The Met. Office

Report for the period 1 January 1989–31 March 1990

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

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Contents

Much of the introductory material to be found in previous annual reports has not been included this year. A comprehensive introduction to the work of the Met. Office can be found in the brochure entitled *This is the Met. Office.* Those unfamiliar with the work of the Met. Office should read the brochure before this report.

Foreword

This report covers the fifteen months' period up to the end of March 1990 prior to the Meteorological Office becoming an Executive Agency on 2 April 1990.

The improved accuracy in weather forecasting continues as a primary aim of the Office. During the past few years increased attention has been given to the forecasting of extreme events, and to the dissemination of information regarding such events to the emergency services and to the general public.

In January and February of 1990 several occasions occurred over the United Kingdom when exceptionally strong winds caused extensive structural damage and disruption to communications. On each of these occasions the exceptional gusts were well forecast and early warnings given. Further, on other occasions of strong gales during the same period, no false alarms of extreme conditions were generated.

The effectiveness of the man–machine mix in the generation of the best forecasts was well demonstrated during this period, since on some critical occasions excellent guidance was provided by the numerical forecast models whilst on others information from satellites and other sources assisted in the correct identification of the likely development of an extreme situation.

New arrangements were set up whereby emergency services receive warnings of the onset of severe weather that are clearer and more structured than before. This service was put to the test by several severe events soon after its inauguration.

In addition to the provision of good warning services the Met. Office is concerned to reach as many as possible of the general public with high-quality weather information and forecasts. Successes during the year included the award of the contract for weather presentation on national ITV, and the extension of weather information of a more specialized character that is available by premium-rated telephone services.

Development work has continued in the Defence Services area directed towards providing advice to military commanders concerning the tactical use of meteorology. Field trials are under way, in conjunction with the Armed Forces, to assess the utility of computer programs developed for this purpose. An information dissemination system has been developed and installed at RAF Marham to illustrate the major benefits for aircrew from improved access to currently available meteorological data and products.

The Met. Office has continued to serve the world's airlines through its service to the Civil Aviation Authority. Recognizing the accurate and timely information which is available from the World Area Forecast Centre at Bracknell, an increasing number of airlines are establishing direct links to the Met. Office computers in order to receive data for flight planning purposes in the most efficient manner.

Late in 1989 a new supercomputer, a Cray Y-MP, was installed which will eventually replace the Cyber 205 installed in 1981. The Cray Y-MP is capable of carrying out almost 4 billion operations per second and in practice is over 8 times faster than the basic Cyber. Weather forecasting models of higher resolution than at present and therefore of significantly higher accuracy can be run on the Cray. An intensive programme is being carried out to write the software which will enable the Met. Office's suite of forecasting and climate models to be run on the Cray.

On the management side intensive work has been carried out on a new financial management system to support the increased responsibilities the Met. Office will have for its own affairs with Executive Agency status. These new responsibilities will in their turn bring new opportunities for the provision of increased services to all the Met. Office's customers, increased revenue and increased job satisfaction for the staff.

J Houghton

Director-General

Functions

The Meteorological Office is the State Meteorological Service and forms part of the Ministry of Defence. Throughout the period it was administered by the Air Force Department with the Director-General being responsible to the Secretary of State for Defence, through the Under-Secretary of State for Defence Procurement, for the supply and support of meteorological services.

The general functions of the Meteorological Office were:

(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 in support of the above services.

d) The collection, distribution and publication of meteorological information from all parts of the world; maintenance of the National Meteorological Library.

(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 took a leading part in international co-operation in meteorology. The Director-General, the Permanent Representative of the United Kingdom with the UN World Meteorological Organization, acted in concert with the national Directors of the other Meteorological Services in western Europe in the co-ordination of their programmes.

Finance

On a fully cost-accounted basis, the total cost of the Met. Office in 1988/89 was £91.2 million. This may be compared with the £84.1 million total cost reported in 1987/88 although the 1988/89 figure includes for the first time £1.0 million estimated supporting expenditure incurred by other Ministry of Defence branches on the Met. Office's behalf. The net cost after earnings from services was £62.5 million compared with £58.3 million in 1987/88. Charges for repayment services were increased in 1988/89 to cover Met. Office pay and price increases.

The Met. Office's voted expenditure is borne on the Defence Budget to which all receipts from repayment services are credited. Summary figures are shown in the *Annual Statement on the Defence Estimates*. However, for costing purposes, a fully cost-accounted Memorandum Operating and Trading Accounting (MTA) is also maintained.

Tables I and II show, respectively, the allocation of costs to functions derived from the MTA and the net cost after deduction of receipts. Table III summarizes the MTA costs by input resource categories. These figures include non-Voted costs that are not shown in Defence Votes in Parliamentary Estimates, such as pension contributions, notional insurance provision, interest on capital and depreciation.

By the same token, the cost of major items of equipment, which appears in Defence Votes for the year of acquisition, is excluded from the table, being covered by annual interest and depreciation charges in the usual commercial accounting manner.

TABLE I Statement of operating expenses for the Meteorological Office for the year ended 31 March 1989

	1988/89	1987/88
	£000	£000
Customer activity costs	24 151	21 746
General Met. Office core activity costs:		
Research	11 090	9 298
Administration and personnel	4 774	5 103
Central Forecasting Office	5 022	4 167
Computing	3 112	1 614
Maintenance	1 383	2 503
Observations	22 623	20 864
Technical support	3 048	2 973
Telecommunications	6 658	5 620
Training	3 019	3 197
Others	2 521	3 056
Total Met. Office management costs	87 401	80 141
Share of MOD HQ costs and interest on capital	3 817	3 996
Total Met. Office costs	91 218	84 137

TABLE II Statement of the cost of meteorological services for the year ended 31 March 1989

	1988/89		1987/88	
	£000	£000	£000	£000
Total meteorological services (cost accounted)		91 218		84 137
Receipts		28 700		25 802
Net expenditure:				
Defence and other Exchequer departments	35 548		34 012	
General public services and international	26 970		24 323	
		62 518		58 335

TABLE III Statement of costs analysed by input resource categories

	1988/89	
	£000	(%)
Staff costs	49 121	(53.9)
Office support, telecommunications and accommodation	11 126	(12.2)
Grants, satellite support and subscriptions to international bodies	10 713	(11.7)
Materials and miscellaneous	13 603	(14.9)
Depreciation and interest on capital	6 655	(7.3)
Total input costs	91 218	(100.0)

Personnel

Competition for recruits in the science-based market place was very active and the Met. Office responded with vigour. The number of recruits in 1989 exceeded the yearly total in each of the past 10 years.

Nevertheless, the Met. Office were left with a shortfall in graduate scientists as well as in administrative support staff. There appears no single reason, but contributing factors were salary level and the location of many posts in south-east England. These factors apply to both recruitment and retention.

An exercise to recruit two new Directors (of Finance and Administration, and of Commercial Services) was successful; the posts were filled from the private sector.

