The Met.Office

Scientific and Technical Review

1993/94

The Met. Office Charter Standard for the Public

We aim to serve the public by providing -

Up-to-date weather information and forecasts

We will provide weather information and forecasts through radio and television, newspapers, telephone and facsimile services.

Weather warnings

We will issue warnings of severe weather through radio and television, and to emergency organisations such as the police and fire services. We will provide warnings of adverse road conditions to the police and to local and national radio. We will provide gale warnings and marine forecasts for radio.

Advice in emergencies

We will provide warnings of coastal flooding to the National Rivers Authority and the police. We will provide weather advice for the statutory authorities in environmental pollution emergencies that may arise, for example, from accidental release of toxic chemicals into the atmosphere.

Weather and climate information

We will maintain the National Meteorological Library and Archive at Bracknell that you may visit free of charge, and we will develop low-cost publications containing basic weather and climate information for schools and the general public.

To measure how well we are doing -

We will set performance targets and publish our achievements against them. We will monitor our forecasts, measure their accuracy and ask you in public surveys, conducted by independent consultants, for your opinions.

Our performance targets set standards for quality of service, accuracy and increases in efficiency. They are reviewed each year and our performance against them is published in the Annual Report and Accounts. Those connected with our services to the public are also published on a separate leaflet available free of charge from the Met. Office or our Weather Centres. Our performance against targets for 1993/94 are summarised in the Public Services section of this Review.

You can contact the Enquiries Office at Bracknell on the number on the back page, or leave a recorded message outside office hours. You can ask for leaflets giving details of our services, including where you can hear the latest forecast on radio or television. Details of our public services are published in programme magazines, newspapers and in telephone directories under 'Weather'.

Should you have a complaint, please telephone the Enquiries Office or, better still, write in. We want to hear your views and learn whether you are satisfied with the services we provide. We welcome your opinions and criticisms and will react positively to them. We aim to respond to a complaint within five working days of its receipt, or at least provide you with an acknowledgement and an estimate of when a full reply may be expected.

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Foreword from the Chief Executive

Once again, it is a pleasure to report to our owners, customers, partners and staff that the Met. Office has had a successful year. We made substantial progress towards our scientific and technical goals, achieved our primary financial targets and steadily improved our efficiency. The result has been a continued growth in our customers' satisfaction with our services.

The three main reasons for this success are our progressive scientific and technological advances, our staff's adaptability to change and our determined efforts to strengthen international co-operation.

All this has been a particularly remarkable achievement during a year of considerable uncertainty, in which the Government has been deliberating over the administrative framework of the Office, and our budget, running costs and staff pay have been affected by restrictions in public spending and adverse fluctuations in exchange rates.

We can also report a growing contribution by our commercial customers to financing the Office's core costs, with an increase in revenue of 8% over last year. TV weather services in the UK and overseas are still the mainstay of our revenues, but there was also significant growth in offshore, land transport and water authority business and in the use of dial-up fax services for mass markets.

One element of our commercial services is to provide our products and data on a fair basis to the private sector and the Met. Office's policy on this has been clarified in general during the year. A study of the implications of moving to Trading Fund status is now under way.

Science and technology

Our Unified Model for numerical weather prediction (NWP) and climate change has been undergoing extensive development since 1990, but during 1993 it really began to show its paces. Its accuracy for NWP now confirms the Met. Office as one of the leading world forecast centres. The version for prediction of climate is being improved by employing observations made by the Meteorological Research Flight's C-130 aircraft to increase the realism with which atmospheric processes are represented and by introducing better coupling between the atmosphere, oceans and sea-ice, which now also includes sea-ice dynamics. The new Cray-90 computer system installed in March 1994 helped meet growing demands for this work.

Our Unified Models remarkable versatility enables us to develop special versions for local forecasts all over the world. These local versions are also being used on smaller workstations by our defence customers, and by research groups in the UK and abroad with whom we collaborate.

However, to improve the accuracy of numerical modelling still further also requires long-term improvements to the quality and quantity of observational data. Remarkably, the broad direction for this was set out as long ago as 1978 by Sir John Mason in a far-sighted article in the *Meteorological Magazine*, and even now continues with our collaboration in EUMETSAT and the COST-75 group, who are planning as far ahead as the year 2010. The Met. Office was among the first in the world to improve its weather forecasts by 'assimilating' measurements from the European Earth Resources Satellite (ERS-1) into the numerical model, and last year saw further progress towards better integration of observations from weather radar, satellites and surface stations. This process is helping the notable reliability of our tropical cyclone forecasts, which are making a significant contribution to the UN's International Decade for Natural Disaster Reduction.

Information processing and communications systems are another vital element of our operation. A logical consequence of the convergence of technology in these areas was the integration of our telecommunications and computing branches during the year. We continued to develop our screen-based meteorological information systems, MIST and ODS. These are designed for commercial, defence and aviation use, and have been extended to serve our outstations, TV and radio studios and a wide range of customers.

This year it is the turn of the Central Forecasting, Commercial Services and Atmospheric Processes Research Divisions to provide longer contributions to the Scientific and Technical Review. The first shows how individual forecasters are being provided with more products while the computer power available ensures they still have time to think. The second is concerned with the efficiency of the process of getting the right products to our customers without duplication of effort. The third is literally about the nitty-gritty detail in the atmosphere that can profoundly affect the behaviour, and computer modelling of layer clouds; this in turn has ramifications from short-range forecasting of night frost to climate modelling.

International

The global scale of weather and climate, and the fact that no organisation can prosper in isolation, means that a vital element of the Met. Office's strategy has to be to improve collaboration with other meteorological services, research organisations and industry. This was the theme of the first and very successful — European Conference on Applied Meteorology, which we organised in conjunction with 30 other organisations at the University of Oxford in September 1993.

On a wider stage, the Met. Office has had a prominent role at the World Meteorological Organization (WMO), working to establish a new framework for a data exchange agreement. Its purpose is to balance the conflicting objectives of close collaboration and mutual support between National Met. Services, while allowing for the rights of commercial customers to purchase meteorological services from any country that supplies them.

The Office is particularly proud that the United Nations awarded the UN medal to our members of the Mobile Met. Unit for their services in Bosnia this year. This is the first time any member of the Met. Office has received this medal. As well as for Bosnia, we provided specialised forecasts and meteorological advice for the UK and United Nations defence forces in the Balkans, Turkey and Iraq.

Closer liaison with and feedback from the Civil Aviation Authority (CAA) has been a special feature of our services to international aviation. The nine major airlines which are served directly from the Met. Office, and the other twenty or more indirectly served, remain loyal customers for Bracknell's products.

The benefits obtained from international collaboration are also obvious in our research work, in fundamental meteorology, forecasting and studies of climate change, including, significantly, contributions which have led to some of the improvements in our Unified Model. This traffic is two-way; the Met. Office has also shared its research with other institutions, many of whom are using our data, computer models and algorithms.

Governments around the world, including those seeking to commercialise their meteorological services, recognise that these collaborative ventures are highly cost-effective. Of course, meteorologists everywhere know that without this interchange of information, providing forecast, climate and environmental services would be impossible, as would their continued improvement. I and my colleagues in the Met. Office will do all we can to ensure the continuation of this 140-year-old tradition.

Observations

The need for observations

Forecasts of weather are impossible without observations of surface and atmospheric conditions at the start of the forecast period. Assessments of climate and climate change similarly depend on observation. The quality of a forecast is very sensitive to the quality of observations of the initial state of the atmosphere and to the density of the observing network. The widespread demands over recent years from government, the public, aviation and industry for improvements to forecasts have only been, and continue to be, achievable through enhancement of the global and national observing systems, and improvement in models including techniques to use observational data. Removal of components will cause the reverse. Enhancement has been accomplished at the same time as major improvements in cost effectiveness through automation. The major international efforts to automate observing programmes depend on significant funding for technological investigation and development.

Even over short time-scales, forecasts of weather over the United Kingdom and surrounding sea areas are dependent on initial surface and atmospheric conditions over the UK, the continent and adjacent waters. To predict changes up to 18 hours ahead, observations of weather conditions are essential over most of western and northern Europe, the North Sea and east Atlantic. To predict changes to 5 days ahead, initial conditions must be observed over much of the globe. Global monitoring is also necessary to predict and detect climate change. Thus weather forecasting for the UK, as in other nations, depends on both input and access to the World Weather Watch (WWW), an integrated network of observations and data transfer systems coordinated by the World Meteorological Organization (WMO).

There is no unique system or technique to make all the necessary measurements in all locations; a variety of space, surface and airborne systems have to be used. Geostationary satellites are the only means of providing frequent images of cloud systems; they also provide other valuable information such as wind vectors where there is cloud. Polar orbiting satellites are the only practical means of providing profiles of upper-air temperature and humidity data at the required horizontal resolutions over the oceans which cover 71% of the earth's surface; they can also measure cloud-top and sea surface temperatures, and sea surface winds. A mixture of ships and buoys are used to determine surface pressure, air temperature and weather in oceanic areas, and to fill-in with wind measurements when the orbiters are not overhead. The main sources of upper-air wind data over the seas remain the commercial aircraft fleets.

Over land the main sources of information are conventional surface stations (manned or automated) and weather radar which measure the extent and intensity of rainfall. Some important measurements are only possible from the surface rather than space (e.g. cloud base and visibility which are of critical importance to aviation), and some cannot be effectively automated as yet. The upper-air temperature, humidity and wind data over land are provided primarily by balloon-borne instrumentation since the satellite data cannot provide sufficient vertical resolution for regional and local forecasting of all variables.

Ground-based systems also provide some backup in the event of launch failures, or problems with space-borne instruments or data transmission systems. Since the satellite measurements are all remotely sensed, there is a need for some directly measured surface and upper-air data for operational calibration and interpretation of satellite output.

Surface-based observing networks

The UK land-based observing network currently consists of 241 surface observing stations. There are 30 key surface observing stations, evenly distributed and fully manned by professional staff, together with 84 secondary stations.

These report throughout each 24-hour period, and the data from key stations are input to the WWW for global distribution. The remaining 127 stations report as needed to meet specific local requirements. Only 70 stations are manned by Met. Office staff, mostly at civil airports, Weather Centres, Defence Service stations and a small number of dedicated observing sites.

Every effort is made to ensure that the network is as efficient and cost-effective as possible. For example, there are eight upper-air stations in the UK releasing balloon-borne instruments every six hours. Six of the eight are also key stations reporting hourly surface data, the other two make regular measurements of total atmospheric ozone, host atmospheric pollution equipment and some experiments from other research organisations. A site in the Shetlands makes regular measurements of ozone profiles using balloon-borne instruments and contributes data to the European Centre which monitors changes in the Arctic ozone layer, as well as to DoE for publication in the UK. Other observing sites host UV-B monitoring equipment and geophysical and seismological instrumentation for other agencies.

Around 60 of the observing sites, mainly the secondary stations, are fully automated. During the year two more harsh-environment Automatic Weather Stations (AWSs) were brought into operational use, on Great Dun Fell and Cairnwell. There are eleven marine automatic weather stations on offshore oil platforms. A degree of automation has also been introduced at 44 manned stations using the Semi-Automatic Meteorological Observing System (SAMOS). This has allowed the site to be left unmanned at times when the provision of the non-automated and predominantly visually assessed part of the observations is not essential. A substantial number of both fully and semi-automated sites are equipped so that automated instrumentation can be installed later to provide cloud height and amount and visibility. Cloud amounts can now be estimated from laser cloud-base records using a recently developed algorithm. The measurement of solar radiation is measured automatically at 18 of the network's 51 stations.

Staff from other organisations, and private individuals contribute significantly to the UK observing programme. Almost 100 'auxiliary' sites provide information for local forecasting purposes. A further 500 sites provide daily measurements of temperature, rainfall and sunshine for climatological purposes. Another 4040 sites make rainfall measurements only. These data serve to maintain a database which had its origins with the British Rainfall Organization of over 80 years ago.

A range of quality-control procedures are applied to observations from both manned and automated sites. Commonly occurring errors, especially in individual observations, are dealt with by computerized techniques; rainfall errors are detected using a PC-based interactive system that merges radar and gauge data on a geographical display. A regular programme of site inspections and observer training is related to the feedback from the quality-control procedures, and a PC-based station inspection and management database has been developed. The increased automation of observing requires that provision is made for early detection and correction of problems. Complete failure of an AWS is immediately apparent, but more subtle trends such as calibration drifts demand a quality evaluation procedure which activates technical action and verifies its success. Such procedures are also applied to fault detection on international systems such as drifting buoys and aircraft instrumentation.

A major study of the requirement for thunderstorm location has been completed, based on an evaluation of the existing Arrival Time Difference (ATD) system, and commercial options. Proposals have been made to enhance and update the present system to meet user needs.

Comprehensive trials of surface and upper-air observing equipment are carried out to ensure that the equipment meets the technical specification derived from the user requirement and to provide information for the choice of future sensors. Trials of anemometers, present weather sensors, and new radiosonde systems are among those now under way. The Met. Office also plays a full part in international intercomparisons of observing equipment.

Marine observing

Much-needed meteorological observations from the oceans are provided voluntarily by observers on merchant ships. Besides these data, the marine observers also provide oceanographic and animal life reports of benefit to the scientific community. The Office greatly appreciates this voluntary co-operation by shipmasters and shipowners. The number of United Kingdom recruits now stands at about 520 ships and 34 oil rigs or platforms out of the total WMO fleet of Voluntary Observing Ships of 7350. On 32 of these UK ships the Office has installed automatic transmission systems enabling the observations to be sent quickly and economically to their destination via satellite. The important work of liaison with the observing fleet benefited from the first ever international conference of Port Meteorological Officers which was held in London in September 1993. Many useful agreements were reached on ways to improve and augment the data, especially by assisting comparatively new shipboard observers with instrumental and coding problems.

Fig. 1. One of the moored buoys used on the continental shelf west of the British Isles.

The Ocean Weather Ship *Cumulus* successfully completed an eighth year of North Atlantic operations since being bought from the Royal Netherlands Meteorological Institute at the end of 1985. Operating from her home port of Greenock on five-weekly voyages, *Cumulus* carried out hourly surface and six-hourly upper-air observations on her station, 500 nautical miles west of Scotland and south of Iceland. *Cumulus* also continued to co-operate with MOD and scientific bodies, taking plankton samples, measuring sea temperatures and salinities, and deploying twelve US current drogues in the North Atlantic as part of the World Ocean Current Experiment (WOCE). Various members of the ship's scientific team are also detailed to observe marine and natural life in the vicinity. The data collected are transmitted via meteorological satellite communications. The spare accommodation on board is employed as a floating classroom for meteorological and oceanographical students.

The offshore buoy network was maintained throughout the year, although severe weather hampered the servicing schedule causing some loss of data from damaged sensors. Discussions began with the French Meteorological Service for a jointly funded moored buoy in the Bay of Biscay. Deployments of drifting buoys in the North Atlantic and one in the Arctic Ocean were made during the year. Tests of a combined low-cost surface drifter and meteorological buoy proved successful and further deployments of production units are planned for 1994.

The Smith's Knoll and St Gowan Light Vessel Automatic Weather Stations were decommissioned in September when the vessels were withdrawn from service. A new Automatic Weather station was introduced on the Sandettie Light Vessel in June 1993.

Technical support to observing

The fourth stage of SAMOS procurement was initiated with an order for 35 systems. The hardware for these systems is based on a meteorological sensor network with intelligent sensor units which allows future installations to meet the full User Requirements of Defence Services Division. The new hardware is fully compatible with existing operational SAMOS equipment to facilitate future expansion and maintenance of the operational network.

The replacement weather radar at Clee Hill entered operational service in September 1993. The products of the Doppler processing system in this radar, and those of the radar at Cobbacombe Cross, are being evaluated by the user Divisions.

A new computer-based central fault reporting system was introduced to improve the effectiveness and efficiency of the equipment maintenance.

(British Airways)

Fig. 2. ASDAR systems are carried by some Boeing 747s.

The UK contribution to the WMO Aircraft to Satellite DAta Relay (ASDAR) programme was enhanced substantially through a procurement of five additional units, three of which entered operational service on British Airways Boeing 747-400s by the end of the year. Thirteen of the 23 ASDAR systems delivered are now installed and carriers identified for a further five units.

Agreement was reached with AGI Limited to manufacture and market a commercial version of SAMOS. The product, called Computer Aided Meteorological Observing System (CAMOS) was launched at the WMO sponsored exhibition 'METEOREX' in Geneva in March 1994.

Operational space programmes, current and planned

The Met. Office contributes to the geostationary satellite programme through EUMETSAT, and to the current polar-orbiter programme by providing Stratospheric Sounding Units (SSU) for the NOAA satellites.

Both morning and afternoon polar orbiting satellites are provided by NOAA. The last SSU flight model was launched into operational orbit on board the NOAA-I satellite in August. Following loss of communications from that satellite a development model has been refurbished ready for launch on a new afternoon orbiter, NOAA-J, in late 1994.

The next series of NOAA polar-orbiting satellites, due to start operating in 1995, will carry improved microwave sounders collectively called the Advanced Microwave Sounding Unit (AMSU). There are two components; AMSU-A, provided by the USA, which will primarily derive temperature, and AMSU-B, provided by the Met. Office. AMSU-B will derive humidity profiles in the troposphere, and should also allow identification of rain cells with an indication of their intensity. Under many cloudy conditions the quality of soundings from these new instruments will be comparable to those available in clear conditions from the current infrared sounding instrumentation. In addition, the improved horizontal resolution (45 km for temperature from AMSU-A, 15 km for precipitation and humidity from AMSU-B), will lead to the provision of improved image products. A series of microwave humidity sounding instruments has been defined to provide the continuity essential for long-term climate monitoring (in addition to meeting basic meteorological requirements); AMSU-B is the first of them.

The three flight models of the AMSU-B humidity sounder have been delivered to the Met. Office by British Aerospace. Full radiometric and operational characterization tests were performed by the Remote Sensing Instrumentation Branch using the specially developed thermal vacuum calibration facility at DRA, Farnborough. The detailed results show that two of the instruments are operating satisfactorily within specification. The first protoflight model was due for delivery to the USA during April 1994 for integration to the NOAA-K spacecraft for further testing and a planned launch of mid-1995.

The future of satellite observing depends on preparations made many years ahead. This year EUMETSAT has begun a significant new programme, the European Polar System (EPS) Preparatory Programme. Its aim is to design a series of polar-orbiter missions carrying an imager and improved atmospheric sounding instruments, together with a number of instruments for monitoring climate and detecting climate change. The European Space Agency (ESA), as part of its POEM-1 Programme, has offered to launch the first of the series; however, current EPS plans for a launch date of 2000 may be influenced by rationalization of the civil, military and environmental components of the USA programmes.

EUMETSAT provides the Meteosat geostationary satellite at 0° W; it has also supported NOAA by moving a spare satellite to act as a replacement for a failed GOES satellite at 75° W. EUMETSAT launched a new satellite in the geostationary series, Meteosat 6, in November 1993. The satellite is located at 0° W and is providing visible imagery and communications facilities; problems with infrared and water vapour output are being investigated. Meteosat Second Generation (MSG) with improved resolution and more-frequent data, will replace the existing EUMETSAT geostationary Meteosat Operational Programme (MOP) after the year 2000.

Over the last two years, the Met. Office has chaired the EUMETSAT Scientific and Technical Group (STG) Working Group on Climate which has reviewed appropriate enhancements to the EUMETSAT Space and Ground segments to extend their use for long-term climate monitoring. The Office also participated in a study for the CEC of the potential for enhancing the use of EUMETSAT data for climate monitoring. A Space Task Group has been set up to develop the initial version of the Global Climate Observing System (GCOS) Space Plan. The Met. Office is playing a leading role in drafting the initial plan for consideration by the GCOS Joint Scientific and Technical Committee and the Committee for Earth Observation Satellites (CEOS).

Studies of future instruments

A contract study on optical and sampling design aspects of Meteosat Second Generation (MSG) was completed for EUMETSAT. Two studies on cloud-sensitive space-borne radar techniques were completed, one contributing to a UK Feasibility Study led by the Rutherford Appleton Laboratory, the other to a Matra-Marconi contract study for ESA. Suitable radars offer the potential for estimating mesoscale winds in cloud, with representativity errors (for numerical models) lower than radiosonde observations, and some potential for observing three-dimensional cloud distribution.

An interim study was completed that indicated that low-cost surface-based radars could be developed to observe ocean-surface winds over wide areas.

Aircraft measurements and theoretical studies

(see also pages 35–42)

The Microwave Airborne Radiometer and Scanning System (MARSS) on the C-130 aircraft has made measurements of the radiative properties of cirrus cloud and precipitation at frequencies of 89 and 157 GHz. The former were made during the EUropean Cloud Radiation EXperiment (EUCREX) over Scotland and the latter were made in the vicinity of the Chilbolton Radar to facilitate comparisons. The analysis of these data will help to interpret the data from AMSU-B. A scheme for retrieving cloud liquid water path has been developed and validated against measurements of maritime stratocumulus. A new lower-frequency microwave radiometer is nearly ready to be installed on the C-130.

The Airborne Research Interferometer Evaluation System (ARIES) is being developed to support studies of the new generation of infrared temperature/humidity sounders with high spectral resolution. The interferometer will be mounted in a pod on the wing of the C-130 to view both up and down. This should allow measurements, at high spectral resolution, of the radiative balance throughout the troposphere; they will be used to validate the models and retrieval algorithms and demonstrate the improved vertical resolution obtained in the soundings.

Computing and Telecommunications

Information systems

Rapid transmission and processing of information are essential to the business of weather forecasting. Timeliness is of the essence when dealing with products as perishable as weather forecasts for a day or two ahead. Observational data and forecast products are stored safely against future needs for research and services to customers. The amount of information to be handled continues to grow, as more observational data become available from sources such as satellites, and improved weather forecasting techniques lead to greater volumes of more detailed products. Improvements in technology help to contain costs while meeting the challenges set by the more demanding customers.

Fig. 3. A view of the new IT Operations Centre.

Operational changes

During the last year, the operations sections of Central Computing and Telecommunication have been brought together in the new Information Technology (IT) Operations Centre. This move became possible because of the convergence of both the technologies used in the two areas, and working practices. The benefits will be better effectiveness (i.e. better customer service) and improved efficiency (i.e. fewer staff needed because of economies of scale).

By 1992 the main message switch at Bracknell was approaching the limit of its capacity and enhancement was essential. It was upgraded early in the current year. Phase IV was the somewhat obscure name of the previous message switch. The system's name is now TROPICS — Transmission and Reception of Observational and Product Information by Computer-based Switching. This new name is the result of a competition.

Large-scale scientific computing

Numerical Weather Prediction (NWP) and the Climate Prediction Programme (CPP) are major users of large-scale scientific computing. Two separate Cray Y-MP8/864 computers were used during most of 1993, one for the CPP, funded by the Department of the Environment, and the second for NWP and meteorological research. The CPP called for a fourfold increase in computing resources in 1994. NWP needed a more modest increase, about 50%, to maximise the benefits of the Unified Model. Cray Research delivered a Y-MP C90/16256 system, which can meet both requirements, in March 1994. The use of a single system to meet the requirements of both the CPP and NWP has led to significant savings on both capital and running costs.

Looking to the future, the Office has been considering how to make effective use of machines of novel architecture (e.g. massively parallel processors (MPP), sometimes now called scalable parallel computers). The incentives for this work are that conventional systems may not be able to deliver the computing resource required and that MPPs hold out the promise of better performance/cost ratios. The Office has let contracts to Edinburgh and Manchester Universities to assist in making the Unified Model portable and parallel. The Office is also participating in an ESPRIT project aimed at proving the use of MPPs in a production environment.

Weather Information Network

The Weather Information Network (WIN) will give full support, through an integrated digital network, for the collection of observations, transfer of data between Met. Offices, and telecommunication to customers. WIN has been some years in gestation but formal procurement began in December 1993. The intention is to share telecommunication networks with other users in MOD and it seems likely that WIN will be based on the Defence Packet Switched Network. WIN and Outstation Display Systems (ODS) are two components of a broader strategy, the Weather Information System. Deployment of ODS is now complete, apart from some upgrades to the earliest systems. However, the existing telecommunication links prevent ODS from achieving its full potential, a problem that WIN will resolve. Pending the completion of WIN, a limited number of faster links (64 kilobits per second) have been set up to connect selected Weather Centres to Bracknell.

