleton Laboratory, Oxford University and the Mullard Space Science Laboratory in the provision of the Along Track Scanning Radiometer (ATSR) for the European Space Agency's earth resources satellite, ERS-1. This radiometer is due to fly in 1989 and will provide measurements of sea surface temperature to an accuracy of better than 0.5 °C. The Office is responsible for the detailed design of the detector assembly in the focal plane of the ATSR viewing telescope. This design is complete and most of the components have been manufactured and assembly and testing started. As is usual with satellite equipment, a specially equipped clean room has been set up and the assembly and test work will be done within this room inside a laminar flow cabinet. The Office is also responsible in part for the validation of the ATSR, and the design review report has been prepared.

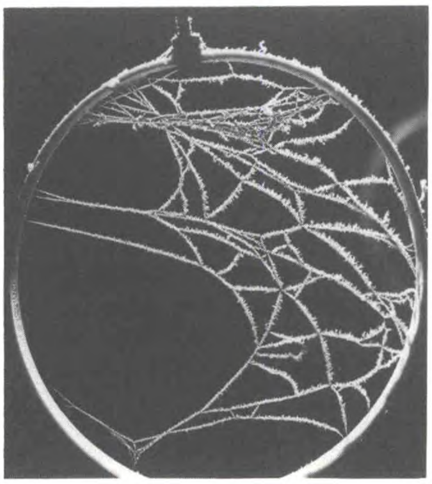
Support for the US polar-orbiting satellites continues through the provision of Stratospheric Sounding Units (SSUs) and the development of the Advanced Microwave Sounding Unit B (AMSU-B). The SSU F2 launched in June 1979 continued to provide stratospheric soundings and is used as a comparison standard for subsequent SSUs on NOAA-7, 8 and 9. The latest SSU F5 on

This is the scene obtainable from the European Meteosat satellite each half hour. A dense band of frontal cloud covers much of Europe while in the United Kingdom it is a day of sunny intervals with showers. The image is for 1155 GMT on 15 September 1985.

NOAA-9 works well and the pre-flight modifications to reduce the 'noise' on the top channel proved successful. Three SSUs await launch before the provision of stratospheric data is satisfied by AMSU-A which is currently under development. One of these SSUs, the refurbished development model, failed a spacecraft qualification test with a broken component in the lowest sounding channel. The preparatory work necessary before attempting an in-house repair is well under way.

The UK/US program leading to the provision of AMSU has developed. The AMSU-A instrument, which gives temperature sounding data from the surface to 1 mb, will be provided by the National Oceanic and Atmospheric Administration, USA (NOAA). NOAA has now placed a contract for three flight units with Aeroject and the first unit should become available for flight on NOAA-K in 1990. The United Kingdom has agreed to provide the B unit, which will measure humidity profiles and provide maps of non-ice clouds and precipitation. The Office has placed a major contract with Marconi Defence Systems at Watford to develop the high-frequency subsystem. This will develop the new microwave technology needed to meet the performance requirement and to generate components developed to spacecraft flight standard. Two other contracts have been placed with industry. In parallel with the industrial effort on AMSU-B the Office is developing a supporting scientific program. This work has two facets. Firstly an in-house facility which will verify that the instrument output can be converted into a temperature measurement with sufficient accuracy to meet the specified performance characteristics. Secondly an experimental program involving the Rutherford Appleton Laboratory and the Laboratorie de Météorologie Dynamique at Palaiseau France. Verification of the science needed to convert the AMSU-B measurements into geophysical variables will be carried out. For this purpose equipment has been set up and measurements at AMSU-B frequencies have been made on the microwave properties of water in its three phases. The illustration shows an example of ice crystals grown on a spider's web. Frames like this are inserted into a microwave cavity in order to measure the properties of ice particles at AMSU-B frequencies.

Ice crystals grown on a spider's web—used in experiments to measure the properties of ice particles at AMSU-B frequencies.



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 complete global 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.

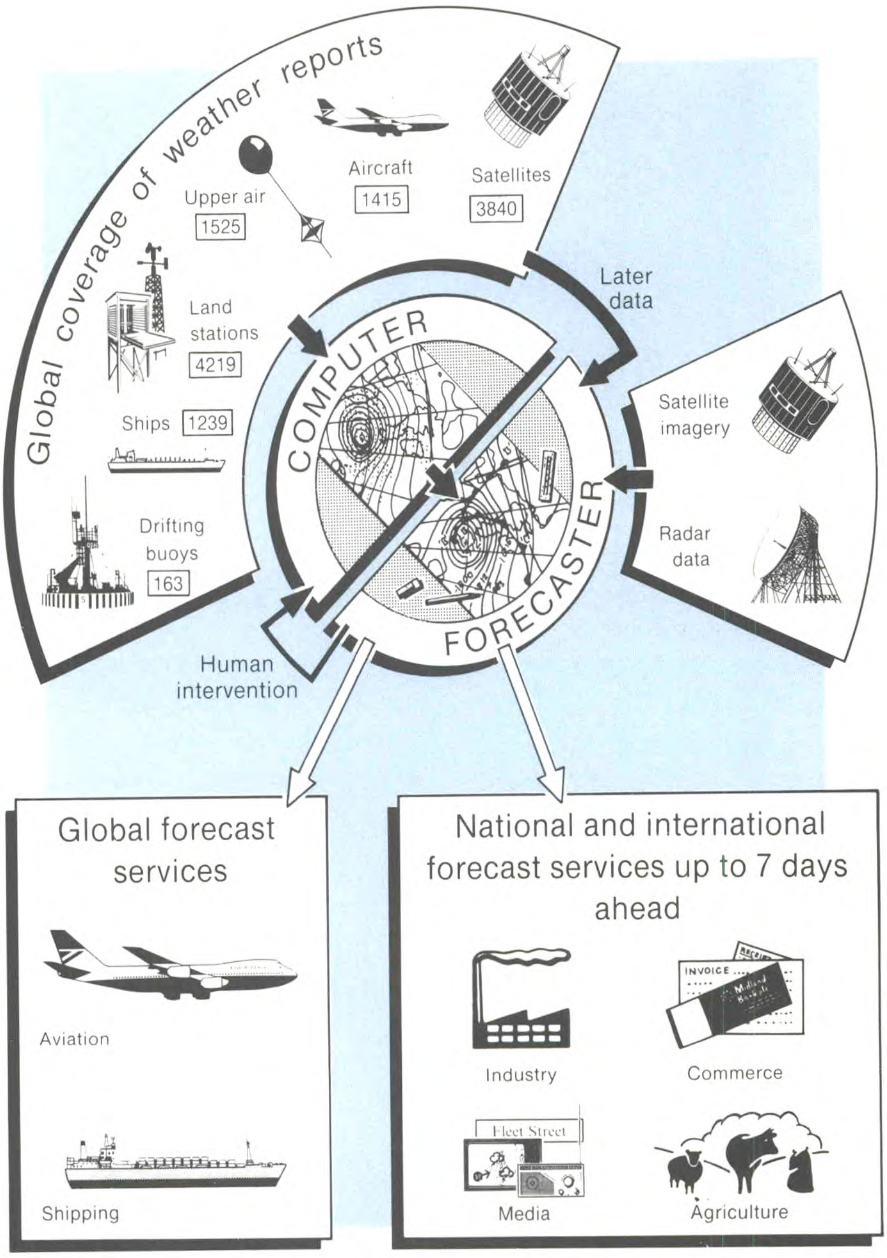


Diagram of flow—from observation to forecast. Numbers indicate the mean number of observations received each day for use in the main 0000 and 1200 GMT global numerical forecast models.

Satellite pictures give much additional information and assist significantly in the location and 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.

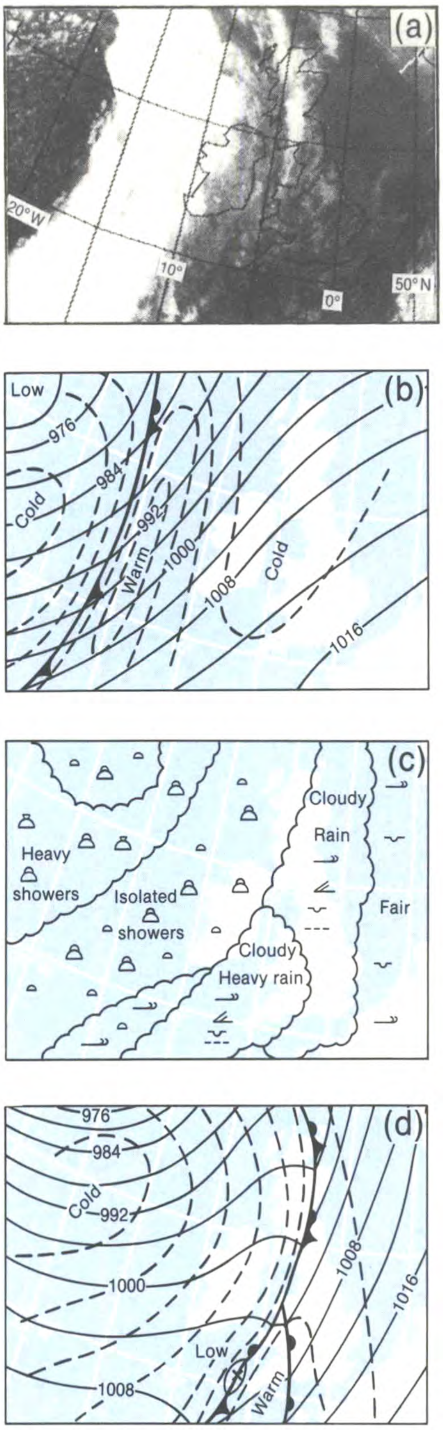
Observations throughout the depth of the atmosphere are essential for weather forecasting. Developments at the earth's surface are strongly dependent on the atmospheric motions above, while the strong flows at about 10 km are important in themselves when it comes to forecasting for aviation. Detailed 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 a perfect knowledge of the current weather the production of a forecast is not straightforward. Simple extrapolation can be used for very short periods ahead but this quickly becomes unreliable as small cloud systems such as thunderstorms do not exist for more than an hour or two, and larger weather systems, such as fronts and depressions, constantly evolve in response to the changing patterns in the temperature, wind and humidity fields. Before the advent of high-speed computers, forecasters, with their considerable experience of weather system behaviour, would use crude and simplistic solutions to the complex differential equations which govern the dynamical and physical processes in the atmosphere. Nowadays these equations are solved completely by numerical modelling methods based on a vast three-dimensional array of points (about one third of a million points 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.

Forecasters at work in the Central Forecasting Office.



Meteosat image for 1434 GMT on 5 October 1985 (a), surface analysis (mb) and distribution of temperature in the lower troposphere (dashed lines) for 1200 GMT on 5 October 1985 (b), weather and cloud forecast for 1200 GMT on 5 October 1985 (c) and forecast for 1200 GMT on 6 October 1985 (d).

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 allowances 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.

The figure left shows a frontal system as identified on the mean-sea-level chart from the satellite picture and the distribution of temperature in the lower troposphere. The forecast frontal position, however, is identified from the cloud distribution deduced from the numerical model output.

Telecommunications

The Meteorological Telecommunication Centre

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

To undertake these tasks the Met TC runs a number of automated message switches based on Ferranti Argus and Tandem TXP computers. The interconnections between these systems and their individual roles are shown.

Principally because of the increase in the dissemination of forecast products, the amount of data received and transmitted has increased by a factor of about three in the last five years.

The Meteorological Telecommunication Centre.

Technical advances

The new Tandem message switch, Phase IV, took over control of the national networks in August. Phase II, which had been in use since 1971, was withdrawn at this time. The new system will gradually assimilate the international data exchange tasks of the Ferranti Argus Phase III message switch.

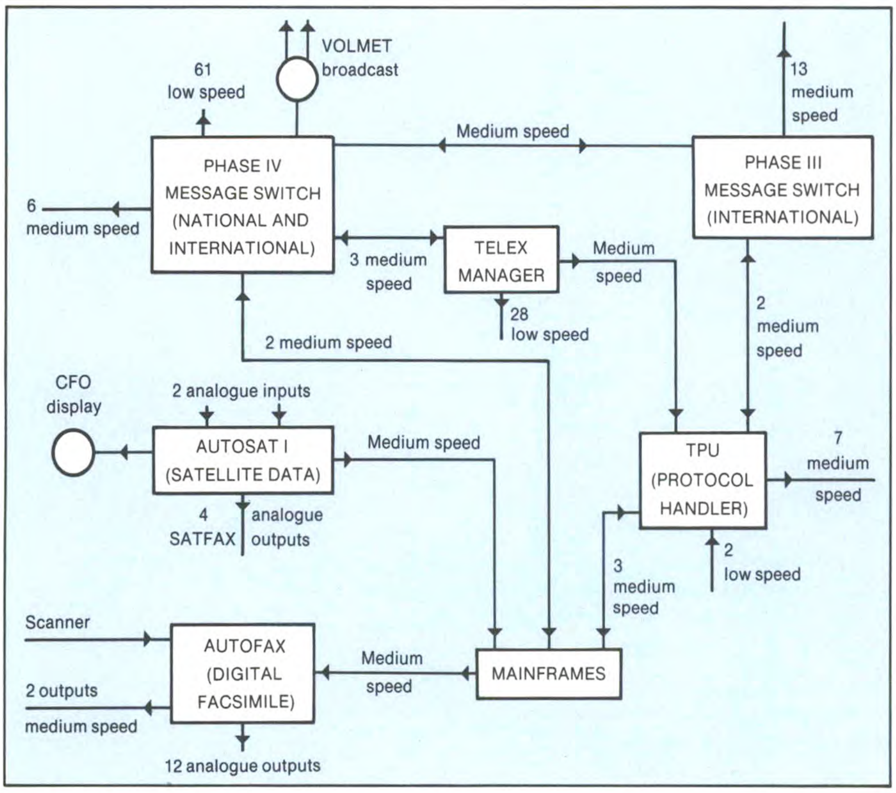
Increasing use is being made of geostationary satellites to relay meteorological observations from data collection platforms to receiving stations. At present the European Space Agency collects such observations through the European meteorological satellite, at their ground station at Darmstadt, and forwards them over the GTS to Bracknell. A new system has been procured which employs the receiving aerials at Lasham to do the collection. The observations are then sent over land-line to Bracknell. This system will both improve the timeliness of receipt of these observations and allow greater flexibility in their handling.

Future developments

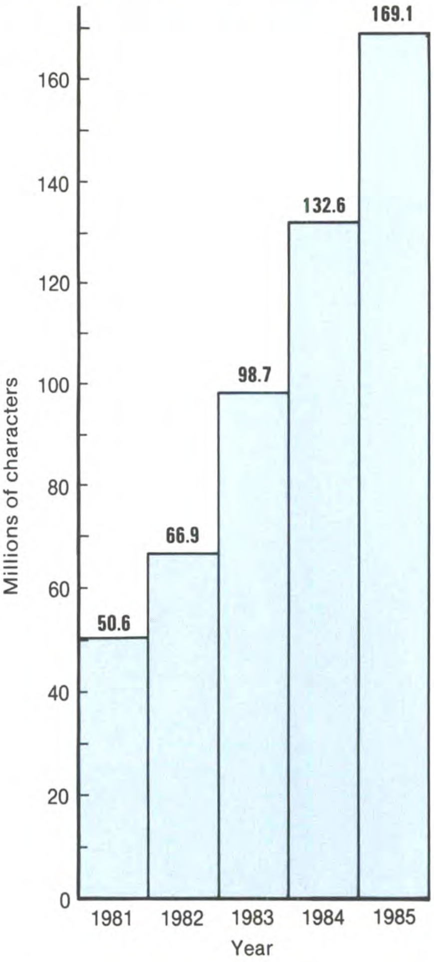
With the increasing flow of data over the GTS it is becoming urgent that modern methods of transmission control are employed. It is planned that the main GTS network links with Washington, Paris, and Offenbach in Germany will be upgraded in accordance with Recommendation X25 of the International Telegraph and Telephone Consultative Committee, and trials of these procedures commenced in the autumn. The links to the other centres connected to Bracknell will be similarly upgraded at a later stage.

The existing national networks are running at full capacity and, because

Computer-to-computer links in the Met TC.



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

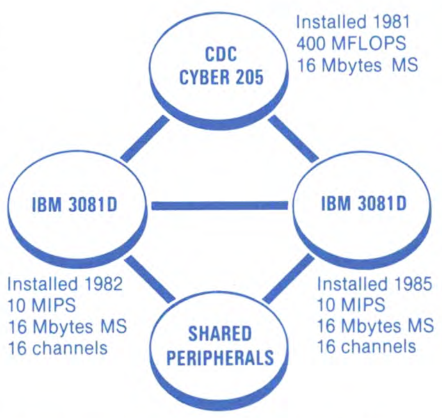


they use analogue techniques, are subject to some corruption of data. Moreover the service is provided over a number of separate networks, which leads to equipment duplication and management difficulties. Much effort has been devoted to the development of a plan to replace these networks by a single high-speed digital network, known as the Weather Information Network, which will, as well as solving the above problems, allow transfer of extra quantities and types of data. Each outstation will need to be equipped with computer-based display terminals attached to the new network. This requirement was specified and procurement of the first batch of equipment (for eight RAF stations) was initiated. The new network and associated displays will significantly improve the service to outstation forecasters at a lower cost than the present networks.

Computing and data processing

The main computing service in the Office is provided by three linked computers: a Cyber 205, manufactured by Control Data Corporation; and two 3081Ds, made by International Business Machines Corporation (IBM). The complete computer system is known as COSMOS and runs 24 hours a day, 365 days a year. Replacement during the year of an ageing IBM 370/158 by a second 3081D has ensured that essential work can continue when one IBM computer is unserviceable. The size of the main storage of the Cyber 205 was doubled in February 1985. With careful programming, this machine can run numerical models at a rate approaching 400 million floating point results per second, some 50 times faster than general-purpose computers. For general data processing, the ratio of performance is much smaller. The Cyber 205 is therefore reserved for intensive numerical modelling work while the IBM computers prepare data for the models, display output from them and provide the general computing service.

A large number of peripheral devices are needed to allow COSMOS to provide a balanced service. The most important requirement is for on-line storage space, of which 29 gigabytes are provided by disc drives, compared with 17.8 a year ago. Magnetic tapes are used to store much of the main archive of climatological data and to provide for storage beyond the capacity of the disc drives. The line printers have provided excellent service but are now 14 years old. However, the volume of printed output is now falling, despite an increasing work-load, thanks to the introduction of microfiche recorders. Graphical output is very important in meteorology and COSMOS is well equipped with suitable devices. Four Calcomp 960 plotters provide high-quality pen-and-ink charts much faster than they can be plotted by hand, while two Calcomp 1581s using 35 mm film are available to handle large volumes of graphical output. The latter can draw in a second what might take a minute on the 960s and can produce a long sequence of charts very quickly even taking into account the time taken to develop the film and make enlarged prints. The use of interactive graphic visual display units continues to spread, but only slowly.

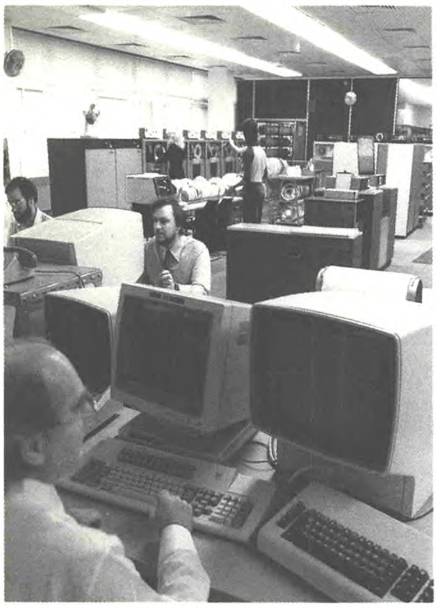


Current central computing facility (MS—main storage, MIPS—millions of instructions per second, MFLOPS—millions of floating-point operations per second).

The major activity on COSMOS is numerical modelling, which utilizes about one third of the resources of the IBM computers in addition to the whole of the Cyber 205. Highest priority is given to ensuring that the operational forecast models, global and regional, are run according to their schedules. The model concerned with research into climate and climatic change is the largest user of the Cyber 205 but could still make good use of more capacity than is available. Trials of the model which provides detailed forecasts over the British Isles have intensified. The Cyber 205 is also used to develop numerical models for ocean wave forecasting and physical research.

Access to the general computing service is now based firmly on the use of terminals; the old style of service using punched cards is still available but plays only a minor role. The number of terminals has doubled in the last year, to 100 or so, and plans are being made for further increases. A majority of the new terminals are actually small microcomputers able to perform some tasks without support from the mainframe computers. The ready availability of terminals and the improving level of service provided by them are leading to improved programmer productivity and ease of access to data and results held on COSMOS. Operational work is effectively based on terminals although its progress through the system is controlled by a console operator rather than a user.

Trends towards making more use of COSMOS in a wide range of applications, with the help of technical



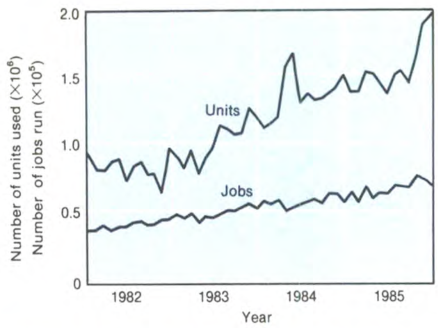
The operators' consoles and magnetic tape units in the COSMOS computer room. Part of the primary tape library can be seen in the background.

improvements, are very evident and all parts of the Office now make some use of COSMOS. For instance, during the 1970s COSMOS was used exclusively for scientific purposes. This is no longer the case, since applications such as the Management Accounting and Information System (MAIS), Computer Based Training and the Meteorological Office Library Accessions and Retrieval System (MOLARS) now use COSMOS. The scope of MAIS continues to grow and useful assistance is available for invoicing and the Memoranda Trading Account, as well as analysis of staff time and preparation of long-term costings. Integrated Database Management System (IDMS), supplied by Cullinet, has been used in the implementation of MAIS and MOLARS to avoid the design and support of another data base from the Office's resources. IDMS is also being applied in the scientific area for a base of agricultural data.

Another marked trend is the move towards direct connection of customers' computers to COSMOS to facilitate delivery of forecast products. Thirty-six connections were added to COSMOS in 1985 although some of them were duplicates to ensure high availability.

There are now a number of computer systems in the Office which need to be interconnected to support operational services. More are expected in the near future. Ideally some sort of local-area network, independent of particular suppliers, is needed. However, it will probably be some years before appropriate standards are accepted and widely implemented. Consideration is being given to how best to design and implement interim schemes.

Weather forecasting depends on timely availability of accurate observational data. Raw data acquired via the automated telecommunication system (AUTOCOM) are passed continually to COSMOS. The data are inserted into a special-purpose data base after being subjected to a limited quality-control procedure that is a compromise between thoroughness and speed. At appropriate times, determined by the availability of data and the needs of forecasters, the basic observations are automatically plotted on maps. In this form, the data are of immediate use to forecasters. The same data base is also used to provide input for the analysis which is the first step in preparing the numerical weather forecast. The third use of the data base is to provide a source of data for the climatological archives. This application is assuming greater importance as more data for climatological purposes are being obtained nationally over the communication network.



Units used and jobs run monthly on the COSMOS computer, 1982–85.

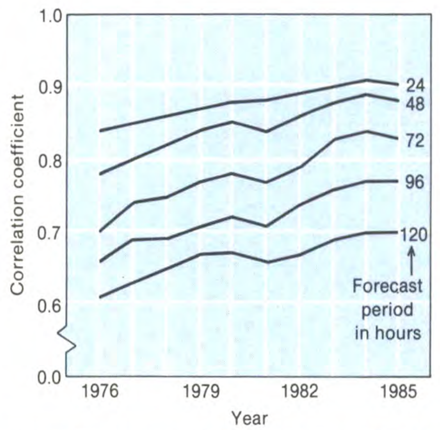
The availability of a powerful computer for numerical modelling is crucial to the Office's success in weather forecasting and meteorological research. A survey of requirements has recently been conducted and the technological position is being reviewed. A strategy for supercomputing in the Office for the next decade is being developed.

The forecast model and its performance

The two versions of the 15-level forecast model, the global version and the fine-mesh version, have now been in operational service for over three years. Sequences of verification statistics continue to show the consistent improvements in skill of the 15-level model compared with its predecessors. Judged by the correlations of forecast and actual changes at sea level in the North Atlantic region, the 1985 performance at three days ahead was as good as that achieved only one day ahead in 1976, and 1985's five-day forecasts had a similar skill to 1976's three-day forecasts.

Quite naturally, forecasters and other users of numerical model results are becoming accustomed to these improved levels of skill. The numerical products are being applied more widely and in more demanding ways than previously. As a result new and less obvious types of error are being identified, thus providing a spur to the continuing work of investigation and research.

The numerical weather prediction carried out at Bracknell is unique among operational systems in using the same scientific formulation at differing horizontal resolutions for global and regional purposes. The wisdom of this arrangement is becoming all the clearer as time passes. The global model has its grid points spaced at intervals of 1.5° in latitude and 1.875° in longitude, which is close to the maximum resolution for global coverage that can be used efficiently on the Office's Cyber 205 computer. Global forecasts up to six days ahead are computed twice daily, from 0000 and 1200 GMT starting conditions derived using observations arriving at Bracknell by 0320 and 1520 GMT. Results up to 36 hours ahead are available by 0415 and 1615 GMT, and the complete six-day forecasts by 0500 and 1700 GMT. The global model is required to fulfil the Office's responsibilities in Defence and as a World Area Forecast Centre for civil aviation, in support of marine and other commercial services world-wide, and as one of the sources of guidance for medium-range forecasting. Certain applications rely on the direct use of the computer-produced global forecasts; these include surface wind fields to drive the ocean wave prediction model and upper winds and temperatures for aviation flight planning. During 1985 the lowest ever root-mean-square errors for upper winds were recorded.

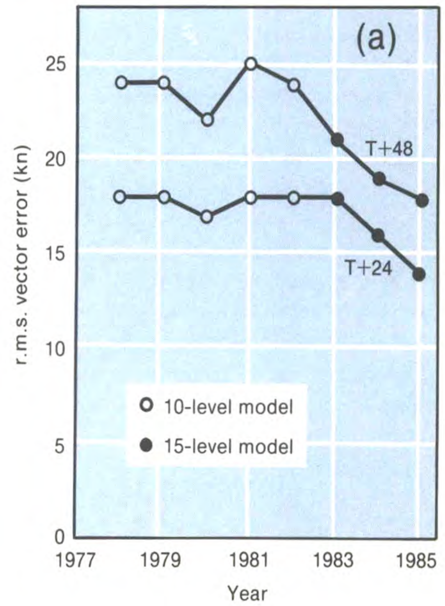


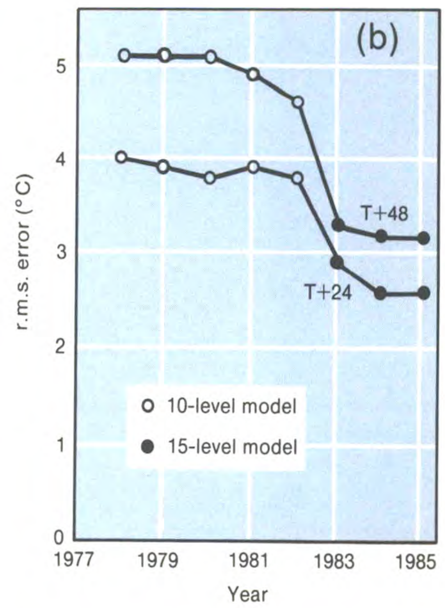
Annual average correlations between 24, 48, 72, 96, and 120-hour forecast and actual pressure changes at sea level for the North Atlantic region since 1976.

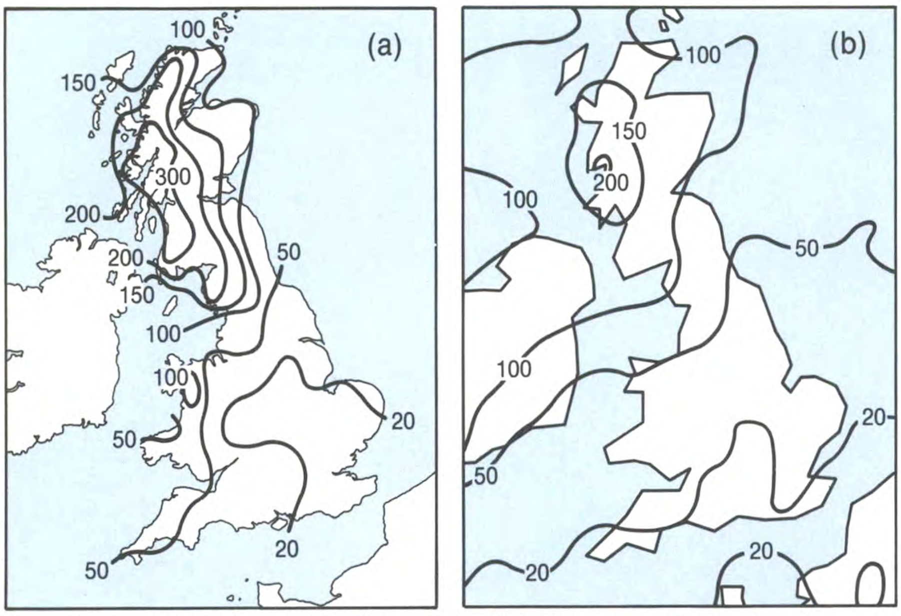
Despite the undoubted successes of the global model, it is known that its horizontal resolution—high by most standards—still limits certain aspects of forecast performance. The limitations have to be accepted for global forecasts until enhanced computing capacity is available. For regional purposes, however, great advantage can be gained from the fine-mesh model which has its grid points spaced at intervals of 0.75° in latitude and 0.9375° in longitude, that is, the resolution is doubled compared with the global model. This is made possible within the present computing capacity by restricting the area of coverage to the region 30–80°N, 80°W–40°E. At the lateral boundaries of this region the calculations make use of information provided from integrations on the coarser grid. Forecasts to 36 hours ahead are computed twice daily, from 0000 and 1200 GMT starting conditions derived using observations arriving at Bracknell by 0200 and 1400 GMT, with results available by 0300 and 1500 GMT. The benefits of the increased horizontal resolution are seen in more accurate forecasts of the positions of fronts, in the wind fields used to drive wave and surge models for the continental shelf region, and particularly in forecasts of precipitation. Monthly climatologies of 24-hour forecast precipitation totals are compared with the best estimates of what actually occurred and usually show good agreement as regards the general pattern and the totals for lowland regions, whilst totals are under-forecast, as is to be expected, in hilly areas.

On occasion the advantages of the fine-mesh model are especially marked in the prediction of rapid intensification of the

Wind (a) and temperature (b) root-mean-square (r.m.s.) errors for 24- and 48-hour forecasts at 200 mb in January, measured against radiosondes, in the North Atlantic region since 1978.







Total observed (a) and forecast (00–24 hour totals) (b) rainfall accumulations (mm) for September 1985.

smaller-scale low pressure systems and the associated strong winds.