Staff numbers (As at 31.3.90)

Deputy Secretary (Grade 2)	1
Under Secretary (Grade 3)	1
Science Group	
Chief Scientific Officer (Grade 4)	2
Deputy Chief Scientific Officer (Grade 5)	5
Senior Principal Scientific Officer (Grade 6)	26.5
Principal Scientific Officer (Grade 7)	121
Senior Scientific Officer	303.5
Higher Scientific Officer	429
Scientific Officer	412.5
Assistant Scientific Officer	494.5
Administrative Group	
Assistant Secretary (Grade 5)	2
Senior Principal (Grade 6)	1
Principal (Grade 7)	1
Senior Executive Officer	2
Senior Executive Officer Management Accountant	1
Higher Executive Officer	5
Higher Executive Officer Management Accountant	2
Executive Officer	20
Administrative Officer	64
Administrative Assistant	40.5
Professional and Engineering Group (including Marine Superintendent staff)	
Superintending Engineer (Grade 6)	1
Principal Professional and Technology Officer (Grade 7)	3
Senior Professional and Technology Officer	5
Higher Professional and Technology Officer	18
Professional and Technology Officer	7
Telecommunications staff	
Senior Telecommunications Technical Officer	7
Higher Telecommunications Technical Officer	33
Telecommunications Technical Officer	47
Assistant Telecommunications Technical Officer	35
Signals grades	18
Teleprinter grades	26
Typing and miscellaneous non-industrial grades	75
Security officers	9
Industrial employees	34.5
Locally entered staff overseas	46

Staff honours and awards

Dr R. Hide FRS was made a Commander of the Order of the British Empire in the New Year's Honours. He was also elected to Honorary Membership of the Royal Meteorological Society.

The L.G. Groves Memorial Prize for Meteorology was awarded to Dr B.W. Golding.

The L.G. Groves Meteorological Observation Award was awarded to Mrs J. Harmer.

The NASA Group Achievement Award was presented to:

Dr J. Austin
Mr A. Buckland
Dr R.L. Jones
Dr D.S. McKenna
Mr D. Merrick
Mr D. Pervin
Mr P. Salter
Mr J. Whitlock

The Eurosense Award was awarded to Dr R.W. Saunders.

Mr P.G. Wickham (now retired) was awarded the Imperial Service Order in the Queen's Birthday Honours.

The Royal Meteorological Society's FitzRoy and L.F. Richardson Prizes were awarded to Dr P.E. Francis and Mr J.M. Murphy respectively

The Rank Prize in Opto-electronics was awarded with others to Dr J.T. Houghton.

Weather highlights

The winter of 1988/89 was exceptionally mild in most parts of the British Isles and 1989 was unusually warm and sunny, being the warmest year in 330 years of record in the register of Central England Temperatures (CET). Braemar in Scotland had its warmest winter in a record beginning in 1856 and Glasgow its mildest January since 1868. In many places along the coast of southern England, from Plymouth to Hastings, sunshine totals for 1989 exceeded 2000 hours. It was the sunniest summer in England and Wales since 1959, in Scotland since 1955 and in Northern Ireland since 1975. May was the sunniest on record in many places with over 300 hours generally recorded south of a line from Devon to north Norfolk; probably the sunniest month over such a wide area since 1909.

The winter of 1989/90 was also mild, mainly as a result of a mild spell in January and February. January was the sixth mildest in 330 years of records of CET, although equal with 1975 and 1983. Provisional data indicate that February 1990 was the mildest since 1779. During March, temperatures in the south continued to rise, reaching levels similar to mid March of 1961 but still lower than March 1948.

Rainfall over England and Wales was again below normal in 1989, particularly in the south and east of England. Provisional figures for England and Wales for the year showed that rainfall was 88% of normal. The dry spell was especially noticeable in the Southern Region of the National Rivers Authority where the 11-month rainfall (January–November) was only 73% of normal. High deficits of soil moisture during the summer coincided, unusually, with a high transpiration demand, placing great stress on crops, and the harvest was taken 2 or 3 weeks early in some areas.

In 1989 western Scotland had one of the wettest Januaries on record with up to three times the average rainfall over the western Highlands but the persistent, moist, south-westerly winds created strong contrasts and there was less than 10% of normal rainfall in parts of Aberdeenshire. As a result, rivers, lochs and reservoirs in western Scotland were already full to overflowing when exceptionally heavy and prolonged rainfall occurred on 5 and 6 February; this caused flooding and landslides. Bridges, roads, housing estates and farmland were affected over a wide area and the 127-year-old railway bridge over the River Ness at Inverness was swept away by floodwater on the 7th.

In February over four times the average rainfall was recorded in the western Highlands; areas in the western central Highlands experienced over two and a half times the normal rainfall, again in March, resulting in the wettest first quarter on record. At Fort Augustus, for example, over 70% of the annual average rainfall was recorded in the first 3 months of 1989.

A record gust for a low-level station of 123 kn was measured on 13 February at Fraserburgh, Grampian Region. Some 90 000 electricity consumers in Scotland were cut off on that day and structural damage was widespread and severe. In Dunfermline nine people were injured when the roof of a hospital ward was blown off.

On 11 April strong winds battered ships in the Irish Sea, blew down trees and caused structural damage to buildings throughout Wales and south-west England. There were severe but isolated thunderstorms in May and on 19 May near Halifax, West Yorkshire considerable damage was caused by flash floods following torrential rain.

Damage in excess of £2 million was caused to the Butlin's Holiday World Centre, Pwllheli, North Wales on Monday 14 August by a freak whirlwind that ripped off the roofs from some 150 wooden chalets, as well as damaging other buildings. Some 3500 people had to be evacuated.

Many places in eastern England had the driest September since 1969 and Durham and Tynemouth in the north-east the driest since 1898; however, localized severe thunderstorms in the south between 10 and 13 September caused lightning damage and flooding. Many places had a further dry spell lasting about 30 days between 11 November and 10 December.

Severe gales from the south or south-west, with an exceptionally high tide on 14 December, brought widespread flooding to many places on the south coast. Torrential rain brought floods to many other parts of southern England with disruption to road and rail traffic; a mini-tornado at Long Stratton, Norfolk caused thousands of pounds worth of damage to over 100 buildings. On 16 December gales and rain brought the worst flooding in years to parts of south-west England. On the 20th torrential rain and thunderstorms were again widespread throughout the south, with further flooding and disruption to traffic. On the 21st a tornado struck the villages of West and East Stour in Dorset, causing structural damage to buildings.

The main feature of January 1990 was the exceptionally strong winds of the 25th. By 09 GMT gusts of over 40 kn were being reported over virtually the whole of England and Wales except for some parts of the east and north of England, and mean speeds had reached 50 kn in the extreme west of Cornwall. For several hours the very strong winds persisted across southern areas of England and Wales with gusts up to 92 kn in south Devon and typically 70–80 kn in many other places. The strong winds occurred over a much larger area than in October 1987 and the storm was notable for causing more fatalities than any other this century, with much widespread damage and disruption to traffic.

Between 29 January and 8 February a series of depressions brought wet and windy weather. Many rivers in the south of Britain were flooded and the Rivers Thames and Severn probably reached their highest levels since the widespread floods of 1947. Northern Scotland also had heavy rain and the River Ness at Inverness broke its banks for the second time in 12 months. On 7 February high winds again swept southern England, and much of England and Wales had spells of heavy rain; Cilfynydd, Mid Glamorgan accumulated 108 mm of rain over the 6th and 7th.

On 26 February strong winds in Gwent swept water up the Severn Estuary and into the Rivers Usk and Wye causing the highest tide for 10 years and severe flooding. On the morning of 27 February an exceptionally high tide in the Bristol Channel, pushed by strong winds, crashed through sea walls in Somerset and Avon leaving a trail of destruction and causing floods at Weston-super-Mare, Portishead, Clevedon and Severn Beach. In North Wales, waves driven by a very high tide and north-westerly gales smashed 200 metres of sea wall flooding large areas of Towyn, Pensarn and Kinmel Bay, Clwyd. Repairs to the breach were overwhelmed on the next day by a further high spring tide.

Observations

Weather forecasting and climate studies depend on vast numbers of observations from both surface and space based systems.