Local networks

The computing infrastructure of the Met. Office is gradually shifting from total dependence on a mainframe computer to an architecture based on a cost-effective distribution of computing resources. During the last two years there has been a large-scale introduction of networks of workstations into the Office, and a trend to install local area networks of personal computers, rather than isolated ones. The impact of these developments is that the networks are becoming the fundamental infrastructure of the Office's IT. Projects are in hand to sustain and manage the flows of data needed for weather forecasting, research and management.

The Hadley Centre for Climate Prediction and Research and the Forecasting Research Division are now benefiting from the much better facilities for visualisation that are available from workstations. Under the HORACE project, which is not moving forward as quickly as planned, workstations are being deployed in the Central Forecasting Office and at the Principal Forecasting Office at the HQ RAF Strike Command. The latter system is now running, and in the first phase replaces some obsolete equipment used for plotting charts.

Resilience

As the Office relies more heavily on automated systems, reliability and resilience become correspondingly more important. Reserve systems or contingency plans cover most of the critical single-points-of-failure in the central infrastructure. However, a very clear single-point-of-failure was identified where the key message switching systems and telecommunication links are concentrated in the main building at Bracknell. British Telecom used to reroute lines in an emergency, but this option is no longer possible with digital connections. A triangle of packet switches, linked by megastream bearers, which interconnect the Met. Office's College at Shinfield Park with Bracknell and HQ RAF Strike Command, has resolved the problem. There is now a very high degree of resilience for critical telecommunications, both internationally and nationally, and enhanced ability to bypass failures in the outfield.

Weather Centres

The installation of a variety of IT systems at Weather Centres, each most appropriate to customers' demands, has caused fragmentation. Outstation Production Unified System (OPUS) is a project to link these systems with a local area network to improve responsiveness to customers. More detail is given in the Commercial Services section. During the year, the first phase of OPUS was installed at two Weather Centres. Later phases will integrate Outstation Display Systems (ODS) into OPUS, and WIN, when complete, will serve OPUS.

Administrative systems

The Finance and Accounting Management Information System (FAMIS) has settled into routine use during the year. The Finance and Contract Management Sub-system, which had to be developed in-house following the failure of an external contractor, came into service later in the year. It is, however, taking time to ensure that all the data are consistent. Further IT support, provided early in the year, was the commissioning of a system to assist personnel management and modelling activities.

A project has started to ensure that electronic mail can be routed to all users in the Met. Office, regardless of the PC, terminal or workstation on which they are working.

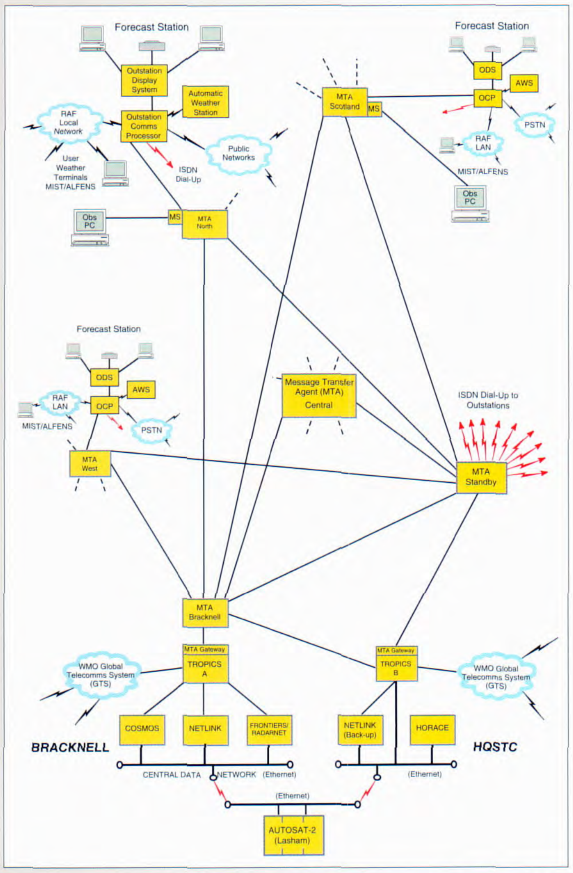


Fig. 4. A schematic of some of the components of the WIN.

The role of Central Forecasting Division

Central Forecasting Division has responsibilities in the following areas:

☐ providing forecasting guidance to commercial and civil aviation outstations;

☐ providing forecasts to airlines as one of two World Area Forecast Centres appointed by ICAO;

☐ operating the Severe Weather Warning Service;

☐ providing guidance to national and local authorities in the event of a nuclear or chemical emergency;

☐ maintaining and developing the operational suite of computer programs that run, and provide output from, the numerical weather prediction (NWP) models.

In addition to the above primary responsibilities, the division also performs several support duties with the object of improving the service to customers.

Developments in the NWP system

The NWP system comprises three versions of the Unified Model: (i) the Global Model, which has 19 levels in the vertical and a horizontal resolution of around 100 km; (ii) the Limited Area Model, which has 19 levels in the vertical, a horizontal resolution of around 50 km and covers an area from North America in the west to Russia in the east; (iii) the Mesoscale Model, which has 30 levels in the vertical, a horizontal resolution of around 17 km and covers the UK. Another mesoscale model centred on the Persian Gulf also runs every day to provide forecasts to Defence Services. This originally used a completely different formulation from the UK Mesoscale Model, but was changed in March 1994 to be another version of the Unified Model. A further mesoscale version of the Unified Model was implemented in August 1993 for Defence Services and covers an area around Italy and former Yugoslavia.

The main changes made to the system during the year 1993/94 were as follows:

April: A parametrization of convective downdraught, and a scheme for non-local mixing in the boundary layer were implemented in the Limited Area Model, resulting in improved prediction of showers.

August: Assimilation of sea-surface wind data from the scatterometer on board ERS-1 into the Global Model was introduced. These data are especially useful in the data-sparse areas of the Southern Hemisphere.

September: Assimilation of high-volume automatic aircraft data began. These data are particularly numerous over North America and Australia. Amendments were made to the physical parametrization schemes in the Mesoscale Model, improving the prediction of precipitation.

October: An extra level, at about 10 m above the ground, was added to the Mesoscale Model; this should lead to improved forecasts of fog and low cloud.

November: The data assimilation system was altered so that as the synoptic situation changed, so did the errors assumed for the background fields of upper-air temperature and wind.

December: Minor changes were made to the physical parametrization schemes in the Limited Area and Mesoscale Models. The net effect on the meteorological performance of the models was small.

January: Changes were made to the physical parametrization schemes in the Global Model, particularly the introduction of convective downdraughts and non-local mixing in the boundary layer. The changes made in December and

January were designed to ensure that the same version of the physics is used in all versions of the Unified Model.

Developments in the Central Forecasting Office

The Unified Model has now been the operational model since mid-1991. This model output forms the essential numerical guidance for the forecasters in the Central Forecasting Office (CFO). The output provided by the numerical model has to be interpreted by the CFO forecasters taking into account analysis defects due to lack of data and misleading data, but also taking account of the characteristics of the model behaviour. It is only in the use of the model by the forecasters on a day-by-day basis that these characteristics become apparent. It is important that they are documented on a regular basis otherwise there is no solid evidence other than a forecaster's feeling that the model behaves differently in different situations. Accordingly a Model Characteristics Working Group was established in the CFO. This Group has recently produced a set of notes for forecasters highlighting such characteristics of specific interest to those working with the model output at the outstations. In particular, evolution and precipitation forecasts from the model are dealt with in some depth while aspects of temperature and humidity forecasts are also mentioned.

An assessment of the Limited Area Model output is based on the guidance provided by the model on the pressure pattern and precipitation. The figures for 1993 indicated that the 24-hour forecasts of pressure pattern assessed as 'well predicted' or having only small errors remained at the high level of 95% with only 5% having errors which were classed as 'serious'. The assessment of precipitation indicated that the percentage of 24-hour forecasts providing good or helpful advice was 81 per cent for 1993, a little higher than the figure for 1992.

An assessment of the usefulness of the mesoscale output is also assessed by the forecasters. This was started towards the end of 1993 and compares the output of the mesoscale Unified Model with that of the Limited Area. The results are encouraging; they indicate that in 24% of the model runs looked at, the mesoscale forecasts of precipitation added value to those from the Limited Area Model for the area of the British Isles.

Other developments in the Central Forecasting Office include the use of the ensemble forecasts received three times a week from the European Centre for Medium-range Weather Forecasts. The use of these products is described on page 15, but they are suggesting new techniques to the forecasters who are involved in providing guidance for several days ahead. It has also been possible to look at the use of positive vorticity advection (PVA) as a diagnostic tool for the forecaster on an operational basis (see page 17). Another contribution highlights aspects of PVA that help forecasters on the bench appreciate the implications of the model output.

Verification results

The numerical model is verified by a number of different objective comparisons of the prediction with the actual event. Statistics of the differences are computed over a period of time — for example a calendar month. A worded forecast is verified by placing each of the weather elements that it contains into an appropriate classification scheme: the forecast class is then compared with the one that actually occurred. Results are accumulated over a suitable period and presented as contingency tables or as standard scores based on these tables. Many of the Office's verification schemes have been in operation for several years. Studying the changes in the results, daily, monthly or annually, is an effective method for assessing the performance of the forecasts.

All numerical forecasts benefited from changes made to the model in March 1993. This is well illustrated by the root-mean-square (r.m.s.) vector wind error in the Northern Hemisphere of the Global Model (Fig. 5). This parameter combines both the speed and directional errors of the model winds. In October

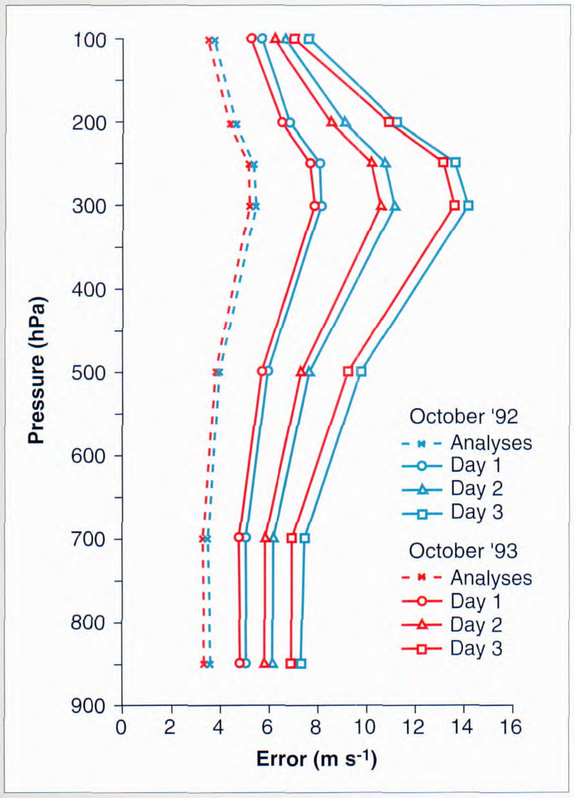


Fig. 5. Vertical profile of r.m.s. vector wind errors ($m\ s^{-1}$) over the northern hemisphere (30–90° N) of the global model, in analyses and forecasts for days 1, 2 and 3: blue=October 1992; red=October 1993.

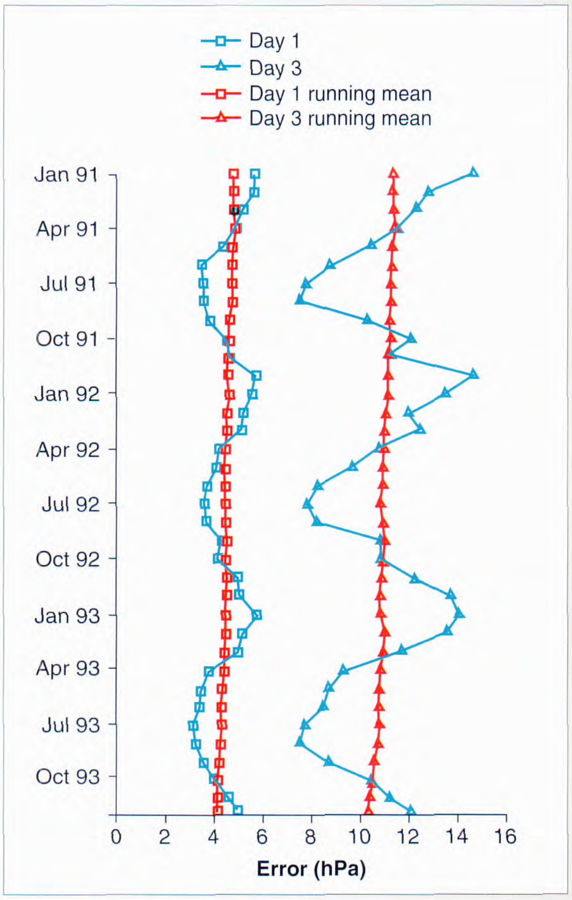


Fig. 6. Monthly time-series of r.m.s. errors of pressure at mean sea-level over north-west Europe, the North Atlantic and parts of North America from 1991 to 1993. Blue lines are the results for forecasts at days 1 and 3. Red lines are the 12-month running means for the same days.

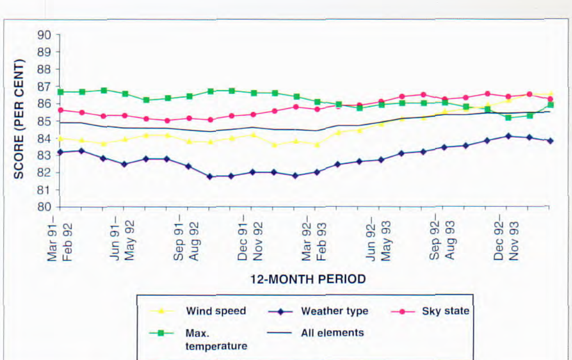


Fig. 7. Results from the verification of BBC Radio 4 forecasts, shown as 12-month running means. Red lines are the scores for individual elements of the forecast, as shown in the key: the black line is the overall score.

1993 the error was smaller than that found in October 1992 on all levels in the vertical and at all forecast times. The improvement is particularly marked in the vicinity of the tropopause — about 250 hPa — where jet aircraft cruise.

The improvement was sustained through the rest of 1993, as shown by the r.m.s. errors of the model's forecast of pressure at mean sea-level over a standard area covering north-west Europe, the North Atlantic and parts of North America. Time-series of the monthly mean results since the start of 1991 exhibit an annual cycle (Fig. 6). However, the running mean over 12 months confirms that the trend is downwards. Taken over the whole of 1993, the 3-day forecasts of pressure were of the same standard as the 2-day forecasts in 1982.

The improved performance was also reflected in the verification of forecasts on BBC Radio 4. This scheme depends on the subjective allocation of a score to four different weather elements — temperature, state of the sky, wind and weather in each forecast. Although some of these elements can be expressed in objective, quantitative terms, they all require a forecaster's assessment of the available observations from the whole of the area concerned. Results are expressed as the percentage of the maximum score obtainable. During 1993 the overall mean rose steadily to reach 85.5% by the end of the year (Fig. 7).

International action on environmental emergencies

(see also page 42)

Significant progress has been made during the year towards achieving coordinated international action by the meteorological community, and others, in response to environmental emergencies such as the accidental release of radionuclides. The 1986 Chernobyl accident demonstrated the need to predict the movement and deposition of such pollution.

The Meteorological Office has a relatively well developed capability to predict the movement of such pollution, using in combination its operational numerical weather prediction models and a 3-dimensional, multi-level Lagrangian model to simulate dispersion and deposition of the pollution.

WMO, in consultation with the International Atomic Energy Agency (IAEA), are seeking to coordinate the capabilities of selected National Meteorological Services (NMSs) to provide the best possible guidance to appropriate authorities worldwide.

Four NMSs have to date been designated as Regional Specialized Meteorological Centres (RSMC) with special responsibility for the provision of services in the event of environmental emergencies. In WMO Region I (North America) the centres are the Canadian Meteorological Centre, Montreal, and the National Oceanic and Atmospheric Administration, Maryland, USA. In WMO Region VI (Europe) the centres are the Meteorological Office, and Météo-France, Toulouse. It is expected that more centres will be designated for the other WMO Regions in the future.

These four centres have specific responsibilities to fulfil. These are to provide services to requesting authorities of countries within their Region; to liaise with WMO and IAEA in the event of an emergency event; to provide backup to the other RSMC within their Region if necessary (e.g. if the emergency incapacitates the other RSMC); to disseminate predictions to NMSs within their Region; and, through liaison with the other RSMCs, to provide an informed commentary to recipients on the differences found between the predictions of the different RSMCs.

During the year the RSMCs have standardized their practices to help meet these responsibilities. Precise information is usually lacking on the duration, concentration, and vertical distribution of the released pollution when an emergency is first notified, so default profiles have been established for use by all four centres. There is a need for consistency among the four RSMCs on the method of presentation of the products; map scales, projections, contour intervals, units, etc. have therefore been agreed. These actions have helped greatly to facilitate the real-time exchange of information and views between the RSMCs.

There is still considerable international action required to render the system adequately operational. In particular there is a need to agree the best practical means of disseminating the information from the RSMCs to the recipients; this issue is currently being addressed.

Workstation and plotter developments

Work continues on the HORACE (HQSTC OASYS Replacement and CFO Enhancement) project which will provide computer systems to supersede those currently used at the two Principal Forecast Offices in the UK (at CFO in Bracknell and HQSTC at High Wycombe). All the equipment has been accepted for both sites. The initial software release was implemented at HQSTC in early 1994 allowing the retirement of the OASYS (Outstation Automation SYStem) at High Wycombe.

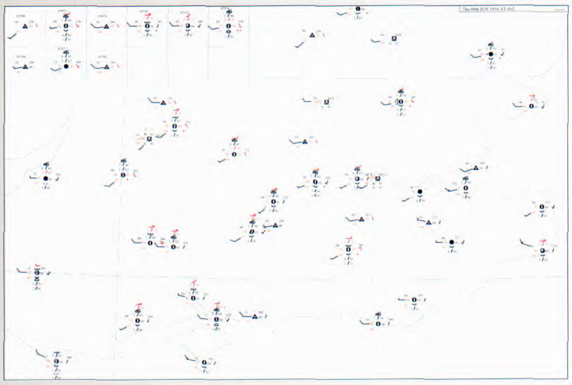


Fig. 8. A part of a typical surface plot for the UK produced on HORACE.

A major part of this initial release covered the display of observational data in graphical form as hard or soft copy. The core modules for plotting data were provided by Met. CC. Following extensive tests and liaison (with both the users and Met. CC) the operational software is versatile and produces high-quality products, as illustrated in Fig. 8, which shows part of a typical surface plot for the United Kingdom. The initial release of HORACE in CFO will extend the observational plotting facilities, allowing for more data types and for overlaying of NWP background fields. When this release becomes operational, CFO will take over the production of hard-copy plotted charts from Met. CC.

The Graphical User Interface (GUI) for HORACE has been the subject of a large amount of effort and dialogue with the users. The aim is to produce an interface that is self explanatory in its use (so that the complete novice can use it with the minimum of training) but which retains the ability to 'short-cut'. In order to minimise the 'work' to be done by the forecaster, defaults are used where appropriate, and extensive software checks are performed to ensure that the user is only offered valid choices (Fig. 9).

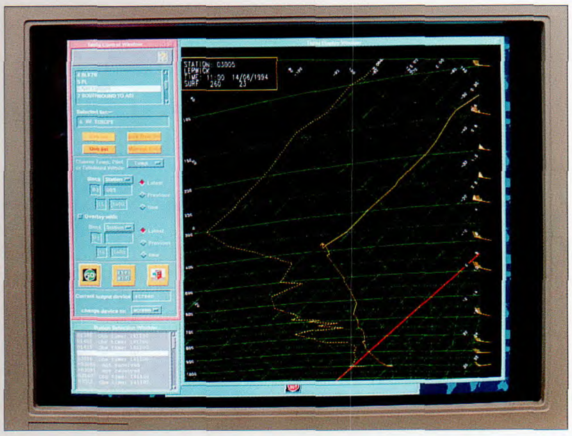


Fig. 9. An example of a Tϕ drawn by the GUI and showing the control window.

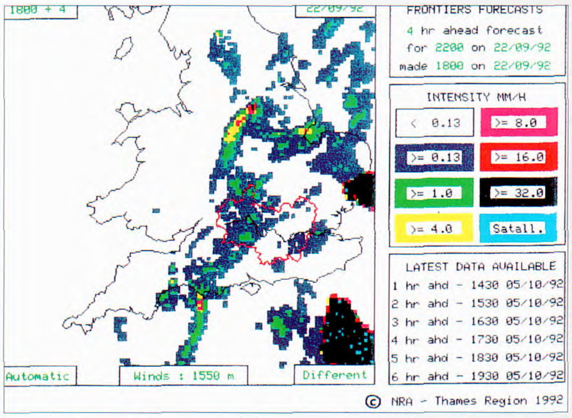
One aim of the HORACE project is to exploit the processing power available on a workstation, by providing facilities to help forecasters in their day-to-day work. An obvious candidate is the plotting of charts: can tools be provided to enable the forecaster to perform the observational analysis on the screen, obviating the need for the generation of hard-copy plotted charts? We have started to investigate whether a useful first-guess analysis can be provided automatically from a field of irregularly spaced observations, but this work is still at a very early stage.

FRONTIERS operational assessment

FRONTIERS is a system within CFO which is used to quality control radar rainfall data and produce forecasts of the position and intensity of precipitation over the UK up to 6 hours ahead. It can operate automatically or under the control of a forecaster.

FRONTIERS forecast data is currently supplied to six of the eight National Rivers Authority (NRA) regions. Over the last two years the Met. Office and the NRA have conducted a careful assessment of the performance of FRONTIERS during flood events and thunderstorms. The NRA are particularly interested in the system's performance as an input to flood forecasting and river management systems.

The study showed that on average flood forecasting models performed better using FRONTIERS forecast data than when using observed rainfall data; this was true for all forecast times up to the maximum of 6 hours. The study concluded that FRONTIERS provides useful information which, in conjunction



(Thames Region NRA)

Fig. 10. A rainfall forecast for 2200 UTC on 22 September 1992 made at 1800. The figure shows the forecast as displayed at the offices of the Thames Region of the NRA.

Fig. 11. The Intervention Forecaster overlaying a Meteosat IR image with the 300 hPa field from the Local Area Model.

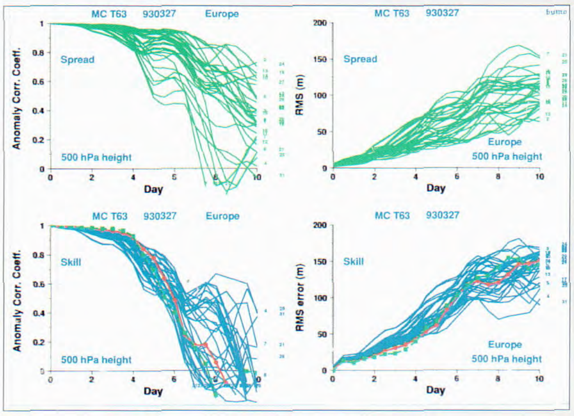


Fig. 12. Anomaly correlations for forecasts from 27 March 1993. Individual ensemble forecasts are indicated by blue lines, the control integration of the ensemble forecast with a red line and the ECMWF operational T213 model with a green line.

with other available tools, is helping to increase the timeliness and accuracy of flood forecasts. The performance of FRONTIERS is however quite variable between events, in particular FRONTIERS is relatively poor at forecasting rainfall in convective situations.

The FRONTIERS system will be replaced next year by a fully automatic system called NIMROD. This system will build on the experience of FRONTIERS and will integrate the rainfall forecasts more closely with numerical model predictions. Figure 10 shows an example forecast.

Image Display System (IDS)

The Image Display System (IDS) is a system which delivers a basic set of image products primarily to the CFO. The system also supports a number of other displays such as those in the Office's front entrance.

Each user position has a standard PC display and a small keypad which are connected to the central IDS system. The keypad allows users to switch instantly between any of up to 32 products. Currently users can choose between satellite images, radar rainfall maps, lightning locations, wind fields, temperature maps, RAF colour state maps and a tabulation of weather conditions at airfields. The system allows stationary and moving images to be displayed. The later are used for animations of the last few hours of satellite images.

Ensemble forecasting for the medium range

Small changes in initial conditions can lead to large changes in the model's predicted evolution of synoptic-scale features during the medium range. Since it is impossible to define the state of the atmosphere perfectly for any given time, it follows that it may be impossible, in the medium range, to correctly forecast a future atmospheric state by means of a single deterministic model prediction.