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

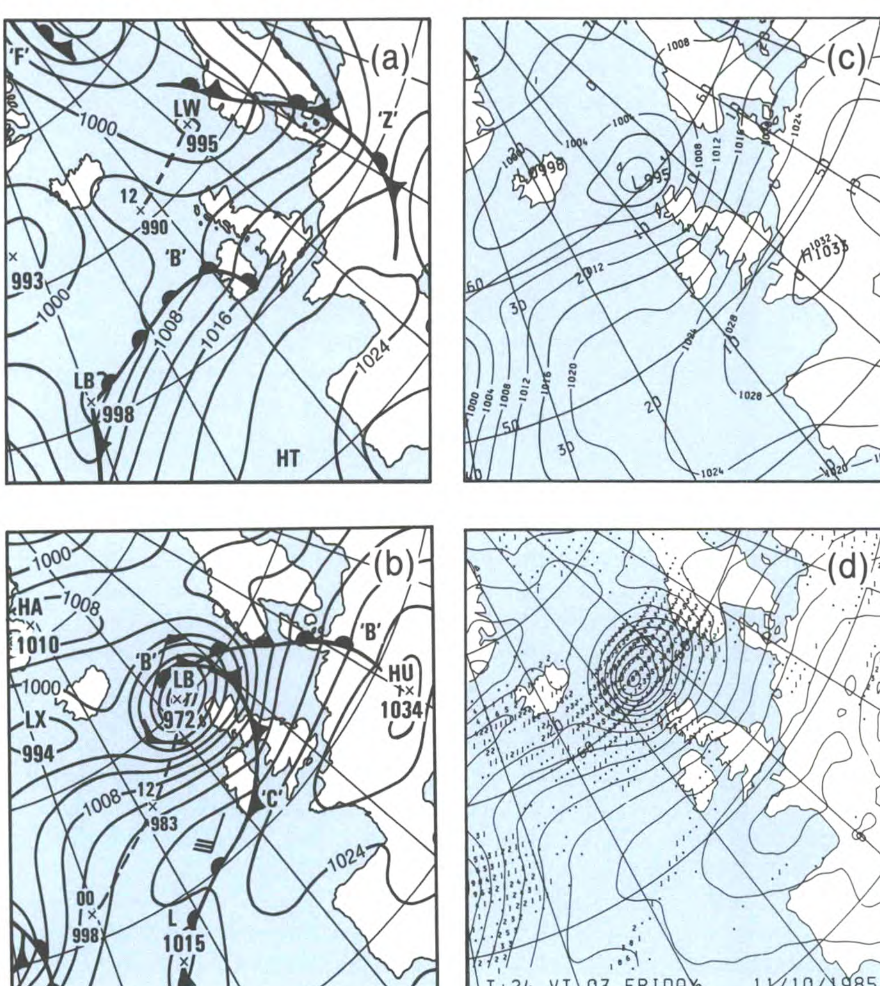
The models include a full range of parametrizations of turbulence, radiation, precipitation and convection. A major impact on the performance in 1985 has come from the inclusion of a new parametrization of the effects on the atmosphere of drag associated with subgridscale orographic features. This drag may be communicated to upper levels by orographically induced gravity waves. The effects are particularly marked for medium-range forecasts from the global model where the systematic errors previously noted, with a pattern of excessive westerly flow in the northern hemisphere winter, have been significantly reduced. Interestingly, however, benefits have also been noticeable for individual low pressure circulations passing over orography, even by 36 hours in the fine-mesh model.

Associated with both the global and the fine-mesh models are data assimilation cycles for the analysis of observations to determine the required initial values at the models' grid points. All relevant observations are used, whether derived from land stations, ships, buoys, aircraft or satellites. After quality control, which plays a crucial role, the selected observations are assimilated into the numerical models by relaxing the grid-point variables towards interpolated values, derived from the observations, after each time step of integration. For the global model this data assimilation is

Error statistics for the extratropical winter circulation in the northern hemisphere, showing the reduced errors in 36-hour forecasts in 1985 compared with 1984.

	Jan	Feb	Mar	Apr
Mean-sea-level pressure mean (mb)				
1984	−1.7	−2.5	−2.3	−2.2
1985	0.4	−0.8	−0.8	−0.9
Mean-sea-level pressure r.m.s. error (mb)				
1984	7.8	7.8	7.2	6.9
1985	6.3	6.8	6.3	5.9
500 mb height r.m.s. error (dam)				
1984	7.0	6.9	6.4	6.5
1985	6.4	6.3	5.7	5.7

Surface analyses (mb) at 0000 GMT on 10 October (a) and 0000 GMT on 11 October (b) showing the very rapid intensification and movement of Low B in 24 hours. The 24-hour forecast by the global model (c) is good as regards position, but the 24-hour forecast by the fine-mesh model (d) has the low about 20 mb deeper and within 3 mb of the analysed value.



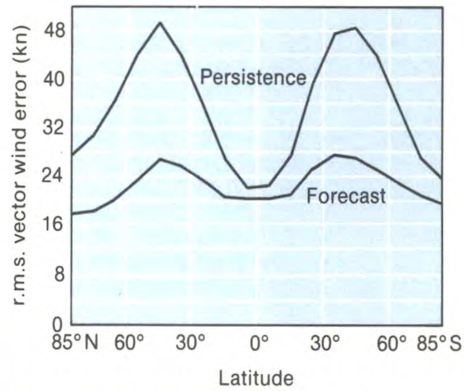
carried out in a six-hour cycle, taking account of all observations made within three hours of each analysis time. For the fine-mesh model the data assimilation is performed in a three-hour cycle, so that no observation is more than one and a half hours from an analysis time.

The inevitably incomplete and imperfect character of the observations available is generally regarded as one of the most serious factors that limit further advances in forecast performance. Hence there is emphasis on quality control. Here a major role is played by automatic procedures based on comparisons with short forecasts and with neighbouring observations. These procedures are expected to be improved by research now in progress. The automatic procedures are complemented by interactive monitoring and intervention carried out by experienced analysts in the Central Forecasting Office, whose contribution can be particularly effective when interpretation of satellite imagery yields information not otherwise available.

To assist the full exploitation of available and planned sources of observations, several studies are in progress to find out more about the effects of individual observations or groups of observations on the results obtained from the operational models. Such studies entail the review of the enhanced observing system that was available during the Global Weather Experiment in 1979, and also the assessment of the likely impact of possible future changes in the global observing system.

During 1985 there was continued expansion of the international dissemination from Bracknell of numerical forecast products to other National Meteorological Services. Regional Meteorological Centre products, from both the global and the fine-mesh models, now go as routine to almost all the countries of Europe. World Area Forecast Centre products have been sent twice daily to the United States of America, France, the Federal Republic of Germany and New Zealand. Selected products are also being routed to Japan, Australia, Hong Kong and to several countries in Africa as a result of bilateral arrangements. This much wider use of Bracknell products in various regions is expected to result in useful feedback on model strengths and weaknesses. It is already encouraging to find that upper-level wind forecasts, for example, have smaller root-mean-square errors than persistence at all latitudes, even at three days ahead. The advantage over persistence (i.e. a forecast of no change) is very marked in the middle latitudes of both the northern and the southern hemispheres, but the performance near the equator, even though the advantage over persistence is much more modest, is also an impressive result by previous standards.

Notwithstanding the prospect of further advances in forecast model performance, the successful interpretation of the numerical guidance remains crucially important. New forms of diagnostic interpretation are becoming available from the 15-level model, including fields of cloudiness based on the model's parametrizations and information about clear air turbulence and convective cloud tops for aviation significant weather forecasts. For surface forecasting, many hopes for the future are pinned on the mesocale forecast model which would, in effect, provide a detailed dynamical and physical interpretation of the fine-mesh model over the United Kingdom. The usefulness of model results can be further enhanced by statistical interpretation that relates the numerical forecasts to the expected observed conditions at particular locations. A trial is being arranged of forecasts of screen maximum and minimum temperatures derived statistically from fine-mesh model forecasts at a group of UK stations. Whatever objective guidance is available, however, the interpretive role of forecasters, working in the Central Forecasting Office and elsewhere with information derived from the models, with satellite and radar imagery, and with the latest observations, will continue to provide the essential final link with many users of surface forecasts.

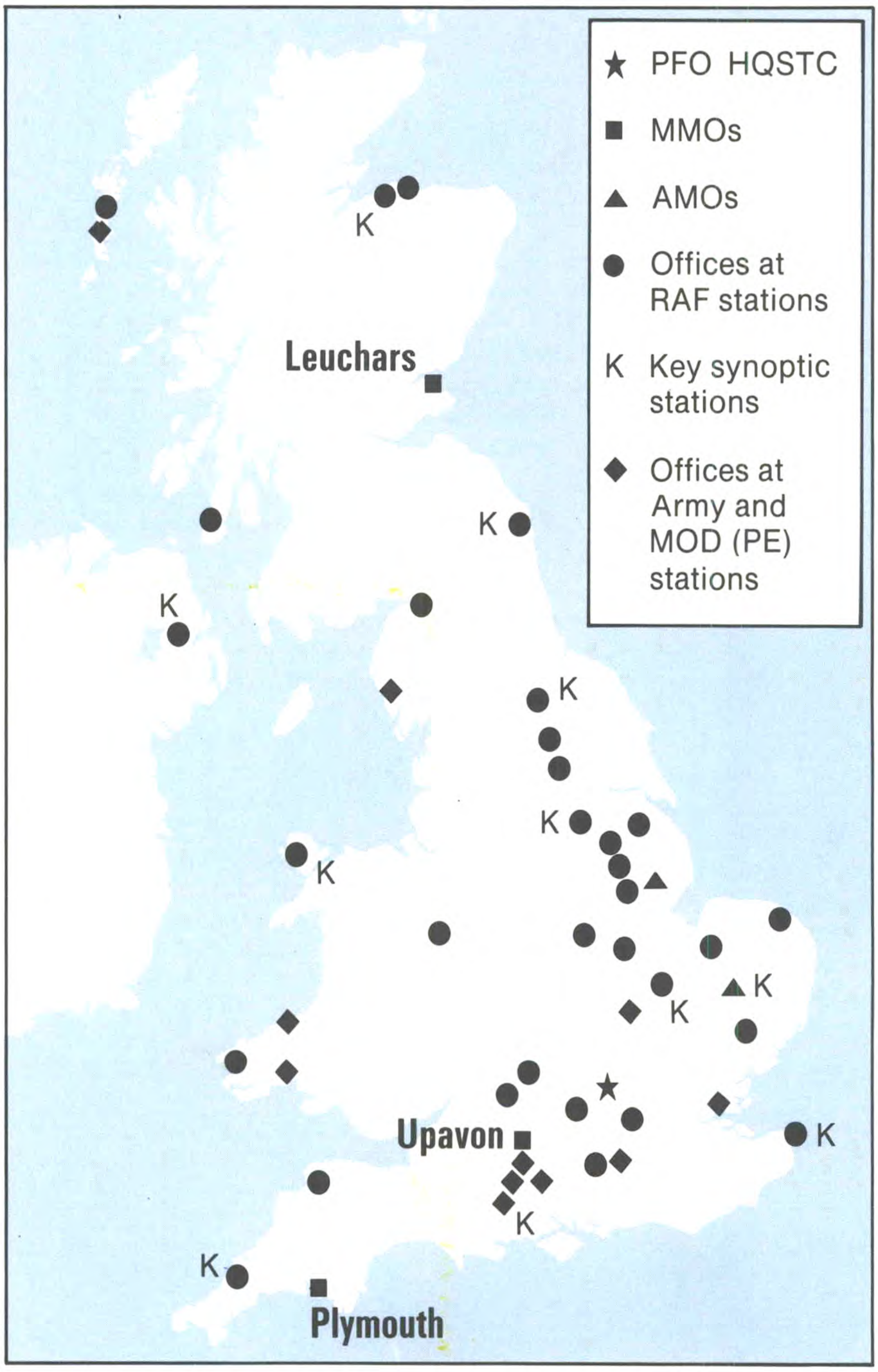


The distribution with latitude of annual average root-mean-square (r.m.s.) vector wind errors at 200 mb of forecast and persistence for three days ahead.

Services for Defence

Historical background

The collection and discussion of weather observations in the United Kingdom began in 1831 in the Hydrographic Department of the Admiralty, but by 1838 a more extensive scheme had been established for obtaining weather information which included the making of observations as one of the duties of the Royal Engineers on foreign service and of consuls in foreign parts. In the United States, James Pollard Espy developed a storm warning service in 1840 and became the first Chief of the Meteorological Bureau of the United States War Department in 1841. In 1845, during the Crimean War, a severe storm in the Black Sea damaged the Allied Fleet, and sank the French ship *Henri IV*, prompting the French War Minister to order a study of conditions by the Observatory of Paris. The Meteorological Office has its origins in 1855 when Admiral FitzRoy became the first Superintendent of the Meteorological Department of the Board of Trade. During the First World War there was a great demand for meteorological advice and specialized services from the Navy and the Army, including the Royal Flying Corps. The close historical relationship between the Meteorological Office and the Royal Air Force goes back to 1918 when the Royal Air Force was formed from the Royal Flying Corps and both found themselves in the newly formed Air Ministry. The close relationship remains. The Office expanded greatly during the Second World War until, by 31 March 1945, a total of 6266 staff was devoted almost entirely to meeting the needs of the Royal Air Force.



Meteorological offices at Defence establishments.

Resource allocation

With the development of many other services, for example in response to the needs of civil aviation, industry, commerce and the general public, and the rise of research in the Meteorological Office to its present leading international position, only 645 staff (24 per cent of the total complement) remain directly employed in Defence activities. A summary of offices meeting military needs at 31 December 1985 and their staff complements is shown on page 20. The distribution of those offices in the United Kingdom, all of which are at Defence locations, is shown above. Main Meteorological Offices (MMOs) overseas are located at RAF Gibraltar and RAF Akrotiri in Cyprus. Meteorological offices are also located at RAF Bruggen, Gütersloh, Laarbruch and Wildenrath, and with the Army Air Corps at Detmold, in the Federal Republic of Germany. Offices are established at RAF Wideawake on Ascension Island and at RAF Stanley and Mount Pleasant Airfield (MPA) in the Falkland Islands. The Royal Aircraft Establishment (RAE) Aberporth, the Royal School of Artillery (RSA) Larkhill and the Ministry of Defence Procurement Executive Proof and Experimental Establishments (P and EEs) at Eskmeals, Pendine and Shoeburyness all have collocated meteorological offices. Senior staff hold the posts of Chief

Meteorological Officer (C Met O) at Headquarters Strike Command (HQSTC) and at Headquarters Royal Air Force Germany (HQRAFG) at Rheindahlen. The C Met O at HQSTC acts as Chief Meteorological Officer to the NATO Commander-in-Chief of the United Kingdom Air Region.

When central resources and services, such as numerical forecasting, communications, and Defence-related research and development are taken into account, around 40 per cent of the net expenditure of the Office can be identified as related more or less directly to the needs of Defence.

Central services

In normal times much of the basic meteorological data and many of the products needed for Defence come from the computing facilities and the computer-based communications centralized at Bracknell, although in an emergency military services can be maintained independently of Bracknell by making use of data and products from other NATO nations through bilateral and NATO-wide arrangements. The Principal Forecasting Office (PFO) at HQSTC provides comprehensive services specifically geared to Defence requirements in the United Kingdom and for British Forces in Germany by means of dedicated facsimile and teleprinter transmissions over military circuits. The transmissions include forecast charts for use as documentation by aircrew and detailed guidance for the forecasters face to face with the users at operational airfields and headquarters.

During 1985 technical and financial approval was given for the implementation of the first phase of the Weather Information System (WIS). The first phase is designed to provide forecasters at certain operational airfields with direct and immediate access to the data and products they require to meet the local need, and will act as a prototype for the fully implemented system. The computer-based systems designed to meet this requirement have been developed within the Office from a definition of the user need, based on the Air Staff statement of requirement. The Defence communication aspects of the Office are fully integrated into Air Staff communication planning through a Meteorological Office/Air Staff Liaison Group on Meteorological Communications, jointly chaired by the Meteorological Office Deputy Director responsible for Communications and Computing and the Director of Signals (Air) from the Air Force Department. Groups of specialists within the Office are available to assist with the Defence aspects of such varied activities as the integration of weather radar outputs to form a country-wide network; research into the meteorology of radar ducting; the development of automatic weather-observing equipment; thunderstorm detection and, of course, the continuous development of numerical forecast models to provide shorter-period and finer-resolution products. All such activities, and many others, carried out centrally at Bracknell, assist the forecasters in meeting the demands at operational military airfields and headquarters for the detailed short-period forecasting of the physical behaviour of the lower levels of the atmosphere, which forms the main part of the military requirement.

Services for the Royal Air Force

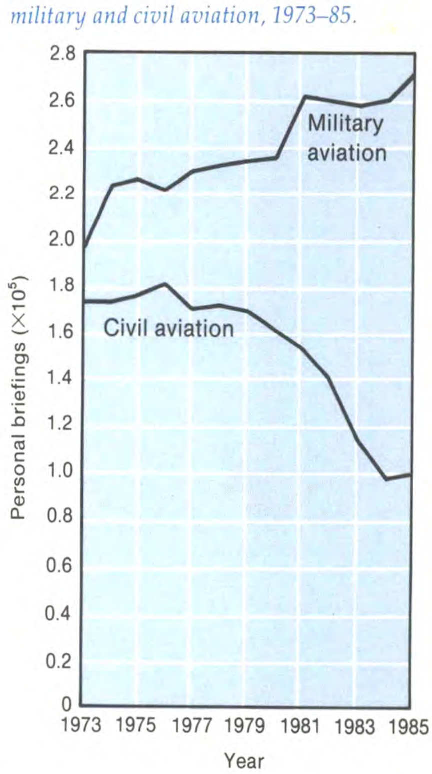
On 1 April, 567 staff (over 21 per cent of the total complement of the Meteorological Office) were providing services for the Royal Air Force at 50 locations in the United Kingdom, Germany, the Mediterranean and the South Atlantic.

In 1977 an Air Staff requirement for meteorological services was formally endorsed by the Vice-Chief of the Air Staff. The formalization of the RAF requirement made it possible for the Office to develop long-term plans on authoritative forward-looking assumptions which took full account of the introduction of new generations of aircraft into service. By 1977 the concept of air power, based on the capabilities of aircraft such as the Tornado, was more or less settled. Particular importance was attached to forecasting for low-level operations for short periods ahead and to the essential role of the forecaster in direct contact with aircrew and operations staff. Aircrew have long since recognized, from experience, that the applied skills of the meteorologist and a local knowledge of the behaviour of, for example, cloud base and visibility, have a real contribution to make to the effectiveness of air operations, particularly in marginal flying conditions. A comparison of the numbers of personal briefings provided for civil and military aviation, year by year from 1973 to 1985 (shown right), illustrates the trend towards the greater use of the services of the forecaster at military airfields foreseen in the Air Staff requirement in 1977. It was also recognized that a close working relationship between forecasters and aircrew improves the effectiveness of the forecaster by extending his understanding of the meteorological sensitivities of the various types of weapons systems and air operations. The 1977 Air Staff requirement was reaffirmed in November 1981 and revised in September 1984. A further revision in August 1985 brought the requirement up to date and provided a firm basis for developments designed to improve the effectiveness of short-period forecasting for low-level operations. Services for medium- and high-level operations, such as tanking and long-range air transport, are still required but no longer generate the main demand from the Royal Air Force.

The PFO at HQSTC and meteorological cells on airfields are being collocated with operations staff and will be able to maintain vital services in peace or war.

It would run counter to the formal Air Staff statement of requirement if the airfield forecaster were to act solely as an agent for a centralized organization rather than as a professional adviser in his own right, particularly when central products relate almost entirely to forecasting beyond 12 hours ahead. The concept of WIS has its origins in the need to give back to the local forecaster a professional and personal role in the direct support of air operations, but there is also an essential need to replace the slow teleprinter and facsimile broadcasts, long established throughout the Office and already obsolete in terms of equipment, with a fast computer-based demand system where the initiative for calling up the data and products needed to meet the immediate requirement is placed in the hands of the forecaster. An immediacy of response is essential if

Number of personal briefings given to military and civil aviation, 1973–85.



meteorological services are to contribute to the effectiveness of air operations. The implementation of the second phase of WIS in support of Defence activities will depend to some extent on experience gained in the first phase but it is planned to extend WIS to the remaining operational airfields in this phase.

As part of the continuous process of matching limited resources to changing Defence needs the MMO at the Headquarters of the Northern Maritime Air Region (HQNORMAR) at Pitreavie was transferred to RAF Leuchars in September to form a combined MMO and airfield meteorological office with a consequent saving of staff. The transfer was associated with the closure of HQNORMAR. The RAF-manned Rescue Co-ordination Centre will remain in the RN operations centre at Pitreavie and will be supported directly from the MMO at Leuchars over a dedicated line, using document facsimile for the immediate transmission of data and products.

Other changes in the organization of services for the Royal Air Force during 1985 included the build-up of the MMO on MPA in the Falkland Islands. This began with the posting-in of staff to oversee the building of the accommodation for the MMO and the installation of equipment, and to start an observing program.

One observer was in post in time for the first wide-bodied jet flight into MPA in May. Forecasting services in the Falkland Islands were maintained throughout 1985 by the RAF Mobile Meteorological Unit at RAF Stanley which has been continuously manned since the Falklands Conflict in 1982 by volunteer Office staff in the Royal Air Force Reserve of Officers.

One of the national responsibilities of the Office is to maintain a long-term record of observations on which climatological and other advisory and data services are based. A number of the long-established Defence locations are at sites from which long and continuous records of observations are available. Such observing sites, most of which are on RAF airfields, are designated within the Office as 'key' synoptic stations (see page 16). Every effort is made to preserve the continuity of long-term meteorological records.

Services for the Army

The Army Air Corps is as aware as the Royal Air Force of the effect of weather on its operations, particularly where the latest weapons-sighting systems are concerned. The wider interest of the Army in the effects of weather on land-force operations, and in the services which could be provided by the Meteorological Office, is less well defined. The Royal Air Force is well versed in using the services of the Office to increase the effectiveness of its operations, mainly because aircrew and operations staff are trained in meteorology, but the effect of weather on land-force operations is not a subject which has been given much attention in the staff training of Army Officers. However, now that a post of Staff Meteorological Officer has been established in the field headquarters of 1(BR) Corps in Germany, at the instigation of the Corps Commander, training on Army staff courses in the effects of weather on the land battle might well lead to Army commanders exploiting the weather rather than suffering it.

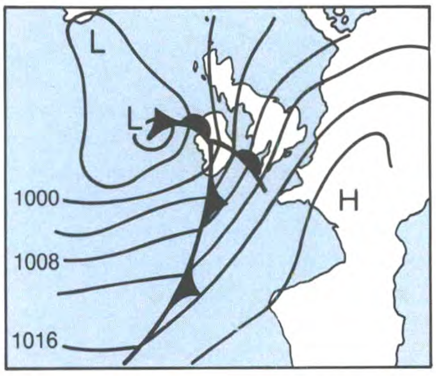
Over the past decade a close association has developed between the Directorate of the Army Air Corps and the Meteorological Office. The Army Air Corps is faced with problems similar to the Royal Air Force in operating helicopters and light aircraft and, in particular, needs to exploit every opportunity provided by the weather if it is to use its anti-armour weapons systems and the associated sophisticated sighting and ranging devices to maximum effect in countering the substantial threat posed by Warsaw Pact offensive armour. The provision of services for the Army Air Corps in the field is a more difficult problem, although support is exercised in Germany by a mobile forecast unit which has been established to meet the needs of off-base Harrier deployments.

Services for the Ministry of Defence Procurement Executive (MOD(PE))

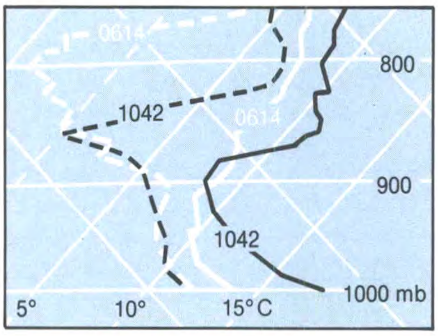
The meteorological offices at P and EE Eskmeals on the Cumbrian coast and Pendine in Dyfed provide services related to the proof firing of artillery and mortar rounds. The P and EE office at Shoeburyness also provides services for the explosives testing ground at Foulness. The office at RSA Larkhill, in addition to the services it provides for artillery training camps, provides a service for the RAE range at Larkhill and for the Chemical Defence Establishment at Porton. The meteorological office at RAE Aberporth provides services for the varied trials carried out on the Aberporth range in Cardigan Bay. Full upper-air sounding systems are established at the Eskmeals, Shoeburyness, Larkhill and Aberporth offices and are capable of providing data up to a height of 30 km for trials.

A meteorological input is essential in making the decisions related to range safety. In addition to that service, which can be decisive in deciding whether or not a trial can take place and in ensuring its safe conduct, a great deal of meteorological data is also provided for post-trial analyses.

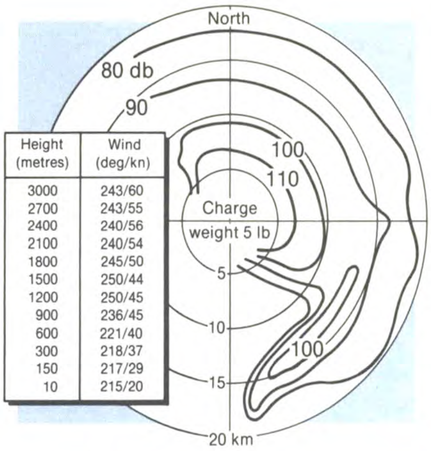
At all the trials establishments an important part of the work of the meteorological offices is the forecasting of noise levels outside the ranges, associated with explosions or gunfire. Ranges are usually sited in remote areas to reduce disturbance to the general public but it has long been recognized that noise from range activities can be intolerable beyond the range boundaries under certain weather conditions. So-called 'blast-focusing' used to be regarded as a somewhat capricious phenomenon. Computer programs have recently been developed, however, which can solve the complicated equations used to determine where the noise will be most intense. For example, on 20 August a warm front was approaching England and Wales from the west (see below). Two radiosonde ascents made 4½ hours apart from the meteorological office on the RSA range at Larkhill (see foot of column) show the rapid development of a temperature inversion at about 900 mb as the warm front moved closer. From the temperatures and humidities obtained from the ascents, the associated wind measurements, and other information



Surface analysis (mb) for 0600 GMT on 20 August 1985.



Radiosonde ascents made from Larkhill at 0614 and 1042 GMT on 20 August 1985.



Height (metres)	Wind (deg/kn)
3000	243/60
2700	243/55
2400	240/56
2100	240/54
1800	245/50
1500	250/44
1200	250/45
900	236/45
600	221/40
300	218/37
150	217/29
10	215/20

Forecast winds and 'acoustic polar diagram' for a trial planned to take place at Larkhill at 1330 local time on 20 August 1985.

available to the forecaster, the distribution of temperature, humidity, and wind speed and direction in the vertical over the Larkhill range was predicted for a trial planned for 1330 local time. The forecast data were then used to compute an 'acoustic polar diagram' (see above) showing the noise levels in decibels (dB), over an area with a radius of 21 km centred on the trial. The 100 dB contour delineates the focus of the sound produced by the trial which, in this case, was situated some 15 km distant over a narrow band lying south-south-west to north-north-east to the south-east of Larkhill. If the forecast had shown that high levels of sound from the trial would focus on centres of population the trial would have been postponed. The techniques are in routine use and have already led to reductions in damage claims and an increase in the efficiency with which trials can be conducted through the elimination of subjective judgement as to whether a trial should go ahead or be postponed on the grounds of noise nuisance outside the range.

Services for the Home Office

The Home Office United Kingdom Warning and Monitoring Organization (UKWMO) has a national responsibility for warning of air attack and monitoring nuclear fall-out. UKWMO controls country-wide monitoring posts and can reach 22 000 locations, such as police and fire stations, hospitals, public utilities and Civil Defence headquarters, across the nation. Meteorology is an essential input in the calculation of fall-out intensities and trajectories. Meteorological support for UKWMO is provided at the UKWMO Sector Controls, each of which has a regional responsibility. In exercises involving the Sector Controls three forecasters provide continuous manning of the meteorological cells, making use of data obtained from Bracknell and through direct links with the eight radiosonde network stations in the United Kingdom.

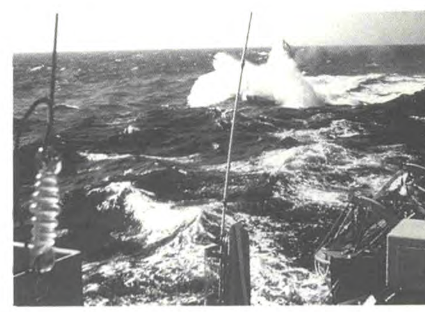
Support for the Royal Navy

Meteorological services for the Royal Navy are the responsibility of the Directorate of Naval Oceanography and Meteorology (DNOM). The Office provides observational data, which are not available through Royal Navy channels, and makes freely available for DNOM use any of the analyses and forecasts prepared at Bracknell. The Office and DNOM work closely together and DNOM's meteorological needs are incorporated into Office planning. WIS, for example, takes account of the requirements of the Naval Air Stations and the Royal Navy School of Oceanography and Meteorology at Culdrose. Close co-operation is maintained at the working level between the PFO at HQSTC and the Fleet Weather and Oceanographic Centre at the Royal Navy and NATO headquarters at HMS *Warrior*, Northwood. A Commander RN on the staff of DNOM occupies the post of Naval Liaison Officer at Bracknell.

The excellent co-operation which exists between the two organizations was demonstrated in the exercise of joint responsibilities during the Falklands Conflict, when the application of meteorology and oceanography at all levels of command from the Commander-in-Chief down to individual units of the Task Force proved to be a vital factor in making the right decisions in the face of the Argentinian threat during the southern hemisphere winter. The same close co-operation in international military affairs ensures that UK meteorological resources from the Meteorological Office and the Royal Navy are co-ordinated when responding to the needs of NATO.

NATO and bilateral co-operation

The importance of meteorology in ensuring that military power can be exercised to its full effect if ever the need were to arise is recognized by the Military Committee of NATO. The Military Committee Meteorological Group (MCMG) is the only body of specialists to report direct to the Military Committee rather than to the major NATO Commanders. The United Kingdom is represented on the MCMG, and on other committees within NATO concerned with meteorology such as the Meteorology Panel of the NATO Army Armaments Group, by staff from the Meteorological Office working in close co-operation with their DNOM colleagues.



Marines on exercise in northern Norway. Harriers arriving at RAF Stanley. Rough seas (Task Force conditions?).

Meteorological activities throughout the NATO area are co-ordinated between National Meteorological Services under policies and procedures agreed between the nations in the MCMG. The small meteorological organization under direct NATO control which exists in some NATO operations centres within Allied Command Europe is directly supported by the United Kingdom through the secondment of a forecaster and an assistant to the NATO Allied Meteorological Office at Maastricht.

The maintenance of close bilateral working relationships with other military Meteorological Services in NATO is also important, both nationally and in making the most of our mutual responsibilities in supporting NATO-assigned forces. A high level of bilateral co-operation in military meteorological matters exists with the United States, between Bracknell and the Department of Defence and various military headquarters in the USA. A similar high level of bilateral co-operation exists with the German Military Geophysical Office at Traben-Trarbach in the Federal Republic of Germany. Bilateral co-operation is based on common interests in supporting our respective national forces in Europe in peacetime and in developing and exercising our ability to work very closely together within NATO as a contribution to deterrence and, if it were ever to prove necessary, in war.