Surface based
Currently the Met. Office manage 83 officially manned, and 129 auxiliary synoptic stations, 517 voluntary climatological and 4096 rainfall-only stations. Additionally, observations are made by personnel on board some 480 voluntary observing ships and from 30 platforms and rigs.

Following termination of the WMO-sponsored North Atlantic Ocean Stations Agreement from the end of November, The Met. Office now manages the OSV *Cumulus* as a national programme providing surface and upper-air observations from the eastern North Atlantic. In addition, two merchant ships on Atlantic crossings carry automated upper-air equipment provided by the Met. Office.

Steps are being taken to implement recommendations of a review of the UK synoptic networks. These include greater use of semi-automatic observing stations (SAMOSs) and the collocation of certain upper-air and surface observing functions. The first SAMOS is operational at Bristol Weather Centre and an airfield variant is on trial with the Royal Air Force.

Synoptic automatic weather stations (SAWSs) and other automatic observing equipments continue to be deployed and maintained on land (45 now operational), light-vessels (2), fixed buoys (2 open-ocean, 1 inshore), drifting buoys (3), offshore platforms and islands (8). Ten comprehensive Automatic Climatological Recording Equipments have been obtained and a further ten Limited Capability Climate Recorders have been deployed.

The SAWS design has been enhanced to provide climatological and other data; installation is in progress. Severe-icing-environment automatic equipment is on trial on two Scottish mountains.

Thirty ships are now equipped with automatic transmission equipment, sending data via meteorological satellites. These very valuable data are received more reliably and at substantially lower cost than by other means.

Eight boundary-layer sonde equipments (two overseas) are now operational and provide data when required for forecasting local phenomena such as fog and low cloud. The new synoptic radiosonde system being developed by Vaisala UK Ltd, in association with the Met. Office, is on trial.

A major trial of visibility instruments was mounted for WMO at RAF Finningley and a report written. A WMO radiosonde trial was held in the USSR with a leading part being played by Met. Office staff.

New weather radars in South Wales and Dorset became operational bringing the British Isles network up to nine in number. A contract was let to Siemens Plessey Radar Ltd for three systems for use in Scotland— at sites to the south of Glasgow, on the Isle of Lewis and in north-east Scotland. A Devon radar is still awaiting identification of a site acceptable to local planning authorities.

The Arrival-Time-Difference scheme for lightning location is now operational and is unique in its ability to detect and position storms thousands of miles away.

Studies have been made of acoustic and radio-acoustic sounders for wind and temperature sensing in the boundary layer. Evaluation has begun of rainfall Doppler radar in UK conditions and arrangements made to test a clear-air Doppler radar (a profiler) to measure winds from the surface up into the lower stratosphere.

Space based
The NOAA polar-orbiting satellite programme has been supported by the supply of Stratospheric Sounding Units and the development of part of the Advanced Microwave Sounding Unit (AMSU). The design of a calibration facility for AMSU-B (humidity sensing) was completed and manufacture is well advanced. The contract to build three AMSU-B instruments was awarded to British Aerospace in March (1989).

The Met. Office has won a European Space Agency (ESA) contract to study the usefulness of space-borne instruments for precipitation measurement.

An Along-Track Scanning Radiometer, built by the Met. Office with Rutherford Appleton Laboratory, was delivered to ESA for use on ERS-1. Calibration at the University of Oxford indicated that the instrument met its high absolute accuracy requirement for measurement of sea surface temperature.

Met. Office representatives to EUMETSAT have been heavily involved in helping to formulate policy for the next generation of geostationary satellites and the European polar programme. The latter is expected to replace the NOAA morning orbiter, to be discontinued by the USA in the late 1990s.

Public services

The Met. Office provides a wide variety of public services. Considerable developments took place during 1989 and the early part of 1990 in the way emergency authorities and the general public are warned of the likelihood of severe weather.

Following on from consultations with the Cabinet Office and various other Government Departments, a new service began in February 1990 whereby the emergency authorities are warned in advance of severe weather. The service is essentially a three-tier one. The first tier covers warnings of very severe weather which may lead to loss of life or cause considerable inconvenience to a large number of people. Warnings up to four or five days ahead of the event are sent out from the Central Forecasting Office at Bracknell. These are quite general in nature but include as much information as possible about the parts of the country which may be affected and the scale of the risk. Once issued, warnings are updated at least once a day. Within several hours of the expected severe weather, specific warnings—FLASH weather warnings— are issued to recipients through the network of regional Weather Centres.

The second tier covers warnings of hazardous weather which could lead to operational difficulties for the emergency authorities. These warnings are also issued by Weather Centres.

The third tier includes all other types of forecasts, warnings or consultancies which the emergency authorities might require to assist with their operations. The first two tiers are provided free of charge; third tier services are arranged on a commercial basis.

Potential recipients of the services were asked to register early in 1990. The number doing so reached over 250; further discussions will be necessary to minimize the number of direct recipients by making use of a cascade system of dissemination through a range of communications networks.

The public are warned of severe weather through routine forecasts on the television and radio, but also by the FLASH weather warnings that are sent to national and local television and radio stations for broadcast as soon as possible after receipt. During 1989, extensive changes were made to this system. The criteria for the warnings were improved while the scheme was extended to cover the whole country; previously only the main urban areas were included. Finally the lead times for the warnings were extended.

While it is essential for the warnings to be issued only when there is a high degree of confidence, it is also important to ensure that the warnings reach as large an audience as possible. Thus if severe weather is expected early in the morning, say near to the rush-hour period, then the aim is to issue warnings in time for broadcast the previous evening. Improvements in general forecasting techniques, including the use of weather radar and advanced numerical forecast models, have allowed warnings to be issued earlier and with more confidence. On television, routine broadcasts highlight severe weather by effective use of graphics and by displaying of words on the screen. Use is also made of Press Releases in advance of hazardous weather. Of course, because of the delay between issue and publication, they have to be issued a day or more before the expected event. Nevertheless they are a very effective way of ensuring widespread awareness.

During the course of the 1989/90 winter there were a number of severe storms which tested to the full the developments described above. On 25 January over 40 people died as a result of widespread storm force winds. A Press Release had been issued the day before while the emergency authorities were warned through the new scheme described above even though its actual launch date was a few days later. On 7 February there was extensive coverage by the media of storm forecasts for the following night. Again the emergency authorities were fully alerted well in time.

Finally the storms of 26 February, which again led to considerable loss of life and widespread damage to trees and property, were preceded by probably the most explicit warnings ever given of a severe weather event in the British Isles. There were extra television broadcasts on the 25th warning of the likelihood of uprooted trees and structural damage, and advising people to take note of later forecasts before venturing out the next day. A Press Release was issued and emergency authorities fully alerted.

The Met. Office is seeking to make further improvements to the service; discussions will continue to take place with the BBC and ITN in particular to see what else can be done to alert the public.

Defence services

The provision of meteorological services for Defence has long been one of the Met. Office's prime functions.

The 50th anniversary, on 1 January 1989, of the formation of the Defence Services Branch was marked by a reception attended by over 100 guests —a number of whom had seen meteorological service during World War II.

The drive for greater efficiency resulted in the closure of the Royal Air Force Meteorological Communications Centre at Akrotiri, Cyprus after 43 years continuous operation. Modern communications had steadily reduced the role of the Centre to the point where its residual functions could be absorbed by the Main Meteorological Office at Akrotiri with a net saving to the Ministry of Defence (MOD) of 14 staff—equivalent to £250 000 in running costs per year.