Over the years we have sought to improve model forecasts by better initialization and increasing the skill of the evolution. More recently a different approach has been adopted, where instead of forcing the atmosphere into a deterministic strait-jacket, the chaotic nature of the atmosphere is accepted and used. In this approach an ensemble of forecasts is run using the same predictive model but with slightly varying initial conditions. If a good sample of possible initial states is chosen and the forecast model correctly predicts the evolution of these states, then the model solutions should give a good sample of the possible solutions.

This type of forecast has several possible uses. For example to estimate atmospheric predictability, to modify a forecast based on a single higher-resolution model, or as a stand-alone forecasting tool. In this last case considerable changes to the forecasting culture would be necessary, since ensemble forecasts, offering a range of solutions, lend themselves to probabilistic rather than deterministic forecasts.

A team of experienced medium-range forecasters is exploring how ensemble forecasts may be used operationally. This includes an exercise in predicting the probability of specific weather events occurring at specific locations during day 7 of the forecast period. The basis for this work is an ensemble of 33 forecasts produced daily by the European Centre for Medium-range Weather Forecasts (ECMWF).

Fig. 12 shows an example where the skill of the ECMWF operational model (in terms of anomaly correlation) falls quickly during day 6 of the forecast but where a substantial number of ensemble members retain additional skill for about an extra 2 days.

Fig. 13 shows the day 8 forecasts and verifying analysis for the same case. The operational forecast (Fig. 13b) and some ensemble members (Fig. 13c) gave similar poor solutions near the UK. However, a separate cluster of ensemble members (Fig. 13d) have a quite different and much better solution. In this example the ensemble forecast clearly added to the information available by indicating an alternative solution which was better than the operational forecast.

Civil aviation services

As a World Area Forecast Centre (WAFC), a Regional Area Forecast Centre (RAFC) and provider of meteorological information for national services, the Met. Office has done much to improve the accuracy of data and the improvement of services and products. However, another important aspect of services is the rapid and efficient dissemination of data to aircrew to ensure that they receive up-to-date information for the flight. Working with the International Civil Aviation Organization (ICAO) and the Civil Aviation Authority (CAA) a satellite-based dissemination system (SADIS) will be implemented by the end of 1994 for the dissemination of aeronautical data on a global beam of an INTELSAT satellite. For national services, especially to offshore helicopter operations, dissemination of meteorological information is being improved by the development of PC systems (MIST) enabling up-to-the-minute reports to be accessed on a PC screen and copied as necessary.

SADIS

Competitive bids for the SADIS service contract were received in Bracknell during February 1994 and are being evaluated. Working with the CAA and the Regional Office of ICAO in Paris, a contract will be placed for the satellite communications service. The INTELSAT satellite will be used to pass WAFC Bracknell and the RAFC's products to users throughout Europe, Africa, the Middle East and parts of Asia. In addition, the system will enable two-way links with selected locations so that vital aerodrome weather reports (METARs) and forecasts (TAFs) can be received in Bracknell and quickly distributed to all users. It is hoped that the service will begin by the end of 1994 if the institutional matters under ICAO are agreed. When it becomes operational the system will mark a significant step in international aeronautical services, and will become a vital part of the Aeronautical Fixed Service (AFS) for meteorological communications serving aviation. The data to be distributed via SADIS will include global upper wind and temperature data on a high-resolution grid (1.25° × 1.25° lat/long) generated by WAFC Bracknell, upper wind and significant weather charts generated by the RAFCs, and METAR and TAF reports from the whole area served. The Met. Office will continue to work efficiently and meet the customers requirements, delivering essential data in a timely fashion. The users will make their own choice of workstation to be linked to the satellite receiving equipment, but in some cases it is expected that software to assist with the handling and interpretation of the data could be made available from Bracknell.

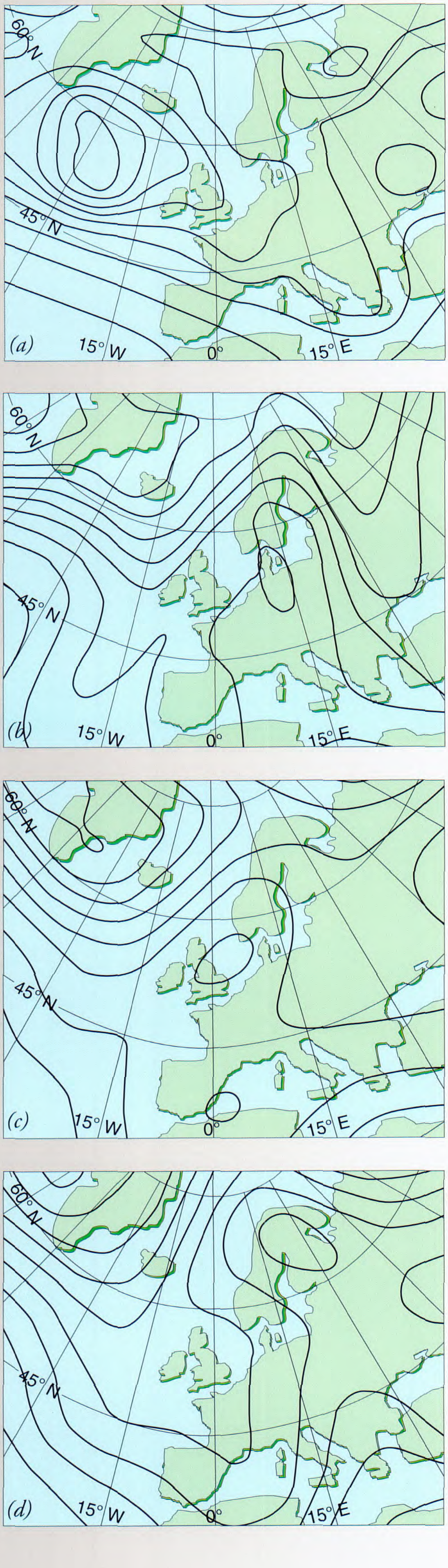


Fig. 13. 500 hPa height for day 8 forecasts from 27 March 1993:
(a) Verifying analysis for day 8.
(b) Operational T213 forecast for day 8.
(c) A mean of 16 similar (in terms of 500 hPa height r.m.s. differences) ensemble member forecasts for day 8.
(d) A mean of 10 similar (in terms of 500 hPa height r.m.s. differences) ensemble member forecasts for day 8.

MIST

The Meteorological Information Self-briefing Terminal (MIST) system developed in the Met. Office enables up-to-the-minute reports and forecasts to be accessed on a PC screen. The system provides full colour text and graphical displays of data which can be printed out. During the past two years, under an agreement with British Aerospace (BAe), the software of the original design has been considerably refined to improve the range of products and the efficiency of the system.

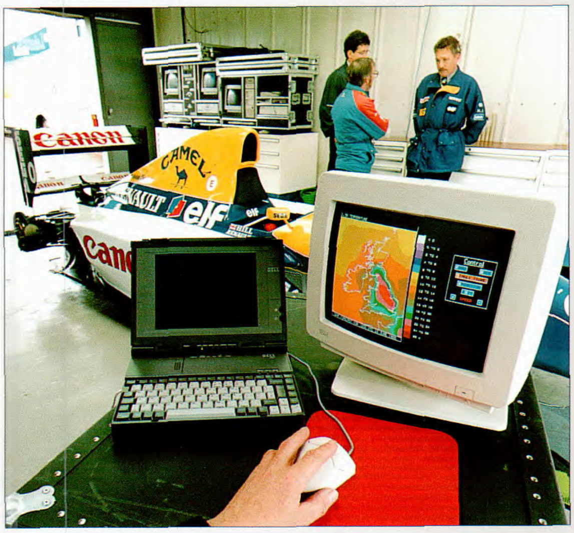


Fig. 14. MIST – photograph of PC system with screen display.

The value of the system has been proven since it was adopted in support of offshore helicopter operations over the northern part of the North Sea. It is expected that during 1994 the Met. Office/BAe system will be launched to improve and extend the MIST support to offshore helicopter services over areas around the UK. It is also expected that MIST will be adopted for other aviation users within the UK to add to the range of services currently provided by the Met. Office using digital facsimile systems. Both the facsimile and MIST services have dramatically improved the delivery of data to pilots, and have the added convenience that the information can now be acquired wherever and whenever the pilot wishes. The extra benefit of the MIST system is that data can be viewed in full colour to help the pilot to assimilate vital information quickly.

Potential Vorticity as a diagnostic tool

A pilot project is being carried out in CFO to investigate ways in which potential vorticity may be used to help operational forecasters. Areas of anomalously high potential vorticity (relative to their surroundings) are associated with forcing of cyclonic motion. It has been shown that potential vorticity anomalies can be tracked in series of analyses and in model forecasts for periods of up to two days. Tracking of such features can give additional help in understanding the processes taking place in the model and so put the forecaster in a better position to adjust the model output if an error is perceived. Probably the most useful feature at this stage is the potential for early detection of model errors through the strong relationship between potential vorticity maps and water vapour channel satellite imagery. A value of potential vorticity of 2 pv units (10^{-6} mks units) lies close to the tropopause and the height of the pv=2 surface correlates well with the water vapour channel radiance in dynamically active areas. Fig. 15 shows several features typical of this relationship. In the base of upper troughs such as at 40° N, 30° W the gradient of pv=2 height is concentrated just to the warm side of the 'dry' area (pink colours), and extends along the cloud edge on the forward

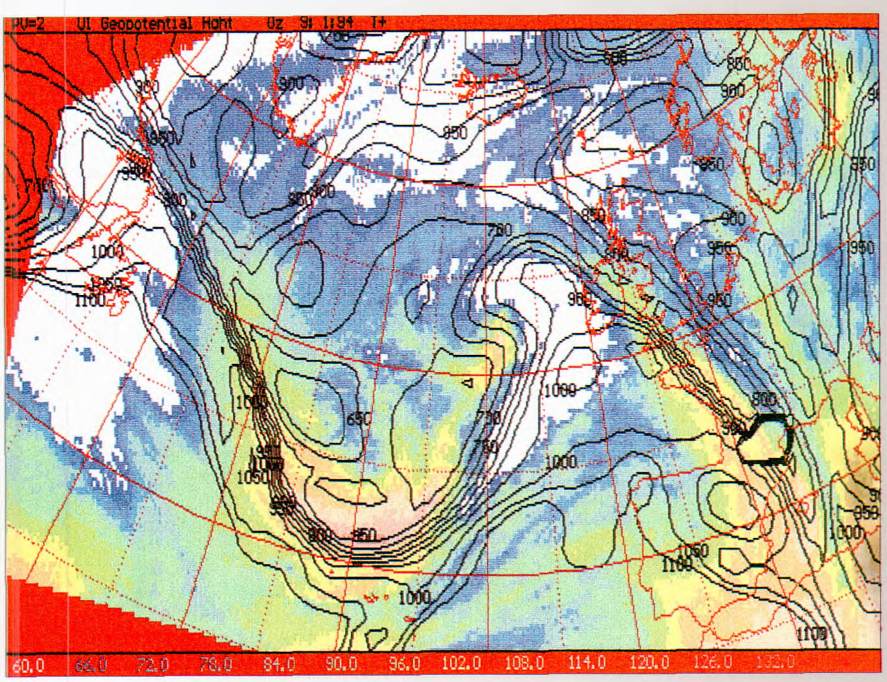


Fig. 15. False colour Meteosat water vapour image overlain with contours of the height of the pv=2 surface (dm), 0900 UTC on 9 January 1994. Dry areas or areas of high radiance are shown yellow or pink, high (cold) cloud is shown white.

side of the trough. To the rear of upper troughs such as over south-west England and near 40° W, the contours coincide with the driest air. Also typical is the signature associated with a deepening wave depression near 52° N, 20° W. The lowest values of pv=2 height tuck in just to the rear of the dry slot, with the contours curving anticyclonically over the developing cloud (white) on the forward side of the wave. The mismatch of any of these features can indicate a model error as illustrated in Fig. 16a, which shows a small but important model error in the 12-hour forecast in the vicinity of the dry area near 52° N, 22° W where the pv=2 height contours were perceived not to have enough cyclonic curvature. The error was already apparent 6 hours earlier but the 12-hour forecast is illustrated for comparison with the analysed pv=2 height (Fig. 16b). The error suggested that the depression, forecast to be over western Ireland 24 hours later (Fig. 16c), would be deeper resulting in its fronts and milder air swinging more quickly east and north across the southern UK — as turned out to be the case (Fig. 16d). The particular value of this comparison is that it can detect errors in cloud-free areas before any development takes place, and the nature of the error can be assessed by gauging the change in forcing if the pv were changed to fit the imagery. Thus the forecaster can be given help in correcting the numerical guidance when an error is detected and given added confidence when no mismatch occurs.

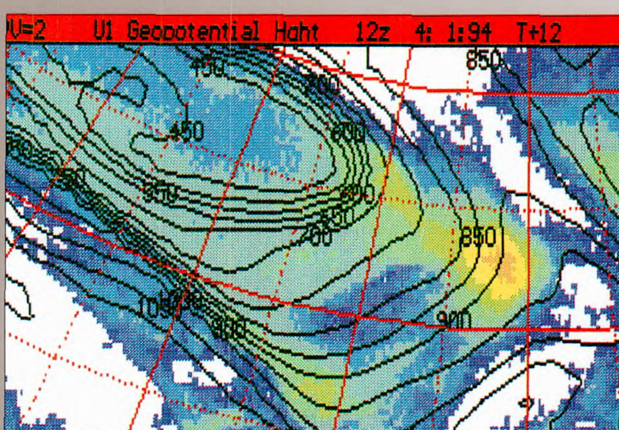
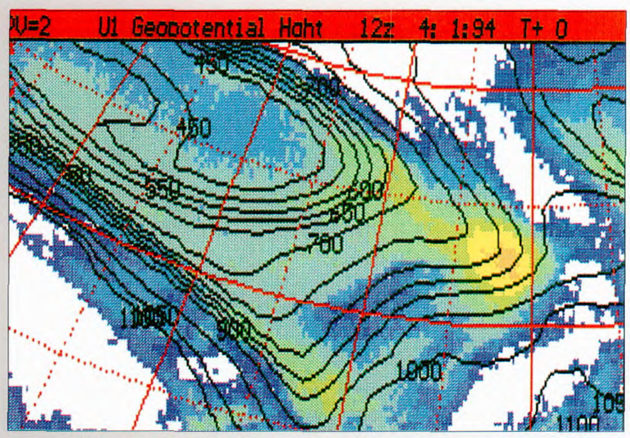
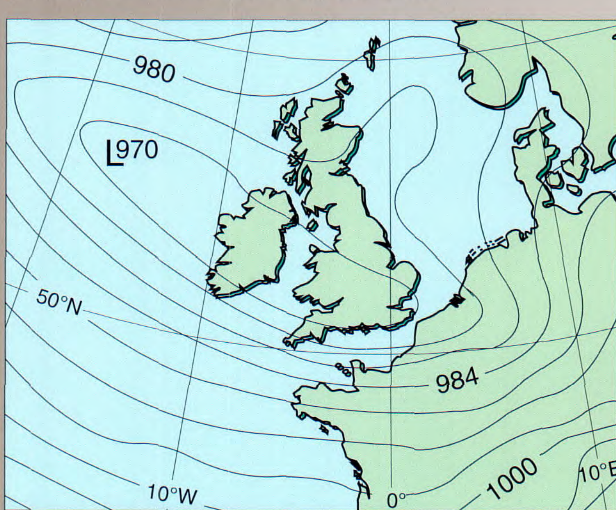


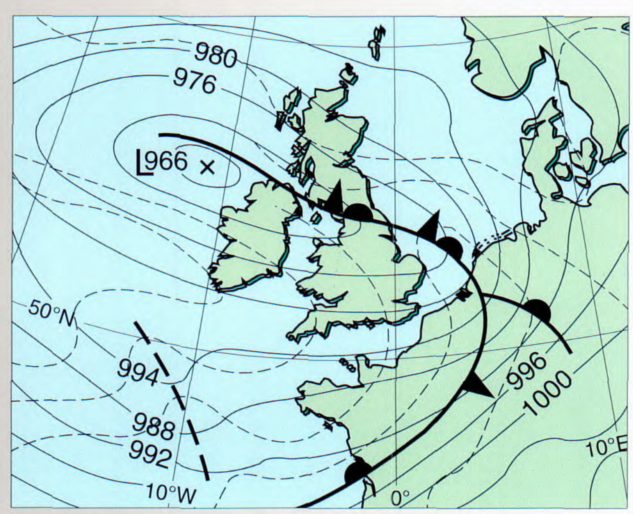
Fig. 16. (a) Meteosat water vapour image for 1200 UTC on 4 January 1994, colours as in Fig. 15, overlain with 12-hour forecast pv=2 contours valid at the same time.



(b) as (a) but contours of analysed pv=2 height.



(c) 36-hour forecast sea-level pressure valid at 1200 UTC on 5 January 1994, for forecast illustrated in (a).



(d) Analysed sea-level pressure for 1200 UTC on 5 January 1994.

Defence Services

Introduction

The Defence Services (DS) Division exists to provide meteorological services to the Army, RAF and MOD(PE) and data to the Royal Navy. The services are provided by staff based on military airfields and ranges in the UK, Germany, Mediterranean and South Atlantic. The Mobile Meteorological Unit (MMU) is established to provide in-theatre meteorological support in crisis situations (e.g. Bosnia), to the ACE (Allied Command Europe) Rapid Reaction Corps and during major exercises. The Division also manages the Office's response to civil and military nuclear and chemical accidents.

Information Technology

Meteorological information is, by its very nature, perishable and reliable communications are necessary to give outstation and deployed meteorologists the information they need to provide an effective service. The exploitation of 'information technology' is vital to ensure that the service provided to the military customer meets their requirements in a timely and cost-effective manner. Increasingly these customers are demanding that meteorological data and forecasts are integrated into their own specialized information systems.

The RAF's Automated Low Flying and Enquiry Notification System (ALFENS) will be installed at all flying stations (including Naval Air stations and Army Air Corps airfields) in the UK. In addition to its primary purpose ALFENS will be used to deliver meteorological data and forecasts to the pilots. Phase I of ALFENS should become operational by mid-1995 and provide basic alphanumeric information generated at Bracknell. Phase II will involve linking local ALFENS networks to the Outstation Communications Processor, thus allowing outstation meteorologists to input customized local products (textual and graphical) into the system. Plans are in hand to enable the outstations to develop such products.

A defence variant of the Met. Office/British Aerospace MIST (Meteorological Information Self-briefing Terminal) has been developed for use by the Army Air Corps in Germany and in a limited fashion, pre-ALFENS, in the UK. From mid-1994 a further system, driven by a host processor linked to COSMOS at Bracknell, will support the Army and RAF in Northern Ireland – where there are no plans to install ALFENS.

A key project is the development of a Mobile Outstation Display System (MODS) for use by the MMU in-theatre or on exercises. A prototype system is currently being put together, using off-the-shelf components in a ruggedized configuration, which will be tested during 1994. MODS will be able to receive data by either land-line or satellite (commercial or military) giving the deployed meteorologist access to most of the functions of the fixed systems installed at all outstations.

All DS stations have now been equipped with 386- or 486-based PCs for administration and forecasting, they are also capable of running sophisticated application models. An increasing portfolio of Operational and Tactical Decision Aids have been made available for use by DS outstation meteorologists, as described below.

Operational Decision Aids

Various Operational Decision Aids (ODAs) have been issued to outstations to assist in the prediction of meteorological parameters. These include ODAs to predict runway icing (using the Runway Surface Temperature ODA, developed from the Met. Office 'OpenRoad' software), low-level wind flow (specifically for the Porton Range), soil moisture deficit/content (to aid trafficability forecasts) and for predicting dew deposition (which can render laser trials hazardous).

Low cloud and fog are amongst the most critical factors in operational flying. The Air Mass Transformation (AMT) model, developed by the Atmospheric Processes Research (APR) division, is being tested at a number of DS stations (details of the model were given on page 49 of last year's Report). Whilst the model gives reliable predictions in some synoptic situations, a number of deficiencies have been identified from the trial, and these are being remedied. Work is progressing on developing a PC-based Airfield Weather Package, and a prototype version is nearly ready. The package allows the meteorologist to rapidly display station climatology, 'colour state' statistics, local weather characteristics and topographical information and should provide a useful guidance tool for outstation meteorologists. It should eventually replace the bulky airfield weather diagram books that cannot be easily updated.

During the year a new Acoustic Prediction Package (APP), developed with the Department of Applied Acoustics, University of Salford, was introduced at the Range stations. The new model has been shown to give more reliable predictions than the semi-empirical Larkhill Mk.II model used previously. The APP allows the forecaster to interact with the meteorological input and uses ray invariant and parametric methods for calculating peak noise levels. The APP gives noise predictions that can be displayed directly on a computer-generated map background, as shown in Fig. 17. Over the coming year it is planned to incorporate the effects of terrain and turbulence into the model.

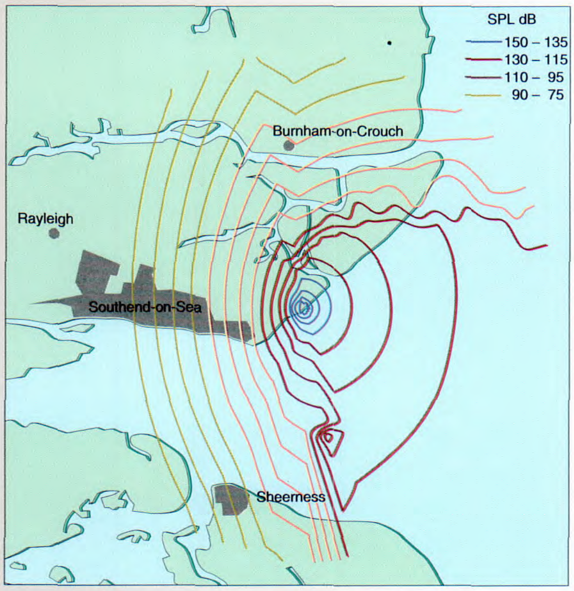


Fig. 17. Example of peak sound level prediction from the new APP (for an 8 kg charge at Shoeburyness at 1230 on 19 November 1992).

Tactical Decision Aids

Tactical Decision Aids (TDAs) are tools that enable the forecaster to predict the impact that meteorology has on military systems and equipment. Meteorological conditions affect the performance of electro-optic systems such as Night Vision Goggles (NVGs) and Forward Looking InfraRed (FLIR). During the year the operational night illumination TDA was significantly improved, by including a more realistic treatment of the effect that cloud has on attenuating the available light, and a more flexible output using graphics. The 'core' calculation module has also been made available for inclusion on the RAF AMPA (Advanced Mission Planning Aid) for the Harrier GR7.

For FLIR, a 'Forecasters' Guide' has been prepared and issued to outstations. Since FLIR systems 'see' the thermal contrast, the temperature contrast of the background is critical to their effectiveness as a navigational aid and for feature identification. A background temperature model has been developed for DS by APR Division. A preliminary comparison of the model against measured data suggests that it is capable of giving more-realistic surface temperature and contrast predictions than the current operational models. Work is progressing to extend the model to include a wider range of background surfaces.

Meteorological conditions affect the propagation of radio waves, and atmospheric refraction can give rise to ducting which can significantly affect radar cover. Sophisticated propagation models exist (e.g. the parabolic equation method) which can reliably predict a radar's cover given the vertical structure of temperature and humidity in the atmosphere. In DS, work has concentrated on assessing the ability of the Mesoscale Unified Model, MUM, and the AMT model to predict these parameters and so diagnose ducting conditions. Fig. 18 gives an example showing actual and predicted profiles. Whilst the MUM tends to smooth out the inversion and hydrolapse at the top of the boundary layer, the AMT formulation gives jumps in temperature and humidity. This work has shown that MUM is considerably better than the old Mesoscale Model at predicting ducting conditions, with a skill of about 28% for a 12-hour forecast. Whilst this is still not as good as a skilled forecaster (around 38%) it is possible that a useful model product could be produced.

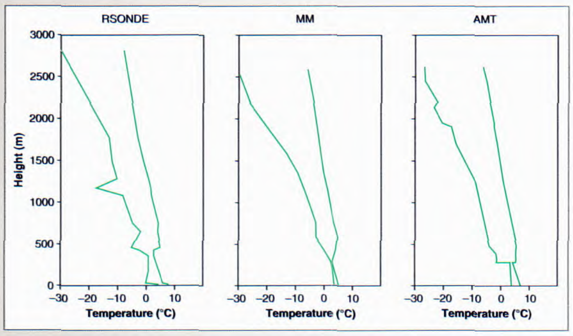


Fig. 18. Profile comparison between the radiosonde, Mesoscale Model and AMT model for Hemsby on 15 April 1993.