Summary

Success or failure in military operations often depends on the exploitation of marginal differences between the opposing sides. The commander who is sensitive to the effects of weather on his own and opposing forces will be in a position to exploit the weather rather than suffer it, and so load the balance in his favour. NATO forces in north-west Europe are likely to remain sensitive to weather because of the incidence of weather that is sufficiently adverse to affect military operations, particularly in winter, even with increasingly sophisticated weapons systems in the hands of highly trained personnel. The aim of the Office and the role of the meteorologist in direct contact with military commanders and aircrew is to provide the advice and services that will allow the opportunities for marginal advantages to be recognized and exploited in war, and for training and exercises to be conducted safely in peace.

The Office, apart from providing advice and services for a wide range of military activities, is concerned with developing an organization and technology which will meet changing and ever-increasing military needs and with training its manpower in a military support role. This work is backed by scientific research which is constantly seeking ways of improving the application of meteorology to a wide range of user needs. For all those aims to be met with limited financial and reducing manpower resources there is a need for all levels of military command, both nationally and within NATO, to understand the effects of weather on military operations and to recognize the support which the meteorologist is able to provide.

Summary of Defence Services offices and staff complements, 31 December 1985

	United Kingdom		Germany and the Netherlands		Mediterranean and South Atlantic	
	Offices	Staff	Offices	Staff	Offices	Staff
HQ Bracknell	1	14				
C Met O HQSTC/HQRAFG	1	6	1	6		
SMO[1] HQ1(BR) Corps			1	1		
PFO HQSTC	1	52				
MMOs	3	74			2	44
AMOs[2]	2	31	2	30		
Subsidiary forecasting and observing offices:						
RAF	32	262	2	18	3	16
Army aviation	2	11	1	9		
MOD (PE) Army trials establishments	7	54				
NATO Allied Meteorological Office			0	2		
Radiosonde units	4	0*			1	15

* Function integrated with subsidiary forecast offices at MOD (PE) establishments
[1]SMO, Staff Meteorological Officer
[2]AMO, Area Meteorological Office

Services for civil aviation

The Meteorological Office provides a comprehensive series of services for civil aviation carried out on behalf of the Civil Aviation Authority (CAA) on a repayment basis. The costs of about £15 million per annum are recovered by CAA as part of the *en route* charges levied on aircraft using the air navigation services within UK airspace.

Civil aviation can be divided into two categories: commercial air transport (which covers all scheduled airline services) and 'general aviation'. The latter includes flying in private aircraft and some business activities such as crop spraying, aerial survey work and air taxiing (using both fixed-wing aircraft and helicopters). It also comprises a range of leisure activities from gliding and micro-light flying to hot-air ballooning and parachuting. It is not surprising therefore that the services provided for commercial air transport are rather different from those for general aviation.

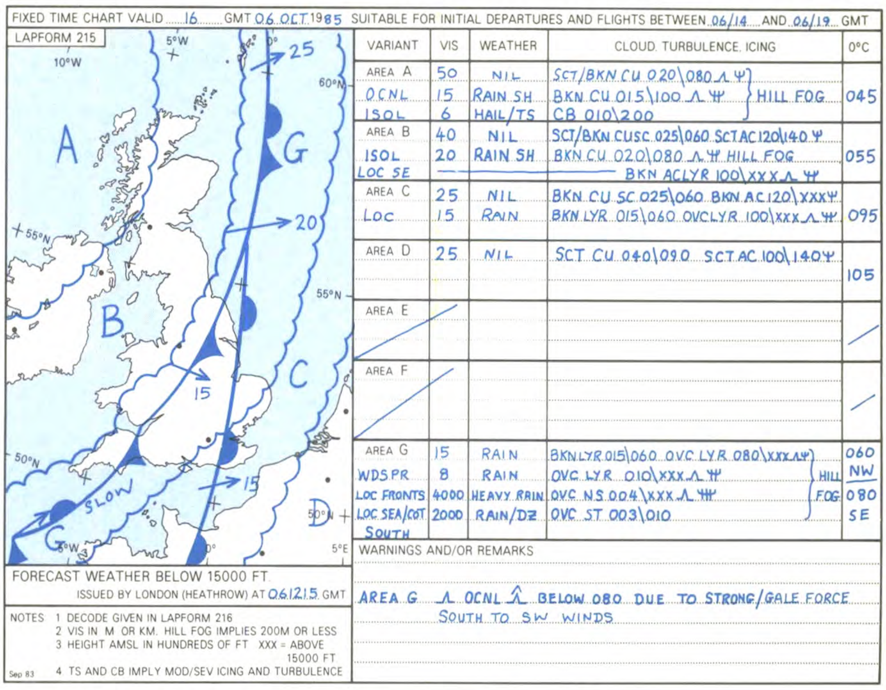
Common services

Some essential services are common to all aviation. Warnings are issued when hazardous weather conditions are expected which could affect the safety of aircraft in flight, while landing or when parked on the ground. Observations are normally made every half hour during the period of operation of the airfield and are coded into Meteorological Aviation Report (METAR) form. Landing forecasts are provided routinely, generally every

Forecasts are provided by the Office for all types of civil aviation including hot-air ballooning and flights by Concorde. (Concorde photograph by courtesy of British Airways)

three hours, for all major airfields and these are disseminated nationally and internationally. Forecasts of minimum pressure values for each of 20 regions over and around the United Kingdom are prepared every hour and distributed by meteorological teleprinter channels and the Aéronautical Fixed Telecommunication Network. These are used to ensure the safe clearance of high ground by aircraft and to maintain a proper vertical separation between them.

The Meteorological Office, on request from the Accident Investigation Branch of the Department of Transport, provides detailed weather information which may be relevant to an aircraft accident. Normally this consists of copies of actual weather reports, forecasts and warnings valid at the time of the accident, together with a résumé of the general weather situation.



This low-level weather chart was used in an investigation for CAA into an incident in which a pilot of a light aircraft got into difficulties whilst attempting to remain below cloud in the Birmingham area.

Services for commercial air transport

The service for commercial air transport is based on the World Area Forecast System which was implemented in November 1984. Under this system the two world centres at Bracknell and Washington each provide forecasts of upper wind and temperature in digital form for a series of grid points covering the entire globe. The forecasts for 12 and 18 hours after observation time are issued twice daily for a series of nine flight levels; 24- and 30-hour forecasts are also issued, for back-up purposes.

These forecasts are sent to selected Regional Area Forecast Centres (RAFCs). Bracknell is one of four RAFCs in Europe whose task is to convert the grid-point data into chart format for distribution to the state Meteorological Services and airports within the region. Six companies now accept the global grid-point data direct from Bracknell for computerized flight planning: British Airways, Scandinavian Airlines System, Japan Air Lines, Pan American Airways, Aeronautical Radio Incorporated and the Société Internationale de Télécommunications Aéronautiques (SITA). In turn SITA provides forecast data and flight planning information to 13 other airlines including Air France, Lufthansa, Swiss Air, Delta Airlines and American Airlines.

In addition to the charts displaying grid-point data, the flight documentation includes charts of 'significant weather' which are produced manually in the Central Forecasting Office (CFO) at Bracknell. The area of particular concern is that for westbound flights from Europe to North America. CFO is also responsible for the issue of in-flight warnings of certain significant weather phenomena (SIGMETs) for the Shanwick Oceanic Control Area. The offices at Heathrow and Glasgow are similarly responsible for the London and Scottish Flight Information Regions respectively.

Services for general aviation

While the above arrangements cater adequately for commercial air transport, general aviation has rather different requirements. Some restructuring of the service for general aviation is planned and much work has been done to try to balance the economic pressures against the desire to provide a complete professional service. The aim is to introduce a comprehensive new service of forecasts and warnings to cover the needs of individual pilots and airfields.

The three main forecasting centres will be Heathrow (with overall responsibility), Manchester and Glasgow, but the local expertise of other regional forecasting offices will also be used. General guidance will come from the low-level weather chart issued by Heathrow and made available on the Civil Aviation Meteorological Facsimile (CAMFAX) broadcast. The forecasting offices will then produce written forecasts suitable for both area and route forecasts. These will be stored in the CAA message-switching computer at Heathrow for onward transmission to airfields on request. The forecasts will also be recorded on an automatic telephone service system which can be used by individual pilots and at those airfields not connected to the CAA message switch. Airfields with the facility to receive charts through document facsimile will be able to receive the forecast charts direct from the main centres. A limited text service will also be available on the British Telecom viewdata system Prestel.

The self-briefing area at London/Heathrow Airport.

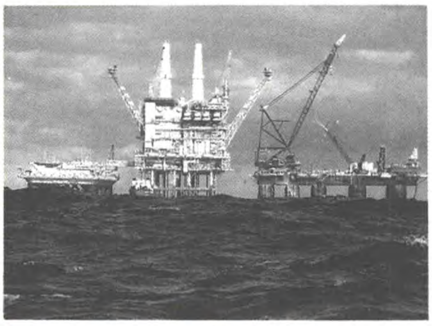
Services for the offshore industry

Many aspects of work in the offshore industry are highly weather sensitive and the Meteorological Office provides specialized services to assist oil companies at every stage of the process.

At the design stage, companies need to know the greatest wind speeds, gusts and wave heights likely to be encountered so that structures can be built to withstand the appropriate loads and stresses. This advice is provided by the Marine Bureau at Bracknell Headquarters using a vast data bank of observations going back many years. More comprehensive analyses of past conditions can also be produced for planning purposes.

The construction, exploration and production phases require forecast information, over various time-scales, tailored to meet each operator's special need. The North Sea experiences extreme weather conditions at times and yet some of the work carried out is remarkably delicate. If the wind speed or wave height is expected to exceed certain thresholds, work has to be stopped, otherwise there are unacceptably high risks of expensive damage to equipment and on some occasions a danger to life.

London Weather Centre is the main office for offshore forecasting, with subsidiary offices at Aberdeen, Sella Ness (Shetland) and Kirkwall (Orkney). Forecasters there receive the computer forecasts of wind and waves from Bracknell, together with an increasing



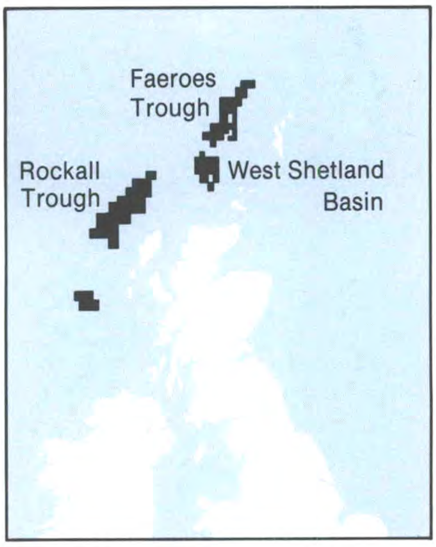
Oil platforms in the Brae 'A' Field. (Photograph by courtesy of Marathon Oil UK Ltd)

number of observations from the continental shelf area. The forecasters use these, together with their own experience and expertise, to produce detailed forecasts for individual locations. For some of the most weather-sensitive operations, a forecaster is required offshore where, with the full support of the Office resources, the weather situation can be discussed directly with the operations team. An increasing number of companies have found considerable benefits from having an experienced forecaster on site in this way.

Many companies require daily or twice daily forecasts for up to five days ahead. These forecasts are usually sent by telex, although it is becoming more common for information to be sent directly into the companies' computing systems.

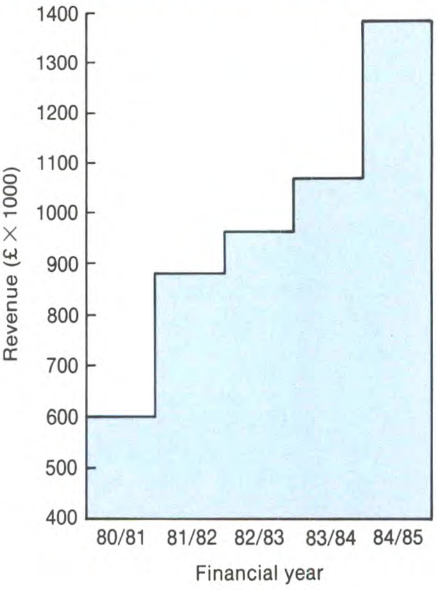
Most of the offshore forecasts are for locations on the UK continental shelf, but the Office is also becoming increasingly involved with forecasting in other areas, particularly the Mediterranean for which there is a special computer wave model. London Weather Centre forecasters were deployed to Spain on several occasions during the year. For one project they were stationed on a rig off the north coast of Spain, where exploration work was being undertaken. On other occasions they gave advice for rig tows from Cadiz and Barcelona to Bilbao.

New exploration areas due to be opened up.

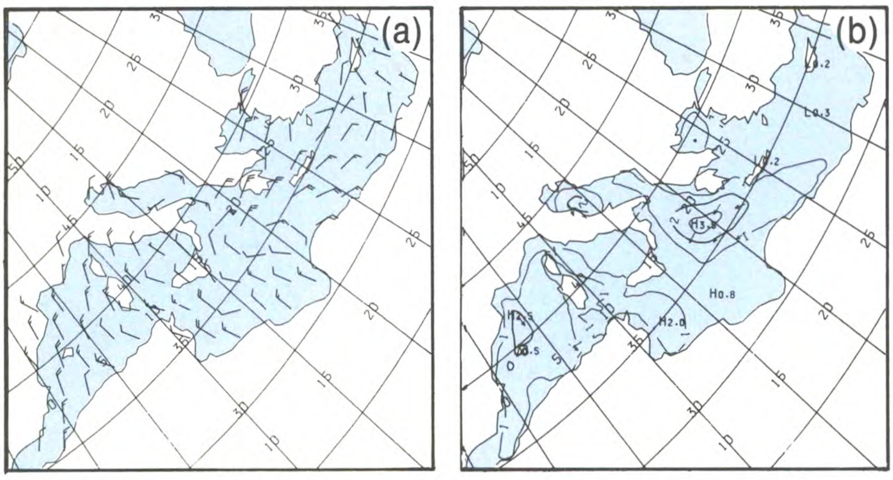


As the search for oilfields continues in new areas, requests for forecasts are expected to expand into other remote locations. For instance, the area to the north-west of Scotland is due to open up as a major region for exploration. The amount of observational data available from this area is very limited and both the performance of the forecast models and the expertise of the forecasters will be tested to the full.

Revenue earned from the offshore industry.



Examples of output from the Mediterranean wave model showing wind speed and direction (a) and sea swell (b).



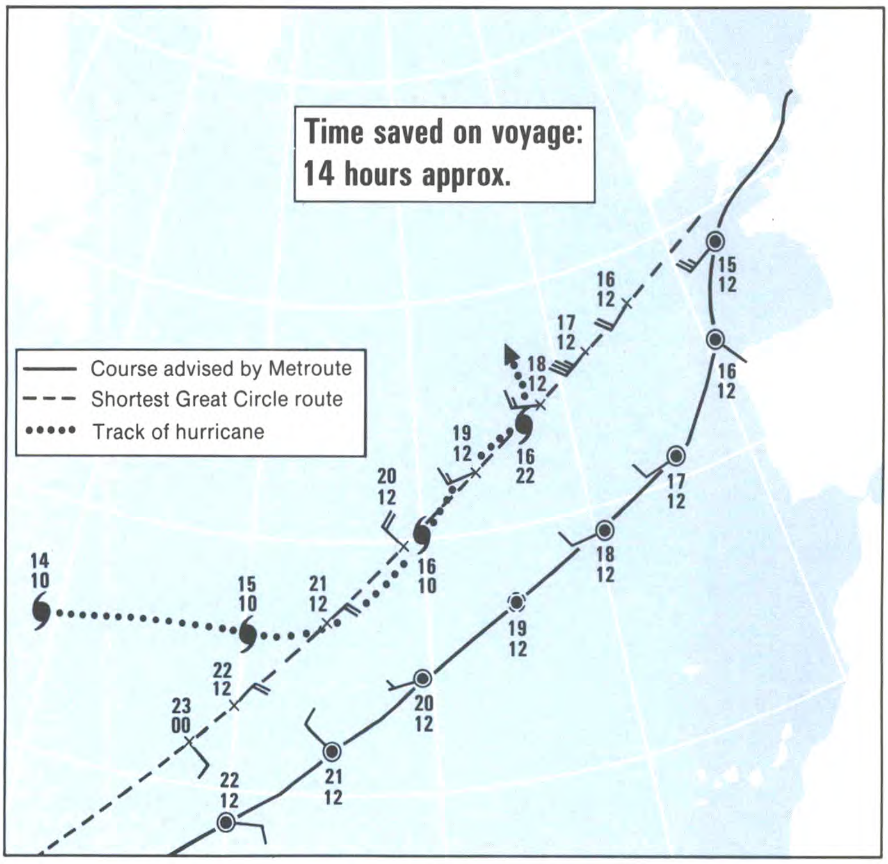
Services for shipping

Metroute, the Meteorological Office Ship Routeing Service, provides a comprehensive range of services for ships and structures on passage or under tow world-wide. Advice, based on global numerical weather prediction and knowledge of vessel performance in the forecast conditions, is provided on repayment to shipmasters at sea regarding the safest and most economical routes to follow. Performance analyses in the form of 'hindcast' charts can also be prepared for the shipowner or operator requiring records of actual weather experienced and performance achieved.

Weather information of all kinds is provided by the Meteorological Office for ships operating in home waters and the eastern North Atlantic. Information in the form of weather bulletins, forecasts and gale warnings is distributed in regular broadcasts by the BBC and British Telecom International. The warnings are also relayed to 35 port and other authorities. For coastal shipping and sailing there is a strong wind warning service, provided through HM Coastguard stations, giving advance notice of winds of force 6 or more for up to five miles from the coast. Between Easter and October a similar warning service is provided through local radio stations for the benefit, particularly, of yachtsmen. Facsimile weather charts consisting of surface analyses, forecasts of weather and sea state and sea ice conditions for the North Atlantic and some adjacent areas are transmitted from Bracknell for use by mariners.

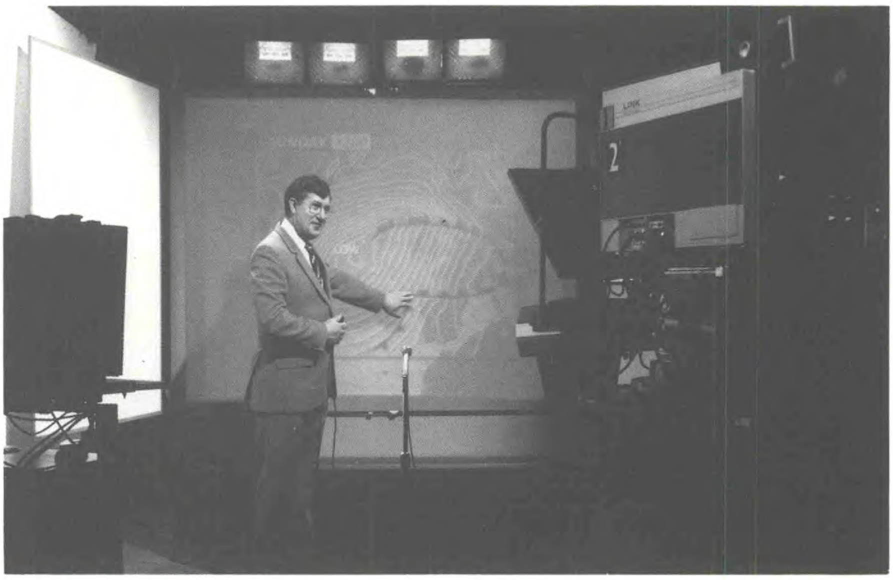
The Storm Tide Warning Service, introduced as a result of the disastrous east coast flooding of early 1953 caused by severe northerly gales, provides tidal forecasts for coastal Water Authorities and monitors levels expected at the Thames Barrier at Woolwich. Unusually low tides may cause problems for deep-draught ships navigating in coastal waters and the Strait of Dover; attention is drawn to these as necessary. Incidence of low tide surges is also passed to the Central Electricity Generating Board to warn of possible loss of inlet cooling water for the Thames Estuary power stations.

Gale warnings and weather forecasts, in addition to navigational and distress messages, are broadcast by British Telecom as part of their Navtex service. Message selection avoids duplication except for distress messages. Such services are available in the North Sea and off the coasts of Argentina, Chile, Saudi Arabia, Iceland, USA, USSR and Uraguay. In due course world-wide coverage is expected and carriage of a Navtex receiver will be mandatory on board ship. (Photograph by courtesy of Racal–Decca Marine Navigation)



Part of a ship routeing analysis chart issued for a voyage from Rotterdam to Trinidad of a 13 000 ton chemical tanker leaving on 13 August. By following the Metroute course the vessel was able to avoid the worst of the weather generated by the remnants of Hurricane 'Claudette'.

Services for the general public, industry and commerce



BBC Weatherman Bill Giles presenting a forecast using the new computer-controlled graphics system. He stands in front of a screen on which he is able to see a faint version of the graphics projected from behind, but which is rendered invisible to the camera by spilling blue light also on to the rear of the screen. The images of man and graphics are electronically combined for the viewer. (Photograph by courtesy of the British Broadcasting Corporation)

Introduction

Services for the general public, industry and commerce are provided primarily through a network of 16 'public service' offices, spread throughout the United Kingdom. Seven of these are devoted almost exclusively to the public services role. The others also have responsibility for forecasting for civil aviation and in some cases an RAF commitment too. The new Weather Centre in Glasgow, which opened in May, took over the forecasting work previously carried out at Glasgow and Prestwick Airports and Glasgow Weather Centre. A further rationalization of this type will occur in the spring of 1986 when the roles of the forecasting offices at Manchester Airport and Manchester Weather Centre are combined in a new office in Stockport.

All these offices are equipped to meet the needs of the community within their own areas of responsibility and concentrate upon the important local weather variations. In addition to these regional responsibilities certain offices have developed specialized wider roles. London Weather Centre in particular provides services to the national media and, in conjunction with the office at Aberdeen Airport, the offshore oil and gas industries.

Services for the general public

A considerable variety of services is provided for the general public at little cost to the customer. These services include telephone access (both via the recorded forecasts and through lines connected directly to forecasters at the Weather Centres) as well as forecasts in the Press, on radio and television and on teletext and viewdata.

Through its 'Guidelines' series, British Telecom (BT) provides a variety of recorded information packages. Weatherline, which has its origins in a recorded telephone service for the London area, started nearly 30 years ago and now covers over 99 per cent of the population of the United Kingdom. The service, developed in conjunction with the Meteorological Office, provides a forecast for each of 28 areas for the next 24 hours, together with a further outlook, updated up to three times daily. Over 26 million calls were made during 1985. The Marineline service began in 1984 with forecasts for the English Channel and was extended at the beginning of April to cover the whole of the UK coastline with the exception of Shetland. In addition a new service called Mountainline was set up in Scotland. This service, for mountaineers, was organized under the auspices of the Scottish Mountain Users Group, Heriot-Watt University and the Scottish Tourist Board.

Areas covered by Marineline and centres from which forecasts can be obtained.

Many newspapers, both national and local, make use of the issue of national forecasts and reports of the previous day's weather supplied to the Press Association. Several supplement this by subscribing to more detailed services. Presentation varies from brief headline forecasts to the comprehensive listings and weather map formats of some of the Fleet Street dailies.

Radio provides a wide range of weather forecast information and on national BBC radio the familiar 'live' presentations are something of an institution. They are supplemented by scripted forecasts, prepared by the forecaster and read by the BBC announcer. A similar mix of scripts and live presentations by forecasters is found on BBC and IBA local radio. Many of the live broadcasts take the form of an informal chat between forecaster and presenter with the emphasis on local weather.

Television is the main source of weather information for the general public with a wide choice of services now available. A major innovation during the year was the introduction of microprocessor technology into the personal presentations by the 'Weathermen' on BBC 1 and 2. The forecaster now has at his disposal animated sequences of satellite imagery and rainfall and pressure patterns generated from numerical forecast output, transmitted 'computer to computer' from Bracknell. He has historical information tabulated for a selection of sites throughout the British Isles and symbol charts constructed electronically (instead of the magnetic symbols used previously). Time allotted to the broadcasts has been significantly increased and includes a new three-minute recorded slot at the end of the BBC 2 'Newsnight' program that provides an opportunity to review the day's weather.

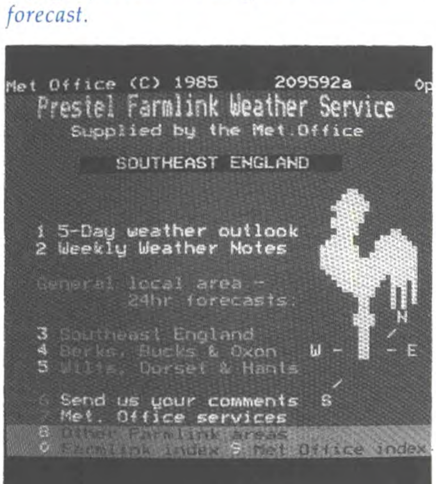
The Prestel workstation where information is input by Office staff.

Animated forecast sequences are also used by Channel 4 in their mid-evening presentation accompanied by a script prepared by London Weather Centre. Both breakfast television channels together with most IBA regional companies and some BBC regions, include personal presentations. A number of these use staff of the Meteorological Office, but where this is not the case, the companies' own presenters are briefed from the appropriate Weather Centre. Scripted forecasts are also supplied, either in lieu of or in addition to the live presentations.

Videotex services

For several years the Office has provided a selection of forecasts, actual weather reports and statistics on the BT viewdata system, Prestel. The information is available to all Prestel users, but the Office also provides specialized services to Closed User Groups (CUGs) on Prestel and to private viewdata systems such as Agviser, ICI's agricultural service. A recent development is the provision of nation-wide weather information on Farmlink, the Prestel CUG agricultural service, which was extended to a national service in October after an earlier launch in south-west England. Other innovations during the year include the provision of a teletext service to a cable television channel, an experimental service for the travel industry and the use of videotex as a means of providing dedicated services to individual customers.

A page of Prestel showing a Farmlink forecast.



To date, information on videotex systems has been input manually by a team of Office staff working 24 hours a day, seven days a week. However, an important development during the year was the installation of a computer system that allows automatic transfer of data from other Office computers to videotex systems. This computer system, when fully functional, will allow an expansion in the services provided. Detailed planning for these services is now in hand following a general review of all videotex services.

Services for industry and commerce

The more specialized requirements of industry and commerce are met by the provision on repayment terms of a diverse range of warnings, forecasts and advice tailored to the specific needs of the customer. The comprehensive service for the offshore oil and gas industries, described elsewhere in the Report, is a prime example, but many other areas of commercial and industrial activity are also highly weather sensitive and can benefit financially as a result of the provision of accurate and relevant weather information.

Services may be classified broadly under three main headings. Some customers require only *warnings* of adverse weather—frost, snow, gales, heavy rain, etc. Where more detail is required, individual *forecasts* are provided for locations ranging from specific sites to large areas of the country, from a few hours ahead to several days, for individual weather elements or complex combinations. Forecasts may be conveyed by telephone, telex, document facsimile or in various computer-compatible forms. Many customers recognize the value of a discussion with the forecaster at a time to suit their needs. The *consultancy* service provides such access, via an ex-directory telephone line and can be very cost-effective. This two-way exchange enables the forecaster to tune the advice precisely to the needs of the customer. Increasingly, packages of services are required that include analyses of historical information as well as combinations of forecast, warning and consultancy.

Major services are provided to the gas and electricity supply industries where the demand, particularly in the domestic sector, for heating and lighting depends on temperature, wind, cloud and rain. Detailed forecasts of these elements are issued as routine for periods up to about 36 hours ahead at 3–4 hour intervals.

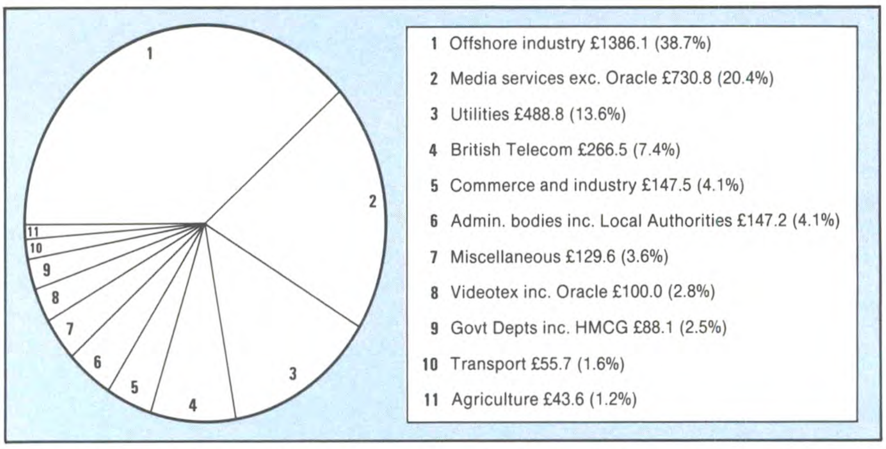
Another area of weather sensitivity is road transport, where large budgets, in the region of £1–2 million per county, are set aside for winter road maintenance. The primary winter requirement is for warnings of bad weather so that action can be taken to prevent ice and snow from disrupting road traffic. Almost all counties and many district authorities receive such 'road danger warnings', but many also recognize the value of a more comprehensive service with tailored forecasts and consultancy elements. The use of equipment designed to monitor the state of the road surface highlights the need for linked site-specific forecast services. The application of microcomputers to produce and disseminate such forecasts is being developed jointly by the University of Birmingham, the Department of Transport and the Meteorological Office. County authorities were also made aware of the benefits of data from radars which monitor precipitation areas. A package of services, including such data, is being developed and should lead to considerable savings in both winter and summer road maintenance operations.

The use of continuously welded rail on railway lines requires precautions to be taken if high rail temperatures are expected and for this purpose British Rail are supplied with forecasts of air temperature and cloudiness during the summer. In winter, warnings of ice and snow are also provided, particularly to the Southern Region of British Rail for whom ice on the third conductor rail can cause severe difficulties for the heavy commuter traffic.

Water Authorities throughout the country take a service that advises them of the likelihood of heavy rainfall over designated catchment areas. The service has been enhanced by the availability of precipitation data from radar and numerical forecasts of rainfall amount at all public service offices in England and Wales. Radar also helped as part of a forecast service, to provide early warning of a severe storm which in a matter of minutes flooded the courts at the Wimbledon Lawn Tennis Championships. The effects of a poor summer provided impetus to a continued expansion in forecast consultancy services for agriculture with as many as 2000 calls during August on the ex-directory telephones at one Weather Centre. The personal contact and effectiveness of the consultancy service also recommends it to other areas, notably construction and civil engineering.

Improvements in the accuracy of forecasts beyond two days ahead have made possible the development of services to retailers, not only of fresh food or other perishable produce but also of hardware such as garden equipment where sales are clearly weather sensitive. An analysis package to identify the relationships between weather and the customer's operations has been developed and the results are encouraging.