Further reorganization took place at Headquarters Royal Air Force Strike Command (HQSTC) when the Principal Forecasting Office moved into new accommodation and became operational on 16 January 1989. At Upavon, the Meteorological Office Communications Centre was closed ending an association between the Met. Office and Upavon of three quarters of a century. A Statement of Unit Policy for the Mobile Meteorological Unit defining its future role has been extensively commented on by staff within MOD, HQSTC and the Met. Office, and now awaits endorsement.

In June, Dr S.J. Caughey was elected Chairman of the NATO Military Committee Meteorological Group and chaired a special meeting in January 1990 which addressed concerns that the major NATO commanders have for meteorological support. During September, the 31st annual Supreme Headquarters Allied Powers Europe Meteorological Committee meeting was hosted by C Met O HQSTC at HQUKAIR RAF High Wycombe.

The programme to improve facilities was continued. During the year, weather radar displays were installed at a further eight Defence offices, and GRAFNET — a digital facsimile system — was extended to 20 more locations. Runway wind component indicators were installed in Air Traffic Control (ATC) at a number of RAF airfields.

A system to demonstrate to the Royal Air Force an improved method for the remote briefing of aircrew in squadrons, and for the provision of meteorological data in, for example, ATC, has been installed at RAF Marham. The computer-based system known as MIST (Meteorological Information System) will make a wide variety of data — alphanumeric, graphic, imagery — available either routinely or on demand, thus relieving meteorological staff of tasks such as preparing overhead-projector slides and enabling them to concentrate on meeting customer operational requirements.

Work is in progress, in collaboration with the University of Salford, towards the development of an improved acoustic model for predicting noise levels around ranges. This model will eventually be integrated with the radiosonde system groundstation.

In recent years the Services have introduced new technology and equipment. These developments are making new demands on the Defence Services forecaster. For example, night-vision goggles are increasingly being used to allow flying during the hours of darkness. A model has been developed which allows the outstation forecaster to predict the expected light level given the cloud cover. Trials with the Royal Air Force and at the meteorological office at Eskmeals to validate the model predictions are currently in progress.

Thermal imaging equipment is also on trial with the Royal Air Force to evaluate its usefulness as an aid to night flying and targetting. These devices are weather sensitive and the Met. Office is assisting in trials to evaluate the various models for predicting the system performance.

Meteorological conditions can also significantly affect the performance of radars, and specialized techniques for predicting these effects are also currently on trial with the Royal Air Force.

Services to civil aviation

The Met. Office provides a wide range of services to civil aviation on behalf of the Civil Aviation Authority (CAA). These services range from world-wide flight planning information, to regional significant weather charts, to detailed observations, forecasts and warnings for many airfields within the United Kingdom.

On the global scale, the Central Forecasting Office in Bracknell is designated under the International Civil Aviation Organization as one of two World Area Forecast Centres (WAFCs). It is responsible for providing global forecasts of winds and temperatures every 12 hours, for use by national and regional centres around the world.

Such an operation requires considerable effort to ensure that high-quality information is provided on time every day. During the year, work behind the scenes has been going on to develop the new numerical weather prediction model for the Cray Y-MP computer. The model is likely to become operational towards the end of 1991, and, with its increased vertical and horizontal resolution, coupled with a better description of the physical processes occurring in the atmosphere, should lead to further improvements in the accuracy of the winds and temperatures provided to civil aviation.

The number of airlines using Bracknell WAFC grid-point data for flight planning has increased substantially and includes North American as well as European companies. There has also been an expansion in the volume of data and services supplied to companies retailing flight planning and information services to the airlines. For example, mean equivalent winds are supplied as a specialized service and it is estimated that some 70% of all UK passenger flights use these data.

At regional level, Bracknell is responsible for the production of significant weather charts for westbound flights across the Atlantic. A new system is being developed to make better use of numerical model products for such things as the definition of jet streams, areas of clear air turbulence and the vertical extent of cumulonimbus clouds. An interactive system incorporating visual display units should enable forecasters to produce a higher quality chart more efficiently, since the numerical model guidance for many of the significant weather elements requires little fine-tuning. This development will also make it possible for the WAFC to produce significant weather charts for anywhere in the world.

Within the United Kingdom, forecasting services for civil aviation are provided from three main offices (at Bracknell, Manchester and Glasgow) plus a number of subsidiary offices for local information. The services comprise warnings of hazardous weather anywhere within the relevant control areas and forecasts for individual aerodromes, helicopter operations and general aviation. In all they represent a very substantial commitment.

The Met. Office is working closely with the CAA by carrying out research in support of the introduction of computerized systems to assist air traffic management within the busy skies over south-east England. It will be necessary to have very accurate wind advice to enable the arrival times of an aircraft at specified locations within the London Terminal Area to be predicted to within 5 seconds. This project involves a study of the observing network required (including high-resolution aircraft data) and the development of methods to produce frequently updated analyses and very-short-period forecasts.

Aviation remains a very important customer for meteorological services. In recognition of this, the theme of the WMO day in 1989 was 'Meteorology in the Service of Aviation'. To commemorate this event, some 50 guests from the aviation community and the Press were invited to the Met. Office headquarters at Bracknell where an exhibition was mounted that illustrated the evolutionary progress in the development of products and services to support the aviation industry. The improvement in forecast wind accuracy over the years was demonstrated. The challenge is to continue increasing the benefits to aviation from meteorological services, while at the same time maintaining full control over the costs.

Commercial services

During the year, commercial activities were guided by the Meteorological Office Marketing Plan 1989–90. This set revenue targets for each of the 16 discrete market sectors. Detailed plans were included for the major sectors as well as those expected to generate significant growth during the year.

Overall, the revenues earned from commercial services were expected to be on, or above, target, with the Offshore, and Media and TV sectors likely to be significantly above target. Less growth than expected was experienced in the Retail sector (due to delays in launching new services) and in the Professional and Legal sector (due to lower demand levels than expected).

New product development was supported during the year, with an important field trial of the 30-day forecasts for a small number of customers. The trial was not only useful for further development of the experimental service but also demonstrated successfully its high potential value to companies in the private sector. A product development group exists whose activities include the assessment of the sensitivity of various industries to weather and the use of weather radar to determine conditions of flood and drought.

For the Media sector, the main success in the year was the start of a new daily weather presentation that incorporates state-of-the-art television graphics. During the year the presentation was sponsored, via ITN, by Powergen; the first television sponsorship of its kind in the United Kingdom. Other important developments in service provision were achieved with BBC TV, the ITV regions and with Channel Four Daily.

There was a considerable increase in the range of weather information available by telephone — largely through the introduction of new services. These included forecasts for European and North American ski resorts, holiday resorts in the Mediterranean, and UK travellers for which road information is also given. General weather news from around the world is also available.

For the Press, improved graphics' capabilities were developed to provide national and regional newspapers with an improved service and source of weather text and maps for publication.

Land transport saw a period of consolidation of the high market share gained in recent years through the introduction of the 'Open Road' service to county authorities. The primary means of achieving this was through improvements to the quality and reliability of existing service levels.

In the medium term, new product enhancements are being developed in line with market research carried out during the year. This research reflects the growing importance of electronic distribution of services in this sector.

Revenues from the Offshore sector increased during the year; this follows a period of decline in recent years. The change is largely attributed to increased exploration activity in the North Sea. This sector has been identified as a major development area for the electronic distribution of services by computer-to-computer links, automated document facsimile distribution, and access to databases, etc.

Further development of the weather-sensitive gas, electricity and water services of the Utilities sector was carried out during the year. For example, plans were made to provide quantitative short-period rainfall forecasts to certain water authorities from the Met. Office FRONTIERS system.