The AMT tended to overpredict the likelihood of ducting conditions and achieved a skill level of 22%. However, it is considered that there is scope for improving the reliability of these predictions as the AMT model is further refined.

Under the auspices of NATO AC/225 Independent Special Working Group No. 3, a co-operative programme is progressing to identify a recommended suite of TDAs to support NATO Army activities. DS are contributing to this programme on behalf of the British Army. With the increasing importance of multi-national operations and forces the harmonization and consistency of tactical meteorological advice is essential.

Civil emergency planning

DS manage the Office's response in the event of a nuclear or chemical accident, and has developed the PACRAM (Procedures And Communications in the event of an accidental release of RadioActive Material) and CHEMET (CHEmical METeorology) procedures. The division has also been involved with the DoE RIMNET (Radiation Incident Monitoring NETwork) programme, phase II of which has recently been declared operational. RIMNET and the Met. Office's NAME (Nuclear Accident ModEl, see page 42) are key components of the National Response Plan developed to cope with the occurrence of a nuclear incident. Plans are in hand for the development of an improved short-range hazard prediction model, based on the UK-ADMS (described on page 42), for possible application in the PACRAM and CHEMET procedures.

Commercial Services

Introduction

The principal objective of the Commercial Services Division (CS) is to satisfy the weather-related needs of clients through the provision of services, and thus make increasing contributions to offset the cost of running the Office. CS obviously has to do this cost-effectively in order to compete in the market.

Because of its limited resources and skills, CS often has to collaborate with others to provide these services. This frequently involves third parties who can bring complementary skills to the collaboration. This is a theme that occurs throughout this section.

CS is a geographically scattered organisation. The Bracknell headquarters complex houses the administration and management functions together with some of the production units. However, most of the production units are distributed throughout the country, mainly in the Weather Centres. This is both a strength and a weakness. It is a strength in that the Met. Office does have a local presence and can build up a rapport with the customer; and the forecasters are familiar with the complex nature of the local meteorology. It is a weakness because, to do their job effectively, the forecasters in the local production units need access to the large amounts of data and information that are produced and stored centrally. A second theme of this section seeks to demonstrate how this weakness is being addressed.

Distribution

Introduction

Most of the products and information made available by CS have a limited life and therefore efficient distribution processes are essential. These distribution processes are determined by the customer's requirements and the technologies available.

Distribution methods can be divided into two types. The first concerns the type of delivery system that services a high volume market. In this instance CS usually collaborates with third parties thereby sharing development costs. The second type involves more customer-specific distribution processes which are normally developed in conjunction with the customer, taking specialist advice when necessary.

Telephone and Fax

Dial-up telephone services (Weathercall) are provided through the Met. Office's collaboration with Telephone Information Services (TIS). A new Marinecall service, Marinecall Select, was launched to provide an automated selection of recent weather reports from around the coast, together with area forecasts, selectable using a tone-dialling telephone. As well as providing telephone services, TIS and CS launched a new range of Weathercall Fax products during the year, examples of which are given in Fig. 19.

The MetFAX range of fax products, which are run by CS using equipment provided by Vodata, continues to grow with as many as 6000 calls per day.

The range of products available via fax services was also increased during the year. A satellite picture based on Meteosat imagery was developed and has proved very popular with all users; Fig. Fig. 19b is an example.

Press

CS services to the Press are largely handled through collaboration with Computer Newspaper Services (CNS). CS production units provide CNS with a database of information. CNS then use these data to provide bespoke camera-ready panels to the individual newspapers. During the past year roughly 50% of Met. Office services to the Press have been through CNS.

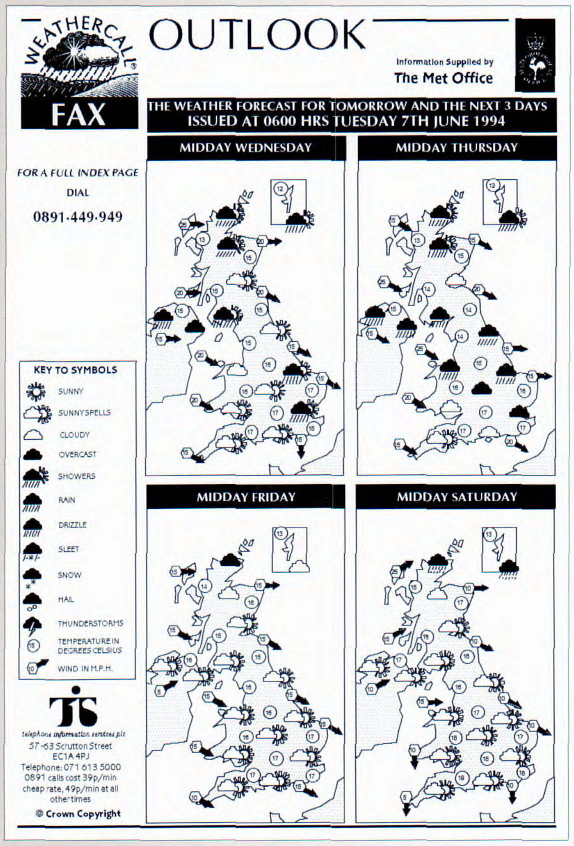


Fig. 19. Examples of Weathercall Fax products, (a) Outlook.

(b) Satellite.

PC–PC

As PCs become more widely used, the requirement for PC-to-PC delivery systems increases. In 1991 the Met. Office collaborated with British Aerospace (BAe) to meet this demand. The idea was to build upon the MIST (Meteorological Information Self-briefing Terminal) system which had been developed internally to meet the needs of both helicopter operators in the North Sea and certain RAF airfields. Commercial MIST is the outcome of this collaboration. It gives registered users, with the appropriate hardware and software, access to a database of products and data. These products and data, which come from a number of sources, are stored on the MIST host system at Bracknell. Registered dial-up users can download the information required, when they want it, provided they have access to the telephone network. Those users who need larger volumes of data routinely can subscribe to a leased line and have their data sent when it becomes available. Where timeliness is not critical, such as display systems in public places, the data can be downloaded automatically under control of the host system via a dial-up line. During the past year the number of customers (varying from public utilities to schools) registering to use this facility has increased to about 35.

As the system develops, it will be possible for weather information to be input directly to a customer's PC network for automatic inclusion into business decision processes ensuring maximum efficiency.

The same system has also been used to provide all the data requirements for the new Forecast Office in Singapore. Approximately 70 charts, along with observational data and ancillary forecast grid-point data, are sent daily to Singapore. Because the data volumes are large, they are sent using ISDN (Integrated Services Digital Network), a digital version of the public switched telephone network.

OPUS — communication

When compared with modern technology, current methods for getting data and information into and out of Weather Centres are a little dated. The Civilian Rented Data Network (CRDN) is overloaded and slow. Surprisingly, in view of its expense, telex still plays a major role in data distribution. Now, as part of the move to the Weather Information Network (WIN), all Weather Centres and Bracknell are starting to be interconnected using a high-speed network supporting the X400 message-handling protocol.

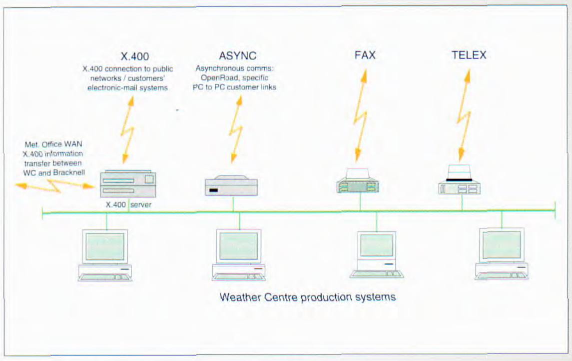


Fig. 20. A simplified view of the communications infrastructure installed at some Weather Centres.

Because of the incremental development process, the Weather Centre production systems are fragmented and unconnected and this makes connection to the X400 wide area network difficult. The Outstations Production Unified System (OPUS) project has been set up to rationalize matters and ease communications amongst Weather Centres, Bracknell and the customer. Fig. 20 gives a simplified view of the communications infrastructure that has been installed at Cardiff and Manchester Weather Centres. The other Weather Centres will follow next year.

The objectives of the enhanced and redesigned communication system are:

☐ more-efficient transfer of information between Weather Centre (WC) and Bracknell;

☐ more-efficient transfer of information between WCs;

☐ to give WCs enhanced facilities for distributing information via fax;

☐ to tidy up all asynchronous (PC–PC) links to customers, and

☐ allow connectivity to customers' networks and electronic mail systems using X400.

GETMET

GETMET is a PC system, developed in-house, designed to interface through dial-up lines to the Met. Office telecommunications computers. The main use of the system has been to make radar, satellite, model forecast output and other data available to the television industry. Application software has been developed to process and customize the data to meet individual requirements. As the data volumes have grown and transmission times increased, the GETMET system has been further developed in the past year to give remote users dial-in access via ISDN. This allows digital transmissions at around 8000 characters per second, significantly in excess of that available via the public network. This has involved collaboration with Software Forge to develop the combination of PC hardware and software needed to communicate with Met. Office computers. It is likely that this technique will be more extensively used in the future to distribute bulk data to customers.

Production

Introduction

The previous section has discussed changes, made in the last year or two, to the distribution processes. This one concentrates on how the products and services are generated before being presented to the distribution systems. The majority of services that CS provide involve a forecaster or enquiry officer interacting with a computer system. Usually this happens in one of the production units. There are a number of these production units; some are in Bracknell, others are in the Weather Centres; some specialize in certain types of activity, others are general purpose.

OPUS — production

The Weather Centres are the main outfield sites for the production and distribution of information. At present, this is accomplished by a network of microcomputers (ICL Quattros) with telex output, supplemented by a miscellany of unconnected special-purpose computer systems and data links. An enhanced system, OPUS, based on a network of PCs and Apple Macs, is planned for installation at all Weather Centres. The aims of OPUS, as a production system, are to:

- integrate the present facilities;
- automate as many of them as possible;
- enable the free interchange of data within the Weather Centre;
- present a standard user interface to the operators, and
- provide a unified method of external data communications.

At the same time, the opportunity will be taken to retire the obsolescent ICL Quattro message-preparation system.

Physically, OPUS consists of an Ethernet local-area network at each site with DEC VAX servers. The workstations comprise a mixture of PC (compatible) and Apple Mac hardware, linked to the server by DEC Pathworks network software. PC workstations on OPUS will offer a Microsoft Windows v3.1 environment running both Windows and non-Windows applications. Software and data will be stored on the server, and be accessible by all workstations. The ODS primary VAX will act as the OPUS server should the latter fail.

After testing and evaluation the applications packages chosen for OPUS PC workstations are:

Word processor:	Microsoft Word for Windows
Spreadsheet:	Microsoft Excel
Graphics:	Lotus Freelance for Windows
Database:	Microsoft Access

The above comprises the basic Weather Centre production platform. The prescribed application packages can be used to generate products and the telecommunications infrastructure described in the previous section can be used to distribute the products to customers. Once the product has been generated the process requires a minimum of intervention. There is significant flexibility in the production process. Because most of the off-the-shelf applications are part of an integrated package, data can be freely exchanged between them. Products generated by other Met. Office systems can also be imported into these applications for further addition or customization.

This flexibility of approach has been demonstrated by the generation of the Aberdeen Production system, an example of a bespoke OPUS application. In this, Excel has been customized by the generation of 'macros'. Time-series of forecast data (basically wind and wave data) are extracted from the forecast model fields at Bracknell and sent to Aberdeen where they are imported into Excel. Excel facilities are then used to present the data as a time-series graph. Forecasters, again using Excel facilities, can manipulate and change the data if thought necessary. The modified data are then resaved in the original format. All products that use these data as source information are then produced and distributed automatically using standard OPUS facilities. Fig. 21 gives an example of output from the Aberdeen Production system which has been sent to the customer via fax.

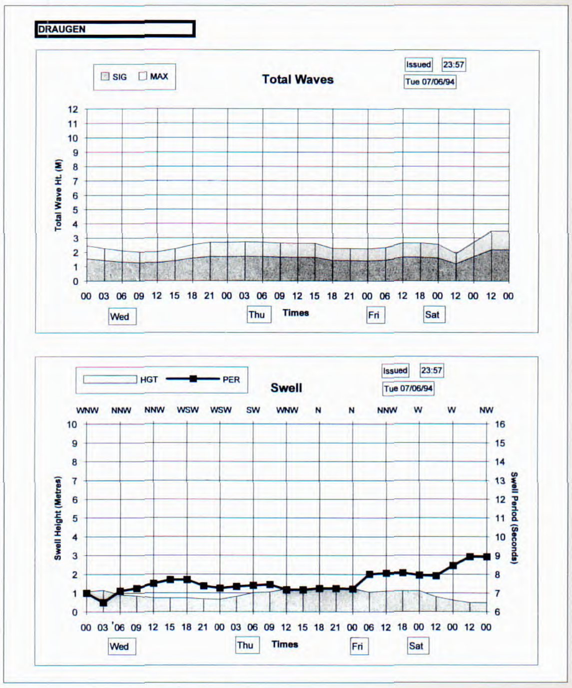


Fig. 21. An example of the Aberdeen Production System output for faxing to a customer.

Another example of an OPUS application is WeatherFAX This is a subscription service whereby information for a number of areas is broadcast by fax to agricultural customers. All the forecast data is held in an Access database. The same database holds details of customers and their requirements in terms of areas and forecast parameters. All the customer specific products are then produced at the touch of a button and distributed via fax. Whilst WeatherFAXwas originally designed for the agricultural sector, it lends itself as a cross-market sector delivery system which is capable of further development. This, like the Aberdeen Production system, is an example of a sophisticated system that has been developed in a short time by customizing standard application software through the use of macros.

OpenRoad

Not all Weather Centre production systems are being incorporated immediately into OPUS. One major omission is OpenRoad; this will not be made OPUS compatible until next year. It is a sophisticated system, used for forecasting road surface temperatures, which has been developed in collaboration with Vaisala TMI. It is a stand-alone PC system that comprises, (a) a one-dimensional heat transfer model of the road and overlying atmosphere, (b) a bespoke but sophisticated user interface, and (c) communications facilities for interrogating and receiving data from roadside monitoring stations and for distributing forecast data via Vaisala TMI Bureau Services to cooperating Local Authorities.

Significant work will be needed from Vaisala TMI to disaggregate these various functions and make the OpenRoad processes OPUS compatible. As part of this upgrading process the production of 'first guess' forecast inputs required by the OpenRoad model will be fully automated. This involves generating the required data on COSMOS (the Met. Office's main computer system) using the mesoscale version of the Unified Model. The data are then sent to the OpenRoad production systems where forecasters can modify them if thought necessary before running the model. This method of working has been successfully tested this year.

TV

International Weather Productions (IWP), a business unit of the Met. Office situated at Camden in London, is the Met. Office's specialist TV production unit providing services to independent TV stations in the UK and overseas. The basic data is provided via GETMET as described in an earlier section. Production processes at IWP are largely based on powerful Apple Mac computers, although other PC-based equipment such as Matisses are also used. The bespoke software used on the Apple Mac is produced and supported by SCL, who have a joint venture agreement with the Met. Office. SCL is a small company with expertise in Apple Mac systems and the television industry; they are also involved in the sales and marketing of services. The SCL Hypercard-based software enables the forecaster to add symbol charts etc. and to put together presentation sequences. These data can then be sent as basic graphics or compressed video to compatible systems at television companies. Again, because of the data volumes, ISDN lines are often used.

The arrangements for most of the BBC services are different. Here data are sent to the BBC Weather Centre at Shepherds Bush, where the production processes take place on Apple Macs and Quantel Paintboxes. These systems were developed by the BBC Graphics Workshop and are operated by the Met. Office presenters at the BBC WC.

Use of science and technology

Introduction

Various groups in CS are involved in work of a scientific or applied scientific nature. This can be undertaken in support of an enquiry from a particular customer, it could be contract work or it could be of a more developmental or generic nature. Specialist help is provided by the Scientific Support Group. A variety of work has been undertaken in the past year. Details of some major studies follow.

Scientific Support Group

The estimation of the climatology of radiation fog is important for road construction, road planning and other purposes. If an observing site is not available at the place of interest, as is usually the case, then an estimate of fogginess has to be made by other means. Most methods rely on a semi-quantitative assessment of the local environment to estimate the likely occurrence of fog. To develop a more quantitative estimate of fog potential, climate data from 76 sites in the UK were investigated and the observed occurrence of fog related to the local environment. This was only possible because of the availability of high-resolution grid-point data sets of topography and land use. The stations were divided into two sets: one set was used to derive a set of regression equations which relate the number of fog spells per year to land use and topography, while the remainder were used as a test of the regression equations. Many combinations of likely variables were tested but the most useful were:

- the percentage of rural land use over a 12 km square area centred on the site;
- the mean height within a 20 km square relative to the minimum height within a 6 km square (essentially a large-scale topographic variable);
- a local slope variable within 0.5 km of the site, a parameter that describes the local topography.

The first of these variables explained 54% of the variance in the fog data. The three variables together with three others in a multiple linear regression explained 89% of the variance. Fig. 22 shows how the derived fogginess generated using this regression analysis compared with the measured value for the test stations.

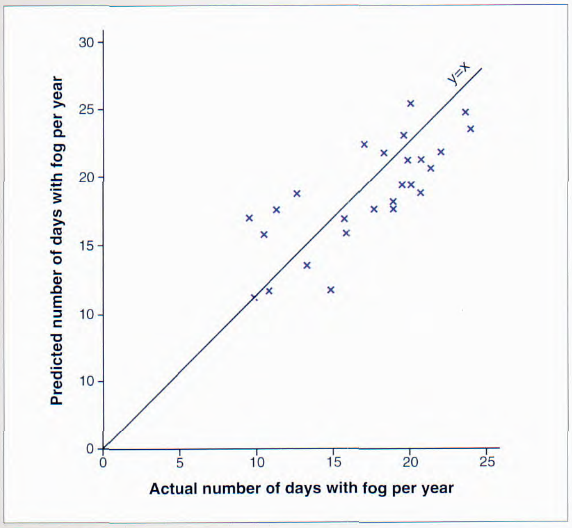


Fig. 22. Forecast fogginess derived from regression analysis compared with actuals.

Another investigation analysed the relationship between water consumption and weather. This is topical because in the past few years it has become clear that areas with limited water storage facilities may need to restrict supplies during periods of peak demand. The NRA Southern Region provided 10 years of weekly water consumption figures. These data showed a marked seasonal variability (consumption high in summer and low in winter) which was approximated by a sine curve. The variability of water consumption about the sine curve was then correlated with the weather data. The weather variables which were the most useful were either sunshine or potential evaporation (PE), and rainfall (R). A multiple linear regression involving PE, R and actual evaporation (AE) explained 68% of the remaining variability in the water consumption data. There was a marked change in the sensitivity to each variable with season. For PE and R the greatest sensitivity was in the summer when water use by agriculture, horticulture and domestic users responded to dry sunny weather. AE had the greatest sensitivity in winter. The inclusion of the sine curve increased the proportion of the variance explained in total water consumption to 87%, indicating good model performance.

The Scientific Support Group is also investigating techniques for estimating site-specific wind climatologies for use in wind-energy turbine siting studies. The estimation of wind speed at the proposed site is critical because the power available is proportional to the third power of the wind speed. Theoretical approaches are far from perfect, and there is always uncertainty in the derived climatology, so the ultimate solution is actually to measure the wind climatology at the proposed site. This, however, takes a long time, 10 years being regarded as a minimum. By making continuous measurements at the proposed site for, say, 6 months and then correlating these data with data from a suitable Met. Office reference station (with a long-period record), it is possible to generate a reasonably accurate wind climatology for the proposed site. This can then be adjusted, using standard techniques, to the hub height of the wind energy converter. The Agromet. Unit offers this as a standard service and can provide all the instrumentation and logging equipment. It also undertakes the installation work, the data analysis and consultancy.

Agromet. Unit

The Agromet. Unit at Wolverhampton provides meteorological advice to the agricultural industry via ADAS (Agricultural Development and Advisory Service). For a small unit it is involved in many types of applied scientific study and activity. A major area of work concerns evaluating odour emissions from livestock units such as pig or poultry farms, and their environmental impacts for planning applications. This type of analysis is continually being refined. Recent research has investigated the use of ADMS (Atmospheric Dispersion Modelling System) in such studies and the preliminary results look promising. ADMS is a computer-based model for investigating pollution dispersion in the boundary layer (see page 42).

As well as being affected by the 'wrong type of snow', British Rail can also suffer disruption to its services through leaf-fall degrading wheel/rail adhesion as well as the performance of its line-side track-circuit and signalling equipment. The Agromet. Unit has been working on the development of predictive leaf-fall models, that take into account tree type and both recent and forecast daily weather (particularly air temperature and wind speed). This model will give British Rail a longer lead time to take preventative action.

Environmental Consultancy Unit

The Environmental Consultancy Unit has offered new services this year. It can now run ADMS in a forecast mode by using the output from the Mesoscale Unified Model as input. Verification shows that the forecast dispersion patterns produced using the model agree well with the observations. Companies wishing to build or modify existing plant can be given advice on the likelihood of visible plumes occurring from their smokestacks. This is a function of both atmospheric conditions and plume characteristics. More-detailed information on the total number of hours for which identified categories of plume visibility occur can also be provided.

Marine and Legal Services

There is increasing interest from offshore analysts in the quantification of weather risk for offshore operations, and this interest extends to an assessment of the likelihood of forecasts being incorrect. The Marine and Legal Services section has developed a method to convert readily available verification statistics, on wind and wave forecasts, to a measure which could prove useful for risk analysis purposes. Further work by the same group, on the North European Storm Study data (a 25-year hindcast archive of data), showed that the highest wind speeds to have been experienced in the northern North Sea in recent times occurred during the New Year storm of 1 January 1992.

METSTAR

The aim of METSTAR, a consultancy group within the Sales branch of CS, is to join the research, operations and commercial arms of the Met. Office together, easing the move of research and operational expertise into the commercial market-place. This also involves developing commercial products through contracts that combine the expertise of these groups and external collaborators.

METSTAR's work encompasses many areas of meteorology including nowcasting, remote sensing, hydrometeorology, the environment and general meteorological systems. They have also been concerned with aspects of badging and licensing of products and software.

METSTAR have been involved in a number of radar and satellite contracts, for example, EUMETSAT contracts (an economic benefit assessment of Meteosat), a science study for the Chilbolton radar and cloud radar studies with the Rutherford-Appleton Laboratories. METSTAR is also undertaking an evaluation of C-band Polarization and Doppler radar in Italy and Germany; this is known as the Polarization Diversity And Doppler Radar Experiment (PADRE) and is directed by the University of Essex. PADRE data are being studied to see if parameters can be identified which can aid in the selection of an appropriate 'conceptual model' of weather systems. These models are helpful in forecasting the subsequent development of weather systems. Fig. 23 illustrates one of the

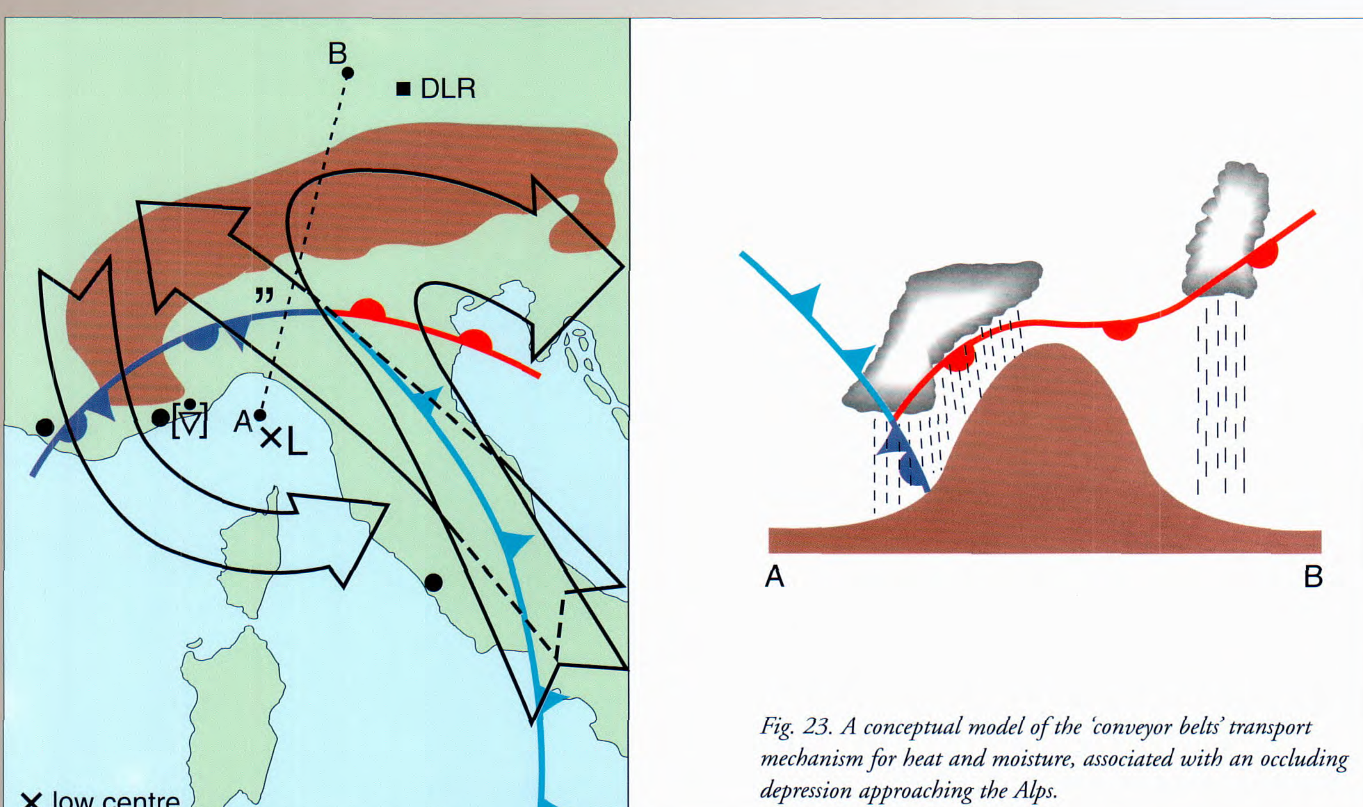


Fig. 23. A conceptual model of the 'conveyor belts' transport mechanism for heat and moisture, associated with an occluding depression approaching the Alps.