In conclusion, a continuing growth has been observed both in the demand for services and the technological possibilities for meeting that demand. Revenue from commercial services continues to show a steady rise and it should be remembered that the benefits to the customer, when measured in financial terms, are considerably in excess of this.



Revenue (£ × 1000) from various customer categories during the financial year 1984/85.

Marketing services

A small specialist team established within the Office has been actively developing marketing strategy and tactics on a broad front. Research has been carried out in a number of specific customer areas leading to a better understanding of the markets served and their true requirements. Consultants under contract have studied the value of forecasts for 2–5 days ahead to the retail and distribution, leisure, and agricultural sectors of the economy. A primary conclusion drawn from this work is that meteorological services should be offered in tailor-made packages rather than as individual items. Parallel research into the building and construction industry, the travel industry, and county authorities led to similar conclusions. A different package of services was found to be required in each case.

The Met. Office Travelling Exhibition.

Based on the results of the research a marketing plan was devised for the promotion of meteorological services to the building, construction and civil engineering industries. This included a co-ordinated advertising and sales campaign aimed at the decision makers in these industries. It was the first such co-ordinated campaign undertaken and mistakes were made and lessons learned. Nevertheless, the pre-set sales target of a 25 per cent increase in revenue for the year was exceeded.

The other marketing campaign of note was to the county authorities in England and Wales who stand to gain financially by using weather radar data to assist with their highways maintenance operations. By pin-pointing areas of precipitation, both rain and snow, the radar enables ready identification of the priority areas for the application of salt and grit in winter, and, in summer, the areas where summer dressings can be applied without suffering delay due to the presence of water on the road surface. A series of one-day seminars was mounted to promote the use of the data. Of the 43 councils represented, 25 indicated a positive interest. Follow-up action is continuing and services to several councils have been expanded.

Consultants have also been assisting in the development of a coherent advertising strategy, and in the production of professional quality brochures that promote specialized services. A keynote to the advertising strategy has been the introduction of a 'Company' logo incorporating the Meteorological Office badge alongside the words 'The Met. Office'. Three of the four brochures produced during the year advertised specialist services to the offshore, agriculture and construction industries. The fourth brochure advertised services generally available to the public.

During the year the Office was involved in ten major exhibitions throughout the United Kingdom. Six of these, promoting services to agriculture, were supported by a portable, low-cost exhibition unit developed in house.

Snow clearing in Scotland on the Cockbridge–Tomintoul road. (Photograph by courtesy of Grampian District Council)

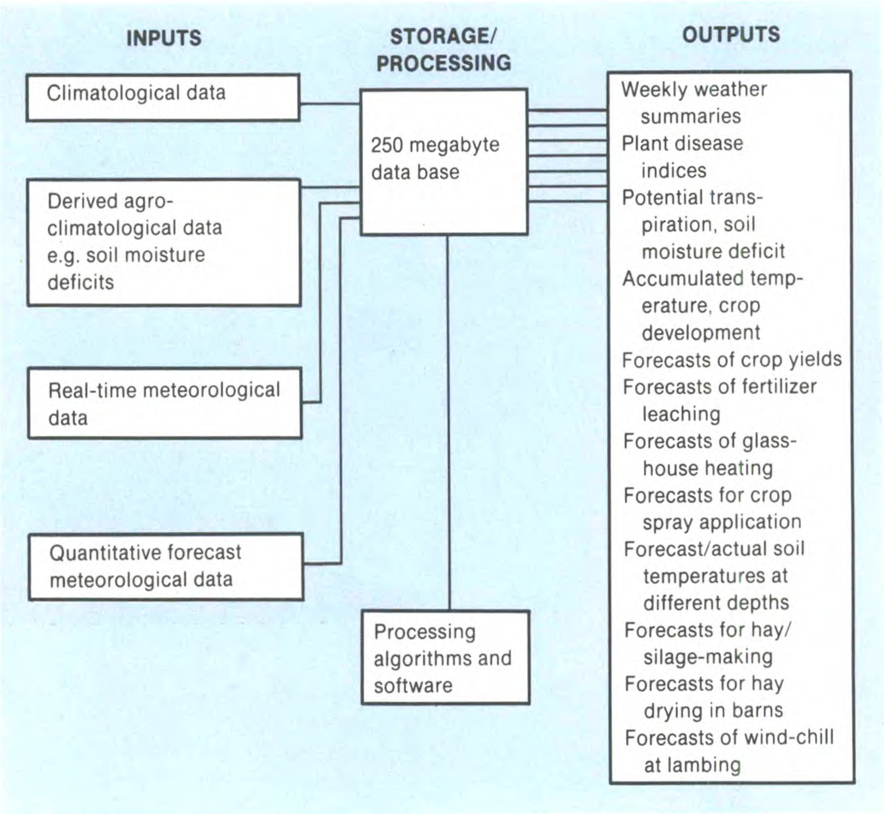
As understanding of markets and marketing improved it became apparent that the marketing and selling activities of the Office required more co-ordination, and an annual marketing plan was instituted. The first stage of this plan is to assist all sections of the Office involved in customer services to produce their own marketing plans which will then be brought together and resolved into a coherent whole.

In view of the importance of data on costs and revenues in the definition of a marketing strategy, considerable work was undertaken on programs that support the Office's Management Accounting and Information System so that information of the required type and format might be extracted.

Enquiries from the Press and other media continued at a high rate throughout the year. An important development was the provision by the Press Officer of regular information to Weather Centres, not only on new developments and progress in weather forecasting, but also on current weather statistics relating recent levels of temperature and rainfall to norms and extremes in the past. This is enabling all staff dealing with the media to answer Press and other enquiries more effectively without reference to Headquarters.

Services for agriculture

Agriculture, one of Britain's largest and most weather-sensitive industries, is served by forecasters and specialist agrometeorological advisers. The most effective forecasting service is given by local forecasters, using ex-directory telephone lines, providing discussion and site-specific advice on the weather up to five days ahead. During the year weather forecasts tailored to meet farming needs were introduced to provide an important component of Farmlink, a closed-user group Prestel service. The main function of the agrometeorological advisers is the provision of comprehensive, dedicated services, on repayment, to the Agricultural Development and Advisory Service (ADAS) of the Ministry of Agriculture, Fisheries and Food. Twelve staff work at the six regional headquarters of ADAS while the others, located at Bracknell, provide effective support to their outstation colleagues in developing new products and services for this and other sectors of the farming industry.



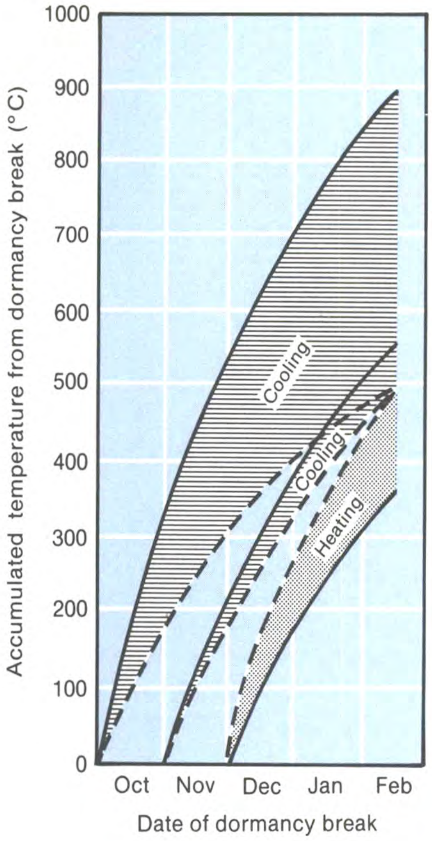
Example of data flow through the new agrometeorological data base, FARMAID.

Working closely with the industry, the agrometeorologists respond quickly to changing requirements and are sensitive to the economic and political factors controlling the state of agriculture. Reductions in European Economic Community intervention support, leading to sharp falls in cereal prices and the constraint of milk quotas, make it ever more important for farming enterprises to make maximum use of tactical and strategic management aids, including weather information. ADAS, itself, is reviewing the whole basis of its support to farming (mostly given free at present); in the meantime a cut in ADAS funding has led to significant reductions in the capacity of the regional agrometeorological units.

Despite this, good progress continues to be made in the development of a wide range of almost fully automated operational agrometeorological services. A major innovation has been the installation, at the outstations and at Headquarters, of microcomputers directly linked to the COSMOS mainframe system. Software is being developed to enable staff to use these facilities without formal computer training. The resulting improved productivity and flexibility compensates to some extent for staff reductions, and shortens response times to many enquiries received by outstation and Headquarters units. The operational implementation of FARMAID (Fully Automated Real-time Meteorological and Agricultural Integrated Database) a 250-megabyte data base incorporating historical and current (and eventually forecast) meteorological information, and a large number of derived operational agrometeorological products is on schedule for the original target date of 1986.

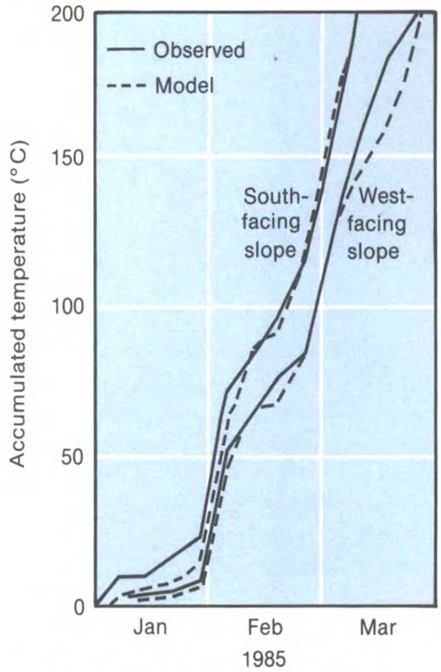
Traditional methods of distribution (for example by post or telex) of FARMAID outputs are slow and labour intensive. Effective utilization of the data base requires, therefore, the use of 'Information Technology'. Negotiations with suppliers of information to, and operators of, viewdata systems are expected to lead to widespread, cost-effective dissemination of FARMAID products, via teletext for example.

The scope of agrometeorological work has again been very wide, reflecting the diverse nature of British agriculture. In addition to the provision of advice and support to ADAS, operational agrometeorological information has been supplied to a variety of users. The number of enquiries increased again, exceeding last year's total by 15 per cent, and were dealt with despite reductions in staff. Experimental and theoretical investigations have also been carried out. This was the first full year of use of small, battery-operated data-logging systems by all the outstations; these instruments, used in conjunction with a variety of environmental sensors, have increased the range and number of ADAS investigations supported, and the accuracy and reliability of recording, and speed of analysis of the results. Investigations included the influence of weather on straw burning, the use of weather data to time the planting of early potatoes, the use of wind machines for frost protection, the effects of weather on the treading of grassland ('poaching') by cattle, the simulation of the climate in crop stores, and the effect of slope and



Early potato yields are improved when sprouted seed achieve a certain physiological age (pa) before planting dependent upon variety, planting date and accumulated temperature (sum of amounts of average daily temperature) above 4 °C from dormancy break (50 per cent sprouting). Store manipulation can approach the optimum pa. In the example shown left, for mid-February planting in Dyfed, solid lines indicate the expected accumulated temperature (10 year in 20 value) and dashed lines the desired accumulated temperature.

Slope and aspect of land markedly affect agricultural productivity. The example shows that measurements at Trawsgoed, Wales and results from a model are in good agreement for an accumulated positive temperature of 200 (the optimal time for application of nitrogen fertilizer to grassland). The dates are three weeks earlier for a south-facing and one week earlier for a west-facing than for a level site and the verification allows the model to be used to produce objective allowances for the effects of slope and aspect.



aspect of land on agricultural productivity. A climatology of evaporation and soil moisture deficit using 20-year long meteorological records from 100 stations in the United Kingdom was created. A system of standard, easily used procedures allows ADAS staff to make effective use of the meteorological data passed daily from Bracknell to the central ADAS computers at Guildford. Other activities included the preparation and manning of displays for various agricultural shows including the Royal Show. The regional agrometeorologists also gave talks and lectures to groups such as farmers' clubs and branches of the National Farmers Union.

Consultancy, advisory and data services

There is a wide and extremely varied demand for meteorological advice and information using data stored on computer, in original manuscript or other paper form. To meet this demand advisory services are provided, on repayment, to industry, commerce, the professions, other government departments and the general public. Charges for individual services range from tens to thousands of pounds but may be reduced or waived altogether to some enquirers, such as students. The work required to service an enquiry may vary very greatly and some large projects can extend over weeks or months. During 1985 the latter included: a revision, on behalf of the Department of Energy, of the wind and temperature sections of the guidance material for the design of offshore structures; an analysis of marine data in support of a wave atlas to be produced by British Maritime Technology Ltd; and a study of the susceptibility of the M25 to fog. Routine services included the supply of temperature data weekly to the Department of Health and Social Security to assist in the determination of single payments to recipients of supplementary benefit during cold weather.

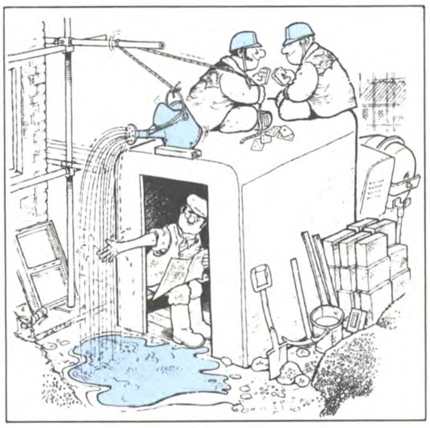
The building and construction industry is very weather dependent in most of its operations. Analyses of meteorological extremes can be required for calculations of wind loading on walls, snow loading on roofs, capacities of heating or cooling plant, and of the size of spillways, drains or culverts, etc. Weather factors can play a part in the determination of routes of roads and the siting or orientation of buildings. Frequency analyses of meteorological elements, singly or jointly, are used for time-loss estimation during construction work as well as for strategic planning purposes. In the event of contractual disputes meteorological information may help to determine the cause of failures to meet target dates or to test the validity of design criteria. A small group, partly funded by the Building Research Establishment, gives particular attention to applications of meteorology to the building and construction industries.

A specialist marine advisory group provides advice to the offshore industry, general shipping and any other person or organization engaged in weather-sensitive operations upon or adjacent to the sea, almost anywhere in the world. The majority of enquiries relate to design studies or the planning phases of marine operations but, increasingly, assistance is being sought in support of existing or proposed litigation. These cases may involve structural damage, breach of contract and, sometimes, personal injury or loss of life. Occasionally, members of staff are required to give expert evidence before the Wreck Commissioners.

Commerce and industry can use weather information for strategic planning and tactical decisions. Standard statistical packages are used to relate weather variables, singly or in combination, to sales, fuel usage or other appropriate elements of direct relevance to the work of the customer. Such analyses may then indicate the most appropriate forecast or actual weather data to be supplied subsequently for tactical use in determining production or distribution of products.

Enquiries from overseas areas are usually handled by the use of material held in the National Meteorological Library or publications produced by other Meteorological Services. Specialist advice was provided for a customer/contractor dispute when heavy rain was alleged to have delayed the construction of a dam in Nigeria. A member of staff gave evidence on behalf of the prosecution in a drug smuggling case to Reading Crown Court on weather in the Bekaar Valley, Israel and Edmonton, Alberta.

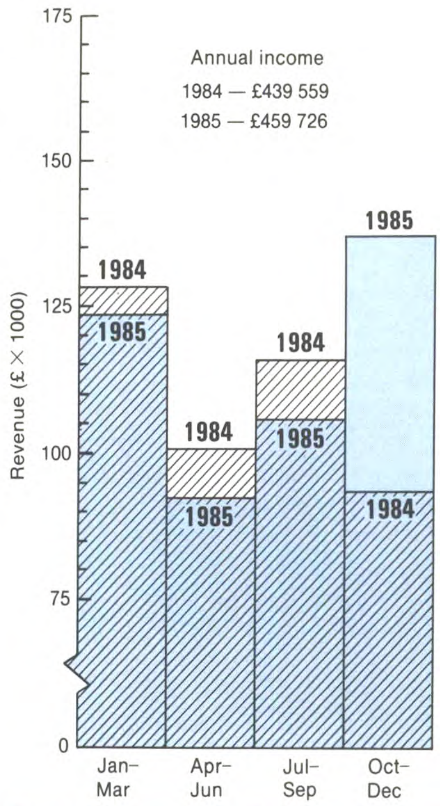
Meteorological evidence can help to resolve extension of contract claims! (Reproduced by courtesy of the Building Research Establishment)



The Office works closely with the water industry, particularly with the Water Authorities, the Institute of Hydrology and the Department of the Environment. For water-budgeting purposes a weekly routine service provides areal estimates of evaporation, effective rainfall and soil moisture deficit for different types of land use. Areally averaged monthly rainfalls are prepared for the 900 catchments of the Department of the Environment Surface Water Archive and requests are received from Water Authorities for historical estimates of rainfall and evaporation over catchments. These latter data are used to extend river flow records backwards in time so providing a better data base for the planning and design of hydrological structures.

A greatly used service is the preparation of statements of actual weather at specific locations and times, for legal and insurance purposes. Certified statements can be provided for use in both Civil and Crown Courts and staff may occasionally be called to the witness stand. A member of staff was called at very short notice to give evidence at Cardiff Crown Court in the murder trial involving the Welsh miners.

The majority of enquiries for the United Kingdom are processed by enquiry bureaux located at Bracknell, Edinburgh and Belfast for England and Wales, Scotland, and Northern Ireland respectively but a small number of enquiries are the subject of special investigations: an assessment was made of rapid changes in barometric pressure for liquid gas equipment design purposes; periods of air temperature below 3 °C with or without precipitation were analysed to help to assess threshold settings and the potential frequency of operation of automatic sensing and heating devices for railway points; a report on methods of measuring wind speed and the nature of gusts was provided to a firm working on the manufacture of devices for maintaining constant tension on cables supporting overhead aerials; help was given to a firm of engineers concerned with meteorological conditions causing enhancement of noise propagation in the vicinity of extensive construction works such as pile driving; a brief climate survey of the United Kingdom was prepared for use in the siting of parking meters; analyses of temperature, humidity and rainfall data for many sites throughout the United Kingdom were prepared for a study of rusting of metalwork on road and motorway bridges; a climate report was prepared for the Winfrith area of Dorset in connection with the construction and operation of a power station. Increasing use is being made of rainfall data obtained by weather radar, one particular example being evidence to the police in a case of attempted murder in the London area on the day of the Wimbledon storm.



Quarterly income from all advisory services including agriculture.

The main data source for advisory services work over the United Kingdom is the computerized archive of data from some 170 synoptic stations, 450 voluntary climatological observers, 5500 rainfall observers and, a recent innovation, several radar sites. All data received are checked by computer for internal, sequential and areal consistency. Staff decide whether to accept, reject or correct the queried data referring back to the original observer as appropriate. Basic data and analyses are stored on computer file in various orders for different applications.

Marine meteorological data, particularly from merchant ships, are archived and exchanged with other countries. These data are now stored in the main marine data bank, a near-global archive containing over 55 million observations dating back to the 1850s. A subset of this archive holding all data available for a major part of the North Atlantic is maintained on behalf of the World Meteorological Organization (WMO) for supply to any other National Meteorological Service on demand. An additional global archive of surface currents calculated from ships' drift is also kept on behalf of WMO. All these data are subjected to manual and computer checks designed to ensure a reasonable quality.

The enquiry bureaux, and quality-control and data-monitoring teams are supported by investigation and development groups. Areal quality-control techniques, methods of determining areal rainfall and extreme-value analyses are all under review. Particular attention is being given to the problem of handling the very large amounts of rainfall data that can be acquired using radar. A suite of computer programs is being developed to access the radar data at the time of observation and make them available for immediate use. The suite will also store the data and combine them with daily rainfalls from the rain-gauge network. Further work is in hand to investigate how best to combine and use the data from isolated rain-gauges with the complete or near-complete coverage of radar-derived data.

Over recent years enquiry bureau revenue has increased in real terms. Partly, this has resulted as staff become increasingly aware of the commercial value of their services and, partly, as services become better known and more widely used. A feature of the year has been the high level of enquiries, even during the July to September quarter when business is usually slack.

Introduction to the research program

Research is vital in any modern Meteorological Service to advance the science and ensure that full account is taken of improvements in technology and changes in observing systems. In the Meteorological Office, research and services are closely integrated partly by close consultation but also through the movement of staff and their expertise. Most of the highest quality graduates joining the Office are keen to contribute fundamentally to science in an area that is exciting, rapidly evolving and of great potential significance for all mankind. Accordingly the great majority start their careers in Research Branches; a small proportion stay in research throughout their service; but the majority eventually move into the Services Directorate to become, for example, the Office's most senior weather forecasters or specialist meteorological advisers.

The facilities used by the research program are primarily the Meteorological Office central computing complex COSMOS, and the instrumented Hercules aircraft of the Meteorological Research Flight which together with the tethered balloon system based at Cardington provides a powerful observing capability for meteorological investigations. For computing, the Cyber 205 number cruncher at the heart of the COSMOS system is an extremely powerful machine, well suited to the highly repetitive types of calculations carried out in weather forecasting research and in studying the climate. The Hercules aircraft carries instruments to measure many atmospheric variables including water and various chemicals and fine-scale turbulence, which can only be measured accurately by *in situ* techniques. These make it suitable for a wide variety of investigations.

The global climate poses many fundamental problems and there is increasing concern that man himself may be becoming the most important agent of change. The World Climate Research Programme, co-ordinated by the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU), is directed to understanding the mechanisms that influence climate, particularly the interactions between the atmosphere and the other components of the climate system, the oceans, sea-ice and land surfaces; atmospheric constituents such as dust and carbon dioxide; and the effects of cloudiness. Many of the problems are relevant also to weather forecasting where some improvements stem directly from climate investigation results.

The development, testing and continuous evaluation of the computer models that provide the basis for almost all the Office forecasts continues to lead to substantial improvements in the forecasts. Advances in the techniques for 'parametrizing' the effects of small-scale features in terms of the larger-scale variables have been introduced. The benefits feed through to virtually all the Office's customers and enhance the growing reputation that its forecasts now enjoy both nationally and internationally.

The emphasis in forecasting research is moving towards the short (less than 24-hour) and very short (less than 12-hour) ranges. The most significant errors nowadays probably occur in regional or local detailed short-period weather predictions. Paradoxically, the associated scientific problems are much more taxing, both observationally and in terms of basic scientific understanding, than for the larger-scale systems which are usually treated very accurately by models.

The problems are being investigated from a number of points of view. The basic scientific problems, such as the development of small waves or secondary lines of precipitation near fronts, how and when cloud at the top of the boundary layer will form or dissipate, the flow deviations and associated weather variations created by orography or the sea fog which in spring and summer often rolls inland, are being studied observationally and by models of the processes. Mostly the investigations involve co-operation with other UK institutions or are internationally organized experiments.

An important operational requirement is for routine observations detailing the occurrence, location and intensity of small weather systems frequently missed by the standard network of observing stations. The FRONTIERS system is used to combine radar and satellite images of rainfall and cloud and to track their movement. The system, developed at the Office's Radar Research Laboratory at Malvern, has been moved to Bracknell, where it will be developed in liaison with the Central Forecasting Office where a further system is being installed for immediate direct use.

The development of an operational model for short-range forecasting over the British Isles is proceeding at high priority. For most of the year it was run twice a day and the results were available for real-time evaluation. Research to improve the performance of models of this kind will continue for many years.

The fuller exploitation of satellite data is essential in a variety of meteorological applications. They give reasonably complete and uniform coverage of observations, especially over the major oceans where the network of surface meteorological stations is very weak. The data, however, are different in kind from those conventionally measured, and their use is far from straightforward. Methods of improving the accuracy of temperatures retrieved from satellite soundings are being pursued, mainly at the Meteorological Office Unit within the Hooke Institute at Oxford University. However, to make a substantial improvement in the quality of temperature data from satellites, the capabilities of on-board instruments must be enhanced and work is proceeding on the microwave sounding equipment for the next generation of American satellites. Preparations are being made to use other forms of data, for example from the European satellite ERS-1, in operational predictions.

Environmental pollution has increased the interest shown in atmospheric chemistry. Some pollutants are dispersed by and chemically transformed in the atmosphere; others are radiatively active and may affect the climate. Solving the environmental problems in matters such as 'acid rain', warming by 'greenhouse gases', and the depletion of the stratospheric ozone shield, depends crucially on understanding the chemical changes within the atmosphere. The dispersion of pollutants downstream from power stations has been studied in association with the Central Electricity Research Laboratories, and the atmospheric budget of ozone has also been investigated.

The research program involves extensive co-operation with other institutions. Nationally this is primarily with the universities but also with other research organizations. Internationally, projects may be arranged directly with other Meteorological Services or be part of a wider program sponsored by WMO or ICSU.

Meteorological Research Flight (MRF)

The Hercules C-130 aircraft, based at the Royal Aircraft Establishment (RAE) Farnborough, is a major Meteorological Office facility for research. It is used by scientists from universities and research institutes as well as by scientists from the Office. It can remain airborne for over 12 hours and operate up to 30 000 ft. It has been an important element in international projects. Recently, as part of an Anglo/American project, a detachment to Bødø, Norway was made to study polar depressions. The aircraft is flown by RAF aircrew and serviced by RAE ground crew. As well as using the aircraft for their own program, MRF scientists also co-ordinate MRF services to scientists in other parts of the Office and elsewhere. In October, the Hercules was grounded for a major overhaul, and the opportunity was taken to install further scientific equipment.

The instrumented Hercules aircraft of the MRF.

Instrumentation

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

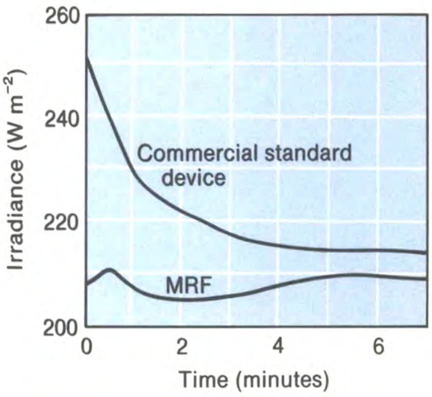
The instrumentation on the aircraft is kept under continuous review. Old or obsolete items are replaced as necessary and new requirements are satisfied as far as possible within resource constraints. A major project to replace the original data-recording system with a modern microprocessor-based device made further progress during the year. The basic recording system completed flight trials and was accepted into routine service and a new facility to provide the scientists on board with a real-time display of the data being recorded has been implemented. Substantial progress was also made with subsidiary facilities such as a rapid tape replay device to enable scientific staff to take a quick look at the data after a flight is complete.

A multi-channel radiometer was fitted and is undergoing flight trials. This radiometer was adapted in collaboration with the Rutherford Appleton and Clarendon Laboratories from a prototype flown on NIMBUS satellites. It measures radiative fluxes in selected wavelength bands in the infra-red, and will complement broad-band flux measurements.

The performance of commercial instruments (pyrgeometers) in measuring broad-band infra-red fluxes is affected by internal temperature gradients. This defect has been cured in a new design developed at MRF. The figure above right shows a comparison between the MRF pyrgeometer and a commercial instrument following a sharp increase of temperature brought about by a rapid descent to a fixed level. There was no cloud above the aircraft, so the signal should remain constant. It remains very nearly constant for the MRF device but not for the commercial device.

Research program

MRF scientists study radiative transfer through clear air and cloud with the objective of improving the representation of radiative transfer in numerical forecast and climate models. A current problem is the representation of radiative transfer through broken cloud fields. By taking some account of the variability in cloud sizes, MRF scientists have improved the agreement of observation with theoretical models. Another major problem is the effect of aerosol in cloud and clear air on radiative transfer. Observations of radiative fluxes through clouds are supplemented by post-flight analysis of the radiative properties of cloud water collected during flight, and of the physical and optical properties of the aerosol found in the cloud water.



Comparison of downward irradiance after a sharp increase in temperature as measured by the MRF pyrgeometer and a commercial instrument.

Forecasting research

The great majority of the Meteorological Office's forecasts are produced either directly by computers or by interpretation of computer products. The main efforts in forecasting research are therefore directed towards improving computer models.

In September 1982 the Office implemented a new global forecasting system. It included a regional model to predict detailed weather over the British Isles up to 36 hours ahead. In October 1984 an additional very-high-resolution mesoscale model was brought into regular use on an experimental basis. It is designed to forecast local weather up to 18 hours ahead for the outstation network. A system of this kind has not been used in any other weather forecasting centre in the world.

Current research activities involve improving the way that the data are presented to these models as well as improving the models themselves. Some examples of projects are presented below.

Improvement of northern hemisphere winter forecasts

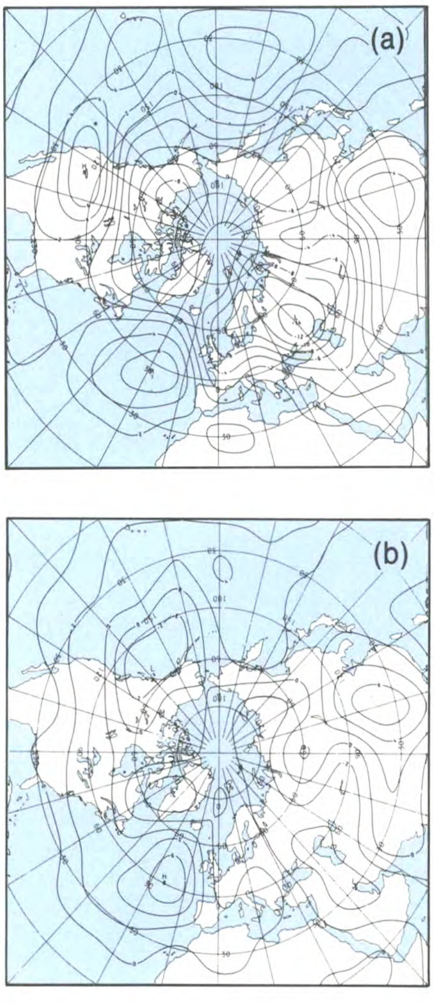
Over the last few years research has clarified the mechanisms maintaining the mean zonal wind and it suggests that one essential mechanism that has not been represented is the drag exerted by gravity waves excited by interactions between the low-level wind and mountains. The waves can propagate upwards through the atmosphere and be absorbed when they break at some upper level so reducing the strength of the wind there. A representation of this drag, using information about the slopes of the mountains and the low-level atmospheric structure, has been developed and used in the forecast models.

The effect of this form of mountain drag on the mean-sea-level pressure forecasts is striking. The diagrams illustrate the average error taken over 20 winter cases in the 5-day forecasts of surface pressure. Without the gravity-wave drag there is a negative error of 14 mb over western Russia, 6 mb over Siberia and 8 mb over north-west Canada. Pressure is too high to the south, especially over the central Atlantic and Pacific and the western part of the USA. Inclusion of gravity-wave drag almost removes the negative errors and the resulting westerly bias in the surface winds. The maximum negative error is now only 5 mb.

Research into quality control of data

Each day, a sizeable number of observational reports sent to meteorological centres are corrupted by instrumental error or by incorrect coding or during transmission along the telecommunication network; failure to reject such data in the forecasting system can reduce the accuracy of the subsequent numerical forecasts. However, distinguishing observations that are in error from those that are correct but unexpected because they indicate where previous forecasts are going wrong is often very difficult.