The Agriculture sector has seen the consultancies for the Ministry of Agriculture Fisheries and Food centralized in a new National Agrometeorology Unit at Wolverhampton. Another new service, 'Weatherbase' was developed to meet the needs of agrochemical companies. Intensive research on crop-growth models continued under contract to the European Economic Community.

The Building and Construction Unit provides meteorological input to the Building Research Establishment, and has also conducted several surveys on the incidence of fog on existing and planned roadways. Monthly summaries of building downtime, 'Metbuild', were improved by the inclusion of averages of periods when construction operations may not be possible.

Comprehensive information was supplied to the Legal and insurance sector on the extent and severity of wind and rainfall in storms over Europe during the 1989/90 winter. Routine bulletins of weather hazards and extremes are now provided to the industry through the 'Weatherproof' publications.

Computing and telecommunications

The Met. Office runs a central computing complex, known as COSMOS, which is required to perform a number of functions: routine numerical weather prediction (NWP); support for a variety of research projects, many of which involve the running of complex models; support of revenue-earning activities such as services to TV companies; and support of administrative functions. Numerically-intensive work is done on a Control Data Cyber 205, and general purpose computing on IBM machines.

The Cyber 205 computer was upgraded in September. This enhancement has allowed twice the throughput of work to be achieved, but the machine continues to be fully loaded. To meet the demands for further capacity to support a new generation of numerical models for NWP and climate research work, a Cray Y-MP computer was installed in December 1989 and accepted in February 1990. It has a capacity of about eight times the enhanced Cyber 205.

The demands for computing resources on the IBM computers continue to increase at 30% per annum. The IBM system was upgraded by replacing one of the two existing 3081 machines with a second-user IBM 3084 in January 1989. The disk subsystem was also enhanced to provide a total of 60 gigabytes of on-line storage. In February a major upgrade in the operating system was achieved.

The majority of electronic data handled by the Met. Office pass through the automated telecommunication centre (Met TC) at Bracknell. The perishable nature of much weather information makes it imperative that data are exchanged quickly and accurately, both nationally and internationally. Technical improvements are made routinely to ensure that customers' requirements and international obligations are satisfied in a cost-effective manner.

During the year the message-switching system based on Ferranti Argus computers was retired. Basic communications are now routed by Tandem computers. Transmission of routine facsimile broadcasts by land-line around the United Kingdom has largely been automated. The increasing demands for document facsimile have also led to automated handling being introduced.

Pending full implementation of the Weather Information Network, an interim network is being used to support printers at an increasing number of forecasting offices. These printers are used to provide items that cannot be fitted into facsimile schedules, such as forecast tephigrams and experimental short-range forecasting products.

In March, a new Private Automatic Branch Exchange (PABX) was brought into use at the Met. Office headquarters. The most obvious change to callers from outside is the provision of facilities for direct dialling to extensions. The PABX also provides many useful facilities within the Met. Office, such as call-back when free, and gives a basis for moving to Integrated Services.

Late in the year equipment was installed that allows broadcast data to be transmitted to the geostationary satellite Meteosat for reception on low-cost systems, particularly in Africa. The Met. Office made test transmissions of pictorial data to assist developers of receiving equipment.

Good progress was also made with automated dissemination of warnings of severe weather, facilities at the Principal Forecasting Office at HQ Strike Command, satellite data reception systems, and international data management.

Progress has been made with the integration of the many computing systems serving HQ and research groups away from Bracknell. The Central Data Network (CDN), mainly based on Ethernet (a commercially available communication system), now inter-connects about 50 systems including COSMOS. A major source of data on CDN is AUTOSAT-2, a new system for processing satellite imagery, which is now routinely generating products from Meteosat.

Procurement of upgrades to the Outstation Display System (ODS), installed at 20 sites, progressed; the improved ODS is capable of displaying products from AUTOSAT-2. At RAF Marham, a demonstration of the use of personal-computer (PC) technology to display weather information directly to aircrew is being mounted .

Steps have been taken to improve Information Technology to the Met. Office's administrative and business functions in preparation for Agency status. A new office automation system is being procured to help support senior managers and commercial functions. PC networks are being used as the basis of systems to support financial, accounting and stock-control functions.

Central forecasting

The Central Forecasting Office (CFO) is the hub of the forecasting organization where over 100 forecasters and support staff work in shifts on a range of forecasting activities.

The opportunity was taken early in the year to create a formal Short Period Forecasting Unit (SPFU) within the CFO. The unit prepares detailed analyses and forecasts (up to 15 hours ahead) for an area covering the eastern North Atlantic and western Europe. The SPFU is directly responsible for the co-ordination of severe weather warnings issued by Public Service Offices and is also responsible for all the civil aviation tasks formerly performed at the Principal Forecasting Office at London/Heathrow Airport.

The SPFU includes the FRONTIERS unit which produces optimized precipitation forecasts for most of the United Kingdom on a 5 km scale up to 6 hours ahead every half hour. The forecasting technique includes integration with the output from the operational Numerical Weather Prediction (NWP) mesoscale model, and objective verification of the forecasts is carried out routinely. By integrating the job positions of FRONTIERS and the Storm Tide Warning Service more closely, and having more flexibility by support from other forecasters, it has been possible to eliminate a roster of five forecasters.

Further improvements were made to the visual display unit facilities in the CFO. Every forecaster has access to an IBM 5080 or 3270 device, with interactive capabilities, for viewing COSMOS data. A major software triumph has been the development of a facility to superimpose satellite imagery upon NWP model fields of data. This permits the most definitive check to be made on the NWP model analysis in (conventional) data-sparse areas and allows the forecaster to improve the analysis, with consequential improvements to the forecasts. Unfortunately, this facility is limited at present to the area covered by Meteosat, the European satellite; reception of imagery from other geostationary meteorological satellites around the globe is too irregular for effective use.

CFO continued to access and use the NWP output of the European Centre for Medium-range Weather Forecasts (ECMWF) in issuing guidance for the period 3–7 days ahead. Intercomparison between Met. Office and other NWP model results plays a significant role in building confidence in forecasts for this period.

As a result, in recent years, of the success obtained in predicting the evolution of tropical cyclones 2–5 days ahead, a twice-daily advisory service was set up for the southern hemisphere cyclone season in 1988–89. Bulletins were prepared in the CFO on the basis of the NWP model forecasts over each 5-day period and were telexed to WMO Member States in the south Pacific and south-east Indian Ocean. This service was extended to the south-west Indian Ocean for the 1989–90 season.

In response to a request from the Foreign and Commonwealth Office (FCO) in summer 1989, a similar advisory service was set up for the Caribbean; advisories were sent to the FCO whenever British Territories and Dependencies appeared likely to be affected by hurricanes.

An international workshop on Bracknell NWP products was organized and held at the Met. Office College in June 1989; over 50 delegates from around the world attended. A prime objective of the workshop was to demonstrate the range and quality of products available at Bracknell to assist WMO members with their local forecasting responsibilities.

Work on implementing enhanced versions of the operational forecast models on the ETA 10 supercomputer was abandoned, but not before the current versions were run successfully for almost a month whilst the Cyber 205 computer was upgraded. The operational forecast suite is now being implemented on the Cray Y-MP computer, and will incorporate new versions of the models, including the wave forecasting models, at higher resolutions.

An additional forecast from the limited-area model was introduced for 18 GMT data to complement those already in place for 00, 06 and 12 GMT data.