Comparison of fisheries forecasts for Thursday 3rd March, 1994

Fair Isle	
Operationally produced:	SW F7 → 9 HIGH
Automated text:	*Southerly 4 to gale 8. Then SW 7 to gale 8 veering westerly 6 to gale 8. Moderate or high.*
Rockall	
Operationally produced:	W→S F6 – 8 VERY ROUGH
Automated text:	*Westerly 6 to gale 8 backing SW 5 to 6. High becoming very rough.*
Malin	
Operationally produced:	W→SW F6 – 8 VERY ROUGH
Automated text:	*SW 6 to gale 8 veering westerly 5 to 7. Then SW 4 to 6. High becoming very rough.*

Fig. 24. An example of automatically produced text, with the forecaster's version of the same for comparison purposes.

conceptual models being used and shows the 'conveyor belts', transport mechanisms for heat and moisture, associated with an occluding depression approaching the Alps.

The hydrometeorological and nowcasting contracts include the assessment of snowmelt for the purpose of engineering design, the estimate of Probable Maximum Precipitation and Probable Maximum Flood (in conjunction with the University of Salford), and the development of a thunderstorm forecast system (Generating Advanced Nowcasts for Deployment in Operational Land Surface Flood Forecasting — the GANDOLF project) for the National Rivers Authority.

Within the environmental area, METSTAR have been involved in the development of a Geographical Information System (GIS) for weather and pollution data in Europe. They are also coordinating a group within Berkshire to consider problems of weather, health and air quality. It is hoped that a substantial research project will develop from this initiative in the near future.

Product Development Branch

The Product Development Branch provides the technical support that helps to keep CS functioning. Many of the topics discussed elsewhere in this article will have a significant input from the branch; this section only mentions work not reported elsewhere. Of particular note is the work being undertaken to produce text automatically from forecast model output. This work is building upon the scheme developed jointly by the Canadian Met. Service and the Department of Linguistics at the University of Montreal. The framework they provided has been modified to work on PCs and can now be tailored to produce various types of simple scripts. An operational trial is automatically producing shipping forecasts. An example of the automatically produced text, with the forecaster's version of the same for comparison purposes, is given in Fig. 24.

Another general theme that has been further developed this year is the automatic generation of 'first guess' products. These are produced centrally, usually from forecast model output. The 'first guess' is then presented to a forecaster who is provided with the facility to interact with and if necessary change it before onward transmission to the customer. OpenRoad, the Aberdeen Production system, automation of text production and the world cities forecast all work in this mode.

Enhancement of services

No organisation can afford to be static. CS has to improve and refine the products it makes available. Our customers are continually updating their needs and CS has to respond to these changes. New opportunities appear and new technologies emerge. CS has to monitor and improve the accuracy of what it produces. Presentational standards need to be monitored and improved. Market Research, verification, innovation and quality initiatives all help meet the above requirements and determine the new technology and science that is required.

Market research, one of the functions of the Marketing Branch, has assisted in the development of many products and services during the past year. The role of market research has been to elicit views from existing and prospective customers on how products and services can be improved, and to establish whether markets exist for new products and services. Among the topics covered have been The Monthly Prospect, the use of atmospheric dispersion models and various fax products.

The Monthly Prospect (a thirty-day forecast issued fortnightly) is currently used by many retail and Public Utility customers. The users were invited to comment on the product and to offer suggestions for improvement, and prospective customers were invited to offer views on their potential usage and requirements. The Met. Office is currently examining various options for enhancements.

The information provided by the research into the use of atmospheric dispersion models is giving leverage to develop enhanced air quality forecast models.

Before satellite images were made available via fax services (Fig. 19b) the views of fax users were canvassed. The ability to interact with users via messages on fax products and header pages has generally enabled products and services to be developed with a high degree of customer involvement. After a number of trials the product was launched and has proved very successful. The MetFAX Education service was launched following market research. It has also proved very successful, winning the Gold Award, from the Geographical Association, for its contribution to the teaching of geography.

Many of the services that CS provide include forecast information. The accuracy of the forecast is required for both internal and customer related reasons. Some services, such as those to British Gas, have agreed levels of accuracy defined by the contract. Others such as OpenRoad and that for the National Grid Company have internal accuracy targets. This type of forecast verification is fairly straightforward; for example a forecast temperature is compared with a measurement. During the last two years considerable progress has been made in the verification of the more general type of forecast, on which the performance of the Office is judged by the general public. In particular, Weathercall forecasts, those made available via the public telephone network, are now routinely verified and the results relayed back to the Weather Centre forecasters so that practices and techniques can be reviewed. Fig. 25, which shows observed frequency of weather event against forecast probability, indicates that severe weather events still tend to be overforecast.

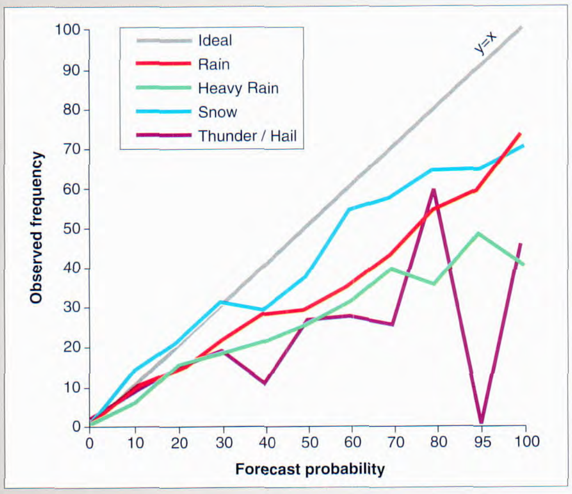


Fig. 25. Showing observed frequency of a weather event against forecast probability.

Innovation, as it applies to CS, means the generation of new ideas for products and services, identifying which of these ideas have commercial potential, and then realising the idea by marshalling the appropriate scientific and technical resources. The past year has seen various initiatives to encourage the generation of ideas and a new post has just been set up to act as a focal point for them.

CS was the first division in the Met. Office to set up and own a Quality Improvement Council (QIC). One of the main aims of the QIC is to improve customer focus. This obviously includes the delivery and quality of the services that CS provides to both its internal and external customers. This initiative is already having an impact. A Quality Policy Manual, meeting the requirements of BS 5750, is being produced for all the production units. As more of our customers become 'quality' companies some of these units will seek formal BS 5750 registration.

Forecasting Research

Introduction

The Forecasting Research Division has the task of developing and extending automatic systems for forecasting the weather on time-scales from a few minutes up to a month ahead. Much of the forecasting is based on assimilation of all available data into a large computer model, the Unified Model, which is then used to make predictions. For very-short-period predictions it is necessary to use extrapolation techniques based more directly on observations. For longer-period forecasts it is necessary to predict a probability distribution of possible weather patterns, and use statistical postprocessing to give the probability of particular types of weather. In addition to this primary task, the Division is also responsible for developing systems to forecast the sea state and the ocean circulation.

Very-short-range forecasting

At present, forecasts of precipitation for up to 6 hours ahead are produced by an interactive system based on radar and satellite data and a choice of options by a forecaster. An automatic replacement for this system has now been developed and will be implemented in the summer of 1995. During the last year, automatic radar and satellite analysis procedures were completed and tested, to add to the automatic forecast step illustrated on page 46 of last year's Review. One specific task was to provide an automatic method of inferring rainfall rate from satellite imagery, so that, as in the present system, forecasts can use information outside the range of the radar network. Another was to develop an automatic method of identifying and deleting radar echoes not caused by precipitation. This requires using a probabilistic technique based on surface observations, satellite data, and climatology.

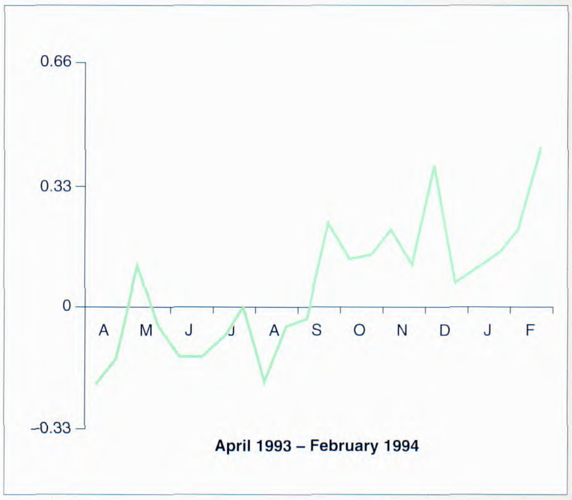


Fig. 26. Average scores for half month periods based on CFO subjective comparison between the Limited Area and Mesoscale Models. Values lie in the range − 1 (all Mesoscale forecasts much worse than the LAM), to + 1 (all Mesoscale forecasts much better than the LAM).

Forecasts of all weather parameters up to 18 hours ahead for the UK are produced by a mesoscale configuration of the Unified Model. This has a grid length of 17 km and covers an area about 1500 km square. The model was implemented operationally in December 1992. In September 1993 a major upgrade took place when the numerical methods used were refined so that smaller-scale weather features (not much larger then the model grid) could be usefully predicted; the representation of convective precipitation was also retuned. The combined effect on precipitation forecasts is illustrated in Fig. 26; this shows that after the upgrade the model consistently produced better guidance than the lower-resolution version of the model used for regional forecasts.

Further major developments of this model are in progress, designed to achieve the aim of useful fog and low cloud forecasts. To this end, the interactive analysis procedure designed to initialize the cloud from surface and satellite data has been automated. The resulting system is at least as good as the one requiring manual intervention. An extra model level has been added 10 m above the ground. In some tests of a continuous data assimilation cycle, fog forecasts up to 6 hours ahead and low cloud forecasts up to 9 hours ahead largely achieved the target figures of a 60% hit rate and a false-alarm rate under 40%.

Global and regional short-range forecasting

Forecasts of the general weather pattern over the UK area up to 36 hours ahead are provided by a regional version of the Unified Model covering the North Atlantic and Europe. Forecasts of the weather patterns, and detailed information required for civil aviation, defence and commercial customers up to 72 hours ahead are provided from the Global Model.

Observation processing

To make these forecasts, maximum use has to be made of available observations. Remotely sensed data is particularly challenging to use, as they are not directly related to variables predicted by the model. During the last year substantial progress has been made on using data from a number of satellite instruments.

A system for locally processing a global coverage of temperature sounding data from the US polar orbiting satellites has been given operational trials. Short-range forecast errors were significantly reduced, with the r.m.s. errors in wind and temperature being decreased by up to 5% in the extratropical regions in both hemispheres. It is hoped that this system will be operational shortly.

A system for using the sea surface wind data measured by the scatterometer carried on the ERS-1 satellite has been implemented operationally. This has a significant impact on forecasts in the southern hemisphere, where r.m.s. errors in the lower troposphere are decreased by 3%.

A system for generating cloud products from imagery data has been brought into regular use. This will be used both for direct assimilation into the forecast models and for generating cloud information to assist in processing temperature and humidity sounding data from the polar orbiting satellites. Some preliminary trials of the assimilation have been carried out.

Work on an international experiment to compare algorithms for inferring precipitation from satellite imagery was completed during the year. In mid-latitudes, it appears difficult to deduce useful information from visible and infrared imagery, but some of the microwave algorithms showed some measure of success.

It is also important to optimize the benefit from direct observations. This can be achieved by improving the deployment of observations around the UK and by conducting studies to guide investment decisions into improvements to the network. For example Fig. 27 shows the contribution that an extensive network of observations from commercial aircraft can make to the accuracy of forecasts, in this case over North America which enjoys a rich coverage of aircraft data. Here use of aircraft winds and temperature observations alone (i.e. excluding all conventional meteorological data) was sufficient to correct considerable errors in the forecast of a vigorous depression over eastern Canada. The study illustrates the potential benefit to weather forecasts for the UK and European area of increasing the coverage of aircraft observations over the North Atlantic. Though the current cover by aircraft reports in this area have increased recently it is still considerably less dense than over much of North America; improvements would increase the frequency of positive impacts of the kind shown in Fig. 27.

Data assimilation

Observations have to be assimilated into the model. Recent work in other institutes, notably ECMWF and the National Meteorological Center in the USA, has shown the benefit of using variational methods of data assimilation, in which a model state is constructed that is the best fit to the observed data in a statistical sense. This method, especially for making use of a greater variety of data types, seems more promising than the current method which 'nudges' model fields towards the observations. It will be possible, for example, to make direct use of satellite radiance data. It will also be possible to construct three-dimensional weather patterns from single-level information. This will allow much greater use to be made, of surface pressure reports from ships, surface wind data from satellite measurements, and upper winds from aircraft. It probably also offers the greatest potential for making effective use of radar rainfall data. During the past year a way of applying these methods within the Unified Model system has been formulated.

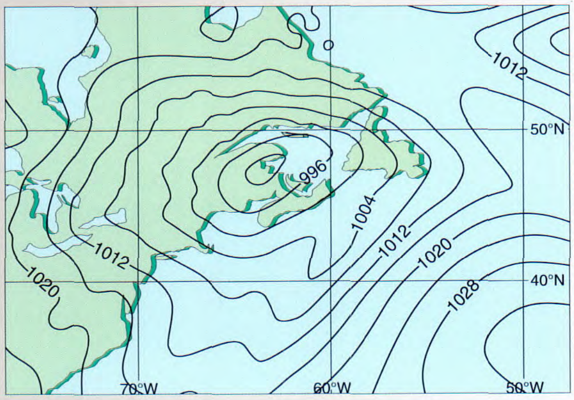
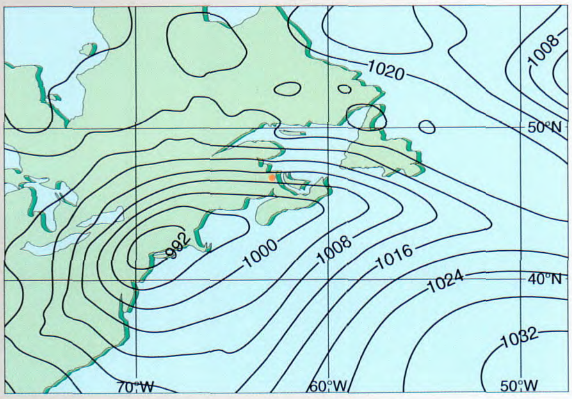
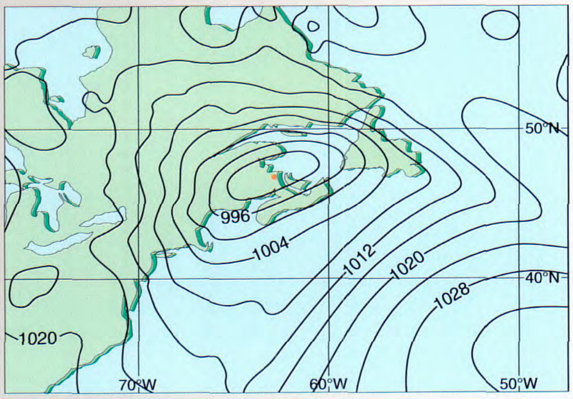


Fig. 27. (a) MSL pressure analysis at 1200 UTC on 5 January 1994 showing a depression centred near the Gulf of St. Lawrence.



(b) Model prediction started from data valid at 1200 UTC on 2 January (a 72-hour forecast). There is considerable error in the location of the depression, which is centred near New York, some 1000 km to the south-west of the true position shown by the dot.



(c) Model prediction obtained when aircraft observations of wind and temperature, valid up to 15 hours after start time, are assimilated. The location of the depression centre is now extremely good. The general shape of the depression is also much improved compared to (b).

A number of improvements have been made to the existing data assimilation system. For example, a method of inferring corrections to pressure and temperature analyses from wind data, which is correlated with horizontal pressure gradients, was shown to reduce the r.m.s. errors in the model by up to 1%.

Model development

During the year the r.m.s. errors in Unified Model forecasts have been markedly lower than in previous years as a result of improvements to the treatment of unresolved gravity waves. Further improvements have been made to the treatment of physical processes in the Global Model, particular of convection and boundary layer mixing. This has brought this configuration of the model back in line with the version considered best for climate simulation. As a result there are marked improvements in the forecasts of convection in many parts of the world and in the forecasting of precipitation in low latitudes. This is important for many of the Office's customers and for forecasting significant weather for aviation. The effect of similar changes to the Regional Model were illustrated on page 37 of last year's Review.

Continued improvement requires tools which allow deficiencies in the model forecasts to be traced back to particular aspects of the model formulation. Momentum, heat and moisture budgets have been calculated from short forecasts by the model. Ideally, changes at the beginning of the forecast should be small; large changes indicate an inconsistency between the model formulations and the atmospheric state given by the analyses. The momentum budget is illustrated (Fig. 28) and shows the contributions from the model dynamics and parametrizations. Clearly the two terms are not in balance with the dynamics requiring a larger drag in the mid-latitude troposphere than is provided by the parametrizations. This imbalance leads to a spurious increase of westerly momentum in middle latitudes at the start of the forecast. This is confirmed in extended integrations of the model at the resolution used in global forecasts, which show a distinct tendency for excessive westerly winds in the Northern Hemisphere winter.

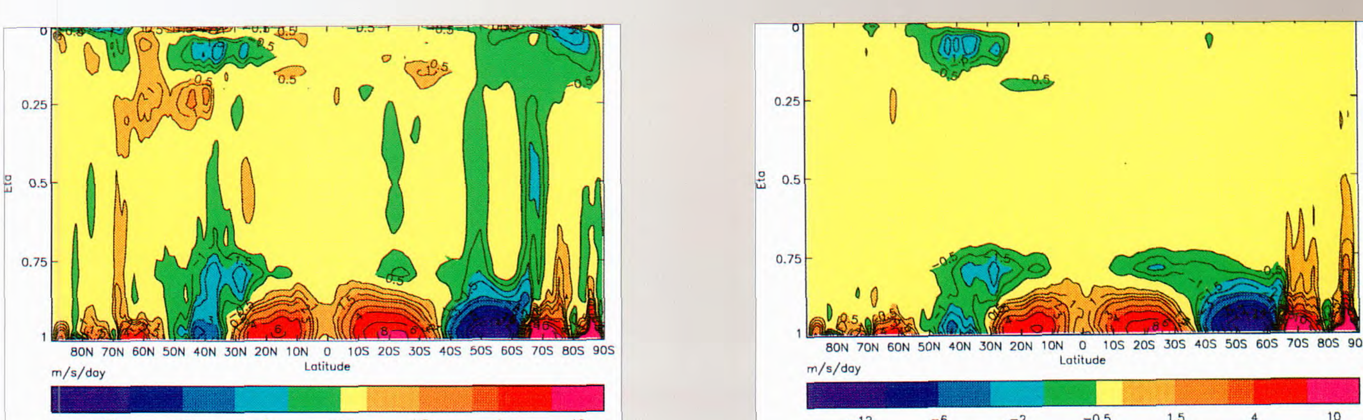


Fig. 28. Calculations from model increments derived from 124 two-time-step integrations of the global Unified Model run from 4 analyses per day. Contour interval 0.5 $m\ s^{-1}\ day^{-1}$ up to 13 $m\ s^{-1}\ day^{-1}$ then 1 $m\ s^{-1}\ day^{-1}$ thereafter. (a) Monthly-mean tendency in zonal wind due to the model dynamics routines for April 1993. The tendency is shown with its sign reversed, and as such, represents the sources and sinks of momentum which need to be applied to the model in order to balance the dynamics.

(b) Monthly-mean tendency in zonal wind due to model parametrizations (boundary layer turbulent mixing, gravity wave drag, and vertical diffusion) for April 1993. These tendencies represent the sources and sinks of momentum actually applied to the model.

Studies of the increments produced by the scheme which represents unresolved gravity waves show that the wave drag is mainly effective at upper levels of the atmosphere. However, comparison with field experiments such as the PYREX experiment (see page 40) suggest that a large proportion of the drag occurs at lower levels. It is hoped that a new representation of the wave drag, currently under development, will further improve the performance.

Oceanographic forecasting

During the year the first complete prototype runs of a deep-ocean forecasting system were carried out. Forecasts are made of the complete ocean structure in the Atlantic north of 30° S. The model used has a horizontal grid length of 110 km and 20 levels in the vertical. This resolution is only sufficient to capture the broader-scale features and is not sufficient to represent, for example, the contrasts across the Gulf Stream. Finer-resolution versions of the system will be needed to represent ocean fronts. In the initial tests, 3000 observations of the vertical structure were available per month. The rate of change of ocean structure is much slower than that in the atmosphere, and each observation gives useful information over a 10-day period. These data were assimilated successfully into the model.

The major development in the forecasting of sea state was the incorporation of ERS-1 altimeter data into the model. This had a major impact on forecasts of wave height (Fig. 29), reducing the bias in mean swell height by about 30 cm.

Extended-range forecasting

The Met. Office is collaborating with ECMWF in developing methods of ensemble forecasting (see also page 15). In this approach a large number of forecasts are run from slightly different initial conditions, reflecting the uncertainty in the initial analysed state of the atmosphere. It is necessary to construct the perturbed initial analyses carefully in order to identify the perturbations which lead to the maximum differences in the subsequent forecasts. The use of the Met. Office Unified Model alongside the ECMWF model has allowed a more complete estimate of the uncertainty in the forecast. This is because an individual model tends to have specifically favoured behaviour patterns which may not correspond to those of the real atmosphere. ECMWF expect to introduce ensemble forecasts as routine during the coming year.

The move towards probability forecasts means that the method of generating medium- and extended-range forecast guidance for customers has to be reconsidered. Probabilities of temperature and rainfall categories for various regions of the UK are routinely generated, by statistical postprocessing, for periods up to 30 days ahead. These are being evaluated against other forms of forecast guidance in this time range.

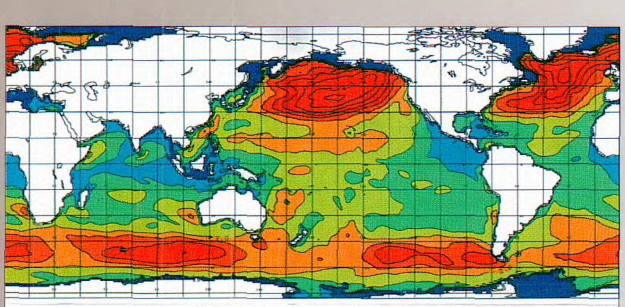
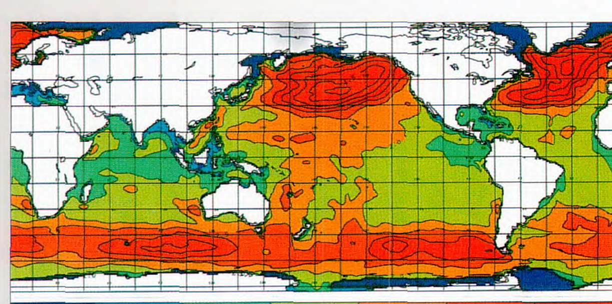


Fig. 29. Impact of assimilating ERS-1 altimeter data into the global wave model in a trial for 1 to 18 January 1993. Contour retrieval 0.5 m, changes in colours highlight waves less than 3 m. Note the increase in wave height in the tropics when data are assimilated. (a) Significant wave height without assimilation,



(b) significant wave height with assimilation.