Average errors (mb), taken over 20 winter cases, of 5-day forecasts of surface pressure from the global operational 15-level model before (a) and after (b) the introduction of gravity-wave drag.

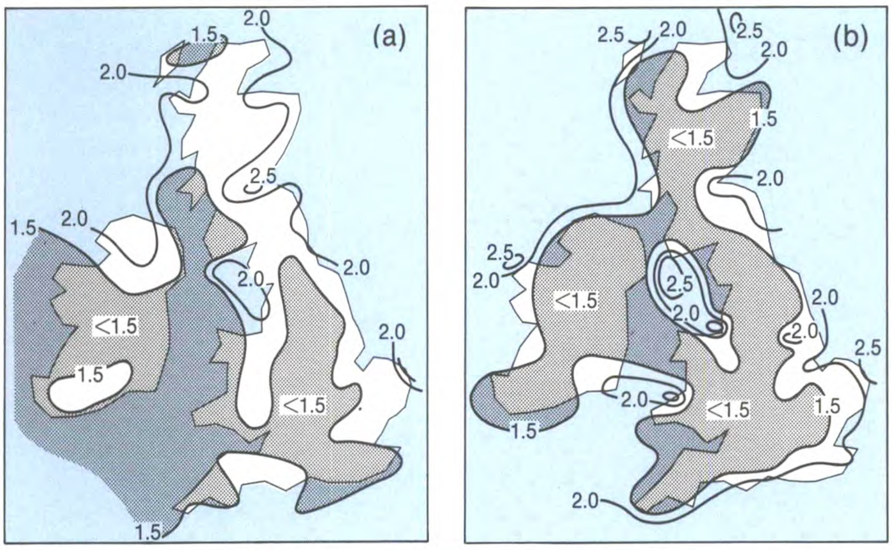


Most large errors can be detected by checking the internal consistency of reports and by comparing them with climatological extremes. However, detecting errors when the reported values are plausible is more subtle and requires the use of all available information. Forecasts from previous times and observations from independent sources are particularly valuable for this purpose. Because of forecast and measurement uncertainties, it is possible to give only probabilistic results which are dependent on the accuracy assumed for the checking information. About 250 000 data from many different kinds of observing system with differing accuracies and reliabilities are processed each day. Automatic checking is thus essential, although some important data are still manually checked by forecasters.

The process of data quality control is being put on a sounder statistical basis, combining information with due regard to its accuracy and reliability. The results of all checks and comparisons are recorded in a computer data base. This information can then be used in an 'expert system' which can learn from the results of previous checks and improve the accuracy of the subsequent checking. The record of observation comparisons will aid the rapid identification of persistent errors and can be communicated to the originators of the observations so that prompt corrective action can be taken. It will also provide detailed information about short-period forecast errors which is useful in developing improvements to the forecast model.

Experimental high-resolution forecast system

A daily trial of the proposed operational very-high-resolution mesoscale forecasting system which began in October 1984 was extended in April 1985 to include two 12-hour forecasts each day, one covering the daytime period 0600 to 1800 GMT and the other the corresponding overnight period. The



Root-mean-square errors (°C) in forecast day maximum (a) and night minimum (b) temperatures for August 1985.

model has grid points every 15 km in the horizontal and has 16 levels in the vertical. Predicted quantities include surface temperature, pressure, wind, humidity, cloud, visibility and rainfall. Initial data are provided by merging the analysis prepared for the regional forecast model, which has a 75 km grid in the horizontal, with extra information from the surface synoptic network. These observations include cloud base and the rate of rainfall, from which the cloud thickness can be inferred. Radar observations of rainfall rate and satellite observations of cloud top will also be used by the model when they become available in a suitable form.

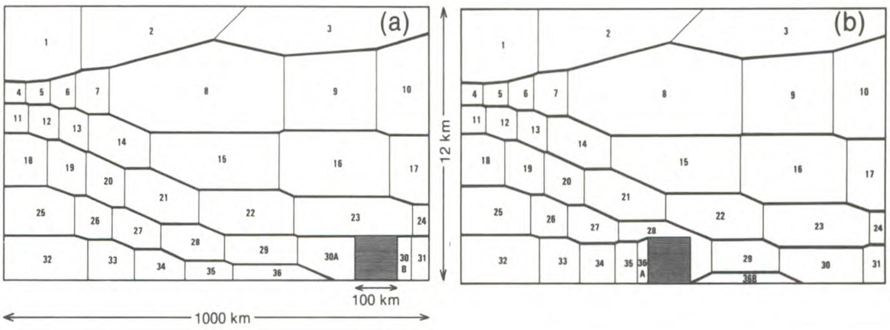
Some of the results of the trial are illustrated above by the temperature forecasts for the month of August. The root-mean-square errors in forecast day maximum and night minimum temperatures are shown. The model forecast errors in maximum temperature were less than 1.5 °C though errors tend to be greater in mountainous areas of northern England and Scotland and near coasts (this can be compared with expected errors of about 2 °C for good conventionally produced forecasts). The apparent errors over high ground may be due to differences between the height above sea level averaged over a model grid square and that of the stations available to verify the forecasts. The errors near the coast reflect the large variations in temperature over the few kilometres close to the shoreline. The model forecast errors in minimum temperature are less affected by problems in mountainous areas because the variation of minimum temperature with height is smaller. The only areas where the errors are above 1.5 °C are near the coasts.

Assessment of the results of the trial is being carried out by objective methods and by use of the products by forecasters to prepare local area forecasts. The assessment by forecasters suggests that the extra detail added to the regional model forecast of rainfall, temperature, cloud and wind is often realistic. Even at this early developmental stage it is clear that the model has the capability of producing guidance that would be of considerable use to outstation forecasters.

Mountain flow

Many of the limitations in the accuracy of forecast models are caused by difficulties in modelling particular types of atmospheric flows. A good example is a situation where the flow is almost discontinuous, because a representation of it in terms of grid points will not be very accurate. A particular example is the flow round large-scale mountain ranges such as the Alps. In many situations the flow is seen to separate, with the upper-level air going across the range undisturbed and the lower-level air being blocked or diverted round the mountains. An example of a method of computation which can handle such a flow is shown below for a two-dimensional flow over a barrier 100 km wide.

Vertical cross-sections 12 hours apart of the flow over an idealized mountain ridge (shaded area). The heavy lines are contours of buoyancy and the numbers identify 'air parcels'. Low-level parcels (see 30 and 36) become blocked by the ridge and then are gradually released over the top, as if over a weir, to take up a new equilibrium position downstream whilst the upper flow is almost unaffected.



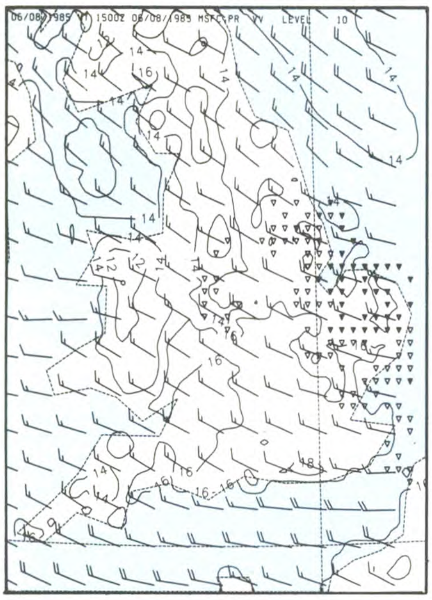
Mesoscale research

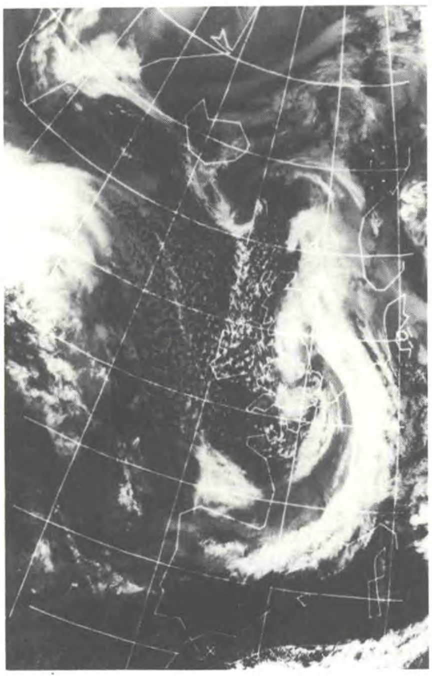
There is now intense interest in predicting variations in the weather on space scales of less than 1000 km and time-scales of less than a day (larger-scale systems are already well predicted by computer forecast models). Current research is focused on the development of suitable computer models and on the use of appropriate observations. This requires a more detailed understanding of the dynamics and physics of the processes involved. The physical processes which affect the distribution of cloud droplets and the formation of precipitation are being examined using detailed observations of clouds and numerical models of microphysical and dynamical processes. The studies are intended to clarify the interactions between clouds and radiation and the factors determining the distribution of precipitation. An example of each aspect of the work is described below.

Analysis and modelling of mesoscale structure

The illustration below shows the representation by a numerical mesoscale model of the weather on a summer afternoon. The British Isles were covered by an unstable north-westerly airstream giving a typical showery pattern. Most of the showers developed following

Mesoscale model forecast of wind, temperature and weather for 1500 GMT on 6 August 1985. Triangles indicate where the showers were expected, the solid ones representing heavy showers.





Infra-red satellite photograph for 1420 GMT on 11 April 1985. (Photograph by courtesy of University of Dundee)

daytime heating, and therefore occurred over central and eastern England away from cool, windward north-west coasts. The mesoscale numerical model represented these features well. The radar and satellite pictures indicated that the heaviest showers (some of which were accompanied by thunder) occurred over eastern England. Enhanced shower activity is frequently observed in similar synoptic situations in summer due to ascent forced by low-level convergence at a sea breeze front. This mechanism is not evident in the mesoscacle model results illustrated, indicating that upper-air structure is also an important factor.

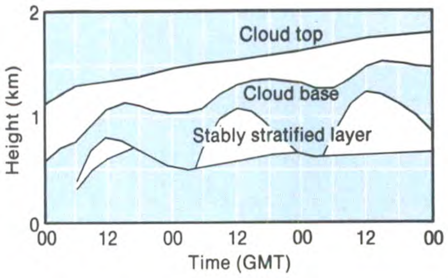
The evolution and structure of weather systems are also being studied using frequent high-resolution satellite and radar data on scales smaller than is possible using the standard network of surface observing stations. The above photograph shows an example of the cloud distribution within a mature depression over eastern England. The sharp edge from just east of East Anglia to the Continent marks the boundary between deep cloud giving widespread moderate rain, and a tongue of dry air that has descended eastwards from the upper troposphere or lower stratosphere. This dry air has overrun a layer of warm, moist air some 2–3 km deep, shown darker grey, whose western boundary extends from the Strait of Dover to the Bay of Biscay. Release of instability caused by this overrunning gave rise to a distinct line of thunderstorms over France and convective rain over part of the United Kingdom. The tongue of dry air can be identified and its motion followed using fields of humidity and potential vorticity from fine-mesh numerical forecast model output. Satellite and radar information, together with complementary diagnostics from the forecast model, have improved our understanding of the airflow and precipitation in such weather systems. As a result the forecaster is better able to recognize the processes at work and predict the pattern of surface weather.

Studies of layer cloud

Stratocumulus cloud sheets significantly affect the temperature observed at the surface but they are difficult to forecast. The factors causing cloud formation and dissipation within the atmospheric boundary layer are poorly understood although a combination of aircraft measurements and detailed models of the boundary layer has resulted in considerable progress in these areas. Layer clouds of this kind often produce widespread, but light, rainfall. Numerical models of growth of cloud particles have demonstrated how precipitation-sized drops may grow in shallow turbulent clouds.

The rainfall from frontal layer clouds is often patchy; the areas of heaviest rainfall can be traced to generation zones in the upper parts of the cloud. Aircraft measurements and measurements using the dual polarization radar at Chilbolton operated by the Rutherford Appleton Laboratory have been used to model the growth of ice particles and the association of variations in particle type with surface rainfall. The experiments will clarify some of the factors which lead to difficulty in interpreting radar rainfall measurements.

Calculated evolution over a 3-day period of the development of a cloudy boundary layer. The thinning of the cloud layer following the formation of a stable sub-cloud layer can be seen.



Satellite meteorology

The Office continued to develop and encourage the use of satellite data, recognizing the importance of both satellite imagery and quantitative satellite measurements. A major financial contribution is made each year to Europe's Meteosat system, and the Office also provides instrumentation for flights on the US operational polar-orbiting satellites. Satellite instrument work has been described elsewhere in this Report.

Local area atmospheric soundings

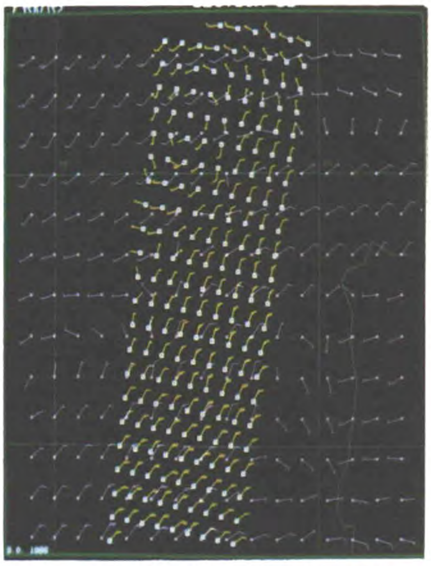
The HERMES (High-resolution Evaluation of Radiances from Meteorological Satellites) system is a minicomputer-based data-processing facility established to aid research into the uses of digital satellite data. Nearly 4000 atmospheric profiles of temperature and humidity are derived each day from satellite data over the Atlantic and Europe, for use both in operational forecasting and in further research. One of the improvements during the year was the replacement of coefficients for global use supplied by the USA, which did not always reflect local conditions, by locally calculated values. An improved scheme for removing the contaminating effects of clouds from the satellite measurements is being tested for future operational use and work has begun on a new inversion method which uses information from the forecast model in the retrieval process. Some of the more theoretical aspects are being studied at the Hooke Institute in collaboration with Oxford University scientists.

Imagery research

The twin satellite data-processing computer systems at Bracknell and Oxford have continued to be used for research into the uses of the digital, high-resolution satellite imagery data. One of the primary aims has been to develop means of extracting quantitative products at mesoscale resolution for use in connection with the Office's mesoscale model. These products will include cloud analyses by day and night as well as surface temperatures.

Development work

The Office already makes extensive operational use of satellite imagery distributed over low-speed land-lines.



In preparation for the launch of the ERS-1 satellite in 1989 surface winds (yellow) are derived from conventional data analyses in a simulation of ERS-1 observations. These are then processed to eliminate the simulated rogues and compared with the concurrent forecast winds (blue).

Substantial improvements to the present system are being planned for integration into the Office's concept of a new Weather Information System. A project team has analysed the sort of computer system needed to handle the available high data rate imagery and an operational requirement is being defined. Some of the necessary pre-development work for the handling of high-resolution imagery is being carried out on the minicomputers now available. A particularly demanding element is the requirement to remap within a few minutes images consisting of several million elements into standard map projections.

Support for European Space Agency (ESA) programs

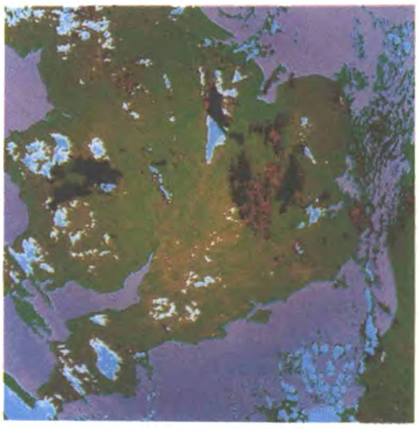
The Office takes a very close interest in the products of existing and planned systems. A joint study with ESA staff identified a number of problems which affect a small percentage of the Meteosat cloud-track winds and will help to identify remedial action. A further series of studies under ESA contract is concerned with the algorithms to be used to derive surface wind fields over the oceans from the earth resources satellite (ERS-1), to be launched in 1989.

Nowcasting

Satellite data are an essential ingredient in many schemes for nowcasting—forecasting for a few hours ahead. The FRONTIERS system is one example, since it can merge radar and satellite information for the purpose of forecasting rain for short periods ahead.

Data from the weather radar network and from Meteosat are processed by the FRONTIERS computer every 30 minutes, monitored by a trained meteorologist who interacts with the data by means of touch-sensitive display screens. The resulting combined radar/Meteosat precipitation field is useful in forecasting for up to six hours ahead.

During 1985 the prototype system was tested successfully on a semi-operational basis, quality-controlled radar pictures being regularly disseminated to forecasting offices. This system will be used for further development as well as for research into other nowcasting techniques. A duplicate system was obtained for operational use in the Central Forecasting Office at Bracknell from early in 1986.



Night-time image of southern England derived from two spectral channels. The red areas indicate fog or low cloud; other colours show variations in surface temperature.

Boundary-layer research

The planetary boundary layer is that region of the atmosphere adjacent to the earth's surface where turbulent eddies transport momentum, heat and moisture vertically. These transports are important in determining the circulation of the atmosphere, and a major objective of the Office's boundary-layer research is to improve the representation of the boundary layer in numerical weather-prediction models. The transport of other species of airborne material such as pollutants is a subject of increasing concern in industrial safety and in studies of the environment. A second objective of the Office's boundary-layer studies is to improve models for determining the dispersion of materials within the atmosphere.

Boundary layers over the sea

The transfers of momentum, heat and moisture which occur with strong winds over the sea are important factors in the development or dissipation of low-level cloud sheets. They are inadequately understood, but it is clear that they are influenced by the presence of breaking waves at the sea surface. The Meteorological Research Flight (MRF) Hercules has been used to make direct measurements of the transfers, though in the last year periods when the aircraft was not available for this purpose and unfavourable weather conditions limited the amount of data collected. However, analysis of previous years' data has proceeded. Included in this work is an involvement in a collaborative international experiment —HEXOS— studying Humidity EXchange Over the Sea.

Boundary layers over complex terrain

Although observations over flat homogeneous terrain are convenient for the testing of theories, many important practical problems are concerned with flow in complex terrain. A study utilizing a two-dimensional terrain-following coordinate numerical model has been carried out in co-operation with the Department of Applied Mathematics and Theoretical Physics, Cambridge University through the CASE (Co-operative Awards in Sciences of the Environment) studentship scheme. This study considers both gentle and steep hills and has involved the application of a complex turbulence closure to provide predictions of the turbulent stresses. To obtain a realistic description of the turbulent stresses a comprehensive model of boundary-layer processes is essential. A so-called second-order closure has been used. It utilizes model equations for all six components of the Reynolds stress tensor together with an equation for the turbulence length scale. In view of the model's complexity it has been reassuring that the field study conducted at Nyland Hill in Somerset during 1984 provided data that agree with the main features of the theoretical model. The measurements describe the mean flow and turbulence over the summit of a smooth rounded hill. Only in the lowest metre above the surface is the turbulence structure similar to that over flat terrain and the complex closure scheme is needed to describe the changes that occur further from the surface. Encouraged by this progress in both theory and observations, it is hoped that future work in this area will be able to address questions of more direct practical value, such as the net momentum transfer due to the hills.

Atmospheric dispersion

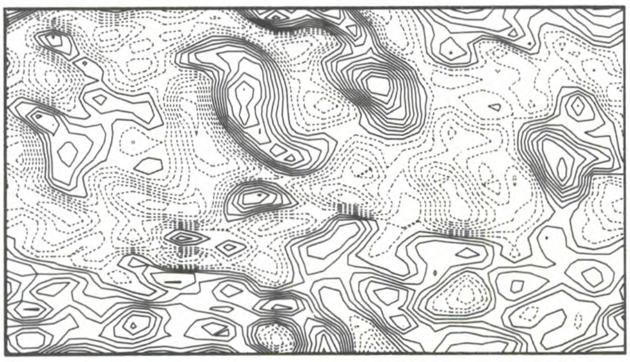
Experimental and theoretical work has continued on the long-range transport of materials and the related 'acid rain' problem. A study comparing trajectories based on wind fields forecast up to three days ahead with those based on the actual observed wind fields showed a useful level of skill. The experimental effort on long-range transport was concerned with observations from the MRF Hercules of the evolution of the Eggborough Electrical Power Station plume over the North Sea. An inert tracer gas was used to identify the plume. This work has been carried out in collaboration with the Central Electricity Research Laboratories, Leatherhead.

An important aspect of the acid rain problem is to determine whether there is a linear relation between the magnitude of emissions and the consequent depositions. Operational models for simulating this process assume such a relation even though the various processes within the chain are known to be strongly non-linear. While such models must therefore be inadequate on a single-event basis, there is evidence that they are surprisingly satisfactory in predicting long-term (one-year) deposition fields. The reason for this is that the changeable nature of the weather (and in particular rainfall) minimizes the long-term effect of the non-linearities. A special model has been developed to quantify these aspects and, as far as the UK emissions/Scandinavian-related depositions are concerned, the model predicts that approximate proportionality can be expected. The same conclusions cannot, however, be drawn for areas at risk that are much closer to the sources in the United Kingdom. They will tend not to benefit to the same degree from any future reductions in emissions.

Theoretical work on shorter-range dispersion has been concerned with the development of so-called 'random walk' modelling techniques. Experimental work on these scales has involved improvements to techniques in an effort to obtain adequate accuracy and reliability. The technique of using the inert gas sulphur hexafluoride as a tracer and collecting 'whole air' samples for subsequent analysis has been adopted.

Large-eddy simulations

It is clear that most turbulent flows have complexities which time-average closure



Horizontal section illustrating an instantaneous vertical velocity field in a neutral static stability boundary layer. The basic geostrophic wind speed is 10 m s^{-1} and the surface roughness length 0.1 m. The isopleths are at intervals of 0.1 m s^{-1} with solid lines indicating upward motion and dashed lines downward motion.

techniques cannot describe. In the main these complexities arise from the dominance of large-scale flow eddies that have properties dependent on the gross character of the flow. The technique of large-eddy simulation seeks to represent these large-scale motions explicitly with a three-dimensional numerical model and to use a turbulence closure to deal only with weaker small-scale eddies. It offers considerable promise as a means of obtaining a detailed understanding of turbulent flows and thus of developing simpler methods of predicting them. A study of a neutral static-stability (strong wind) boundary layer was completed and shows more surface drag than conventional models. This and other features will be checked against future field studies and the combination of simulation and observation should allow confident progress. The technique is also being applied to a convectively unstable boundary layer with a capping inversion. In this case much needs to be understood about the dynamics of the entrainment process that occurs at the temperature inversion and the ability of the large-eddy simulation to represent this process will have to be confirmed.

Tethered kite balloon used by the Meteorological Office.

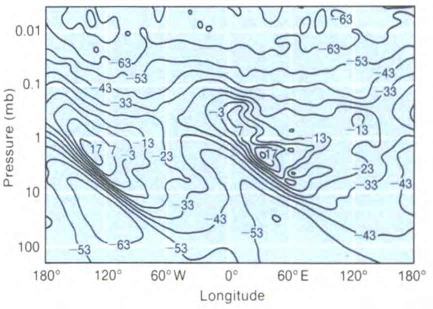
Facilities and instrumentation

Following the withdrawal of the Royal Aircraft Establishment from Cardington, the Meteorological Office has set up its own tethered kite balloon facility there. This facility uses modern helium-filled balloons and has demonstrated a capability of carrying packages, such as the Cardington turbulence probe, to heights of 2 km above ground level. A number of such turbulence probes are now available for use and work to complete a set of ten probes is proceeding. When complete, the combination of the probes and the balloon system will allow detailed studies throughout the whole depth of the boundary layer to be carried out.

The middle atmosphere

The middle atmosphere extends from the top of the troposphere to a height of about 85 km. It comprises a lower layer, the stratosphere, where temperature generally increases with height, and an upper layer, the mesosphere, where temperature decreases with height. Remote sensing from satellites has transformed our ability to investigate this region and numerical models which can now simulate the main features of the circulation enable us to investigate interactions between the middle atmosphere and the troposphere. One topical impetus for this work is a need to learn more about the movement of trace chemicals which could influence the ozone layer of the middle atmosphere.

Analysed data from Stratospheric Sounding Units (designed at the Meteorological Office and flown on the US NOAA series of satellites) now provide seven years of daily global synoptic maps for various stratospheric levels. They delineate the seasonal evolution of the stratospheric circulation and show interesting inter-hemispheric differences whose causes are being investigated. These analyses are made available to researchers at home and abroad to support other observational and theoretical studies of the stratosphere.



Vertical section of temperature through the middle atmosphere taken along latitude 58°N during a simulation of the major sudden warming of 1984/85. Isotherms are plotted every 10°C.

A striking departure from the regular seasonal cycle in the stratosphere occurs during so-called sudden warmings. Temperatures may rise locally by 50 °C in a matter of days as the westerly circumpolar vortex breaks down. A notable strong warming occurred in the northern hemisphere during the winter of 1984/85. Its salient features were reproduced successfully by a numerical model, including two frontal-like zones where the isotherms were packed closely together. These are illustrated left, in the vertical section through the middle atmosphere taken along a line of latitude. Frontal regions of the middle atmosphere seem to share a number of properties with fronts in the upper troposphere. The numerical model used in this study is being further developed as part of a joint modelling project with the Department of Atmospheric Physics, University of Oxford.

Office participation in the international Middle Atmosphere Program has included a proposal for a concerted study of the dynamics of the middle atmosphere of the southern hemisphere. Observations from satellites have only recently allowed detailed studies of this region.

Important studies of the chemistry of the stratosphere, which complement the dynamical studies reported here, are included under Atmospheric chemistry.

Aviation research and development, and special investigations

Aviation studies

Safety and cost-effectiveness in aircraft operations are much influenced by meteorological factors. Developments in aviation ensure that requests continue to be received for meteorological assistance and information on various aspects of aircraft operation and design. The demands are paralleled by an unabated need for better methods of forecasting for aviation. Such requirements result in various investigations; a description of some of these studies which were under way during the year is provided here.

Operations

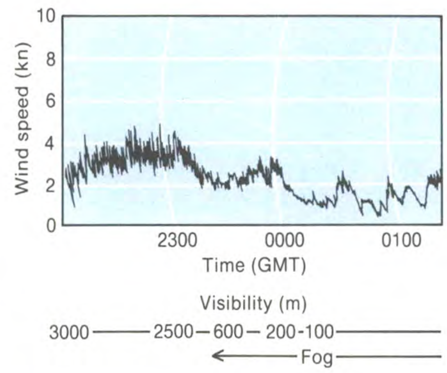
A study on the frequency of adverse weather at diversion airfields in Iceland and Greenland was completed for the Civil Aviation Authority. The report on this work included, for the period September 1984–May 1985, assessments of the reliability of forecasts for those airfields which may be used in emergencies by twin-engined aircraft on transatlantic flights.

Investigations to assess the value of inserting real-time aircraft meteorological data in the numerical forecasts used for flight management and air traffic control purposes have continued.

Radiosonde data were provided for a Civil Aviation Authority/Eurocontrol radar study of aircraft height-keeping performance. Fuel could be saved by a reduction in the height separation between mandatory cruise levels, provided other safety criteria are satisfied.

Forecasting

The requirements here range from those of the International Civil Aviation Organization (ICAO) for forecast significant weather charts covering the whole world to be produced automatically from numerical model outputs to the localized needs of the outstation aviation forecaster. The significant weather charts for ICAO indicate areas of expected clear air turbulence (CAT), deep convection and icing. A year-long CAT verification trial in collaboration with British Airways has

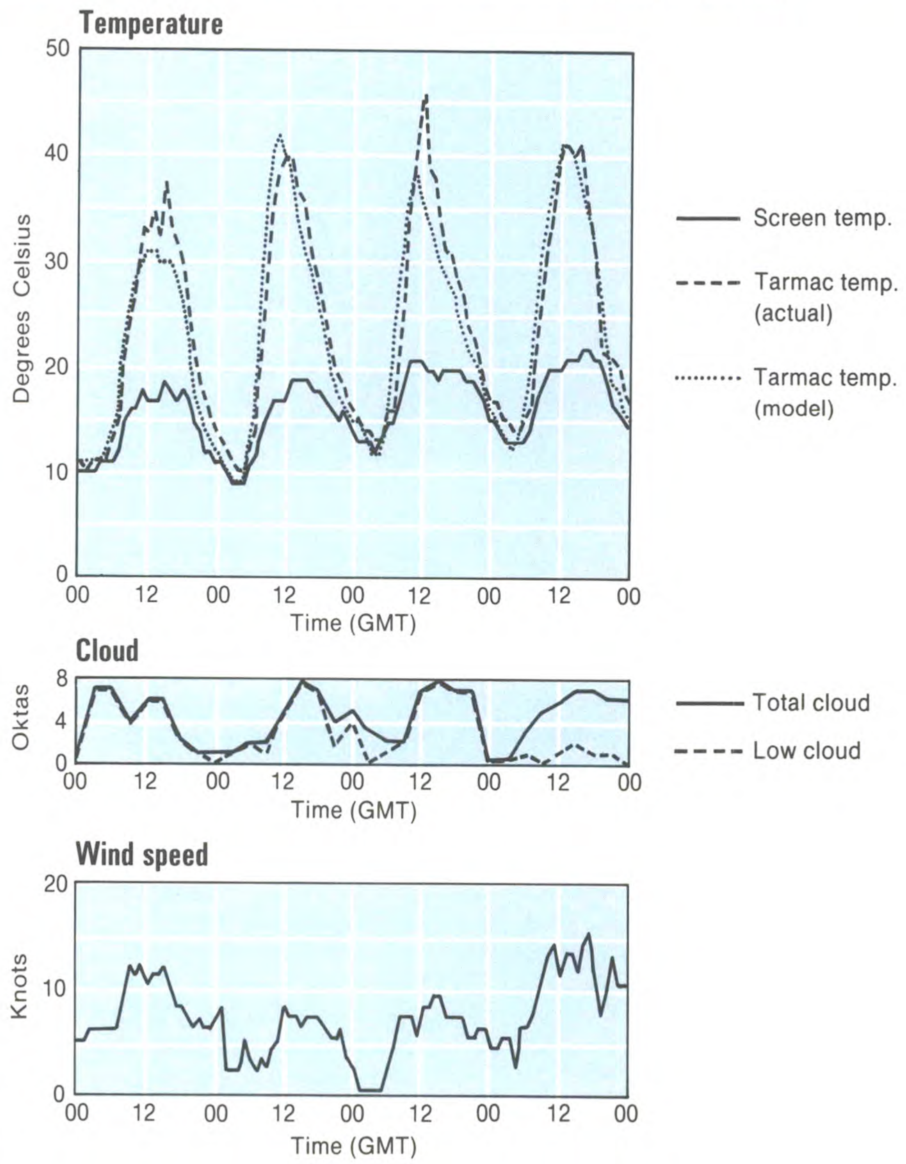


Example of a record from a sensitive cup anemometer mounted 2 m above ground level during the formation and thickening of radiation fog. A change in the degree of turbulence is evident as the fog forms and becomes denser.

been completed, and the results are being analysed.