The Local Area Sounding System (LASS), which derives information on vertical temperature profiles from data measured on the National Oceanic and Atmospheric Administration polar-orbiting satellites, was maintained in operation. The retrieved information was provided both to forecasters and to the NWP system. Refinements were introduced to the quality control and error monitoring aspects of LASS, and the presentation of the information on charts was revised to permit a more effective assessment by forecasters. A major change was the transfer of the core of the processing from a dedicated minicomputer to the COSMOS mainframe. This allowed a closer coupling of the LASS processing with the NWP system. As a result, the forecast background profiles used by LASS are now more accurate, i.e. short-period forecasts are used.

The first images from the Met. Office's new image-processing system AUTOSAT-2 were provided to forecasters in the CFO, and also to TV weather presenters. The imagery is of much higher quality and frequency than that from the previous operational system (AUTOSAT-1) which it is expected to replace.

The quality of observations used in NWP was monitored continuously during 1989. Observations from several stations that were identified as providing unreliable data were corrected before being used in NWP. Where a correction could not be provided they were either given less weight in the data assimilation or were excluded completely. Monthly lists of ships producing suspect pressure observations were distributed to meteorological centres in other countries, and a report to WMO on the quality of ship observations over a 6-month period was presented.

Development work is in progress to create a scheme for assimilating observational data into the wave model, mainly looking to remotely-sensed data from satellites. A simple method has been shown to work successfully in the present model.

A database has been created for monitoring the observations and analyses of sea surface temperature (SST) over the entire globe. Among other things, early results confirm the generally good quality of satellite observations of SST from the latest radiometers.

The main production tasks for the North European Storm Study were completed. A number of other co-operative studies were completed for locations as diverse as Labrador and Hawaii. The wave model also contributed to a feasibility study of forecasting 'run-up' at specified coastal sites.

The number of NWP and wave products disseminated routinely to customers, both internal and external, continued to increase; data were also supplied for projects of a more limited duration such as the Arctic Stratospheric Ozone Experiment and the North Sea Project. The archive of past model analyses and forecasts were a further source of data, and in one instance was used to generate trajectories in connection with an investigation into locust migration.

Several charts are being generated for dissemination via the Meteorological Data Distribution mission of EUMETSAT (the organization set up to run meteorological satellites for Europe), and a new facility to distribute charts directly via docfax has also been introduced.

Verification of a wide range of operational forecast products continued. The steady reduction of forecast errors over the years is mainly as a result of improved numerical models. Verification results in standardized format are exchanged regularly between the major forecasting centres world-wide, enabling a comparison of the different models to be made.

Professional training

Most formal training is conducted at the Met. Office College at Shinfield Park, Reading. The College has teaching facilities that range from small seminar rooms to large, well equipped lecture theatres, and specialized facilities for forecasting, observing, computing, and technical courses.

Courses are usually residential, with 108 study bedrooms available on site. The longer duration courses are run by College staff (17 instructors plus 10 support staff) and by the 4 instructors of the School of Technical Training. Shorter, specialized computing courses and seminars are run by the staff from the Computer and Data Processing Branch; courses on staff reporting and appraisal are run by the Personnel Management Branch. The Personnel Branch also has a Training Liaison Officer who plays a key role in arranging training for staff at the College and elsewhere.

The demand for initial training is very dependent on recruitment. During the current academic year (ending July 1990) the demand for training of graduate recruits has been very high; 60 such students have been trained, 50%more than usual. Organizational changes and the move to Agency status have created new needs; seminars on budgets and accounting systems have been held. Further additions and changes to the training programme are planned.

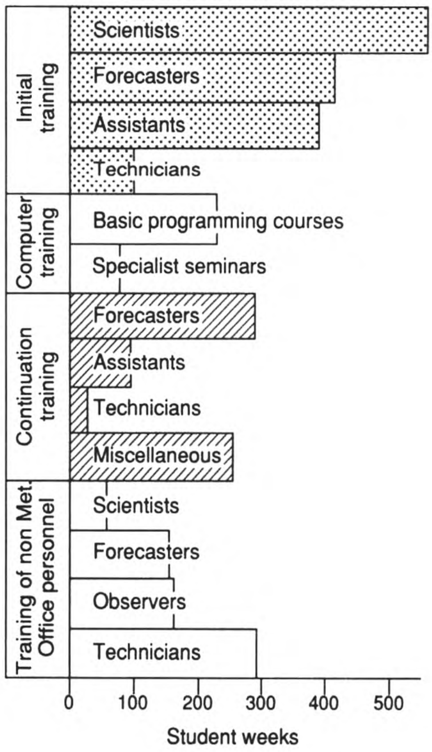
Changes of equipment often have training implications. Training in the UNICOS operating system is under way for the dozens of staff who need to be able to use the new CRAY Y-MP supercomputer.

The total amount of training given at the College during 1989 was 3100 student weeks. Compared with 1988, the amount of training of forecasters and assistants (both initial training and continuation training) was down by about 30%.

Other categories of training showed a substantial increase. Initial training for graduate recruits rose by 16%, computer training by 80%, 'miscellaneous' continuation training (including commercial courses) by 25%, and training of non-Met. Office students by 25%. Some of these students not employed by the Met. Office are being trained as observers; of these some are sponsored by the Civil Aviation Authority, others by the Met. Office, as part of the UK observing network. The remaining non-Met. Office students are from overseas. Some are taking up spare places on the courses, with the fees paid for by their own National Meteorological Service or perhaps by WMO, the United Nations, or the British Council. One technical course, in meteorological engineering, is run solely for overseas students, mainly from developing countries. This new course, running for a second year, again succeeded in attracting suitable students. This helped to raise the College's revenue to £230 000 in financial year 1989/90, a 25% increase in earnings compared with the previous year.

Revenue has increased in each of the last 3 years and now offsets about 15% of the cost of running the College.

Throughout the year many staff benefited from the opportunity to take external training courses, in Technical Colleges, universities and at the Civil Service College for example. In January 1990 a new venture in external training got under way when ten graduate recruits, having completed their initial training at the College a year or more before, went to the University of Reading for the Lent term of the M.Sc. course in meteorology. The aim was to provide them with a greater depth of knowledge of theoretical meteorology and its practical applications, and to make them better equipped to assimilate new research developments. The venture will be repeated each year as part of the Met. Office's response to the official report on the storm of October 1987. It is expected to provide a valuable external input into the training of the Met. Office's future research scientists and senior forecasters.



Student training at the College during 1989

International services

International collaboration is the hallmark of operational and research activities in meteorology.

The Met. Office subscribes to the World Meteorological Organization (WMO), European Centre for Medium-range Weather Forecasts (ECMWF) and European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). It provided the UK representation at a number of major international conferences including: the Financial Advisory Committee and constituent bodies of WMO, including its Technical Commissions for Instruments and Methods of Observation, Climatology and Marine Meteorology, and its Regional Associations for Asia and the South-west Pacific; the North Atlantic Ocean Stations Board; and Council and supporting bodies of EUMETSAT and ECMWF.

In addition, the Director-General was supported during his attendance at sessions of WMO's Executive Council as Third Vice-President. He also attended sessions of the Organization's Bureau.

Altogether the Met. Office ensured that its views and those of the United Kingdom were considered at more than 100 international meetings during the period, covering topics as diverse as agriculture meteorology, Anglo–Japanese co-operation and Antarctic telecommunications. An example is the Met. Office's provision of the Chairman for WMO's Commission for Basic System's new Working Group on Data Management — the Group aims to develop an integrated approach to the generation, transmission, storage and application of meteorological data.