Atmospheric Processes Research

Atmospheric processes (radiation, clouds, convection, gravity waves, atmospheric chemistry, turbulence and dispersion) are fundamental to numerical weather prediction and climate models; it is acknowledged that inadequacies in their representation are a primary cause of poor forecasts and of systematic errors in climate simulations. Better methods of including their effects in models depend on improved understanding of the underlying physics involved. Effective research on atmospheric processes can only be conducted using a combination of measurements in the atmosphere itself, and trials and tests using a variety of highly detailed and carefully constructed process-models. The experimental research facilities provided by the Meteorological Research Flight (MRF) C-130 aircraft and by the Meteorological Research Unit (MRU) tethered balloon and boundary layer instrumentation are essential to this, as are the various numerical models derived from the very high resolution Large-Eddy Simulation (LES) model. Developments in these facilities and in the research undertaken with them, much of which is being conducted in close collaboration with scientists at universities and research institutes in the UK and abroad, are described below

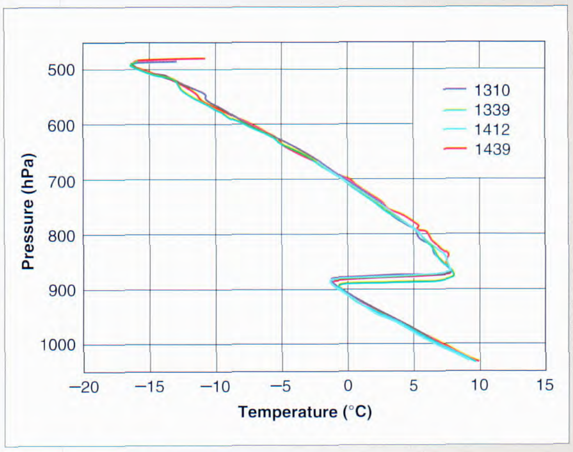


Fig. 30. Profiles of temperatures through a sharp inversion over Carmarthen Bay on 27 October 1993 as recorded by four parachute-borne radiosondes of the type currently under development by MRF and Vaisala. The rapid temperature change at the top of the profile is due to the sonde cooling as it leaves the aircraft.

Technical development of facilities

Improvements to aircraft instrumentation

The MRF is developing, jointly with Vaisala Meteorological Systems, a new parachute-borne radiosonde which uses the same sensors as a standard RS80 radiosonde but is much lighter and much cheaper than the previous sonde. It is hoped that is will be possible to use it over land without advance clearance from Air Traffic Control. Six were ejected from the C-130 in trials over Cardigan Bay in October 1993 and gave good results, some of which can be seen in Fig. 30.

An instrument to characterize the chemical composition of aerosol was installed on the aircraft in 1993 for the University of Manchester Institute of Science and Technology (UMIST). Aerosol, captured by the air sampling port, is passed to a commercial sizing spectrometer after going through one of four differently heated tubes which volatilize specific aerosol components.

Very low dew-points have been measured with a self-calibrating Fluorescence Water Vapour Sensor, developed and built at MRF, which detects the fluorescence of water vapour when illuminated with a Lyman-α source; accuracy is estimated to be ± 1 °C down to dew-points of -80 °C. Results have compared favourably with a cryogenic device on the German Falcon aircraft when flown side-by-side with the C-130.

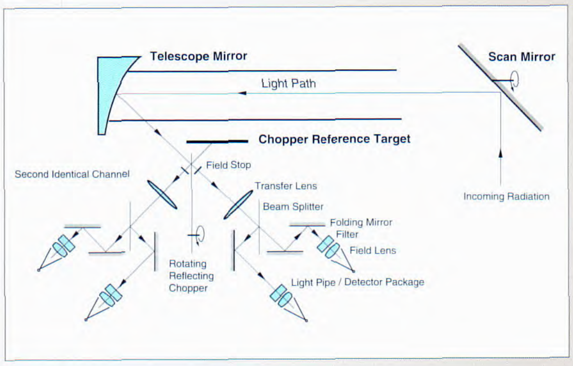


Fig. 31. The optical layout of the SAFIRE radiometer being installed in the wing pod of the C-130.

Funding from a consortium of oil companies (IPIECA) has allowed the development of the Scanning Airborne FIlter RadiometEr (SAFIRE) to replace the outdated multi-channel radiometer which has been used for many years. It uses liquid-nitrogen cooled detectors to cover a wavelength range from 0.5 μm to 15 μm, and is mounted in a pod suspended from the aircraft wing (Fig. 31). The instrument has sixteen filter channels and a field of view of 1.5° half angle, scanning from nadir to 60° off-nadir plus a zenith view. The instrument is essentially complete, and will be flown for the first time in the middle of 1994.

The aircraft has also been fitted with the means to collect air samples in 'Tedlar' plastic bags; the air is then analysed for chemical composition. This was used for the first time in summer 1993 to determine the methane emissions from wetland areas in Caithness for the Institute of Terrestrial Ecology; air samples were taken by the C-130 at heights down to 35 m (Fig. 32).

Fig. 32. The C-130 collecting samples of methane emitted from the wetlands of Caithness.

Tethered-balloon instrumentation

The MRU balloon-borne turbulence probes measure the turbulent flow with fast response anemometers and other instruments, and use inclinometers and magnetometers to measure the cable catenary curve and hence determine the slow motions of the probes as the balloon drifts about its tether point. A method

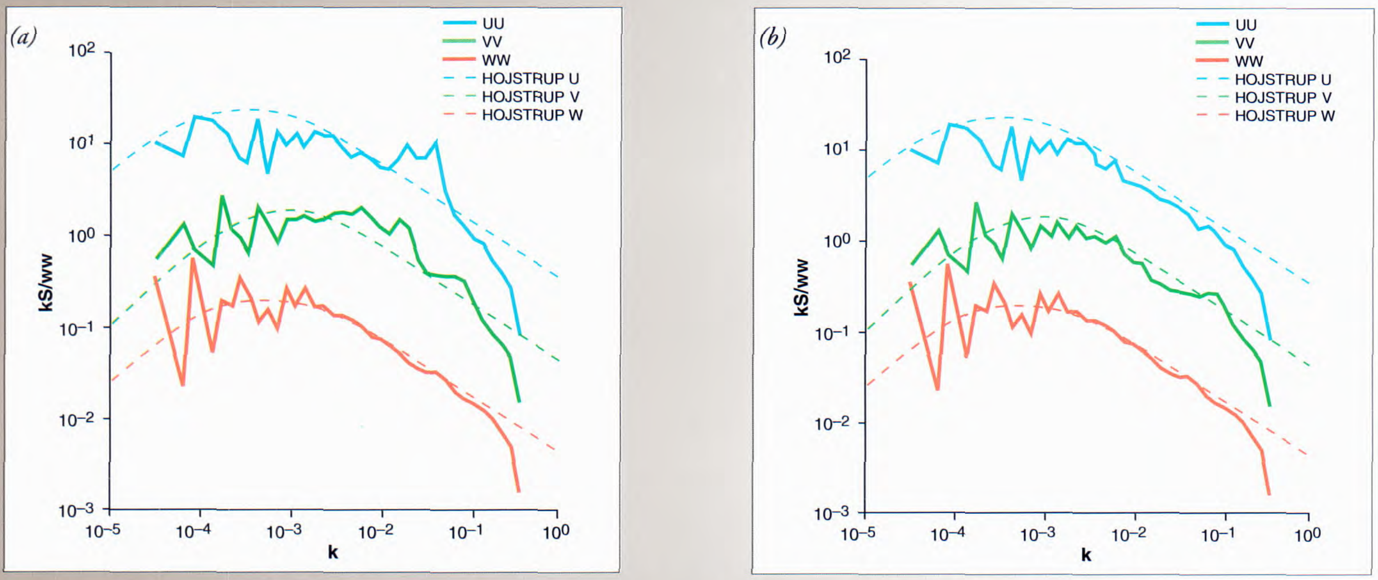


Fig. 33. The spectra derived from the Cardington balloon-borne probe on 6 May 1993 at a height of 350 m, (a) without correction for cable motion, and (b) with correction applied. Each figure shows the three spectral components, u'^2, v'^2 and w'^2, separated for clarity by multiplying v'^2 and u'^2 by factors of 10 and 100 respectively. For reference, idealized surface layer spectra due to Hojstrup are also shown. The ordinates are spectral density in m^2s^{-1} and the abscissa shows wavelength in metres derived from G.I. Taylor's 'frozen turbulence' hypothesis.

has been devised for using the inclinometers as accelerometers, thereby enabling the offsets of the harmonic tether-cable vibrations to be removed from the turbulence measurements. The errors removed from measured variances, fluxes and spectra amount to 30%, or more, as the wind strengths increase. It should thus be possible in future to take better data in more severe conditions. Fig. 33 shows turbulence spectra before and after the correction has been applied. The latter match theory better.

Modelling techniques

Multi-dimensional extensions of flux-limited advection schemes have been derived and implemented in the LES model. These yield highly accurate solutions, at moderate cost, even when the advected field contains near-discontinuities. Recently a conservative, flux-based scheme, built on the basis of an explicit, single-step, forward-in-time update (without any restriction on the size of the allowable time-step) has been successfully demonstrated for one-dimensional advection. This work has been carried out in collaboration with Prof. Leonard (University of Akron, USA).

Clouds and radiation

Cumulus penetration of stratocumulus

During the Atlantic Stratocumulus Transition Experiment (ASTEX) the marine boundary layer underneath the subtropical subsidence inversion was found to be relatively deep (1500 m). The most common cloud conditions observed were cumulus clouds under a thin, broken layer of stratocumulus. The dynamics of the cumulus clouds are considerably different from those associated with the stratocumulus and, as a result, the entrainment processes cause quite different droplet spectra. As a result, cumulus clouds have a significant effect on the microphysical and radiative properties of the stratocumulus layer when they penetrate its base. In general, the change in the droplet size, and the increased liquid water content due to the cumulus clouds, add to the stratocumulus; there they cause localized areas of increased albedo and mix in with the rest of the cloud as the cumulus clouds die away. Fig. 34 shows a time-series of droplet spectra from a transit of the C-130 inside a stratocumulus layer. Where cumulus clouds are penetrating the layer (near the end of the run) and mixing with it, bimodal spectra are observed; in areas of the cloud that have not been affected by cumuli in the recent past, unimodal spectra are seen. The presence of bimodal spectra can enhance coalescence and produce precipitation-size particles. During

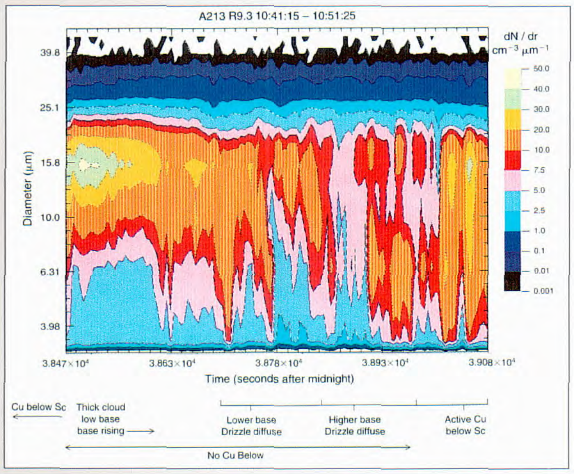


Fig. 34. Time-series of droplet size distributions measured by the C-130 aircraft during a run in stratocumulus on 19 June 1992.

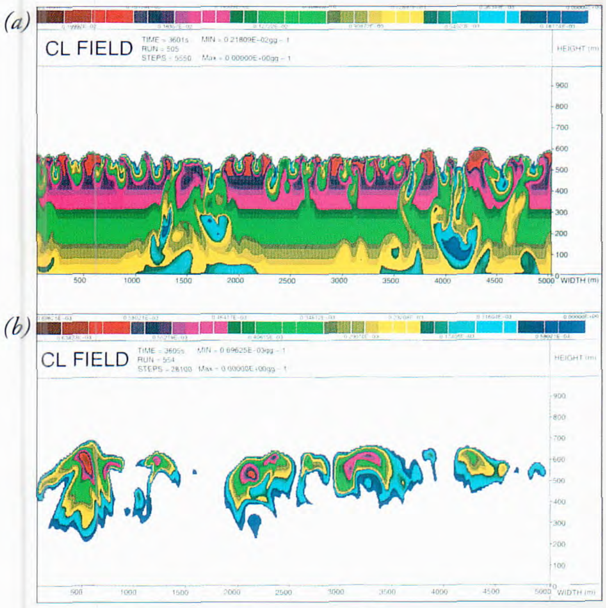


Fig. 35. Cloud liquid water in a 1-hour LES model simulation of stratocumulus when the temperature and humidity differences across the top of the boundary layer (a) satisfy Bretherton's criterion for stratocumulus break-up but not Mason and MacVean's criterion, and (b) satisfy Mason and MacVean's criterion.

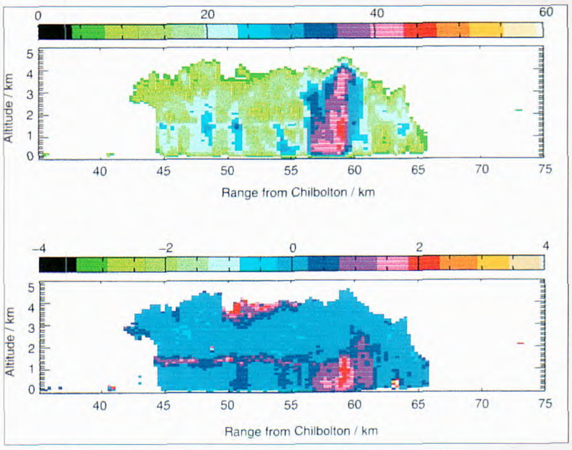


Fig. 36. An RHI scan from the Chilbolton radar at 1249 UTC on 22 June 1990. The upper figure shows the reflectivity, Z, whilst the lower figure shows the differential reflectivity, Z_{dr}.

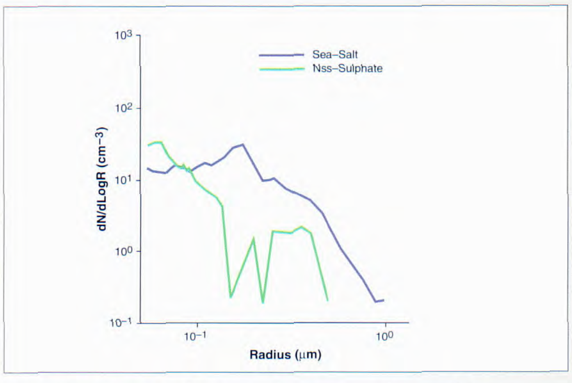


Fig. 37. Size distributions of sea salt and nss-sulphate aerosols measured in the marine boundary layer to the north-west of Scotland on 16 November 1993.

the experiment the occurrence of drizzle was highly correlated with cumulus clouds penetrating the stratocumulus base even though, generally, neither the cumulus nor the stratocumulus were considered deep enough to produce precipitation by themselves.

Break-up of stratocumulus

It is notoriously difficult to forecast the dissipation of a stratocumulus deck. Mason and MacVean (1990) (Meteorological Office) have derived a criterion for determining whether cloud-top entrainment instability is sufficient to break up stratocumulus; this is in good agreement with observational data. Very-high-resolution, two-dimensional LES model simulations have suggested that this instability might indeed be a potent mechanism for the rapid break up of stratocumulus sheets and further support has been provided by three-dimensional simulations. Another criterion has been proposed by Bretherton (1990) (University of Washington, USA) based on a model of the underlying process which is very similar to that used by Mason and MacVean. An attempt has been made to discriminate between them using a series of high-resolution, two-dimensional integrations. All had the same initial structure below the inversion, with a horizontally homogeneous cloud with a base at ground level and top at 500 m; only the initial profiles in and above the inversion differed. Fig. 35 shows the liquid water mixing ratio from two runs after 1 hour of integration. The run shown in (a) was stable according to Mason and MacVean's criterion but unstable according to Bretherton's. The cloud cover is still complete and remains so for at least 6 hours. In contrast, when Mason and MacVean's instability criterion is satisfied but Bretherton's is not, as in (b), the cloud deck breaks into individual cumulus-like elements within 1 hour and dissipates completely within about 2 hours. The integrations suggest that Mason and MacVean's criterion is both necessary and sufficient for instability, while that of Bretherton is not. The latter is, however, very important in determining the entrainment rate.

Precipitating cumulus

The LES model developed for cumulus parametrization studies needs to have its microphysics parametrization scheme validated against observations. The C-130 aircraft has made detailed measurements in deep cumulus clouds in combination with data from the dual-polarization radar facility at Chilbolton. Fig. 36 shows a radar cross-section of reflectivity (Z) and differential reflectivity (Z_{dr}) through a precipitating cumulus cloud. Z_{dr} (the ratio of reflectivities observed with horizontally and vertically polarized radiation) is positive when there are aspherical particles with their major axis horizontal, e.g. large raindrops below the freezing level, melting low-density snowflakes in the region outside the main precipitation core, or smaller plate like crystals near the cloud top. The Z_{dr} values close to zero above the freezing level in the main precipitation core suggest the dominance of tumbling graupel particles. A model simulation of this case has successfully reproduced a number of the main features, in particular the dominance of graupel in precipitation production, with predominantly unrimed ice and snow elsewhere in the cloud. The ice water contents compare favourably with those measured by the aircraft, whilst radar reflectivities, calculated from the model particulate fields, are similar in magnitude and spatial distribution to those observed.

Cloud condensation nuclei

A volatility technique, developed at UMIST, has been used on board the C-130 aircraft to investigate the chemical composition of aerosol in the marine boundary layer. Size distributions for non-sea-salt (nss) sulphate and sea salt are presented in Fig. 37. The results indicate that sub-micron sea salt is present in higher concentrations compared with that of nss-sulphate, and comprises more than 50% of the total concentration of particles with radii greater than 0.05 microns. The sea-salt nuclei are biased towards the larger sizes due to the different production mechanism of sea salt (mechanical) compared with nss-sulphate (gas to particle). The implication of these results are that sea salt nuclei, which are very effective cloud condensation nuclei (CCN), are well mixed throughout the marine boundary layer and, for clouds with maximum supersaturations less than 0.3% (i.e. stratiform clouds), the majority of the CCN population will be derived from sea salt nuclei produced by the mechanical disruption of the ocean surface. Nss-sulphate nuclei become more important in cumulus clouds with supersaturations of 0.5% or greater.

Cloud ice formation

It has been suggested that the ratio of the mass of ice to water in a variety of cloud types is best parametrized in numerical forecasting and climate models using the environmental temperature. A collaborative project with UMIST has extended this work by partitioning the parametrization between convective clouds and frontal clouds, and investigating the processes responsible for the production of ice particles. It has been concluded that ice splinter production during riming is the main mechanism for producing large concentrations of ice in these clouds. This is the well known Hallett–Mossop process which occurs at temperatures around −6 °C. Fig. 38 shows a profile of the concentrations of small ice particles through a front; it indicates a significant peak at this temperature. Ice columns are the crystal habit that would be expected to grow on ice splinters when the air is supersaturated at this temperature. This process is most effective in regions of cloud with low vertical velocities; here a parcel of air is resident in the Hallett–Mossop generation zone long enough for a very high multiplication factor to occur. Consequently it was found that the process was more effective in frontal clouds with lower vertical velocities.

Radiative impact of cirrus

Recent studies have shown that the results of climate simulations can be very sensitive to the assumptions made about the scattering properties of the ice crystals in cirrus clouds. Groups from the UK, Germany and France operated three aircraft, including the C-130, in coordinated flights to investigate the radiative, microphysical and dynamical structure of cirrus clouds during EUCREX (European Cloud Radiation Experiment), a major field campaign conducted from Prestwick in Scotland in the autumn of 1993. The angular dependence of the radiances deduced from these observations has been compared with simulations made using a Monte Carlo multiple scattering model (see Fig. 39); scattering phase functions derived from laboratory-grown ice crystals give better agreement with the measurements than do those derived from theoretical calculations on idealized shapes, such as ice spheres or hexagonal columns.

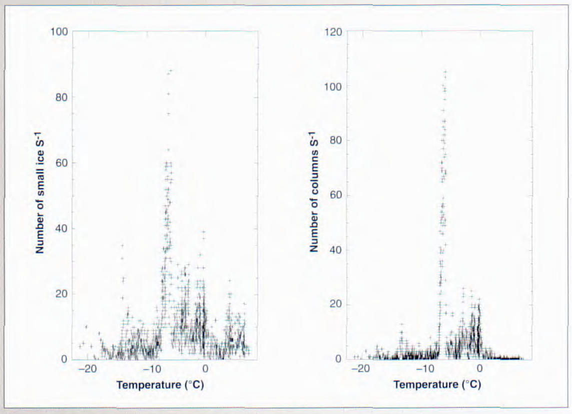


Fig. 38. Plots of small ice and column concentrations measured by the C-130 during a profile through a cold front on 10 April 1990.

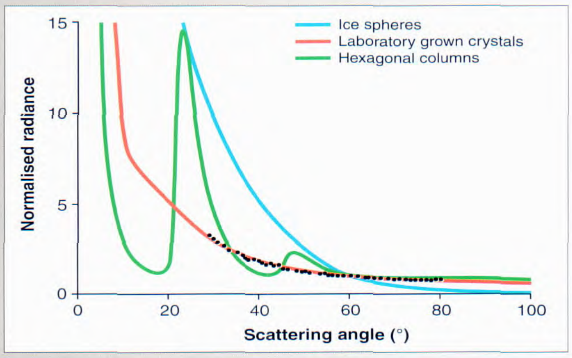


Fig. 39. Comparison between 0.55 μm radiances (solid circles) and those simulated with a Monte Carlo multiple scattering model using a number of different scattering phase functions.

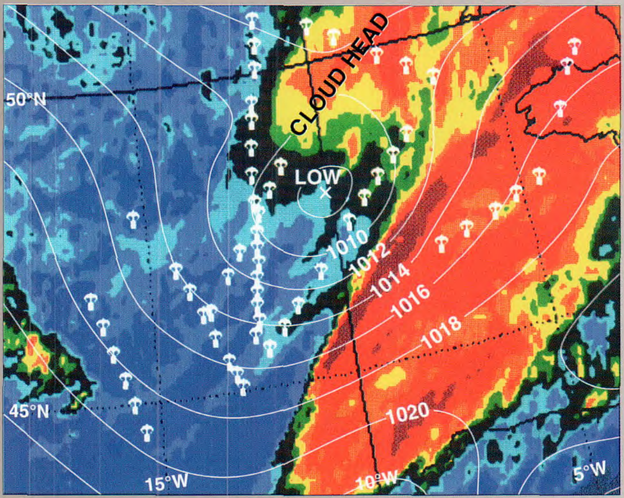
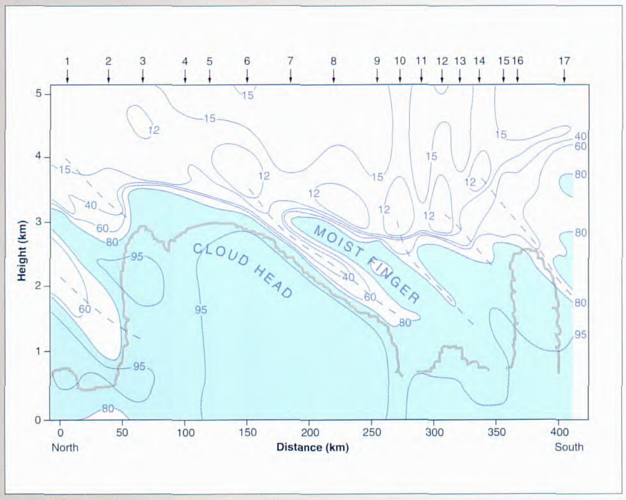


Fig. 40. (a) False-colour infrared image giving cloud-top temperature at 1800 UTC on 27 April 1992, with surface pressure pattern and dropsonde locations superimposed. Reds correspond to cloud tops colder than −35 °C, and blues to warmer than 0 °C. The dropsonde positions are given in a system-relative reference frame corresponding to the time of the satellite image.