Many of the problems of the outstation forecaster are associated with the forecasting of fog or low cloud at airfields; collaborative studies with these forecasters have been concerned especially with fog, at both inland and coastal airfields. A report on an investigation which used a minisonde and an acoustic sounder to study the lower atmosphere during the onset and dissipation of fog has now been published. A low-speed anemometer is being used in another study to assess the

Comparison of actual observed temperatures of a tarmac slab at Lyneham airfield with the temperatures predicted by the RST model. Also shown are the actual air temperature, cloud and wind speed which were used to force the model during a 4-day period in July.



predictive potential of the transition from turbulent to non-turbulent flow near the ground which is often observed before the formation of fog.

Further observations of sea fog over the Moray Firth were made on two occasions from the Meteorological Research Flight Hercules aircraft, and were supplemented by minisondes released at intervals from Lossiemouth during the flight. These studies of haar have already provided many valuable results, and it is hoped that one or two further flights in 1986 will give sufficient additional data to allow a comprehensive analysis of this notable hazard to aviation which affects the east coast of Scotland in particular.

Special investigations

Requests for meteorological advice in non-aviation topics also lead to special investigations. These require expertise in assembling fact and theory from diverse sources, and applying the results to practical problems. Two examples follow:

Fall-out from early British nuclear test
Following allegations that some Australian Aborigines were affected by radioactive fall-out from a British nuclear test carried out in South Australia on 15 October 1953, a study was made in collaboration with the Atomic Weapons Research Establishment of the effects of wind, turbulence and gravity on the bomb cloud. It was found that the fall-out probably did occur at some of the reported sites but at very low levels of concentrations. Subsequently, evidence of this study was presented to the Royal Australian Commission.

Forecasting of road surface temperature (RST). see illustration below left.
Highway authorities have a requirement for forecasts of RST in cold (for icy road warnings) and hot (for road surfacing operations) conditions. A model of RST has been developed for this purpose. Its performance in tests against actual data is promising.

Climate research

Climate has a major influence on the economic and social life of all sections of the world community. The World Meteorological Organization and the International Council of Scientific Unions have recognized that research into climate and climate change involves problems of such complexity and magnitude that they have established the World Climate Research Programme (WCRP) to promote and co-ordinate research activities at an international level. The Joint Scientific Committee for the WCRP has identified three broad lines of research based on the time-scales of interest.

On the longest time-scales (decades to centuries), models are being used to simulate the atmospheric general circulation to establish the physical basis of climate and its very long-term variations and to assess the potential response to natural influences and those due to man's activities. The continuing rise in atmospheric carbon dioxide CO_2) concentrations, which may cause a substantial warming of the earth's surface in the next 100 years, is one aspect of particular interest. The CO_2 effect has, however, to be disentangled from natural variations as studies of data for the past 100 years or so readily indicate.

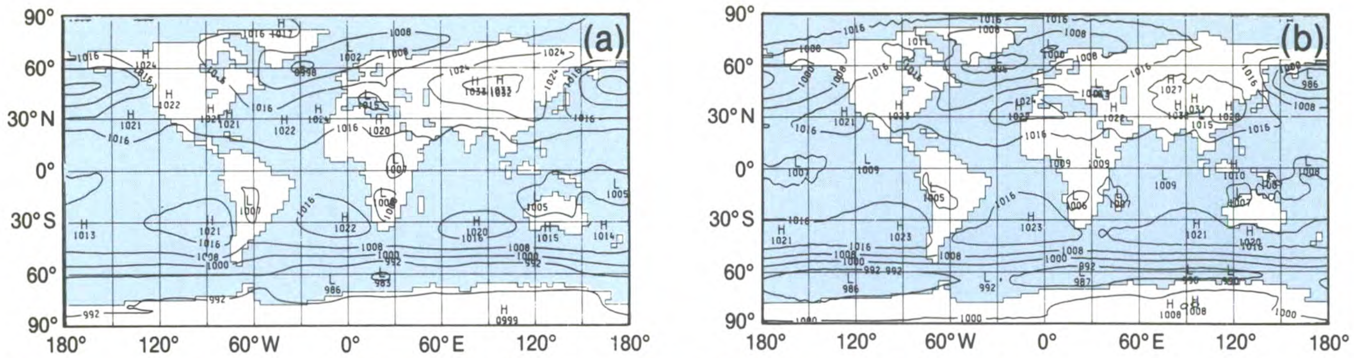
Variations of climate over periods ranging from one to several years are particularly evident in tropical regions. The prolonged drought in sub-Saharan Africa, where the rainfall has been disastrously low for 17 years, has attracted much recent public attention. Another notable event was the spectacular warming of the equatorial east Pacific (the El Niño event) during 1982–83 which appeared to be associated with widespread drought in the Australia/Indonesia region, floods in Ecuador and northern Peru and a violent hurricane season in the central Pacific; it also caused a catastrophic failure of the east Pacific fisheries. The largest influence on the atmosphere over inter-annual time-scales is now seen to be that of the oceans, especially tropical ocean surface temperatures, and coupled ocean–atmosphere models are being developed to study this.

The shortest time-scale of interest in the WCRP is one month to a season, with emphasis on the problem of long-range forecasting. As forecasts are extended, the influence of the boundary forcing, i.e. the ocean and land surfaces, increases relative to that of the initial state of the atmosphere. The assumption can probably be made that the sea surface temperature (SST) anomalies are persistent over this period, but that faster changing land surface conditions have to be modelled.

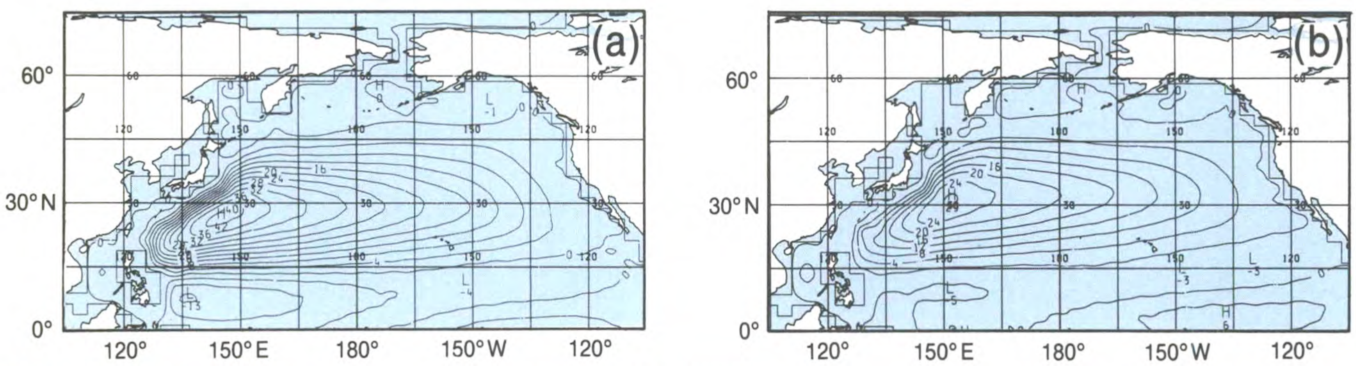
Climate modelling

Climate models enable controlled experiments to be carried out as a means of understanding the physical basis of the global climate. The physics of the atmosphere, ocean, sea ice and land surface are represented as mathematical equations to be integrated on a computer, as in numerical weather forecasting models, but climate models may be run for many years of simulated time rather than just a few days. Although detailed features cannot, after the first week or so, be expected to be well forecast, a properly designed climate model is capable of reproducing a circulation similar to that of the real atmosphere. By averaging several years of such a simulation a model's climatology can be produced and compared with the observed (see top illustration overleaf).

The simulation shown used an 11-layer model with a mesh size of 2½° latitude by 3¾° longitude and included the seasonal cycle of solar radiation. Seasonally varying SSTs and sea-ice extents were prescribed from climatology. For climate change experiments on long time-scales, the ocean and its interaction with the atmosphere must also be modelled. In this context, it is particularly important to simulate the atmospheric surface winds realistically, as they strongly influence the ocean–atmosphere interaction. Atmospheric models have tended to produce excessively strong westerly winds, which would generate a poor simulation of the ocean circulation.



Average mean-sea-level pressure (mb) observed for January (a) and modelled for December–February (b).



Observed (a) and modelled (b) ocean circulation stream function (10^6 m^3 s^{-1}) forced by annual mean wind stress.

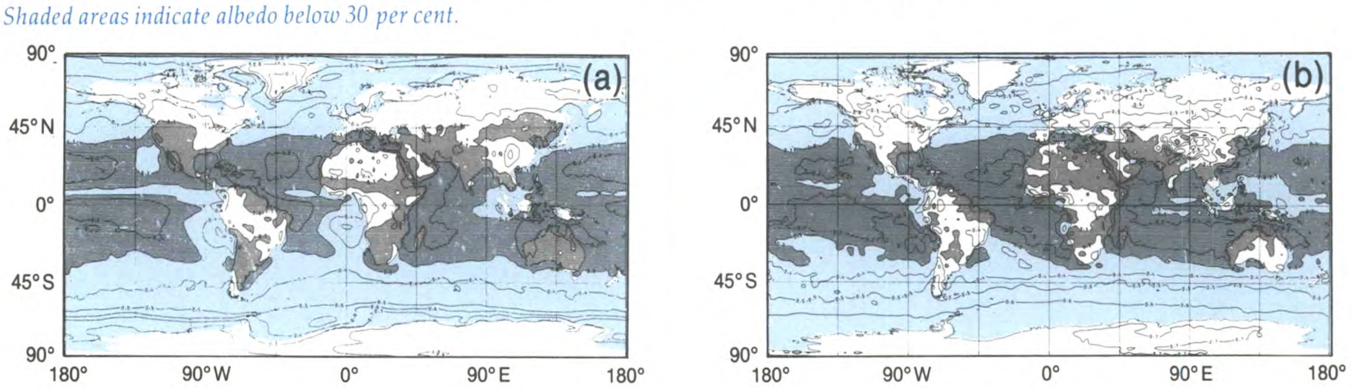
As with weather forecasting models, the introduction of drag caused by mountain-induced gravity waves substantially mitigates this shortcoming. The northern winter atmospheric circulation is improved (see top right) while the northern summer, southern hemisphere and tropical circulations—already quite realistic—are little affected. When the winds are used to drive an ocean model, the vertically averaged circulation is similar to that obtained with observed winds (shown above), though its strength is somewhat weaker.

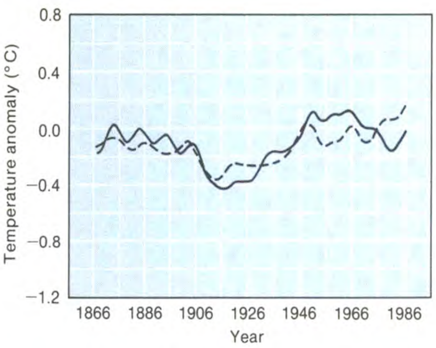
Successful integrations of an ocean–atmosphere model also depend on maintaining realistic sea-ice distributions. This is now being achieved with a simplified representation of the ocean after adopting ice reflectivities which allow for the partial ice cover typical of much of the Antarctic and parts of the Arctic in summer. Representations of sea ice which recognize the existence of broken ice more explicitly have been constructed. The presence of quite a small fraction of open water could give heat transfers closer to that of ice-free conditions than of full ice cover. The importance of a proper representation of sea ice has been shown by an experiment in which the edge of full ice cover in the Antarctic in winter was withdrawn to 66°S from its normal location at between 51 and 63°S. This gives large changes in the distribution of atmospheric heating and a southward shift of the sub-Antarctic low pressure belt.

It is particularly important to represent the effects of clouds in determining the radiative heating of the earth's surface. Cloud amounts and heights are diagnosed mainly from the modelled humidity and convective activity. Improved techniques have led to better simulations of deep convective and boundary-layer cloud so that the radiative forcing of the ocean–atmosphere system is now similar to that observed (see below). New formulations of the physics of boundary-layer mixing and precipitation, which include the introduction of conserved variables and cloud liquid water, should lead to further improvements in this aspect and allow the use of model-dependent cloud radiative characteristics.

The land surface is of great importance in a climate model because this is where the most detailed results are required and where man is particularly likely to alter the environment. The land surface interacts with the atmosphere through exchanges of momentum, heat and moisture. The atmosphere is especially sensitive through these interactions to the reflectivity of the land surface for solar radiation which largely determines how much energy is available for transfer to the atmosphere, and to the surface moisture availability which determines

Observed (a) and modelled (b) September–November mean reflectivity of the earth–atmosphere system. Shaded areas indicate albedo below 30 per cent.





Smoothed annual mean SST anomalies averaged over the northern hemisphere excluding the northern Indian Ocean (solid line) and the southern hemisphere plus the northern Indian Ocean (dashed line).

how this transfer occurs—as heat or moisture. These in turn, by affecting the atmospheric humidity, can change the rainfall amounts. The seasonal variation of temperature is also sensitive to heat storage and transfer in the soil. Representations of each of these processes are being improved through the introduction of a more realistic treatment of near-surface moisture and temperature which will allow the use of spatial distributions of vegetation and soil properties. It is hoped that, as well as improving the simulations, these changes will allow representation of perturbations of the land surface such as deforestation and soil degradation to assess their effects on climate.

Climatic trends

Data

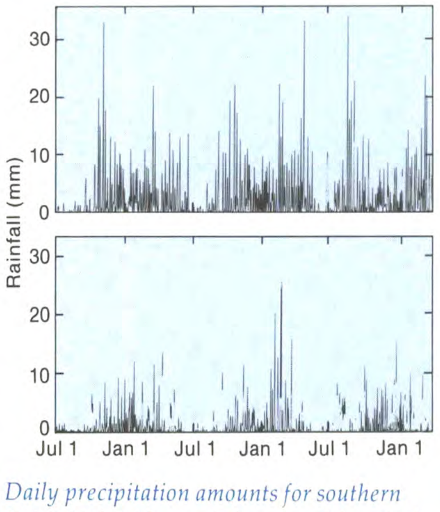
Climate data from many parts of the world are collected routinely for monitoring the climate and for use in long-range forecasting. The data are archived in the COSMOS computer. The availability of large data sets, and the computing power to process them, is one essential to climate research.

The length of the archives varies from 35 years for upper-air data, to 330 years for monthly Central England Temperatures (CET). Daily values of CET have been constructed back to 1772. Because of the significance of global data sets for detecting climate change a comparison is being made between the Meteorological Office Historical Sea Surface Temperature (MOHSST) and the Marine Air Temperature (MOHMAT) data sets (world-wide back to 1854) and the northern hemisphere land surface temperature data set of the Climate Research Unit, University of East Anglia. Both land and sea records show similar variations in global or northern hemisphere mean temperatures over the past 100 years but the divergence in trend between the northern and southern hemisphere in recent decades (see left) is of particular interest. The spatial and temporal coherence and variability of the marine data sets are being studied by spectral analysis, empirical orthogonal function analysis and extreme-value analysis.

Atmospheric carbon dioxide

Historical studies of global temperature variations can contribute to the detection of changes in climate expected as a consequence of increasing atmospheric CO_2 concentrations. Experiments with climate models suggest that a CO_2 doubling might lead to an equilibrium global mean warming of 3 to 4 °C. The 25 per cent increase in CO_2 content estimated to have occurred already since the start of the industrial era would, on this scale, give an equilibrium warming of about 1 °C, but its effects would be delayed by the large heat capacity of the oceans. Accurate modelling of heat transfer processes in the ocean will be necessary for detailed prediction of the warming trend.

In the Meteorological Office experiments on the CO_2 issue, the problem of modelling the oceans has been temporarily circumvented by using atmospheric models in which the changes in SST were prescribed on the basis of previous co-lateral experiments. Experiments with a 5-layer model showed important impacts of the CO_2 increase over Europe—notably a marked winter warming in the north; and a drying in the south throughout the year (see below). Recent work comparing the results of similar experiments with the 5- and 11-layer climate models has shown that the response may depend strongly on the existing climate. Thus the 5-layer model experiments had relatively weak westerlies over Europe in winter



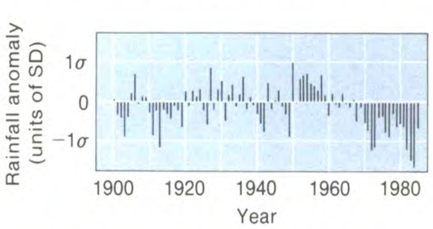
Daily precipitation amounts for southern Italy obtained from a 5-layer model control experiment (a) and experiment with increased SSTs and CO_2(b).

with occasional cold easterly outbreaks. A strengthening of the westerlies in a high CO_2 simulation brought a much warmer climate by reducing the frequency of the easterlies. In the 11-layer model simulation cold easterlies were rare so that stronger westerlies had a smaller impact on temperature.

Most models used in CO_2 impact experiments including those described here have given increased warming when the model was allowed to determine its own values for cloudiness rather than having them prescribed. This is because the increase in CO_2 leads to a reduction in cloud cover and further solar heating. Detailed investigations of the heat and moisture budgets are in progress to determine if the mechanisms are realistic.

Sahel Drought

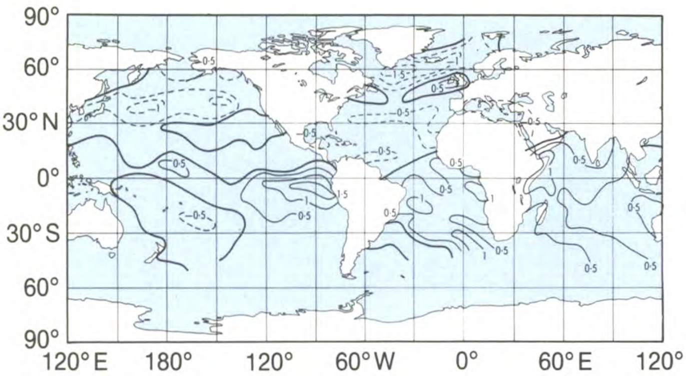
The figure below illustrates the annual rainfall anomalies for the Sahel for 1900–84. For many years the inter-annual variability was large but there was a remarkable trend between about 1950 and the present with an unbroken run of deficits after 1965. Most of the rain falls between June and September and the



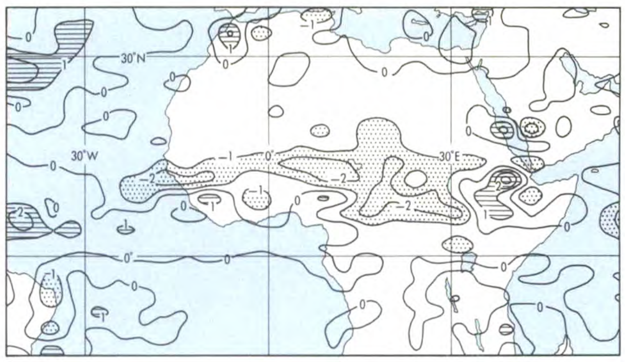
Standardized rainfall anomalies for the Sahel area, 1900–84.

largest shortfalls were in August and September. On an annual basis, Sahel rainfall is normally low when the South Atlantic, Indian Ocean and south-east tropical Pacific are warmer than normal and the North Atlantic, Mediterranean and North Pacific are colder than normal (see top left overleaf). This result applies particularly to the past 40 years but also has some validity for the earlier part of the twentieth century. Experiments with climate models support the physical reality of this link; the imposition of the illustrated SST anomaly pattern resulted in a reduction in rainfall over the western Sahel and changes in atmospheric circulation over equatorial Africa which accord with observations.

Summer rainfall has also declined in the United Kingdom in the last 20 years and analysis shows that in the period 1901–84 summer rainfall in England and Wales and drought in the Sahel were related on a time-scale of about 30 years, with weaker links on time-scales of 2–8 years.

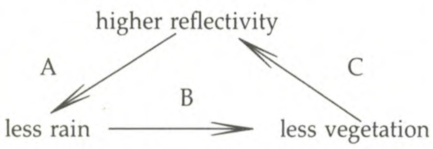


SST difference (°C) July–September related to the average of the five driest years in the Sahel (1972–3, 1982–4) minus the average of the five wettest years (1950, 1952–4, 1958). Dashed lines indicate negative values.



Modelled changes in daily rainfall amounts (mm) caused by reduced soil moisture storage and increased albedo over north Africa.

Other mechanisms may play a part in explaining the persistence of the Sahel drought, perhaps with positive feedbacks such as that involving surface reflectivity for solar radiation:



The validity of step A has been established in climate models while step C follows from the generally higher reflectivity of dry soil than of vegetation. Another possible mechanism concerns the lack of evaporation from a dry surface which tends to reduce rainfall and so maintain the surface aridity. Experiments in which the capacity of the soil to retain moisture was reduced and the reflectivity was increased over the Sahel (both of which could have been caused by a decrease in vegetative cover) have given reductions of rainfall quite similar to the observed patterns (see top right). However, there are inadequate quantitative observational data to confirm whether such changes to the land surface have actually occurred.

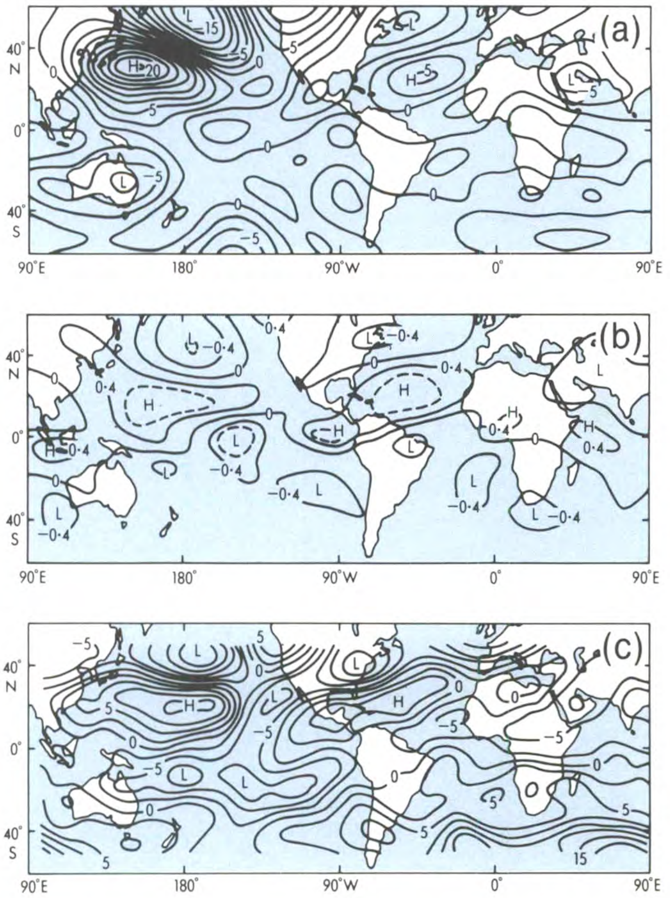
Deforestation of the tropics is another land surface change which could affect tropical rainfall. Experiments made jointly with the Geography Department of Liverpool University showed that the increase in reflectivity associated with deforestation could lead to substantial reductions in rainfall over the deforested regions. Some adjacent regions were also affected; further experiments will be needed to confirm whether this mechanism is relevant to Sahel drought.

Year-to-year variations

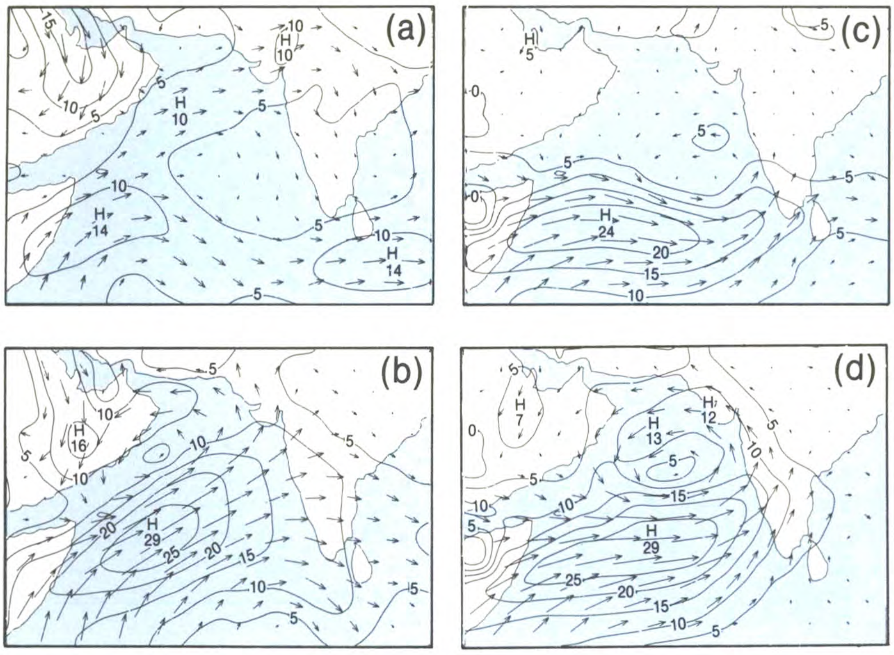
Atmospheric response to SST anomalies

Climate models are used to study the influence of SST on the atmosphere on interannual or shorter time-scales. The warmest oceanic waters in the world are in the tropical west Pacific (twP), and the release of latent heat in the convective clouds overlying the ocean is sensitive to small variations in SST. Two 1½ year-long climate simulations were run under fixed winter conditions; one with climatological SSTs, the other with a positive SST anomaly of about 1 °C. The figure below shows the difference between the time-averaged 200 mb flow patterns as represented by the stream function. The pattern, with centres over the north Pacific and North American continent, is highly reproducible. However, it also arises naturally in time variations within the run with climatological SST indicating that the small anomaly in the twP is preferentially exciting a mode of variability that arises naturally. This Pacific, North American (PNA) pattern is frequently found in the real atmosphere, and in the winter of 1976/77 (a winter which was particularly severe in the USA), when the anomaly was greater than 1 °C in the twP, the PNA pattern was clearly evident in the observations (see (c) below).

SSTs can have important impacts on quite short time-scales. Perhaps the best-defined annual atmospheric transition is the onset, usually in June, of the Asian summer monsoon. Experiments in forecasting the onset have demonstrated its sensitivity to the local ocean temperature distribution. The atmosphere and ocean in this region were particularly well observed in 1979, the year of the Global Weather Experiment, and this allowed identification of an area with sea temperatures above average by nearly



The 'Pacific, North America' pattern (see text) which arises in modelling experiments with high SST in the tropical west Pacific (a), in modelling experiments using climatological SSTs when precipitation is high over the tropical west Pacific (b) and in the real atmosphere—winter 1976/77 when SST was high in the tropical west Pacific (c).



Wind vectors and isotachs (m s⁻¹) at 850 mb: ECMWF analysis for 1200 GMT on 11 June 1979 (a), ECMWF analysis for 1200 GMT on 19 June 1979 (b), control forecast for 1200 GMT on 19 June 1979 (c) and anomaly forecast for 1200 GMT on 19 June 1979 (d).

2 °C off the west coast of India. The eight-day forecast of the monsoon onset was much better with actual than with climatological SSTs.

TOGA

Because the influence of tropical SST anomalies is so important, there is a major program within the WCRP to study the interactions between the tropical ocean and global atmosphere (usually referred to by the acronym TOGA). The aim is to determine the predictability of the coupled tropical ocean–atmosphere system and its impact on global climate on time-scales of months to years. The initial approach is to develop a high-resolution model of the tropical Pacific Ocean which will be linked to the global atmospheric model. The rest of the ocean will be assumed to change according to the normal seasonal cycle.

Although hopes for future predictive capabilities rest with comprehensive coupled models, simpler models can contribute to an understanding of key processes and thus play a valuable, guiding role in the development of the more complete models. For example, a surface heat source such as warm SSTs causes warm air to rise with compensating low-level inflows from all directions. For large tropical-scale SST anomalies, the effects of the earth's rotation and geometry need to be included also. The solution of equations describing this process indicates that there are regions of low-level outflow (Figure (a) below). Such patterns of low-level flow are often encountered in the equatorial zone as shown in Figure (b) below. This particular situation is representative of the anomalous flows during the 1982–83 El Niño period and was particularly significant because of the subsequent development of an unprecedented and devastating hurricane.

Long-range forecasting

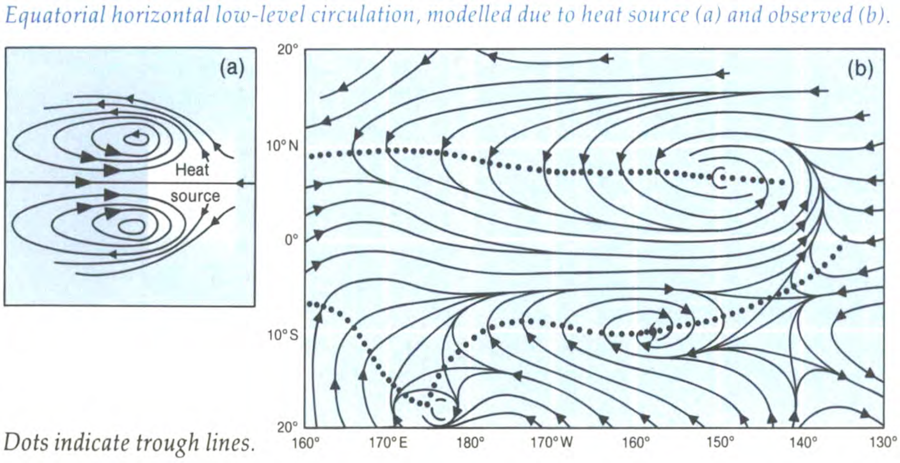
An understanding of the causes and mechanisms of fluctuations of the ocean–atmosphere system on a wide range of time-scales from ten days upwards is an essential element for progress in long-range forecasting. Experimental forecasts for the month ahead are produced every half month by combining numerical weather prediction and statistical methods.

Theoretical estimates of the period ahead for which the transient details of atmospheric flow can be forecast place the limit at 2–3 weeks partly because of the growth of features too small to be observed initially. However, the slower variations of the atmosphere are generally associated with atmospheric motions on very large scales and these seem to be more predictable. Experiments have shown that if several numerical forecasts are run from slightly different initial atmospheric conditions then although the individual forecasts will differ from each other, the ensemble mean often has higher skill than the average skill of the individual forecasts. Recently, for the first time, an ensemble of seven 11-level model forecasts was available for consideration at a routine long-range forecasting conference.

As forecasts are extended, the influence of the underlying boundary forcing increases in proportion to the influence of the initial atmospheric conditions and it has been demonstrated that winter model forecasts for a month ahead are generally more accurate if real SSTs are used in place of climatological values.

A statistical forecasting method employing cluster analysis and multivariate discriminant analysis has been used for the past few years and provides a framework for incorporating into practical long-range forecasting our increasing knowledge of the long-term behaviour of the atmosphere. For four years this scheme has been the main basis for forecasting the mean surface pressure pattern a month ahead for ten areas of the United Kingdom and has made a major contribution to increased skill in forecasting rainfall and temperature (see below).

Equatorial horizontal low-level circulation, modelled due to heat source (a) and observed (b).