A major international activity of the Met. Office is support of WMO's Voluntary Co-operation Programme (VCP) through the provision of equipment, services and fellowships to developing countries. The largest component was initiating a 2–3 year programme to refurbish eight wind-finding radars by contract with Siemens Plessey Radar Ltd. The first refurbished radar was dispatched to Ghana in January 1990. Separately, a ninth radar was refurbished and installed on Gan, Maldives, as part of the UK's contribution to the Tropical Ocean and Global Atmosphere project of WMO's World Climate Research Programme.

Other VCP projects provided synoptic observing instruments to Jamaica to replace some of those destroyed by Hurricane Gilbert, and pressure calibration equipment to Ghana for use with precision aneroid barometers that had been provided earlier. Provision of an automatic weather station to the Turks and Caicos Islands is nearly complete. As part of *Co-ordinated projects*, managed by the WMO Secretariat, funds were provided for the improvement of telecommunications in Africa, Jordan and Cyprus.

Eleven people from developing countries were supported by fellowships for long-term studies, mainly on university degree courses. Short-term fellowships were provided for 29 students; most attended courses at the Met. Office College at Shinfield Park, Reading. Six were trained as part of the wind-finding radar project. Lecturers were provided to the Regional Meteorological Training Centre in Nairobi for a course on TV weather presentation.

In late May and early June, the Director of Services and Messrs Collier and Hunt visited the State Meteorological Administration in the People's Republic of China.

In June, at the Met. Office College, a session of the 4-yearly Conference of Commonwealth Meteorologists was hosted.

The Intergovernmental Panel on Climate Change (IPCC) set up three Working Groups to prepare authoritative statements on science, impacts, and policy responses. Dr Houghton, on behalf of the United Kingdom, chairs the first of these Working Groups. A small international team of scientists assist him; support for this has come from a £700 000 contract from the Departments of the Environment and Energy.

So that international action can be based on commonly agreed, sound scientific understanding, the Working Group has assembled over 150 of the world's leading climate-change scientists to prepare the assessment, has organized 15 international workshops to discuss and draft sections of its report and has arranged for thorough peer reviews to be completed before the report is presented to the IPCC in August, the Second World Climate Conference in October, and the UN General Assembly in November 1990.

Research

Improvements in the quality, range, effectiveness and efficiency of meteorological services are required by the Ministry of Defence and other government departments, the Civil Aviation Authority, industry and the general public. Key requirements relate to the development of improved weather forecasting services and the maintenance of a broad and up-to-date knowledge base for provision of advice on meteorology and climate to government. Fulfilment of these requirements calls for a diversity of expertise and a wide range of research activities. It calls for long-term fundamental research as well as applied research.

The three areas of research described below deal with weather forecasting, climate research, and research into atmospheric processes. A fourth area, concerned with the development of operational instrumentation, is dealt with under the Observations section.

Forecasting research

During the early part of 1989, considerable effort was expended on transferring the operational and mesoscale forecast suites to the ETA 10 computer, and on developing code to exploit this computer using higher resolution forecast models. This was largely achieved, but considerations of the long-term development and reliability of the ETA 10 system led to a decision to replace the ETA 10 by a Cray Y-MP. Increased effort was then placed on producing a flexible model that could run efficiently on different computer systems, and which would satisfy the requirements to provide global and regional forecasts on all time-scales, and to simulate the global climate. All components of this unified model system were designed and coded, and testing of the integrated model was started.

The system for processing observations used in the numerical weather prediction (NWP) system was redesigned. Quality control and monitoring of the observations was enhanced, and made consistent with their assimilation to initialize the NWP forecast model. Automatic quality control systems were tested. Processing of local area satellite soundings, to give temperature and humidity information, has been more closely integrated into the suite. Tests show that this avoids problems encountered when attempting to use independent soundings. Work to assess observing systems and prepare for new remote sensing observations continued.

The quasi-operational mesoscale model was enhanced by enlargement of its domain, and inclusion of a new long-wave radiation scheme. The interactive initialization procedure was developed to reduce the amount of repetitive work, and to initialize the divergent wind field. Work started on a new dynamical formulation in which both sound waves and gravity waves are treated implicitly, and which uses a semi-Lagrangian advection scheme. A new short-wave radiation scheme was also tested.

A new representation of quasi-equilibrium atmospheric dynamics was implemented and tested in a forecast model. Simulations of mesoscale dynamical processes were studied for depressions, fronts, and gravity waves, and compared with field experiments.

A model under development to provide forecasts of ocean interiors for the North Atlantic and Arctic Oceans is producing anomalies in surface temperature which resemble those observed in both position and magnitude.

Ensemble 30-day forecasts of UK temperature and rainfall (nine forecasts run from analyses 6 hours apart) have shown significantly more skill than those using traditional statistical techniques: beyond 15 days the skill is only marginal however. Forecasts are being evaluated by selected customers, with a full commercial service in view.

Recent achievements in the automation of significant weather forecasting for aviation include the production of forecasts of liquid water content, sandstorms and convergence zones. Further guidance is now available that helps position surface fronts, and an improvement was made to the algorithm to identify the lower tropopause in areas of multiple tropopauses.

A model is being developed to provide frequently updated analyses and very-short-period forecasts of winds and temperatures for use by future air traffic control and airborne flight management systems. Aircraft-derived data relayed via the Mode S datalink will be input to this model, along with conventional radiosonde data and any future profiler or scanning Doppler radar data.

Good progress was made on development of a numerical model which will predict low cloud and temperature in the boundary layer up to 24 hours ahead, when no change in air mass is anticipated.

A method of forecasting lightning, using routine output from the operational NWP models, is under development and already performs better than existing methods out to 12 hours ahead.

As part of the expansion of statistical forecasts from the NWP models using an updatable Model Output Statistics (MOS) model, a world-wide archive was created to allow forecasts around the globe, and progress was made towards the introduction of a multivariate MOS model. Work on the prediction of elevated radio ducts from fine-mesh model output using a MOS model is now being extended to use output from the mesoscale model.

Work has continued on AUTOSAT-2, which will take over and expand the current operational system supplying satellite imagery and derived data. A large range of imagery products from the Advanced Very High Resolution Radiometer (AVHRR), the geostationary satellite Meteosat and Geostationary Operational Environmental Satellite (GOES) digital data and analogue imagery are now being produced. Two interim schemes are being investigated for providing the outstations with these products before the implementation of the Weather Information Network .

Major contributions have been made towards a manual for forecasters on interpreting satellite and radar images of mid-latitude weather systems. The manual is edited jointly by the Met. Office and Pennsylvania State University, and was the subject of an international Workshop, organized at the Met. Office College in 1989, when draft contributions to the manual were discussed.

The FRONTIERS computer-based system for producing very-short-range precipitation forecasts from weather radar and satellite data has been further developed. The radar quality-control scheme was redesigned to ensure compatibility with other corrections applied during the analysis. To improve forecasts, in particular to allow for rotational motion, a scheme was devised to produce a selection of forecasts by advecting precipitation areas with the mesoscale model wind field at different heights. Operational reliability has been improved by using the FRONTIERS development computer (Merlin) as an operational back-up.

The application of artificial intelligence techniques to the short-period forecasting of frontal precipitation and convective storms in the United Kingdom is being investigated. An overall structure for an intelligent automatic system and the relations between its component parts were proposed, and a start made on formulating forecasting strategies.