(b) Cross-section of relative humidity (%) along the long north–south line of sondes passing west of the low centre. The arrows at top indicate the positions of soundings. The cloud-top height deduced from IR satellite imagery is also indicated for comparison.

Mesoscale processes

Frontal weather systems

Studies of frontal systems, which produce most of the rain and severe weather around the UK, have been undertaken by releasing dropsondes from the C-130 in special field experiments. Fig. 40a shows the surface pressure analysis and satellite infrared image, together with the pattern of sondes used in an intensive observing period during the FRONTS 92 project. The main precipitation comes from the cloud head formed in the ascending circulation north of the surface low; lighter precipitation from the colder cloud-band south of the centre evaporates before reaching the surface. The relative humidity observed in the north–south line of soundings along the western edge of the cloud head (Fig. 40b) agrees well with the cloud top, showing the transition from the cloud head to the drier air south of the low centre. Also evident are shallow moist and dry 'fingers' in the clear air above the cloud, symptoms of complex mesoscale circulations within the system.

The use of special model diagnostic information combined with satellite imagery is being investigated as an aid to forecasting. An assessment is being undertaken on a daily basis using the Joint Centre for Mesoscale Meteorology's advanced display system in the Central Forecasting Office. Potential vorticity, together with water vapour imagery, is proving helpful in evaluating and comparing the performance of forecasts of upper tropospheric development. (See also page 17.)

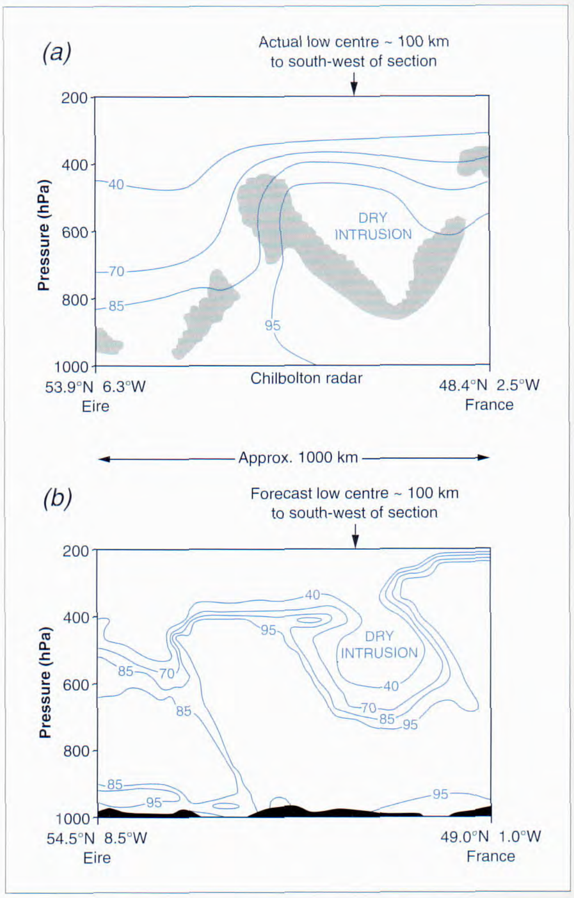


Fig. 41. Cross-section of model-derived relative humidity (%) at 0600 UTC on 28 April 1992, orientated north-west to south-east and passing through the cloud head and dry intrusion. (a) Limited Area Model analysis (solid isopleths) with satellite-determined cloud top superimposed. A relative humidity of 85% is the threshold for cloud production above the boundary layer in the Unified Model. Note the failure of the model to represent the dry intrusion. (b) Mesoscale Model (17 km grid) 36-hour forecast showing the dry intrusion to be well represented.

Mesoscale modelling of frontal systems

The performance, formulations, and configurations of the forecast model are being investigated using data and results obtained in field study experiments, particularly those obtained by the C-130 and Chilbolton radar, to supplement satellite and routinely available synoptic data. Detailed observations obtained during the FRONTS 92 experiment have been used to investigate the ability of the forecast model to predict the mesoscale structure associated with a developing frontal wave. The operational Limited Area Model's analyses did not capture the details of the distribution of cloud, humidity and precipitation shown by the satellite, dropsonde, radiosonde and radar data; in particular, the intrusion of dry air into the centre of the deepening cyclone was underdone (see Fig. 41a) as was the intensity of the precipitation associated with the cloud head. However, including the data from the C-130 sondes in the assimilation process greatly improved the fit to the satellite observations, and the 36-hour forecasts reproduced the dry intrusion much better than the original analyses, especially when using the higher resolution of the Mesoscale Model (Fig. 41b).

Convective-scale dynamics

An optional stretched horizontal grid has been implemented in the LES model. This is particularly useful for studying localized phenomena which require high resolution, such as convective storms. It has been used to good effect in studying the geostrophic adjustment accompanying deep convection events where a wide variation of scales has to be encompassed.

Numerical simulations of the geostrophic adjustment process following the growth of a single deep convective plume in an atmosphere with a real planetary rotation rate (in contrast to earlier runs which use a much speeded-up planetary rotation rate) have shown that high proportions of kinetic energy released in convective updraughts may be converted into balanced flow (up to 60%). Whilst this probably represents the extreme case, it may be achieved in mesoscale convective systems (earlier estimates in the literature have suggested conversion values of only a few per cent). The practical ramification of this is that a proportion of small-scale convective energy may evolve into quasi-balanced mesoscale structures which subsequently partake in an inverse energy cascade to synoptic scales, thereby affecting predictability. Such processes are not parametrized at present and it is important to ascertain whether or not they should be.

Flow over orography

Numerical simulations of lee waves over the Pyrenees have been carried out using a non-hydrostatic mesoscale model. Using a 2 km horizontal grid, a realistic terrain specification and an upstream profile from a French field experiment in the Pyrenees (PYREX) it has been possible to reproduce many features of the observed flow. One interesting feature (Fig. 42) is the appearance of shallow (less than 1 km deep) vortices, with typical diameters of 10 km, in the lee of the Pyrenees. These form in two shearlines created on the lee side of the mountains and a stagnant region trapped behind. Explicitly simulated vertical momentum fluxes due to gravity wave motion have been compared with those derived from a new gravity wave drag parametrization: the agreement is encouraging.

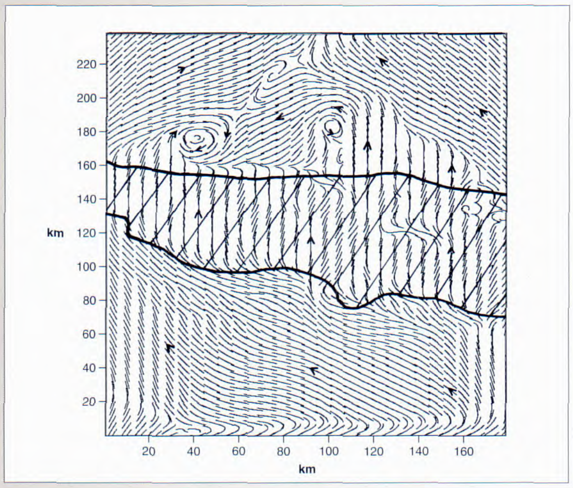


Fig. 42. Streamlines at model level 2 = 110 m at T+4 hours from a mesoscale model simulation of PYREX. Thick solid line outlines the foothills of the model's 'Pyrenees'. The upstream flow is south-westerly and taken from a radiosonde ascent at Zaragoza (0000 UTC on 15 October 1990). Although the resulting gravity wave field is quasi-steady the lee vortices evolve and move with time.

Boundary layer

The marine boundary layer (see also page 36)

One of the aims of ASTEX was to study the boundary layer processes involved in the transition from persistent sheets of stratocumulus, found under subtropical anticyclones, to the trade-wind cumulus regime. Observations from the C-130 during the experiment indicate that the transition involves an evolution of the boundary layer that is more complex than originally thought. Over the lowest sea surface temperatures (SST) the boundary layer is shallow and well mixed with a thick layer of stratocumulus (Fig. 43). Over warmer SSTs the boundary layer deepens and the cloud layer becomes permanently decoupled from a surface mixed layer (SML). The stratocumulus then thins because its moisture supply has been cut off but slow entrainment of free tropospheric air continues. As moisture builds up in the SML it becomes conditionally unstable and cumulus clouds form. These locally recouple the SML and cloud layer, and can either maintain the stratocumulus by supplying it with moisture from the SML, or quicken its dissipation by enhancing the entrainment of free tropospheric air into the cloud layer. The latter dominates as the cumulus clouds become more active over the warmest SSTs.

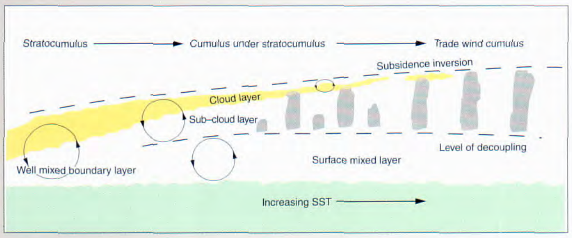


Fig. 43. Schematic diagram of the evolution of the subtropical boundary layer from persistent stratocumulus (yellow) to trade wind cumulus.

Evaporation is an important component in the exchange of energy between the atmosphere and ocean. TOGA–COARE (Tropical Ocean–Global Atmosphere: Coupled Ocean–Atmosphere Response Experiment) was an international experiment which aimed to study the interaction between the atmosphere and ocean in the tropical western Pacific. This is a region of high SST and strong convection. An intensive observing period, involving scientists from twenty countries, took place between November 1992 and February 1993. Observations were made from buoys, ships and aircraft (including the C-130) in an area centred 2° S, 155° E. Fig. 44 shows the relationship between the latent heat flux and the product between the mean wind speed and the sea to air specific humidity difference deduced from the observations. The latent heat flux was estimated from turbulence measurements made by the C-130 between 30 m and 60 m above the sea.

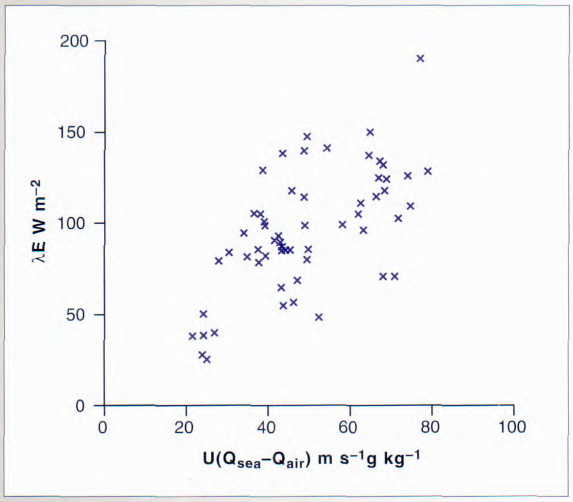


Fig. 44. Plot of the latent heat flux λE against the product of the mean wind speed U and the sea to air specific humidity difference ($Q_{sea} - Q_{air}$) for data obtained during TOGA–COARE.

The boundary layer over land

The MRU balloon facility is particularly suited to making direct turbulence measurements throughout the boundary layer, and hence testing models. Results are compared with the operational forecasting models and with fine-scale research models, including the LES model. The stable nocturnal boundary layer poses particularly difficult forecasting problems, and Fig. 45 illustrates how such measurements can help in devising better parametrizations by identifying differences between flow over 'heterogeneous' and 'homogeneous' terrain in such conditions.

Describing the surface transfer of momentum and heat in terms of effective roughness lengths requires a method of averaging the latter over the component surfaces within semi-rural areas. Observations of both local and area-average fluxes were compared with the various roughness length averaging schemes by using the balloon facility, combined with surface instrumentation, at Pershore, Hereford and Worcester. The intention was to recommend a scheme suitable for

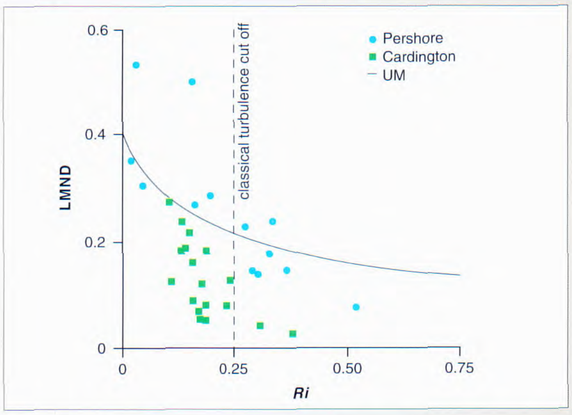


Fig. 45. Non-dimensional mixing-length (LMND) versus gradient Richardson number, Ri, in stable nocturnal conditions. Results shown for a 'heterogeneous', non-uniformly wooded area (near Pershore, circles) and at a more ideal site (Cardington, squares), together with a model parametrization. LMND is a measure of the effectiveness of turbulent momentum transport, and also closely related to heat transport.

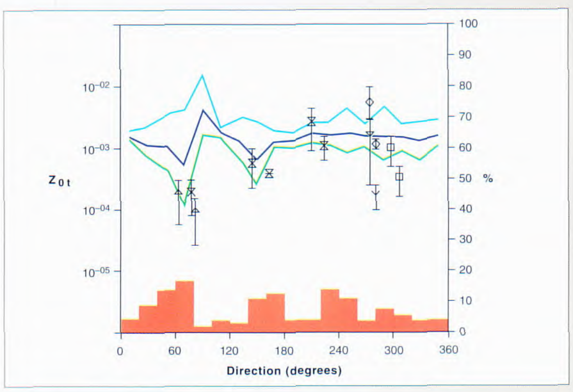


Fig. 46. Plot of effective roughness length for temperature (z_{0t}) against direction of fetch for an inhomogeneous, semi-rural landscape. The solid, dashed and dotted lines represent the averaging of terrain characteristics. The blending height method (full) of Mason, compared with two methods proposed by other authors the diffusion height (dashed) method and the simple logarithmic average (dotted). The histogram is the percentage rough cover in each direction.

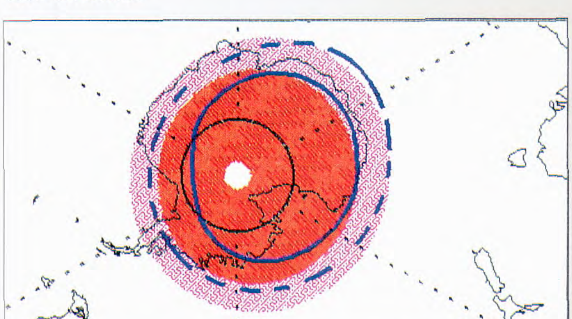


Fig. 47. Model simulations of the Antarctic ozone hole. Red region: ozone hole for current levels of chlorine; magenta region: ozone hole due to levels of chlorine expected in the year 2000. The blue contours show the approximate size of the ozone hole for the easterly phase of the quasi-biennial oscillation for current (continuous) and future (dashed) levels of chlorine.

numerical modelling that was applicable to both momentum and heat transport; the observations (Fig. 46) confirmed the method proposed earlier by Mason (1989).

Boundary layer over hills

Hills exert a net drag on the air that flows over them, and water waves exert a drag on the flow above them (but, unlike hills, the reaction on the waves themselves results in a flux of energy that may result in wave growth). Understanding and quantifying both mechanisms is important for subgrid-scale parametrizations in numerical weather prediction models and ocean wave models. However, recent studies have shown that predictions of drag and growth rates are very sensitive to the type of turbulence model used. LES model simulations of flow over surface undulations are particularly useful for this purpose because in a LES model only the smallest scales of turbulence are parametrized; the larger energy-containing eddies are explicitly resolved circumventing the dependence of the drag on the turbulence parametrization. The problem with flow over hills (and over waves) though, is that the scales on which the shear stresses change are relatively very small and so LES model simulations of such flows require more resolution than similar studies over flat terrain. Recent developments in computing power make such simulations possible and preliminary tests are under way.

Atmospheric chemistry and air quality

Stratospheric chemistry modelling

Data for the Antarctic stratosphere allow three-dimensional photochemical models to be validated quantitatively. Fig. 47 shows the results of a simulation with a stratosphere–mesosphere model of the Antarctic ozone hole. It illustrates the effect of increasing chlorine concentrations to levels that might be experienced by the year 2000. Also indicated are the effects of interannual variations of the tropical winds on the size of the ozone hole for current and future chlorine amounts. We are developing the operational Unified Model for fully coupled troposphere–stratosphere simulations; a 10-day test run has been completed with stratospheric chemistry involving 15 trace gas species.

In order to assess the risk of increases in ultraviolet (UV) radiation at the ground, and to provide forecasts of extreme events, a simple forecast scheme has been devised that relates the level of clear-sky UV radiation at the ground to the solar zenith angle and the total vertically integrated ozone; the latter can, in principle, be predicted by dynamical models. The operational UV forecasting scheme, however, deduces the total ozone amount from empirical relationships with meteorological predictors.

Tropospheric chemistry

OCTA (Oxidizing Capacity of the Tropospheric Atmosphere) is a project sponsored by the Commission for the European Communities, involving the Meteorological Office, two UK universities, and one Norwegian and three German research institutes. Measurements have been made with the C-130 during winter and spring to investigate the build-up of pollutants north of and across the polar front; these show strong contrasts across the polar front with increased hydrocarbon concentrations poleward, extending from the surface to the tropopause, and a strong seasonal decline in hydrocarbon concentrations between March and May. In summer the principal interest is in the transport of pollutants over long distances under photochemically active conditions; this is when the maximum removal of photochemical pollutants occurs. Many profiles of atmospheric composition were made in August from the coast of Europe across to Canada and south to Tenerife. Typically, free atmospheric values were representative of old tropospheric or stratospheric air, but on a few occasions concentrations of ozone, water vapour, carbon monoxide and hydrocarbons were all positively correlated. These positive correlations indicate a contribution to the tropospheric ozone budget from anthropogenic sources; such signatures can often be identified far away from the source regions.

Long-range dispersion

The NAME model, developed to simulate the transport, dispersion and deposition of radionuclides following a nuclear accident, is being reprogrammed to nest the global, regional and mesoscale grids, together with a high-resolution (5 km) deposition grid. Concentrations and deposition fields will be analysed over any, or all, the grids and a facility will be provided to transfer 'particles' (used to identify elements of the plume) across the boundaries from one grid to another. This will allow the highest available resolution to be used for any chosen locality; for example, a release being modelled at mesoscales over the UK can be transferred to the regional-scale grid as it moves over Europe, or vice versa. A more sophisticated parametrization of near-source diffusion than used hitherto, involving a random-walk, has been tested with excellent results. Fig. 48 illustrates the evolution of the Chernobyl plume using the latest version of the NAME model.

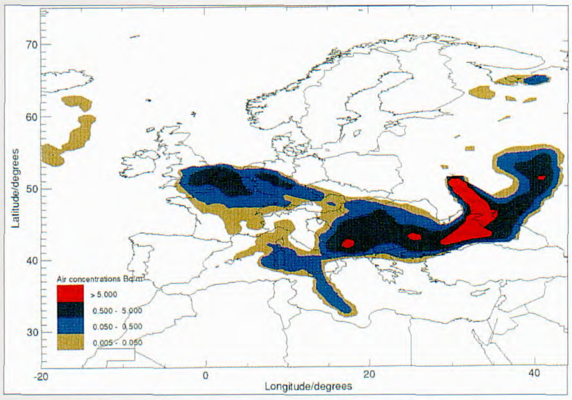


Fig. 48. The evolution of the Chernobyl plume as simulated by the regional version of the NAME model, using the latest available code and new graphics output now under development.

Short-range dispersion

Over short ranges, up to say 20 km downwind of a source of pollution, dispersion is dominated by turbulence in the boundary layer of the atmosphere. The UK Atmospheric Dispersion Modelling System (UK–ADMS) is a practical PC-based short-range dispersion model which is being developed jointly with Cambridge Environmental Research Consultants and National Power. The model addresses a variety of short-range dispersion problems and has sub-models to calculate deposition, radioactive decay, gamma radiation from elevated plumes, aspects of fluctuations in concentration, and the effects of hills, buildings and coasts. Phase 1 of the development of UK–ADMS will be completed soon with the release of version 1.06.

The Meteorological Office has also contributed to a project to harmonize European short-range atmospheric dispersion models. A number of dispersion models have been compared against three sets of atmospheric dispersion data. One of the achievements of this project was the establishment of agreed methods of using observations to evaluate and compare dispersion models (this is far from straightforward because of the large intrinsic variability and unpredictability of the dispersion process).

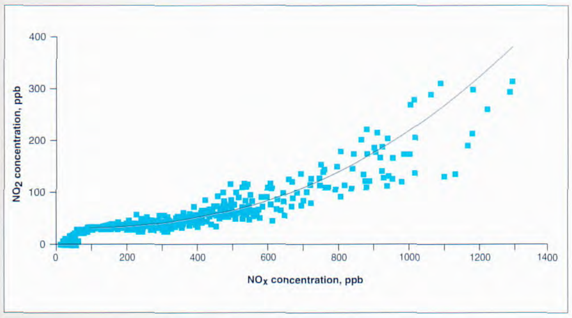


Fig. 49. A plot of the observed hourly mean NO_2 concentrations against those for NO_x from 20 May 1991 to 30 June 1992 for the Exhibition Road, London site. The full line shows the best-fit curve.

Urban pollution

Simple box models are used by the Meteorological Office to forecast urban pollution and provide the general public with forewarning of poor air quality. During summertime the pollutant of concern is ozone which is produced in high concentrations by sunlight-driven chemical reactions involving hydrocarbons and oxides of nitrogen. In wintertime, air quality can deteriorate during cold, stagnant and foggy conditions when concentrations of nitrogen dioxide (NO_2) and sulphur dioxide become significantly increased. The main source of the high concentrations of NO_2 in wintertime has been shown to be the reaction of the nitric oxide (NO), emitted from motor traffic, with oxygen :

$$2NO + O_2 = 2NO_2.$$

The production of NO_2 rapidly increases during episodes of poor atmospheric dispersion because the above reaction rate is proportional to the square of the NO concentration. Fig. 49 shows how this reaction influences the split between the concentrations of NO_2 and the total oxides of nitrogen (NO_x) in one year's air-quality observations at a roadside site in London. This relationship has important ramifications for air quality management. If the episodes of poor air quality can be reliably predicted, then the general public can be encouraged to leave their cars outside urban areas and use public transport.

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Mason, P.J., 1989, QJR Meteorol Soc, 114, 399–420.

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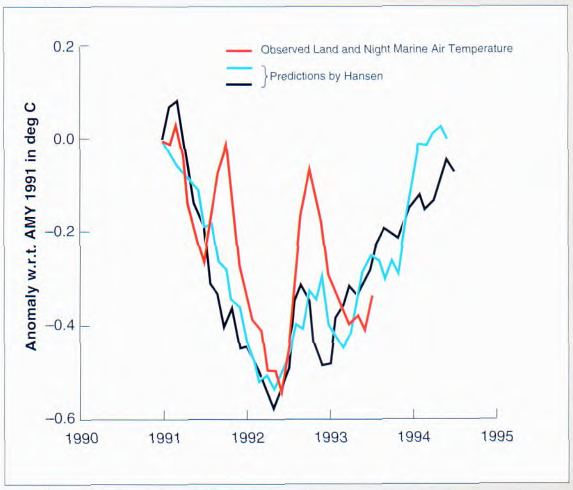


Fig. 50. The effect of the Mt. Pinatubo eruption (June 1991) on global surface air temperature.

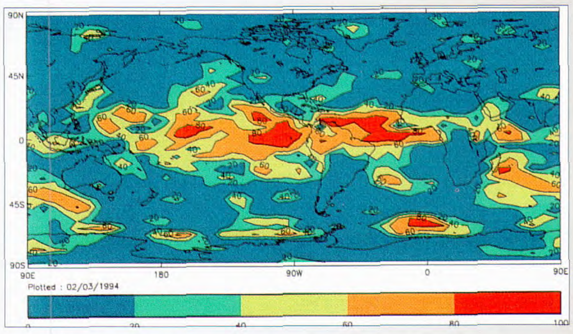


Fig. 51. Showing the strong influence of SST variations on decadal rainfall variability in the tropics: June, July and August.

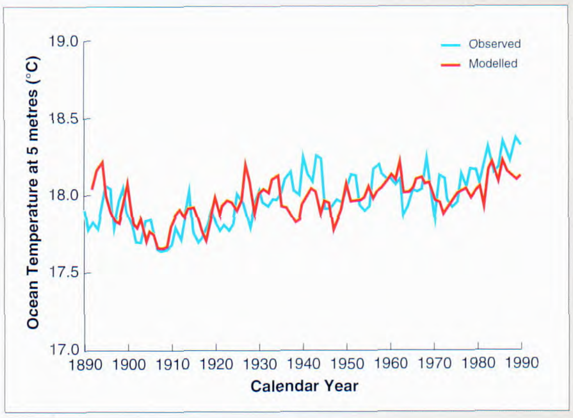


Fig. 52. Control run showing forecast SST to have interannual to decadal time-scale variability similar to that observed, with little or no trend overall.