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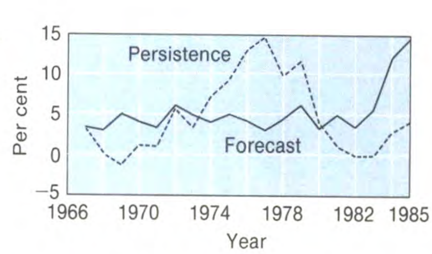


Four-year running means, plotted at the end of each 4-year period, of skill score for combined forecasts of mean monthly temperature and monthly total rainfall for the period January 1964 to September 1985 compared with persistence.

Atmospheric chemistry

The chemical composition of the atmosphere is important in determining the radiative transfer properties of a cloudless atmosphere and because certain airborne chemical species directly affect the biosphere. In order to understand the factors which determine the distributions of important constituents of the atmosphere better, a program of atmospheric chemical measurement is being undertaken together with a program of modelling research.

Tropospheric chemistry

The gases injected into the atmosphere during fossil fuel combustion are converted into sulphuric and nitric acid by complex processes which often depend on the presence of catalytic chemical species. An understanding of the conversions is fundamental to effective pollution control measures. Research on individual meteorological events is undertaken using the Hercules aircraft of the Meteorological Research Flight which carries a range of air-sampling equipment. Some of the equipment is designed to analyse samples in flight while others collect air samples for subsequent detailed chemical analysis. It has been suggested that peroxyacetyl nitrate (PAN) plays a significant role in the oxidation of combustion gases because it represents a significant fraction of the tropospheric reactive nitrogen. The gas chromatographs on the aircraft have been modified to permit detection of PAN and, provided a suitable calibration can be achieved, should permit measurement at low concentrations. PAN has been detected during a flight over the North Sea in the atmospheric boundary layer. Samples of air were also taken and these are being analysed for light hydrocarbons so that the chemical evolution may be determined.

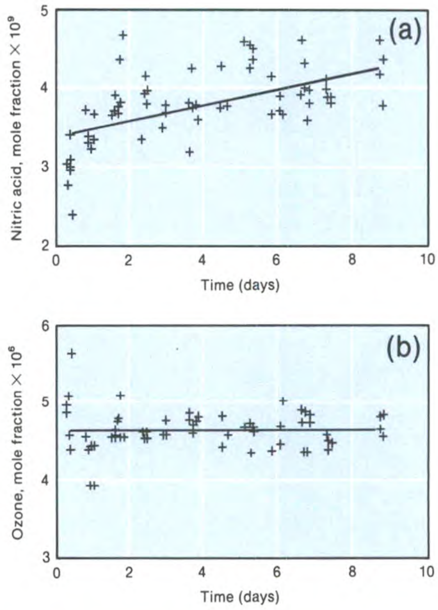
Careful monitoring is necessary if the effects of chemical species of anthropogenic origin are to be assessed. For many years the Meteorological Office has obtained samples of rain-water at three sites in the United Kingdom using specially designed opening and closing rain-gauges to prevent contamination of the water sample by dry deposition. Recent studies have suggested that it is necessary to obtain these samples on a daily basis, rather than on the monthly basis which was being used, because the composition of rain-water varies between rainfall events and even within a shower. The rain-gauges are being modified so that daily samples of sufficient volume can be taken for analysis.

The exchange of air between the stratosphere and troposphere is, on average, a slow process but nevertheless it has a significant effect on the residence time of gases and particulates in the atmosphere. Most exchanges take place in the vicinity of jet streams where the tropopause becomes folded. To clarify earlier chemical observations made near a jet stream, a flight was made in April along the length of a jet extending from Scotland to Iceland. The interpretation of the aircraft measurements of ozone and water vapour requires estimates of the atmospheric motions over a larger area and these are being derived from numerical forecast products. There is good agreement between the detailed water vapour and ozone measurements made from the aircraft and the deductions from the humidity and potential vorticity fields extracted from the forecast model. This has proved of substantial benefit in interpreting the results.

Stratospheric chemistry

In view of the importance of ozone as an absorber of radiation in the wavelength range 280–320 nm, a world-wide program of monitoring is being undertaken under the auspices of the World Meteorological Organization. As part of the program routine measurements of the total ozone in an atmospheric column have been made daily at Bracknell using a Dobson spectrophotometer. Assistance has also been given to those making measurements at several other sites around the world both by calibrating instruments against the Meteorological Office standard and by making modifications to the instruments to improve their operation. During the year the calibration of the Office's standard instrument was checked against the world standard instrument.

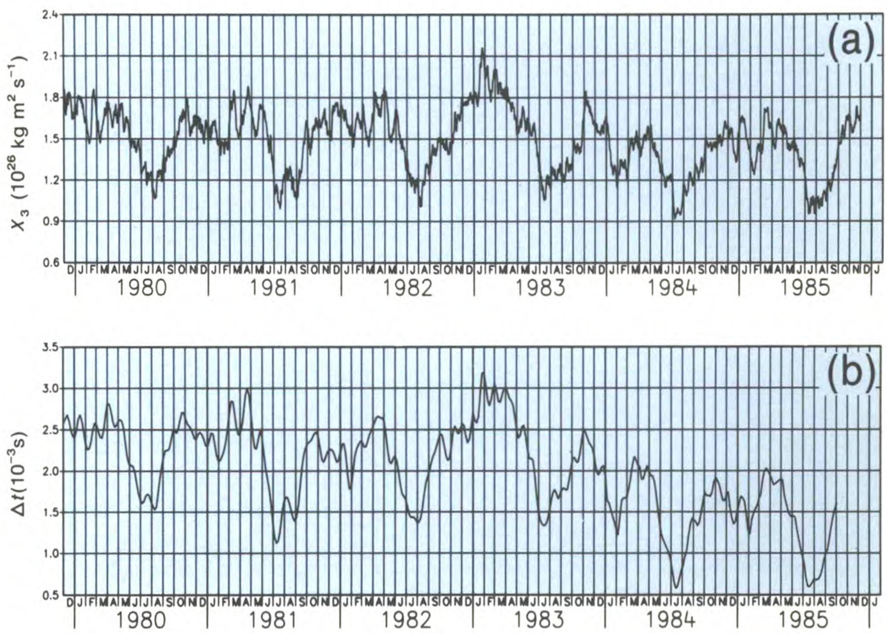
The distribution of ozone and other chemical species depends on the general circulation in the stratosphere and on photochemical reactions. A numerical model has been developed to calculate the photochemical evolution of different species within a parcel of air which follows an atmospheric trajectory derived from satellite observations. Results have been compared with satellite observations of ozone, nitrogen dioxide, nitric acid and water vapour which coincide with the air parcel trajectory. The integrity of the modelling technique has been established but studies undertaken in collaboration with NASA, Langley and NOAA Environment Research Laboratory, Boulder have indicated that there is an unexplained source of nitric acid in the arctic winter stratosphere.



Satellite measurements along back trajectories at an initial potential temperature of 850 K from 80°N, 72°E on 30 December 1978 with calculated regression lines:nitric acid (a), ozone (b). The photochemical model incorporating currently accepted reactions predicts zero change in both species over ten days. (Note that mole fraction is the same quantity as volume mixing ratio.)

Geophysical fluid dynamics

The solution of many of the major problems of dynamical meteorology will require 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. 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.



Angular momentum fluctuations (χ_3) of the atmosphere (a) and changes in the length of day (86 400 s + $\Delta t 10^{-3}$ s) (b) showing that most of the short-term fluctuations in the length of the day are due to angular momentum exchange between the atmosphere and the solid earth.

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 it has also been shown that meteorological phenomena contribute significantly to polar motion. The International Union of Geodesy and Geophysics has set up a special co-operative program through which these results can be exploited by geodesists and other scientists concerned with fluctuations in the earth's rotation due to meteorological and other causes. Attempts are now in hand to use meteorological models to make forecasts of changes in the earth's rotation for use in astronomy and spacecraft navigation.

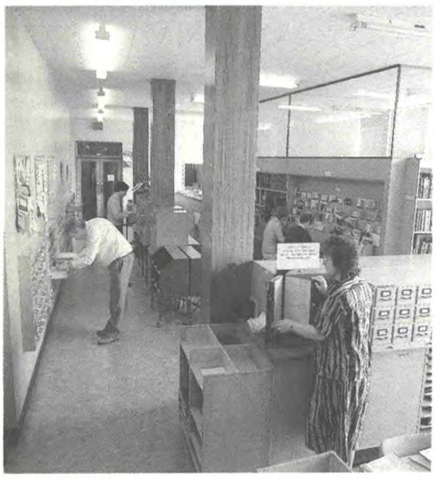
Many features of the large-scale atmospheric circulation can be reproduced in differentially heated rotating tanks of liquid, including long-lived eddies reminiscent of the stable eddies seen in the atmospheres of Jupiter and Saturn. Studies based on the joint use of laboratory systems and their counterparts 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. A numerical model based on the Navier–Stokes equations now reproduces most of the different types of phenomena seen in the laboratory system.

The National Meteorological Library and Technical Archives

The origins of the present National Meteorological Library go back to the holdings of meteorological books and research papers built up by the Meteorological Office in the closing decades of the last century.

In its present form the Library owes much to C.E.P. Brooks (1888–1957) who transformed it into a meteorological library of the first rank and adopted the Universal Decimal Classification system under which every book, individual scientific paper, review article, or climatological bulletin is classified. The aim of the Library is to hold and catalogue all published material of interest or value to the professional meteorologist or serious amateur in the field of atmospheric science; within the inevitable constraints affecting Government expenditure, this aim is achieved with a high degree of success. Many rare books of meteorological interest are held, and these are catalogued jointly with the collection owned by the Royal Meteorological Society. The Library and the Society also possess a number of original weather diaries compiled before official reporting networks were set up. These are often useful for answering historical enquiries.

Part of the card index system in the National Meteorological Library.

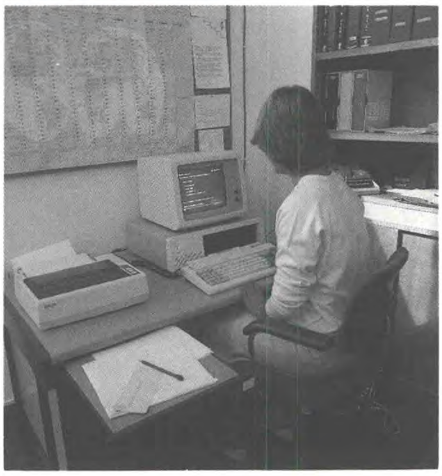


In total about 200 000 books and pamphlets are held, as are runs of several hundred journals and over 25 000 slides and photographs; the holding of microfiche sheets is increasing rapidly, currently standing at about 28 000. Computer methods have been increasingly used during the last 15 years to produce the Monthly Accessions List, and the Meteorological Office Library Asscessions and Retrieval System—MOLARS for short—is being steadily extended to cover information retrieval and loans control. On-line bibliographic search facilities are publicly available from the European Space Agency Information Retrieval Service at Frascati in Italy.

The Technical Archives hold all the original records, observation books and forecasters' working charts deemed worthy of permanent retention. They have been carefully selected to provide both an adequate public memory of the weather affecting particularly the United Kingdom and neighbouring sea areas and a continuing picture of the operations of the Office. They 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 retained in archives at Edinburgh and Belfast respectively. All these records are available for inspection by the public during normal working hours.

The National Meteorological Library and Technical Archives at Bracknell together form a source of meteorological data which for geographical coverage, fineness of detail, and depth of classification is probably unsurpassed anywhere. They are visited by professional meteorologists from all over the world. Some 30 000 items a year are supplied as loans, photocopies or microfiche.

The MOLARS terminal.



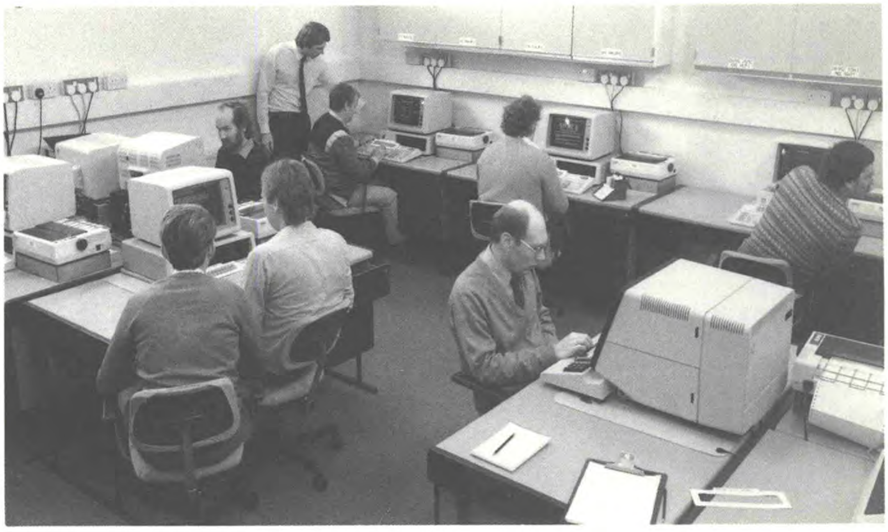
Training

The training needs of the staff of the Meteorological Office are kept under constant review. During the year a detailed appraisal of the training of Assistant Scientific Officers was carried out. Most of the training is carried out at the Office's residential college at Shinfield Park, near Reading, where courses are available at all stages of a career both to learn new skills and to keep abreast of new developments. Residence at the College fosters the sharing of experience and allows courses to be shorter, more intense and therefore more cost-effective.

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 student is going initially to an observing/forecasting office or to another part of the Office. Suitably qualified students training to be forecasters learn about meteorology and it's application and also practise the arts of communication and decision making. Those going into research are encouraged to think independently whilst working as one of a team.

In-service courses occur at regular intervals with objectives linked to a stage in a career. For example, newly promoted Assistant Scientific Officers embarking on careers as forecasters start by taking the Initial Forecasting Course followed by the Advanced Forecasting Course about two years later. They then return to the College periodically for courses which update their forecasting skills.

Some courses concentrate on management problems peculiar to the Office; others teach specialized subjects such as computer programming, statistics and telecommunications. One-week courses are held for auxiliary and co-operating observers—people who are not professional meteorologists but who assist the Office in making weather observations. Some of these observers



The new computer laboratory

work in aviation, and continue their training with a week at an airfield meteorological office. During the year courses were also run for members of the British Antarctic Survey and the British Petroleum Company.

A new venture was a Summer School organized jointly by the Office and the University of Reading. The School brought together some 70 meteorologists from both operational and research backgrounds, to participate jointly in a week of advanced study of mesoscale meteorology. The format, which consisted of formal lectures supplemented by practical case study investigations, was a key factor in the School's success.

The increasing use of new technology in the Office is mirrored by the installation and training in the use of new equipment at the College. Recent additions to in-house facilities include a computer laboratory, television studios and 'current weather' forecasting/observing offices with associated equipment. The computer laboratory is equipped with IBM Personal Computers which can either be linked to the Office's main computing facility at Bracknell or be operated independently of any external links.

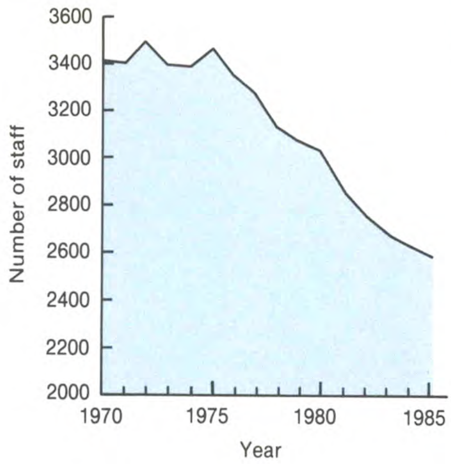
Training of staff on topics not covered by the Meteorological Office College syllabus takes place elsewhere when suitable courses are available. Principles of management training are undertaken at the Civil Service College and other establishments run by the Civil Service. Technical staff learn basic electronics at Reading College of Technology and train specifically on meteorological equipment at the School of Technical Training.

Staff are encouraged to improve their academic qualifications, especially in mathematics and physics, and where possible concessions are made available for external study. During the year 129 staff took advantage of this facility so that they might progress to the mutual benefit of themselves and the Office.

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

The new computer classroom

Personnel



Number of Meteorological Office staff 1970–85. (From 1981 figures are for 1 April, earlier years are for 1 January)

During 1985 manning levels in the Office continued to fall in order to meet government targets. At the end of the year, total strength had fallen to 2587, a reduction of 127 from the December 1984 figure. However, the loss of expertise was not as serious as these figures indicate because 90 staff working wholly and exclusively in support of civil aviation were placed on loan to the Civil Aviation Authority but remain Meteorological Office employees. In addition around 30 staff were seconded for periods of 3–5 years to international bodies and commercial organizations both in the United Kingdom and overseas and are therefore not included in the strength figures.

Despite the enforced reductions considerable effort had to be devoted to recruitment at graduate and school-leaving levels. The number of retirements was not as high as in 1984 but there was a large number of resignations. These latter gave special cause for concern as they were mostly trained and experienced staff, the Headquarters-based computing and computing-related areas suffering particularly on account of the many job opportunities in local high-technology industries. The attraction of the private sector was also apparent from the marked reduction in the number of applications from graduates for appointment in the Office and the increased tendency for potential recruits to decline offers of appointment.

The cutbacks and above-average staff losses were reflected in the increased number of staff movements necessary to maintain operational services at an acceptable level and to place expertise where it was most needed. Careful attention to training and career development, which aims to meet the needs of the Office in ways which also develop the potential and satisfy the aspirations of individual members of the staff, has so far made it possible to keep pace with the Office's changing needs and commitments.

Staff numbers

Deputy Secretary	1
Under Secretary	1
Science Group	
Chief Scientific Officer	2
Deputy Chief Scientific Officer	5
Senior Principal Scientific Officer	26
Principal Scientific Officer	108
Senior Scientific Officer	292
Higher Scientific Officer	435
Scientific Officer	446
Assistant Scientific Officer	644
Administrative Group	
Assistant Secretary	1
Principal	1
Senior Executive Officer	2
Senior Executive Officer Management Accountant	2
Higher Executive Officer	7
Higher Executive Officer Management Accountant	1
Executive Officer	18
Executive Officer Management Accountant	1
Clerical Officer	51
Clerical Assistant	51
Professional and Engineering Group (including Marine Superintendent staff)	
Superintending Engineer	1
Principal Professional and Technology Officer	3
Professional and Technology Officer Grade I	5
Professional and Technology Officer Grade II	17
Professional and Technology Officer Grade III	4
Professional and Technology Officer Grade IV	3
Telecommunications staff	
Telecommunications Technical Officer Grade A	1
Telecommunications Technical Officer Grade I	9
Telecommunications Technical Officer Grade II	29
Telecommunications Technical Officer Grade III	60
Radio (Meteorological) Technician	33
Signals grades	39
Teleprinter grades	50
Typing and miscellaneous non-industrial grades	127
Security officers	11
Ocean Weather Service	2
Industrial employees	46
Locally entered staff and employees overseas	52

Staff honours and awards

Mr F. Mott, Mr N.J. Harris, Mr G.W. Farrow and Mr G.D. McCulloch (all now retired) 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 Dr J.F.B. Mitchell.

International

To run a global model, observations are needed from all parts of the world: they must be accurate, representative, internationally comprehensible and punctual. As part of the World Weather Watch (WWW) each Member State of the World Meteorological Organization (WMO) provides observations from its territory. USA, USSR, India, Japan and certain European states, including the United Kingdom also fund meteorological satellites which provide data over the oceans and in lightly inhabitated areas. Other systems include aircraft, ships in the Voluntary Observing Fleet and ships in the Automated Shipboard Aerological Programme.

The cost of WWW and its integral Global Telecommunication System (GTS) is well over £1000 million each year but the resulting data are available to all National Meteorological Services (NMSs) free of charge. In return, some of the more advanced NMSs make processed data, including electronically computed weather predictions, freely available. During the year, forecasts for the whole globe, computed at Bracknell, were offered to all NMSs on the GTS.

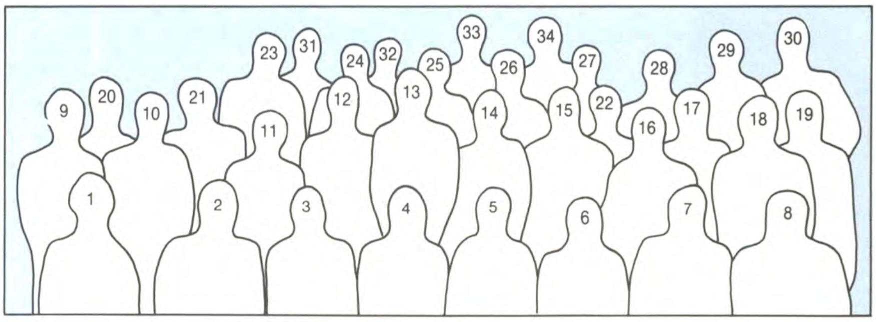
WMO's Commission for Basic Systems (CBS) provides the framework for this international co-operation. The Technical Commissions usually meet once in four years but an Extraordinary Session of CBS was held this year in Hamburg; Dr D.N. Axford led the UK Delegation. The Commission spent much time revising its plan for WWW for 1988–97. The Commission for Climatology met in Geneva in December and considered its plan for the same period. These and similar volumes from other Commissions will be brought together by the Executive Council and recommended to the next World Meteorological Congress in 1987. As well as providing UK representatives for these bodies the Office has hosted meetings, such as a WMO Training Workshop for Instrument Technicians from Africa, and has offered training Fellowships. The Office also has members on many of the Working Groups of the constituent bodies of WMO and in groupings such as those which develop and operate an aircraft system for acquiring and relaying meteorological data (ASDAR) and execute and evaluate experiments on observing systems for the North Atlantic (CONA).

Data are needed for both operations and research. The latter is co-ordinated through the Commission for Atmospheric Sciences, sometimes in conjunction with other bodies such as the International Council of Scientific Unions, and through particular programs such as the World Climate Programme and its components on applications, data, impact and research.

Outside the WMO structure but allied with it, the European Centre for Medium Range Weather Forecasts celebrated its tenth anniversary. The Office continues to represent the United Kingdom on the Council and on each of the Centre's Committees.

The major event, though, was the Conference of Commonwealth Meteorologists. Opened by the Under Secretary of State for Defence Procurement, Mr John Lee MP, the Conference was attended by directors and senior staff from 19 different countries. Discussions and visits ranged widely and freely over fields of common interest.

Members attending the Conference of Commonwealth Meteorologists held at the Meteorological Office College, Shinfield Park, June 24–27.



1 *Mrs T. Cowell UK (Secretariat)*
2 *Mr V.A. Simango Zambia*
3 *Dr S.K. Das India*
4 *Mrs H.A. Jaafar Brunei*
5 *Dr J.T. Houghton UK*
6 *Miss G.K. Ramothwa Botswana*
7 *Mr L.A. Chang-Ko Seychelles*
8 *Mr C.E. Berridge Caribbean Meteorological Organization*
9 *Mr Ooi See Hai Malaysia*
10 *Mr P. Msafiri Tanzania*
11 *Dr A. Kalu Nigeria*
12 *Mr D. Smith WMO/Canada*
13 *Dr J. Zillman Australia*
14 *Mr J.S. Hickman New Zealand*
15 *Mr D.F. Best Barbados*
16 *Mr I.O. Emore Nigeria*
17 *Mr Y. Valadon Mauritius*
18 *Dr D. Gauntlett Australia*
19 *Mr D.H. Johnson UK*
20 *Mr J. Downing UK (Secretariat)*
21 *Mr S.G. Cornford UK*
22 *Mr D. Linehan Ireland*
23 *Dr P. Hutchinson Commonwealth Science Council*
24 *Dr U.B. Lifiga Tanzania*
25 *Mr Ho Tong Yuen Malaysia*
26 *Mr J.P. Bruce Canada*
27 *Mr P. Sham Hong Kong*
28 *Mr S.E. Tandoh Ghana*
29 *Mr S. Geno Papua New Guinea*
30 *Mr I. Williams ODA UK*
31 *Dr C.J. Readings UK*
32 *Mr C.G. Collier UK*
33 *Mr B. Coburn Kiribati*
34 *Dr I. Rutherford Canada*

Interaction with the national infrastructure

The Meteorological Office interacts with the national infrastructure in many ways. In connection with its forecasting and advisory service it works closely with the Building Research Establishment of the Department of the Environment, the Agricultural Development and Advisory Service of the Ministry of Agriculture, Fisheries and Food, and there is liaison with the Departments of Transport, Energy, Health and Social Security and the British Standards Institution. Staff also serve on government interdepartmental committees and other bodies. Examples are the Physical Sciences Committee of the Chemical and Biological Defence Board, the Working Group on Atmospheric Dispersion Modelling of the National Radiological Protection Board, the Working Group on Acid Rain of the Watt Committee and the Flood Protection Committee of the Joint Consultative Organization for Research and Development in Agriculture and Food.

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

The Office also interacts with other scientific communities through the Royal Society and its committees, the research councils, and through contacts with the universities. Three members of staff (Dr J.T. Houghton, Dr R. Hide and Dr K.A. Browning) are Fellows of the Royal Society and several members serve on its committees; Dr K.A. Browning FRS is Deputy Chairman of the British National Committee for Geodesy and Geophysics and Chairman of its subcommittee on Atmospheric Physics. Staff also serve on the British National Committees on Problems of the Environment, Solar Terrestrial Physics, Space Research, the World Climate Research Programme and some of their subcommittees. Dr R. Hide FRS was President of the Royal Astronomical Society until March.

Meteorological Office representatives serve on the Natural Environment Research Council, its Marine Science Committee, Services and Facilities Committee, and its Aquatic and Atmospheric Physical Sciences Grants Committee, the Advisory Committee on Ocean Circulation Modelling, the Co-ordinating Committee on Research in Atmospheric Chemistry and the Advisory Committee on International and Oceanographic Affairs. An Office member chairs the Science and Engineering Research Council (SERC) Mesosphere Stratosphere Troposphere Radar Project Management Committee and also serves on the SERC Solar System Committee.

The Meteorological Office is represented on the National Remote Sensing Programme Board and the Core Group determining the UK position on the proposed European Polar Platform.

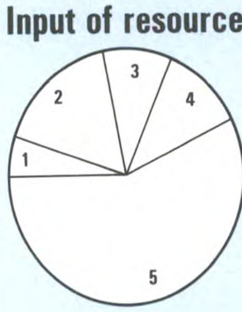
Staff have participated in the work of the Joint Working Party on Advanced Research Computing and its sub-groups to consider advanced research computing facilities for the University and Research Council Community.

Oral evidence has been provided to Sub Committee II Marine Science of the House of Lords Select Committee on Science and Technology and to the Royal Australian Commission concerning fall-out from a British nuclear test in South Australia on 15 October 1953.

Finance

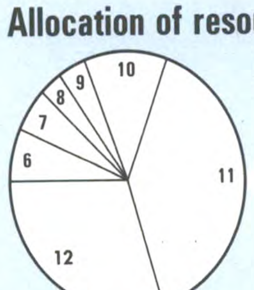
On a fully cost-accounted basis, the total cost of the Office in 1984/85 was £68.4 million compared with £63 million in 1983/84. The net cost after earnings from services was £47.5 million compared with £44 million in 1983/84. Over the last five years, apart from the cost of Meteosat (the development and early operations of which were paid for by the Department of Trade and Industry), the gross cost of the Office has fallen by about 4 per cent in real terms and the income from repayment services (other than the Civil Aviation Authority (CAA)) has risen by 100 per cent; all this during a period of

Input of resources



1 Depreciation of interest on capital (5.1%)
2 Grants and subscriptions to international bodies (16.8%)
3 Office support, telecommunications, accommodation (9.5%)
4 Materials (11.4%)
5 Staff costs (57.2%)

Allocation of resources



6 Technical support maintenance (6.7%)
7 Miscellaneous overheads including MOD costs (5.5%)
8 Training (3.1%)
9 Administration (3.9%)
10 Research and development (11.3%)
11 Observations, telecommunications, computing, central forecasting (39.8%)
12 Met. services for customer activites 29.7%

substantial growth in the Defence Budget as a whole. Charges for repayment services were increased by 5 per cent on 1 April 1985.

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

Arising from a recommendation of the 1983 Resource Control Review, a revised basis of allocating overheads has been adopted in the preparation of the 1984/85 MTA. Under this revised method, the attribution of customer costs consists of those directly attributable plus a fixed percentage of central operational costs and general overheads as recommended in the Sharp/Hansford study interim report. In the case of CAA, for instance, their charges included 22½ per cent of these central costs, excluding the cost of research of which 21 per cent continues to be allocated on the basis of the Macfarlane formula.

Meteorological Office Receipts 1984/85 (Cash recoverable)

	1984/85 £000	1983/84 £000
Services to:		
Ministry of Agriculture, Fisheries and Food	596	728
Other Exchequer departments (Department of Environment etc.)	151	131
Civil Aviation Authority	15 427	14 264
Other non-Exchequer departments	256	29
European Economic Community	119	117
Public and Local Authorities	565	209
Meteorological Office College (training of meteorologists)	144	187
Secondments to outside bodies	16	43
Comprehensive forecasting for the offshore oil industry	1 203	1 314
Forecasting and climatological services tailored to meet users' special needs:		
Ship Routeing Service	106	81
Gas Boards	219	185
Central Electricity Generating Board	169	170
British Rail	39	26
Independent Broadcasting Authority	518	293
British Broadcasting Corporation	340	275
Press	73	70
Other customers' special services	711	568
Automatic Telephone Weather Services (British Telecom)	266	239
	20 918	18 929

Statement of the cost of meteorological services for the year ended 31 March 1985

	1984/85		1983/84	
	£000	£000	£000	£000
Total meteorological services (cost accounted)		68 415		63 021
Receipts:				
Training and secondments	160		230	
Exchequer departments	747		859	
Non-Exchequer bodies	17 381		15 641	
Industry and commerce	2 592		2 159	
General public	38		40	
		20 918		18 929
Net expenditure:				
Defence and other Exchequer departments	27 818		29 619	
General public services and international	19 679		14 473	
		47 497		44 092

Statement of operating expenses for the Meteorological Office for the year ended 31 March 1985

(1) Expenditure	(2) Defence services £000	(3) Exchequer departments non-repayment £000	(4) Public services £000	(5) International £000	(6) CAA £000	(7) 1984/85 Total £000	(8) 1983/84 Total £000
Customer activity costs	8 655		5 736	1 229	4 727	20 347	20 428
General Meteorological Office core activity costs:							
Research	3 143		2 946		1 619	7 708	8 049
Administration and personnel						2 652	3 188
Central Forecasting Office						3 020	2 346
Computing						744	512
Maintenance						1 901	1 216
Observations	15 413		14 449		8 670	19 358	14 041
Technical support						2 657	3 877
Telecommunications						4 146	5 193
Training						2 094	1 540
Others						1 960	913
Total Meteorological Office management costs	27 211		24 360		15 016	66 587	61 303
Full cost items:							
Share of MOD HQ costs						632	508
Insurance						81	74
Interest on capital:	731		686		411		
Fixed						874	917
Working						241	219
Total Meteorological Office costs	27 942		25 046		15 427	68 415	63 021

Appendices

APPENDIX I
BOOKS OR PAPERS BY MEMBERS OF THE STAFF

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

AUSTIN, J.
Calculation of stratospheric air parcel trajectories using satellite data. *NASA Langley Research Center, Hampton, Virginia.* 8 August.
Problems and successes of chemical trajectory modelling using LIMS data. *NOAA Aeronomy Laboratory, Boulder, Colorado.* 12 July.