Climate research

Climate issues have continued to be very much in the public eye. Numerical models of the atmosphere, of the ocean and of the coupled atmosphere, ocean, sea ice and land surface system, provide a powerful facility within the Met. Office for studying the physical basis of climate and climate change. Work continued with the development of these models. Experiments were carried out with the atmosphere and coupled atmosphere–ocean models with improved atmospheric physics, and a scheme was developed to ensure that the oceanic temperature and salinity remain close to climatology in long runs of the coupled model. An important enhancement to the ocean model was the inclusion of an embedded-layer representation. A new two-layer ocean model was also developed for studies of the basic physics of the coupled ocean and atmosphere in the tropics. Tests were also carried out of the impact of data sets of the surface forcing of the ocean derived from the operational forecasting models.

A detailed study of the coupling between radiation and dynamics was made using data from polar-orbiting satellites and from simulations with a stratospheric model. The study showed that during strong stratospheric warmings, when temperatures may rise by more than 50 °C in a matter of days, radiation leads to systematic changes in the circulation which may have long-lasting effects. The transport of trace chemicals, such as ozone, is also affected. Front-like zones which develop during these warmings were also studied, using a high-resolution numerical model, and their dynamical origin investigated in detail.

In studies of climate change, the atmospheric general circulation model (AGCM) was used to deduce the impact of deforestation on the climate of the Amazon basin. Significant increases in surface temperature and decreases in rainfall were predicted and the surface and atmospheric mechanisms causing these changes identified. Improvements in the treatment of surface hydrology in the model formed an integral part of this work. Investigation of the response of climate to increase in greenhouse-gas concentrations included studies of the impact of the simulation of cloud using four different cloud parametrizations ranging from a relative-humidity dependent scheme to one in which both the amount and radiative properties of clouds were diagnosed from the cloud water content. A range of global mean surface warming of between 1.9 °C and 5.2 °C was found for doubled carbon dioxide (CO_2) concentrations, highlighting the uncertainty in, and importance of, the representation of cloud.

A high-resolution version of the model used for climate simulation was set up and run to enable the study of regional climate change and to investigate the impact of doubling CO_2 concentration on climatic variability. A preliminary study of results indicates that the intensity and frequency of simulated tropical disturbances increase on doubling CO_2.

Model calculations, in which the AGCM was run from observed sea surface temperatures (SSTs) for the past 8 years show seasonal rainfall totals to have been well simulated in seven of the years. Complex, but coherent, changes in the model's atmospheric circulation parallel the rainfall changes; the most important being the rate at which atmospheric moisture reaches the Sahel. Analyses of observed atmospheric data support the model results. Earlier evidence that SST variations throughout the global ocean influence Sahel rainfall were confirmed in model and empirical calculations. The latter, in co-operation with the Climatic Research Unit (CRU), University of East Anglia, utilized an improved tropical African data set.

Real-time experimental seasonal rainfall predictions were made for the Sahel in 1989 and for north-east Brazil for March–May 1989 and 1990. Model hindcasts of the main Sahel rainfall (July– September) made from June SST anomalies for each of five past years have proved very skilful. So far six of the seven real-time Sahel and north-east Brazil forecasts issued since 1986 have had some or considerable skill.

Estimates of long-term changes of global and regional marine surface temperatures since the mid-19th century have been progressively refined. In particular, improved corrections for the use of uninsulated buckets have been applied to SST data sets measured before the Second World War. Also, improved adjustments have been made to 19th-century marine surface air temperatures. Trends in the adjusted marine data agree well with those in air temperature at nearby coastal and island land stations, except in part of the early 20th century when the latter were biased high by the use of different exposures at tropical stations. In co-operation with the National Oceanic and Atmospheric Administration (NOAA), a pilot study has begun to assess the benefits of augmenting the historical marine data base by blending ours with NOAA's and adding 15–20 million as yet unkeyed observations for 1850–1950. The use of satellite-based data to complete the coverage of SST from the early 1980s onwards is being developed.

In liaison with CRU, the fields of adjusted SST have been blended with quality-controlled fields of land near-surface air temperature to enable calculation of global surface temperature trends. SSTs and night marine air temperatures, analysed in the Met. Office, and land air temperatures provide corroboration of the overall global warming of about 0.4 °C since the mid-19th century. The coldest period, shortly after the turn of the century, was about 0.5 °C colder than at present. The 1940s to 1950s were a little warmer than the 1960s to 1970s. Data from glaciers support these trends. On a global average, 1989 was the fifth warmest year at the surface since comparable records began in the mid-19th century. Six of the ten warmest years in the entire record occurred during the 1980s which were, on average, about 0.2 °C warmer than the 1951–80 reference period and about 0.4 °C warmer than the average for 1861–1900.

Atmospheric process research

Research into atmospheric processes, such as clouds, radiation, turbulence, fronts and atmospheric chemistry, is necessary so that they can be better represented within predictive models.

The C-130 Hercules of the Meteorological Research Flight flew in excess of 500 experimental hours in the period. As part of this there were detachments to St Mawgan in support of the aircraft's NATO role, to Norway for ERS-1 satellite calibration trials and to Finland to measure the microwave properties of ice and snow. Additionally, the aircraft was involved in a major collaborative exercise (International Cirrus Experiment) over the North Sea with groups from France, Germany and Sweden to measure the radiative, dynamical and microphysical properties of cirrus clouds. During the period, data were analysed from a previous detachment of the C-130 to Dakar when clear-air atmospheric absorption in the infra-red window region was measured. An assessment of the effect of the water vapour continuum on atmospheric cooling/heating rates was possible. Analysis was also undertaken of the data from the First ISCCP Regional Experiment (FIRE) detachment to San Diego when the radiative properties of stratocumulus cloud were studied. A paper was published showing a discrepancy between the measured droplet sizes and those calculated from present theories of the radiative properties of such clouds. A new criterion for the dissipation of stratocumulus cloud due to cloud entrainment has been derived in a theoretical analysis. This criterion is much more consistent with available data than previous criteria.

Data from the FRONTS '87 experiment were analysed and used to test and develop models of frontal development. Comparisons were made with the forecast development obtained with the fine-mesh and mesoscale models. An analysis was conducted showing the importance of the evaporation of ice in the development and structure of fronts. Observational studies of flow over complex terrain have been undertaken by deployment of the tethered-balloon facility from Cardington. Related theoretical studies have considered the transfers of heat and momentum over heterogeneous terrain. Marked differences are found between the heat and momentum transfer coefficient.

Experimental studies of concentration fluctuations in a dispersing plume have been undertaken under stable night-time conditions. Analysis of data from past experiments conducted at ranges between 50 m and 1 km from the source has led to empirical scalings for these fluctuations.

As part of the National Response Plan that followed the nuclear accident at Chernobyl, a numerical model was developed which is capable of simulating the transport, dispersion and deposition of radio-nuclides released into the atmosphere from any European installation. This model is ready for very rapid response, and can either forecast the transport of the radio-nuclides or analyse the plume from a past release. A major recent enhancement of the model is the estimate over most of the British Isles of washout and deposition using a highly resolved archive of hourly rainfall rates derived automatically from weather radar imagery.

Tropospheric measurements were made of ozone, peroxyacetylnitrate, chloroflurocarbons, hydrocarbons and water vapour, and (in collaboration with scientists from Germany and the University of East Anglia) of nitric oxides, reactive nitrogen and hydrogen peroxide with the aim of providing quantitative tests of the photochemistry involved in determination of greenhouse gases. These are currently being interpreted using meteorological and photochemical numerical models.

In the winter of 1988/89 the Met. Office participated in a NASA-led campaign to study the Arctic vortex composition. A coupled microphysical Lagrangian model developed jointly to interpret the results elucidated the dynamical and photochemical processes leading to ozone loss. Calculations predict substantial local ozone losses in the northern hemisphere with current levels of atmospheric chlorine.

Appendices

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