Climate variability and change

Introduction

The issue of climate change continues to attract a high level of public attention and debate. Research into prediction of climate change is the main focus of the Hadley Centre, which is jointly funded by the Department of the Environment (DoE) and the Met. Office. The major objectives of the Centre are (a) to simulate the present climate, (b) to monitor and understand natural climate variability, (c) to understand the factors controlling climate change, and (d) to predict global and regional climate change to the end of the 21st Century. It aims to provide a focus for other national research programmes relevant to these areas of work, in particular by incorporation of their results into predictive models of the atmosphere, ocean, land surface and sea ice.

Climate prediction requires these models to be run in coupled mode, so allowing the interactions between the components to be represented. A major facility for this task has been provided by a DoE-funded Cray YMP8/864 supercomputer dedicated to climate research. As noted in the section on Computing and Telecommunication, this facility has recently been considerably enhanced by the Cray Y-MPC90/16256 system delivered in March 1994. Rapid and effective analysis of results is provided by a graphics workstation system.

Observed climate variability and change

Databases for studying and monitoring observed climate variability and change continue to be improved. Tests have confirmed that global and hemispheric temperature changes over the last century are insensitive to the method of analysis. Sea surface temperature analyses that include satellite data are being blended with a land-surface air temperature data set, developed in collaboration with the University of East Anglia's Climatic Research Unit, to provide improved global data coverage. With the help of international collaboration, the Centre's historical monthly-average mean sea level pressure data set is being extended to enable analysis of near-global changes in circulation over the last century. Available worldwide maximum (day) and minimum (night) surface air temperatures now cover over 40% of the land surface. Analysis confirms the view that minimum temperatures have risen more than maximum temperatures over recent decades. The eruption of Mount Pinatubo in June 1991 was widely expected to cause a cooling of global mean temperature of up to 0.5 °C. Comparison of global surface air temperature changes over the land and oceans since then confirms this, though the observed record contains other influences (Fig. 50). As a result 1993, like 1992, was globally cooler than the very warm years preceding the eruption.

Simulated climate variability

The links of climate variability with sea surface temperature (SST) are being examined in ensemble experiments using the Unified Model run with the Centre's Global analyses of sea Ice and Sea Surface Temperature (GISST) which extends from 1871 to date. Initially these runs concentrate on the years 1949–90 and 1904–13, periods when the observed atmospheric flow showed marked differences. By way of illustration, Fig. 51 shows the strong influence of SST variations on decadal rainfall variability in the tropics.

Simulation and prediction of climate change

Improvements to the Coupled Atmosphere–Ocean Model for a second 'transient response' experiment, to determine how climate will change as a result of the continual rise in the atmospheric concentrations of greenhouse gases, included incorporating a simple representation of sea ice drift. This substantially improved the behaviour of sea ice in the simulation of the 'control' (present day) climate of the model and eliminated the need for corrective fluxes over sea ice. A 100-year control run has since been completed. Fig. 52 shows this to have interannual to decadal time-scale variability similar to that observed, with little or no trend in SST overall.

When carbon dioxide is doubled in the Unified Atmospheric Model coupled to a mixed layer ocean model, the global mean equilibrium temperature of the model increases by 4 °C. This compares with 3.4 °C simulated by the previous Hadley Centre model. The largest difference in the patterns of warming occurs over the tropical oceans resulting from differences in feedbacks associated with high cloud. Both models show good agreement with satellite observations in their calculations of present-day radiative fluxes. This highlights the need for in-cloud data to verify the microphysical characteristics of simulated cloud to help tell which model is the more realistic.

Industrial activity over the past century has been accompanied by increased concentrations of atmospheric sulphate aerosols. Their effects on climate can be both direct, through scattering of sunlight, and indirect, through a modification of the droplet size of water clouds and hence the cloud brightness. The direct effect has been investigated by representing the scattering as an increase in surface albedo. Adding the current industrial loading of aerosol reduces the warming due to doubled CO_2 by about 20% globally, and by over 50% in the main industrial regions. This leads to a simulated pattern of temperature change due to increased carbon dioxide more like that observed over the last century.

The indirect effects have also been assessed, using relationships developed at University of Manchester Institute of Science and Technology (UMIST) and MRF. Using sulphate distributions generated by a chemical transport model, the indirect aerosol effect was tentatively estimated as a cooling of -0.9 W m^{-2}. This figure should be compared with the estimated 2–2.5 W m^{-2} warming to date from emissions of greenhouse gases.

Comparisons of model calculations and of past climate with palaeoclimate data may help to understand the longer-term processes leading to climate change. A simulation of conditions 115,000 years ago has suggested that changes in orbital parameters alone may not be sufficient to produce ice ages.

Regional climate modelling

Two approaches are being used to address ways of generating information at finer resolution on the regional scale than is possible with the current generation of climate models. The first is to use a nested high-resolution model within the GCM. As would be expected the Regional Model shows greater and more realistic detail. Output from the global sensitivity study to assess the impact of doubling carbon dioxide concentrations in the Unified Model has recently been used to drive this model for three years using a 50 km mesh. Work has also continued on the alternative approach of developing statistical relationships between variables from the Global Model and locally observed weather.

Atmosphere and land-surface models — development and validation.

The formulation of the physical processes in the Unified Model continue to be improved. In particular, revisions have been made to the evaporation of precipitation, convection, moisture diffusion and the cloud layer schemes of its climate and operational forecast configurations. Improvements have also been made to the representation of the land surface; a new radiation scheme has been further developed, as has an explicit representation of the radiative effects of trace gases.

Surface, boundary layer and convective processes

Results of detailed modelling studies carried out at the Joint Centre for Mesoscale Meteorology (JCMM) have been used to revise the Unified Model's evaporation scheme for rain and snow. The revised scheme brought improvements to both the climate version and mesoscale and limited-area forecasts. Comparison of the convection scheme against the JCMM's three-dimensional cloud model suggested reducing the Unified Model's entrainment rate for deep convection. The benefits were a reduction of the model's cold bias, and improvements in the simulation of the Indian Monsoon flow and the Hadley circulation.

A new multi-layer soil hydrology scheme for the model has been further improved as a result of an intercomparison study, sponsored by the Commission for the European Communities (CEC), in which the Centre took part. The changes significantly increased the model's northern summer rainfall in regions which were otherwise deficient. The revised version has been used in collaborative studies (with NERC's Institute of Hydrology at Wallingford and the Instituto Nacional de Pesquisas Espacias, Brazil) of surface characteristics over forested and deforested areas of Amazonia.

A simplified version of a photosynthesis model, developed at NERC's Institute of Terrestrial Ecology, Edinburgh, has been directly coupled into the Unified Model. This follows studies which emphasized the need for such coupling to avoid overestimating the response of plant growth due to increased carbon dioxide. A climate model experiment to assess the sensitivity of climate to increased stomatal resistance, which may be a consequence of increased carbon dioxide, has been carried out. It showed a 1 °C global warming for a 50% increase in stomatal resistance.

Radiation, clouds and aerosols

A systematic error common to many climate models is their poor representation of subtropical stratocumulus (see also page 40). Studies have shown its simulation to be significantly improved by increased vertical resolution. The impact of including minor trace gases in the existing Unified Model radiation scheme has been assessed in preparation for experiments to determine the importance of explicitly including minor trace gases in investigations of future greenhouse warming. Methods have also been developed for estimating the greenhouse warming potential of atmospheric gases. A new radiation code for the model has been further improved to produce results very close to those from state-of-the-art radiative models. It has also been made computationally more efficient. A scheme for the growth of aerosols with humidity has been devised for future studies with the new code.

The system for the Simulation and Analysis of Measurements from Satellites using Operational aNalyses (SAMSON) uses global analyses, produced by weather forecast models as the input to a detailed radiative transfer code to simulate atmospheric heating rates. The system has been used to assess the climate model simulation of the clear-sky greenhouse effect. The model's results are affected by air which appears to be too dry in the model in the middle to upper troposphere at low latitudes, but elsewhere they compare favourably with SAMSON and with other models.

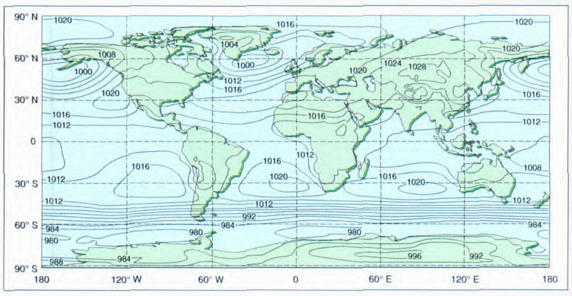
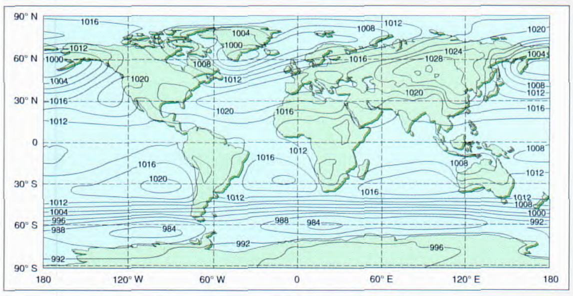


Fig. 53. The result of a run of the Unified Model at climate resolution for December, January and February. (a) AMIP run 10-year run 1978–88



(b) Met. Office analyses 1983–92.

Model validation

Validation of the atmospheric component of the Unified Model has been given particular impetus this year through the Hadley Centre's participation in two model intercomparison studies. The first of these is the Atmospheric Model Intercomparison Study (AMIP), sponsored by the World Climate Research Programme. It aims to compare model runs using observed SSTs and ice extents over the period 1979–88. A run of the Unified Model at climate resolution has been performed and the results contributed to the project. The simulated climate has been compared with a variety of data and, as illustrated by Fig. 53, its general quality is high.

A run is also being carried out at operational resolution as part of an international project sponsored by the National Meteorological Services' European Climate Support Network and based on the same principles as AMIP. The study is providing useful insight into model performance at this resolution.

Development of ocean, sea ice and ocean carbon cycle models

A version of the Coupled Atmosphere–Ocean Model with the ocean on a basic 1.25° grid, but with higher resolution (1⁄3°) in the tropics, has been further developed for use in studies of climate variability and for climate prediction. The model can now be run with an option for enhanced resolution in the tropics, and is being modified to include a dynamical model of sea ice. Ice dynamics have also been incorporated into the 2.5° × 3.75° model. A particular issue in coupled modelling is the degree to which it is necessary to bring the ocean component of the model to equilibrium. This requires integration times of the order of millennia so further investigation has been made of the use of techniques to accelerate the spin-up of ocean models. Another issue is the need, in the present generation of coupled models, for sizeable adjustments to the fluxes at the air–sea interface so as to prevent the model's climate from drifting. Work has been carried out to identify the causes of the largest of these flux adjustments and to develop methods which reduce them.

Ocean model intercomparison studies, carried out in collaboration with NERC's James Rennell Centre for Ocean Circulation, have provided valuable insight into the formulation of the models involved. A simplified ocean biology model, developed in collaboration with the James Rennell Centre and the NERC Plymouth Marine Laboratory, has been coded into the Ocean Model in combination with the inorganic model developed previously, and used to simulate the annual cycle of biological growth and decay.

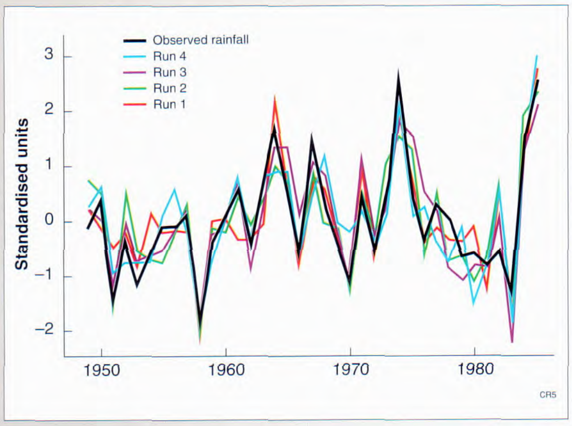


Fig. 54. Standardized rainfall from the Unified Model for four runs and an observed series provided by C. Nobre (personal communication): the wet season in North-East Brazil.

Seasonal variability and forecasting

Coupled interactions between the tropical oceans and global atmosphere associated with the El Niño-Southern Oscillation (ENSO) provide an important mechanism for developing techniques of seasonal prediction. A tropic-wide mode of rainfall variability has been discovered and its relationships with ENSO studied. Long runs, made with the tropical Pacific-global atmosphere and the high-resolution global coupled models, show ENSO-time-scale variability. These and simpler models are now being used in hindcast experiments of past ENSO events to explore the potential for prediction. Techniques of ocean data assimilation are being introduced to initialize the Pacific Ocean circulation model used in these studies.

Seasonal rainfall forecasts produced for tropical North Africa and for North East Brazil all verified with good skill overall. Further areas of potential predictability are being sought in the ensemble runs with the atmospheric model forced by GISST. On seasonal time-scales, SST and sea ice extent variations are assessed to have a relatively small, but significant, impact on sea level pressure variations over Europe. As might be expected, however, SST variations have a much larger influence on seasonal tropical rainfall. Fig. 54 shows the high skill of the Unified Model in simulating the February to May wet season over North-East Brazil.

Middle atmosphere research

The international Upper Atmosphere Research Satellite (UARS) project continues to provide a focus for research into the middle atmosphere. The Met. Office contributes to the project by using a version of the Unified Model data assimilation scheme to provide analyses of available data. These are produced daily and supplied to the UARS science team via the NASA Goddard Space Flight Center. The evolution of winds in the tropics has been examined using the analyses. They show very clear quasi-biennial and semi-annual oscillations (Fig. 55) in the westerly wind, previously recorded in rocket soundings. This is believed to be the first time that the semi-annual oscillation in the upper stratosphere has been captured in analysed wind fields. The data assimilation system has also been successfully used to analyse temperatures from the UARS Improved Stratospheric and Mesospheric Sounder.

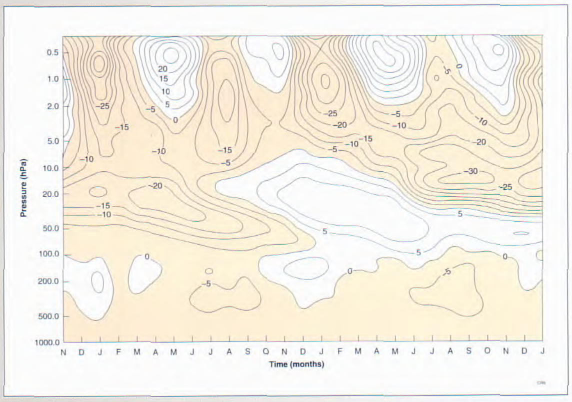


Fig. 55. An analysis of zonal-mean westerly winds at the Equator using UARS data showing quasi-biennial and semi-annual oscillations in the westerly wind. Average from November 1991 to January 1994.

Theoretical studies are helping with interpretation of UARS measurements. Domain-filling trajectory techniques, in which one hemisphere is filled with about 40,000 particles, have been used in tracer studies. They show that measurements of nitrous oxide are consistent with trajectory calculations. The trajectories, and observations of water vapour by the Microwave Limb Sounder indicate transport of low-latitude material across the stratospheric jet and into the polar vortex.

Much improved analyses of potential vorticity have been produced by combining a simple Lagrangian method for 4-D variational analysis of it with conventional data. The scheme has also been extended to analyses of chemical species by incorporating a chemical model developed at the University of Cambridge.

External liaison

Strong links are maintained between the Hadley Centre and other groups involved in research on climate change, both in the UK and throughout the world. A few of these have already been indicated above, and there is an active programme of exchange visits, in particular as part of the DoE-funded Climate Prediction Programme within the Centre. Active involvement with other European groups is maintained, especially by participation in the CEC Environment Programme, the European Climate Support Network and the newly established European Climate Computing Network.

Intergovernmental Panel on Climate Change (IPCC)

The Hadley Centre hosts the Technical Support Unit for the Scientific Assessment Working Group (WGI) of the IPCC. The unit, which is funded by the DoE, coordinates the planning, preparation, review and publication of the periodic IPCC reports. It also provides a central reference point for IPCC activities.

Much of the work of the IPCC is aimed at supporting implementation of the Framework Convention of Climate Change (FCCC), originally signed by around 150 countries at the Earth Summit in Rio de Janeiro in June 1992. Developed countries are required by the FCCC to submit national inventories of greenhouse gas emissions. IPCC, with the assistance of the Organisation for Economic Cooperation and Development, has been developing guidelines for the calculation and reporting of these inventories. Work is also proceeding on the IPCC 1994 WGI report on the radiative forcing of climate; this will include the most recent and reliable calculations of the greenhouse warming potential of a wide range of gases and a detailed review of the global carbon cycle, atmospheric chemistry and aerosols. The second IPCC Scientific Assessment of Climate Change is being organised and is due to be completed in 1995.

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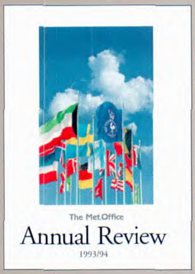
List of acronyms used in this report

(UK) - ADMS	Atmospheric Dispersion Modelling System
ALFENS	Automated Low Flying and Enquiry Notification System
AMIP	Atmospheric Model Intercomparison Project
AMSU	Advanced Microwave Sounding Unit
AMT	Air Mass Transformation
APP	Acoustic Prediction Package
ARIES	Airborne Research Interferometer Evaluation System
ASDAR	Aircraft to Satellite DAta Relay
ASTEX	Atlantic Stratocumulus Transition EXperiment
ATD	Arrival Time Difference
AWS	Automatic Weather Station
CAMOS	Computer Aided Meteorological Observing Sysytem
CCN	Cloud Condensation Nuclei
CEC	Commission for the European Community
CEOS	Committee for Earth Observation Satellites
CFO	Central Forecast Office
CHEMET	CHEmical METeorology
CNS	Computer Newspaper Services
COSMOS	Met. Office's central computing complex
CPP	Climate Prediction Programme
CRDN	Civil Rented Data Network
ECMWF	European Centre for Medium-range Weather Forecasts
ENSO	El Niño—Southern Oscillation
EPS	European Polar System
ESA	European Space Agency
EUCREX	EUropean Cloud Radiation EXperiment
FAMIS	Financial and Accounting Management Information System
FLIR	Forward Looking Infrared
FRONTIERS	Forecasting Rain Optimized using New Techniques of Interactively Enhanced Radar and Satellite
GCOS	Global Climate Observing System
GISST	Global analyses of sea Ice and Sea Surface Temperature
GOES	Geostationary Operational Environmental Satellite
GUI	Graphical User Interface
HORACE	HQSTC OASYS Replacement and CFO Enhancement
HQSTC	Headquarters Strike Command
IAEA	International Atomic Energy Agency
ICAO	International Civil Aviation Organization
IDS	Image Display System
IPCC	Intergovernmental Panel on Climate Change
ISDN	Integrated Services Digital Network
IWP	International Weather Productions
JCMM	Joint Centre for Mesoscale Meteorology
LES	Large-Eddy Simulation
LMND	Non-dimensional mixing-length
MARSS	Micrwave Airborne Radiometer and Scanning System
MIST	Meteorological Information Self-briefing Terminal
MMU	Mobile Meteorological Unit
MODS	Mobile Outstation Display System
MPP	massively parallel processors
MRF	Meteorological Research Flight
MRU	Meteorological Research Unit

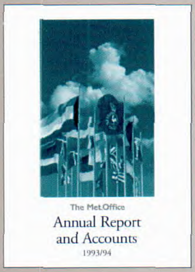
MSG	Meteosat Second Generation
MUM	Mesoscale Unified Model
NAME	Nuclear Accident ModEL
NASA	National Aeronautics and Space Administration
NERC	Natural Environment Research Council
NOAA	National Oceanic and Atmospheric Administration
nss	non-sea-salt
NVG	Night Vision Goggles
NWP	Numerical Weather Prediction
OASYS	Outstation Automation System
OCTA	Oxidising Capacity of the Tropospheric Atmosphere
ODA	Operational Decision Aid
ODS	Outstation Display System
OPUS	Outstation Production Unified System
PACRAM	Procedures And Communications in the event of an accidental release of RadioActive Material
PVA	positive vorticity advection
RAFC	Regional Area Forecasting Centre
RSMC	Regional Specialised Meteorological Centre
SADIS	satellite distribution system
SAFIRE	Scanning Airborne FIlter RadiometEr
SAMOS	Semi-Automatic Meteorological Observing System
SAMSON	Simulation and Analysis of Measurements from Satellites using Operational aNalyses
SML	surface mixed layer
SST	sea surface temperature
SSU	Stratospheric Sounding Unit
TDA	Tactical Decision Aid
TIS	Telephone Information Services
TOGA–COARE	The Tropical-Ocean Global-Atmosphere Programme's Coupled Ocean Atmosphere Response Experiment
TROPICS	Transmission and Reception of Observational and Product in formation by computer-based Switching
UARS	Upper Atmosphere Research Satellite
UK-ADMS	UK Atmospheric Dispersion Modelling System
UMIST	University of Manchester Institute of Science and Technology
WAFC	World Area Forecasting Centre
WC	Weather Centre
WGI	Scientific Assessment Working Group
WIN	Weather Information Network
WMO	World Meteorological Organization
WOCE	World Ocean Current Experiment
WWW	World Weather Watch

Met. Office Annual Report Publications

The Met. Office publishes its annual reports in three booklets, the Annual Review, Annual Report and Accounts and the Scientific and Technical Review.



The Annual Review summarises the Met. Office's activities during the year. Its broad view of the Met. Office is of particular interest to those who do not specialise in meteorological science, but who are interested in the uses of weather intelligence. It is available free of charge, while stocks last, by contacting the Enquiries Office at Bracknell.



Full details of the Met. Office's accounts are contained in the Annual Report and Accounts, as required by the Treasury. Copies of the Annual Report and Accounts are available from HMSO bookshops in London, Bristol, Birmingham, Manchester, Belfast and Edinburgh, and from HMSO's accredited agents listed in Yellow Pages.

The Scientific and Technical Review gives a more detailed account of the research work being carried out at the Met. Office. This year the emphasis is on developments in Central Forecasting, Commercial Services and Atmospheric Processes Research Divisions. There is also a bibliography of papers published by scientists at the Met. Office over the last year. Copies are available, while stocks last, from the Enquiries Office at Bracknell.

To find out more about our services, you can contact your nearest weather centre or the Enquiries Office at Bracknell. The new number, operational from 1st August 1994, is shown in brackets.

Weather Centres

Aberdeen	0224 210574	(01224 210574)
Belfast	08494 22339	(01849 422339)
Birmingham	021-717 0570	(0121 717 0570)
Bristol	0272 279298	(0117 927 9298)
Cardiff	0222 397020	(01222 397020)
Glasgow	041-248 3451	(0141 248 3451)
Leeds	0532 451990	(0113 245 1990)
London	071-831 5968	(0171 831 5968)
Manchester	061-477 1060	(0161 477 1060)
Newcastle	091-232 6453	(0191 232 6453)
Norwich	0603 660779	(01603 660779)
Nottingham	0602 384092	(0115 938 4092)
Plymouth	0752 251860	(01752 251860)
Southampton	0703 228844	(01703 228844)

Most Weather Centres are open 24 hours a day, 7 days a week. A few are closed overnight but an answering service is provided.

Past weather and climate information can be obtained from our Bracknell Headquarters or

Belfast Climate Office	0232 328457	(01232 328457)
Edinburgh Climate Office	031-244 8362	(0131 244 8362)

These offices are open during normal working hours.

International Marine and Offshore services enquiries: +44 (0)224 211840 (+44 (0)1224 211840)
International Commercial Enquiries: +44 (0)344 856283 (+44 (0)1344 856283)
Recruitment 0344 856038 (01344 856038)

Information on our Library and Archive, including the loan of weather books, videos, slides etc., can be obtained from The National Meteorological Library at Met. Office headquarters:

Enquiries Office 0344 854455 (01344 854455)

The Met. Office, London Road, Bracknell, Berkshire RG12 2SZ,
Telephone: 0344 854843 (01344 854843).

Data Protection Act

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The Met.Office

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