BALLARD, S.
Parametrization of viscosity in three dimensional vortex methods and finite difference models. *ICFD Conference on Numerical Methods for Fluid Dynamics, University of Reading.* 1–4 April.
Three dimensional turbulance simulation and mesoscale modelling. *2nd Conference on Mesoscale Processes, American Meteorological Society, University Park, Pennsylvania, USA.* 3–7 June.

BARROWCLIFFE, R.
Weather and cereal yields. *British Association of Plant Breeders, Plant Breeding Institute.* 29 January.

BELL, M.J.
The stability of baroclinic jets. *Department of Mathematics, University College, London.* 15 November.

BELL, R.S.
Data assimilation in the Meteorological Office regional model. *Royal Meteorological Society Specialist Group on Dynamical Problems.* 5 November.

BENNETTS, D.A.
The relevance of meteorology to military planning. *NATO Defence College, Rome.* 7 July.

BORTHWICK, C.A.S.
Ship weather routeing. *Nautical Institute, Humberside.* 17 October.

BOYACK, C.F.
Wind statistics and ocean modelling. *Seminar on Design of Offshore Structures—Errors and Uncertainties in Loading due to the Environment, Society for Underwater Technology, London.* 28 February.

BROWNING, K.A.
Conceptual models of precipitation systems. *Nowcasting IIA Symposium, IAMAP/IAPSO Joint Assembly, Honolulu.* 6 August.
Towards the more effective use of radar and satellite imagery in weather forecasting. *Seminar on Weather Radar and Flood Forecasting, University of Lancaster.* 17 September.
Keynote lecture. *COST-72 Final Seminar: An Integrated Weather Radar Network for Western Europe, Erice, Sicily.* 1 October.
Perspectives, future research and the Mesoscale Frontal Dynamics Project. *Royal Meteorological Society Discussion Meeting, London.* 20 November.
Structure and dynamics of cold fronts. *Seminar at Institut für Meteorologie und Klimatologie der Univerisität, Hannover.* 26 November.

BROWNSCOMBE, J.L.
Weather in relation to herbicide damage to cereals in autumn 1983. *Weed Research Organisation.* 24 April.

BUTCHART, N.
Area diagnostics for the northern hemisphere middle stratosphere. *Fifth AMS Conference on the Meteorology of the Stratosphere and Mesosphere. Boulder, Colorado.* 23–26 April.

CALLANDER, B.A.
Short-range dispersion within a system of regular valleys. *15th NATO/CCMS International Technical Meeting on Air Pollution Modelling and its Applications. St Louis, Missouri.* 17 April.

CARTER, M.J.
Recent improvements in global prediction at Bracknell. *Seventh Conference on Numerical Weather Prediction, Montreal.* 17–20 June,.

CATTLE, H.
A 2-dimensional version of the Bryan–Semtner Ocean General Circulation Model. *Meeting on Palaeoclimates and Two-dimensional Modelling for Long-term Climate Variations, Institut d'Astronomie et de Géophysique, University of Louvain-la-Neuve, Belgium.* 1 May.
The sensitivity of ocean model integrations to observed and atmospheric model forcing. *IAMAP/IAPSO Joint Assembly, Honolulu.* 9 August.
Modelling the ocean on the quaternary time scale. *CCCO Palaeoclimatology Panel, Villefranche sur Mer, France.* 24 October.

CAUGHEY, S.J.
Observed characteristics of the atmospheric boundary layer. *Gaskell Memorial Lecture, University of Manchester.* 22 January.

CHYNOWETH, S.
Geometric solutions to the Lagrangian semi-geostrophic equations. *University of Reading Numerical Analysis Seminar.* 25 January.
Applications of a geometric Lagrangian method. *Joint Research Students' Symposium, University of Oxford Computing Laboratory.* 1 October.

CLOUGH, S.A.
Project Scillonia and other frontal studies. *Mesoscale Frontal Dynamics Project Workshop, Royal Society.* 21–22 November.

COCHRANE, J.
Forecasting of cutworm and pea moth attacks. *Symposium on Comparison of Pest and Disease Forecasting Systems, Association of Applied Biologists, University of Reading.* 24–26 September.

COLLIER, C.G.
Accuracy of radar measurements of rainfall. *North West Radar Project Final Seminar, Lancaster.* 16–17 September.
Two lectures: (1) Accuracy of real-time estimates of rain made using radar, (2) Future development of the UK weather radar network. *Symposium on Weather Radar and Flood Forecasting, University of Lancaster.* 16–18 September.
COST-72: The way ahead. *COST-72 Final Seminar, Erice, Sicily.* 3 October.

CULLEN, M.J.P.
Numerical modelling of discontinuous atmospheric flow. *ICFD Conference on Numerical Methods for Fluid Dynamics, University of Reading.* 1–4 April.
Computational aspects of weather prediction. *University of Oxford Computing Laboratory.* 7 November.
Lagrangian theories of atmospheric dynamics. *University of Leeds.* 11 November.
Modelling of fronts in fine mesh and mesoscale models. *Royal Meteorological Society.* 20 November.

DALTON, F.
Weather radar and a regional forecasting service. *Weather Radar and Flood Forecasting Symposium, University of Lancaster.* 16 September.

DAVEY, M.K.
Results from a moist equatorial atmosphere model. *NERC Ocean Modelling Meeting, Imperial College, London.* 28 March.

DICKINSON, A.
The impact of some physical parametrizations on the UK Meteorological Office's forecast models. *ECMWF Seminars on Physical Parametrizations for numerical models.* 13 September.

DONOPHY, E.H.C.
Cardiff Weather Centre—forecasting in the 1980s. *Cardiff Scientific Society, University of Cardiff.* 27 March.

EPHRAUMS, J.J.
Wind statistics and ocean modelling. *Seminar on Design of Offshore Structures—Errors and Uncertainties in Loading due to the Environment, Society for Underwater Technology, London.* 28 February.

EYRE, J.R.
Research and development on TOVS retrievals in the UK. *Second International TOVS Study Conference, Igls, Austria.* 18 February.

FAIRLIE, T.D.A.
The stratospheric sudden warming of winter 1984/85: a case of frontogenesis in the stratosphere. *The 5th Conference of the American Meteorological Society on the Meteorology of the Stratosphere and Mesosphere, Boulder, Colorado.* 23–26 April.
NASA/Goddard Space Flight Center, USA. 1 May.

FINDLATER, J.
Outstation investigations related to fog forecasting. *Royal Meteorological Society, University College, London.* 27 April.

FLOOD, C.R.
The meteorological factors affecting aircraft safety. *International Conference on Security and Safety in Air Transportation, Madrid.* 27 June.
Bracknell forecast products for civil aviation. *8th Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems, University of Tennessee Space Institute, Tullahoma.* 12 March.

FOLLAND, C.K.
Two lectures: (1) A simple numerical model of the loss of rainfall from a standard 5" gauge due to wind, (2) A simple numerical model of the loss of rainfall due to wind from a conically-shaped collector. *WMO Workshop on the Correction of Precipitation Measurements, Zurich.* 3 April.
A multivariate technique for use in long-range forecasting. *WMO 1st Workshop on the Diagnosis and Prediction of Monthly and Seasonal Atmospheric Variations over the Globe, College Park, Maryland.* 2 August.
Is long-range forecasting possible? Some recent developments in the science and the practice. *Royal Meteorological Society, Manchester Centre.* 12 December.

GADD, A.J.
The development and application of the fine mesh models. *International Conference on the Results of the Global Weather Experiment and their Implications for the World Weather Watch, Geneva.* 30 May.
Aviation digital forecasts from Bracknell. *CCS Aviation Services Conference, Los Angeles.* 8 November.

GILCHRIST, A.
Long-range weather forecasting. *Royal Meteorological Society, Scottish Centre.* 18 October.
Presidential Address, Royal Meteorological Society, London. 19 October.

GILL, A.E.
Effects of topography on the adjustment of a rotating fluid. *Mathematics Institute, Oxford.* 28 January.
Remote sensing needs of the World Climate Research Programme. *Rutherford Appleton Laboratory.* 5 February.
Ocean–atmosphere coupling and tropical dynamics. *NATO Advanced Study Institute on Large Scale Transport Processes in the Ocean and Atmosphere, Les Hoveles, France.* 19–22 February.
Effect of topography on the adjustment of a rotating fluid. *Mathematics Department, University College, London.* 13 May.
An overview of dynamics relevant to the TOGA Programme. *IAMAP/IAPSO Conference, Honolulu.* 5 August.
A simple moist model response to varying sea surface temperature patterns. *IAMAP/IAPSO Conference, Honolulu.* 15 August.
A short history of ocean modelling in Britain. *Royal Meteorological Society/Challenger Meeting, Imperial College.* 16 October.
Remote sensing aspects of TOGA. *Mullard Space Science Laboratory, University College.* 12 December.

GOLDING, B.W.
Interactive mesoscale analyses. *Royal Meteorological Society Specialist Group on Dynamical Problems.* 5 November.
Observational requirements for numerical modelling of fronts. *Royal Society Mesoscale Frontal Dynamics Workshop.* 21–22 November.

GRAHAME, N.S.
Simulation of the seasonal cycle of sea surface temperature with simple ocean models used in coupled ocean–atmosphere experiments. *Department of Oceanography, University of Southampton.* 1 March.

GRANT, A.
Results from the preliminary phase of HEXOS. *KNMI, De Bilt.* 21 October.

HALL, C.D.
Limited area modelling in the UK Meteorological Office. *Seventh Meeting European Working Group on Limited Area Models, Zurich.* 8–11 October.

HIDE, R.
The earth's differential rotation. *Presidential Address, Royal Astronomical Society, London.* 8 February.
Stable eddies in the laboratory and in atmospheres and oceans. *NATO Advanced Study Institute, University of Newcastle-upon-Tyne.* 9 April.
Frozen vector fields and the inverse problem of inferring motions in the electrically conducting fluid core of a planet from observations of secular changes in its magnetic field. *Royal Astronomical Society, University of Liverpool.* 11 April. IAGA, Prague. 12 August.
Topologically axisymmetric and non-axisymmetric magnetic fields. *IAGA Meeting, Prague.* 5 August.
Is a week a long time in meteorology? *Gresham Lecture, Barbican, City of London.* 11 November.

HILL, F.F.
Examples of mesoscale convective systems near the British Isles. *Seminar at the Department of Meteorology, University of Reading.* 13 March.

HINDS, M.K.
Techniques for speeding up climate models on the Cyber 205. *GAMM Workshop on the Efficient Use of Vector Computers with Emphasis on Computational Fluid Dynamics, Karlsruhe University, FRG.* 13–15 March.

HOUGHTON, D.M.
Wind strategy. *Royal Meteorological Society, Scottish Branch.* 8 March.
The benefits of a marketing strategy. *Australian Bureau of Meteorology, Melbourne.* 19 March.

HOUGHTON, J.T.
Developments in global forecasting at Bracknell since FGGE. *International Conference on the Results of the Global Weather Experiment and Their Implications for the World Weather Watch, WMO, Geneva.* 31 May.
Maintaining the quality of the science group. *1985 Forum for Scientists and Technologists, Management and Personel Office, London.* 4 June.
Remote sensing for weather forecasting and climate research. *Remote Sensing Society and CERMA Conference, University of London.* 11 September.
The impact of satellite remote sensing on climate and research. *Mullard Space Science Laboratory Remote Sensing Group, Dorking.* 10 October.
Modern developments in satellite meteorology. *Welsh Centre of Royal Meteorological Society, University of Swansea.* 13 November.

HUME, C.J.
Potato blight forecasting. *Conference of ADAS plant pathologists, Harrogate.* 19–21 February.

JONAS, P.R.
Meteorological Office research programme on arctic lows. *Workshop on Arctic Lows, Boulder, Colorado.* 10 May.
Simulations of tropical convection using the Meteorological Office (UK) cumulonimbus model. *WMO Cloud Modelling Workshop, IRSEE, FRG.* 15 July.
Proposals for UK contribution to MFD field programme. *Mesoscale Frontal Dynamics Project Workshop, London.* 22 November.

JONES, D.E.
The use of ensemble of integrations in extended-range dynamical forecasting. *First WMO Workshop on the Diagnosis and Prediction of Monthly and Seasonal Atmospheric Variations over the Globe, College Park, Maryland.* 29 July–2 August.
Two lectures: (1) Atlantic and Indian Ocean sea-surface temperatures related to the Sahel drought, (2) Current aspects of long-range weather forecasting in the Meteorological Office. *Association of British Climatologists, University of Sheffield.* 18–20 September.

JONES, M.V.
The BBC/Met Office television weather system. *Royal Society, London.* 27 November.

KEERS, J.F.
Climate input to an improved agricultural land classification. *Joint meeting of Royal Meteorological Society and Bristol Society of Soil Scientists.* 1–3 April.

KERSHAW, R.
Sensitivity of the onset of the south-west monsoon to sea-surface temperature anomalies in the Arabian Sea. *ECMWF Reading.* 22 May.

LEE, A.C.L.
The detection and forecasting of fog. *2nd International Conference on the Aviation Weather system, Montreal.* 19–21 June.

LORENC, A.
Data assimilation—an overview. *Royal Meteorological Society Specialist Group on Dynamical Problems.* 5 November.

MACVEAN, M.K.
Experience with the GFDL ocean model at the Meteorological Office. *NERC Ocean Modelling Group Meeting, University of Exeter.* 15 November.

MASON, P.J.
On cloud streets and the role of cloud in the planetary boundary layer. *Massachusetts Institute of Technology, Boston.* 5 February.
Turbulent flow over hills, observation and theory. *GFDL Princeton University.* 8 February.
A numerical study of cloud streets in the planetary boundary layer. *NCAR Boulder, Colorado.* 19 February.
Large eddy simulations of the neutral planetary boundary layer. *NCAR, Boulder, Colorado.* 25 February.
Large eddy simulation of turbulent channel flow. *Thermoscience Division, Stanford University, California.* 4 March.
Structure and variability of the atmospheric boundary layer. *Royal Meteorological Society/IMA Symposium on Uncertainty in Modelling Atmospheric Dispersion, Shinfield Park, Reading.* 2 April.
Observations and theories of flow over hills. *Scottish Special Topic Lecture, Meteorological Office, Edinburgh.* 10 April.
On the parameterization of orographic drag. *ECMWF Seminar on Physical Parameterization for Numerical Models, Shinfield Park, Reading.* 12 September.
On the magnitude of the sub-grid scale eddy coefficient in large eddy simulations of turbulent channel flow. *Euromech 199—Colloquium on Direct and Large Eddy Simulation of Turbulent Flows, Munich.* 30 September.
Fronts and the boundary layer. *Mesoscale Frontal Dynamics Project Workshop, Royal Society, London.* 21 November.

MITCHELL, J.F.B.
Two presentations: (1) On CO_2 and climate, (2) Simulated changes in climate and climate variability over western Europe. *Third Conference on Climate Variations and Symposium on Contemporary Climate, Los Angeles.* 7–11 January.
Numerical modelling of climate. *Department of Pure and Applied Physics, Queen's University, Belfast.* 6 February.
Climate sensitivity: evidence from numerical studies. *NATO/NSF Workshop on Abrupt Climatic Changes, Grenoble.* 16–22 October.
Two presentations: (1) Soil moisture changes in four CO_2 experiments using Meteorological Office General Circulation Models, (2) Possible soil moisture changes over western Europe due to increased atmospheric CO_2. *Conference on Parametrization of Land-surface Characteristics, Use of Satellite Data in Climate Models and First Results of ISLSCP, Rome.* 2–7 December.

MONK, G.A.
Weather forecasting using radar. *Royal Meteorological Society, Manchester.* 19 February.

MORRIS, R.M.
Support for the offshore industry. *Conference on Electronics in Oil and Gas, Novotel, London.* 15–17 January.
Seminar on local forecasting problems. *Royal Meteorological Society.* 27 April.
Weather and weather forecasting. *Rutherford Appleton Laboratory.* 3 December.

NASH, J.
Comparison of tidal theory with satellite observations. *Royal Meteorological Society, London.* 17 April.
Four lectures: (1) Evaluation of temperature, pressure and geopotential measurements obtained during Phase I of the WMO International Radiosonde Comparison, (2) Comparison of relative humidity measurements from Phase I of the WMO International Radiosonde Comparison, (3) Operational evaluation of NAVAID windfinding systems in the United Kingdom, (4) Methods of observation—assessment of the efficacy of modern radiosonde measurements. *Third WMO Technical Conference on Instruments and Methods of Observation, Ottawa.* 8 July.

NICHOLLS, S.
The physics and dynamics of stratocumulus clouds. *University of Reading.* 27 March.
Modelling the cloud topped boundary layer. *WMO Workshop, Colorado State University, Fort Collins.* 22–26 April.

OFFILER, D.
Two lectures: (1) Algorithms for wind scatterometer processing, (2) Wind direction ambiguity suppression algorithms. *Conference on The Use of Satellite Data in Climate Models, Alpbach, Austria.* 10–12 June.

O'NEILL, A.
The seasonal evolution of Ertel's potential vorticity in the stratosphere and interhemispheric differences. *The 5th Conference of the American Meteorological Society on the Meteorology of the Stratosphere and Mesosphere, Boulder, Colorado.* 23–26 April.
The seasonal evolution of the stratosphere and implications for the transport of tracers. *NOAA Environmental Research Laboratories, Boulder, Colorado.* 29 April.
Two lectures: (1) A critical review of numerical modelling and analysis of the middle atmosphere circulation, (2) Observations and numerical simulations of frontogenesis in the winter stratosphere. *5th General Assembly IAGA/IAMAP, Prague*, 5–17 August.

PALMER, T.N.
Modelling experiments of the influence of tropical and extra-tropical sea surface temperature anomalies on the atmospheric general circulation. *University of Oxford.* 7 March.
A study of wintertime circulation anomalies during past El Niño events, using a high resolution general circulation model. *Goddard Laboratory for Atmospheres, Maryland.* 19 April.
Orographic gravity wave breaking in the lower stratosphere and its influence on the troposphere. *IAMAP Symposium, Prague.* 5 August.
Modelling experiments of the influence of the Atlantic, Pacific and Indian Oceans on Sahel rainfall. *CCCO Workshop, Rio de Janeiro.* 10 September.
Alleviation of a systematic westerly bias in general circulation and numerical weather prediction models through an orographic gravity wave drag parametrization. *University of Cambridge.* 25 October.
Two lectures: (1) Influence of model climatology on a GCM response to the El Niño event, (2) The skill of ensemble of extended range forecasts with real and climatological sea surface temperatures. *WGNE Workshop, NCAR.* 9–12 December.

PARKER, D.E.
Two lectures: (1) African drought and anomalous sea-surface temperatures, (2) The response of the UK Meteorological Office 11-layer model to observed SST anomalies in the tropical Pacific. *First WMO Workshop on the Diagnosis and Prediction of Monthly and Seasonal Atmospheric Variations over the Globe, College Park, Maryland.* 29 July–2 August.

POPE, V.D.
Diagnostic studies and numerical simulations of final warmings in the middle atmosphere. *5th General Assembly IAGA/IAMAP, Prague.* 5–17 August.

POTHECARY, I.J.W.
Weather influences on invasions—the Battle of Salamis 480 BC. *History Group, Royal Meteorological Society, University of Birmingham.* 26 October.

PRATT, I.
Work of the Storm Tide Warning Service. *Coastal Conservation Congress, Hastings.* 25 September.

PRIOR, M.J.
Recent design application of the UK Meteorological Office climatological data base. *International Council for Building Research Studies and Documentation, Gaule, Sweden.* 29 May.

READ, P.L.
Laboratory and theoretical models of long-lived Jovian eddies: weakly-dissipated 'free-modes'? *Seminar at Atmospheric Physics Department of Imperial College, London.* 28 February.
Stable baroclinic eddies in the laboratory: quasi-geostrophic 'free modes' with weak dissipation and forcing. *27th British Theoretical Mechanics Colloquium, University of Leeds.* 28 March.
Quasi-geostrophic 'free-mode' models of long-lived Jovian eddies: forcing mechanisms and crucial observational tests. *NASA Conference on the Jovian Atmospheres, Goddard Institute of Space Studies, New York.* 7 May.

REED, D.N.
Sea-surface fluxes diagnosed from a global numerical weather prediction scheme. *Canadian Meteorological and Oceanographic Society Congress, Montreal.* 12–14 June.

ROWNTREE, P.R.
Two lectures: (1) Climate of the Sahel, (2) Theories on causes of the persistence of the Sahel drought. *Royal Meteorological Society meeting on Drought in the Sahel, London.* 16 January.
The role of the land surface in climate change. *Meeting on Palaeoclimates and Two-dimensional Modelling for Long-term Climate Variations, University of Louvain-la-Neuve, Belgium.* 2 May.
The need for remote sensing of the African land-surface as indentified in climate model experiments. *Conference on Parametrization of Land-surface Characteristics, Use of Satellite Data in Climate Studies, and First Results of ISLSCP, Rome.* 3 December.

ROY, M.G.
The Scottish Meteorological Society. *Summer Meeting of the Royal Meteorological Society, Edinburgh.* 24 July.

RUMNEY, R.
Lamb wind-chill warning service. *Sheep Conference, Hadlow College.* 9 January.
Meteorological influences on the spread of foot and mouth disease. *Summer Conference of the Society for Applied Bacteriology, University of Kent.* 11 July.

RYDER, P.
Future developments of the UK weather radar network. *Symposium on Weather Radar and Flood Forecasting, University of Lancaster.* 16–18 September.

SHUTTS, G.J.
Parametrization of sub-grid scale gravity wave momentum transfer and its influence in forecast/climate models. *ECMWF Seminar.* 13 September.

SLINGO, A.
Boundary layer cloud in the Meteorological Office GCM. *WMO Workshop on the Modelling of the Cloud Topped Boundary Layer, Fort Collins, USA.* 23 April.
Recent simulations with the Meteorological Office GCM. *National Center for Atmospheric Research, Boulder, Colorado.* 1 May.
Introduction to Nuclear Winter discussion. *Royal Meteorological Society, London.* 18 December.

SMITH, F.B.
A summary of the uncertainties associated with modelling atmospheric dispersion. *Royal Meteorological Society/IMA Symposium on Uncertainty in Modelling Atmospheric Dispersion, Shinfield Park, Reading.* 2 April.
The atmospheric boundary layer. *NATO meeting RSG 11, Ottawa.* 9 October.
Acid rain: production, transformation, transport and deposition. *Watt Committee on Acid Rain, London.* 4 December.

STARR, J.R.
Forecasting lamb wind chill. *EEC Symposium on Lamb Mortality, Brussels.* 22 January.
Flukes, frosts, calves and crops. *Biological Society, University College of Wales, Aberystwyth.* 4 February.
Meteorological aspects of animal health and production. *National Congress of Agriculture for Puglia, Bari, Italy.* 29 March.
Weather and animal health and housing. *WMO Seminar on Operational Methods in Agrometeorology, Puna, India.* 2 December.

TAYLOR, J.J.
Weather forecasting. *Royal Aeronautical Society, University of Manchester Institute of Science and Technology.* 16 January.

THOMAS, J.P.
Wave model products and their applications. *WMO RAI Training Seminar in Marine Meteorology, Meteorological Office College, Shinfield Park, Reading.* 11 December.

THOMSON, D.J.
Large eddy simulations of the neutral planetary boundary layer. *Euromech 199—Colloquium on Direct and Large Eddy Simulation of Turbulent Flows, Munich.* 1 October.

THOMPSON, N.
Applications of current weather data in agriculture. *Joint meeting of Royal Meteorological Society and Bristol Society of Soil Scientists.* 1–3 April.
Weather forecasts—their scope and accuracy in crop protection. *Symposium on Comparison of Pest and Disease Forecasting Systems, Association of Applied Biologists, University of Reading.* 24–26 September.
Weather observations and their use on the farm. *Symposium on Farm Electronics and Computing, Royal Agriculture Society of England, Warwick.* 20–25 October.

TUCK, A.F.
Photochemistry along stratospheric trajectories using LIMS data. *Middle Atmosphere Programme Meeting, Royal Society, London.* 15 February.
Photochemical modelling along stratospheric trajectories in early 1979. *NOAA Aeronomy Laboratory, Boulder, Colorado.* 3 June.
Aircraft studies of tropospheric ozone. *Gordon Conference: Environmental Sciences—air, New Hampton, New Hampshire, USA.* 25 June.
Effects of stratospheric ozone. *Royal Meteorological Society Meeting on the Climatic Impact of Nuclear War.* 18 December.

TURNER, J.
Some possible multi-channel products to be derived from a second generation Meteosat system. *Fifth Meteosat Scientific Users' Meeting, Rome.* 31 May.

WARRILOW, D.A.
Two lectures: (1) The sensitivity of the UK Met Office 11 level GCM to recent changes to the parametrization of land surface processes, (2) Indications of the sensitivity of European climate to land surface variations using a one dimensional model. *Conference on Parametrization of Land-surface Characteristics, Use of Satellite Data in Climate Studies, and First Results of ISLSCP, Rome.* 2 December.

WATTS, P.D.
Regional tropospheric sounding products available at Oxford. *Department of Atmospheric Physics, Oxford.* 17 June.

WHITE, A.A.
The stability of internal baroclinic jets. *Department of Mathematics, University College, London.* 15 November.

WHITEFORD, R.P.
Results from the preliminary phase of HEXOS. *KNMI, De Bilt.* 21 October.

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 1985; 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 1984 (0 11 400450 5)*
Meteorological Office Almanack 1986 (Leaflet No. 11) (0 86180 191 1)
Monthly and annual totals of rainfall for the United Kingdom 1981 (0 86180 189 X), 1982 (0 86180 192 X)
Monthly Weather Report, annual summary 1982 (0 11 727254 X)*, 1983 (0 11 727554 9)*
Snow survey of Great Britain 1983/84 (0 86180 198 9)

Quarterly
*Marine Observer**

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

Fortnightly
Meteorological Office Rainfall and Evaporation Calculation System (MORECS)

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. 113, *The climate of Great Britain: Introduction* (rev) (0 86180 195 4)
Climatological Memorandum No. 127, *The climate of Great Britain: North-east England* (0 86180 187 3)
Climatological Memorandum No. 128, *The climate of Great Britain: Pennines and the Lake District* (0 86180 181 4)
Climatological Memorandum No. 129, *The climate of Great Britain: East Yorkshire and north Humberside* (0 86180 188 1)
Climatological Memorandum No. 131, *The climate of Great Britain: Trent Valley* (0 86180 180 6)
Climatological Memorandum No. 138, *The climate of Great Britain: Somerset and Avon* (0 86180 190 3)

Occasional

'And now—here's the weather . . .' (0 86180 200 4)
Daily Register (rev) (0 86180 185 7)
Global forecast products from Bracknell (rev) (0 86180 201 2)
Leaflet No. 3: *Weather bulletins, gale warnings and services for the shipping and fishing industries* (0 86180 197 0)
Leaflet No. 4: *Meteorological Office professional training courses* (0 86180 152 0)
Leaflet No. 12: *Publications* (0 86180 193 8)
Offshore weather services and Metroute (0 86180 194 6)
Operational instruments (0 86180 196 2)
Services for agriculture (0 86180 199 7)
Services to the construction industry (0 86180 203 9)
Special Investigations Memorandum No. 113, *Temperature and humidity data for design—British Forces area of West Germany* (0 86180 184 9)
Your holiday weather (0 86180 204 7)

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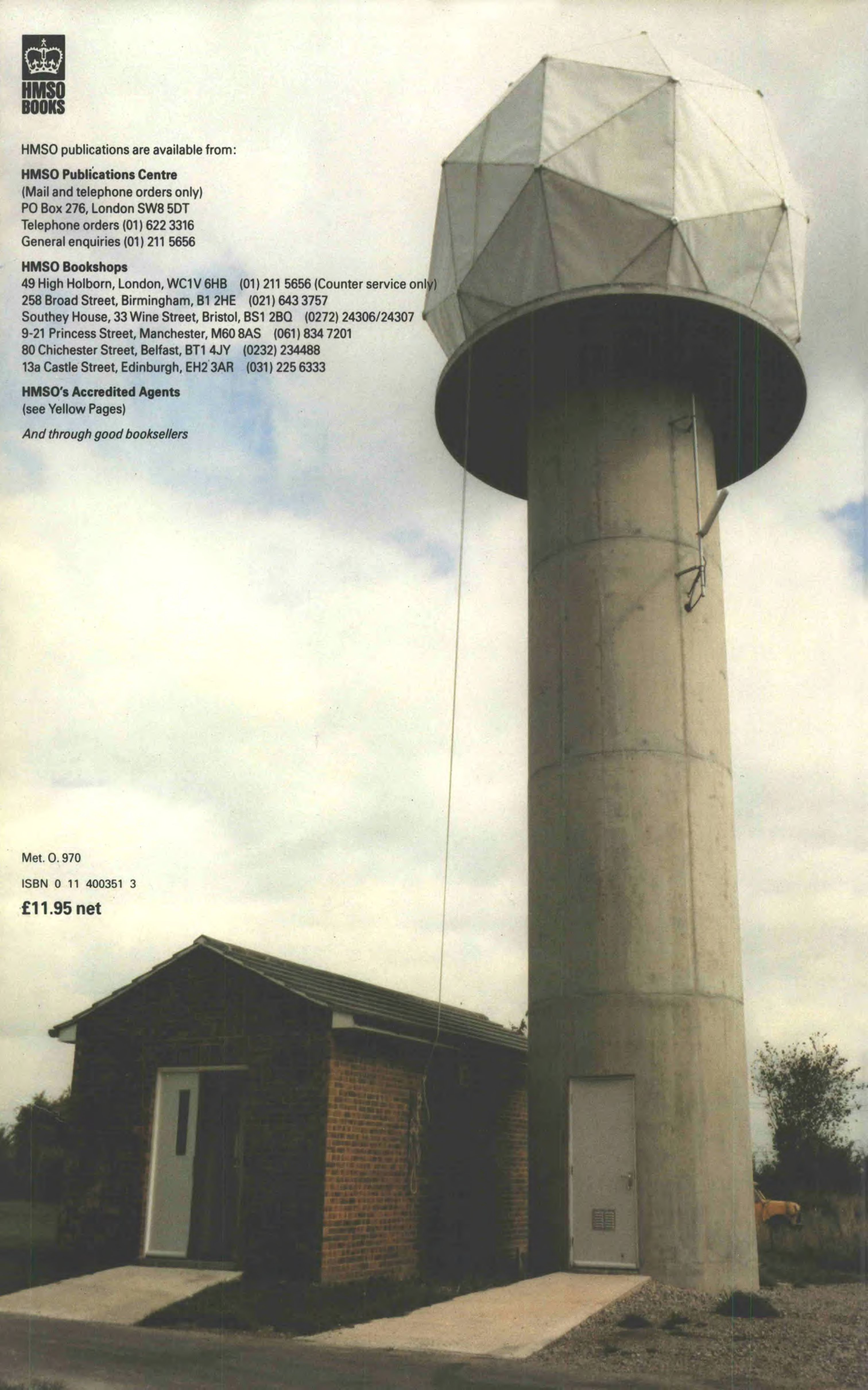

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