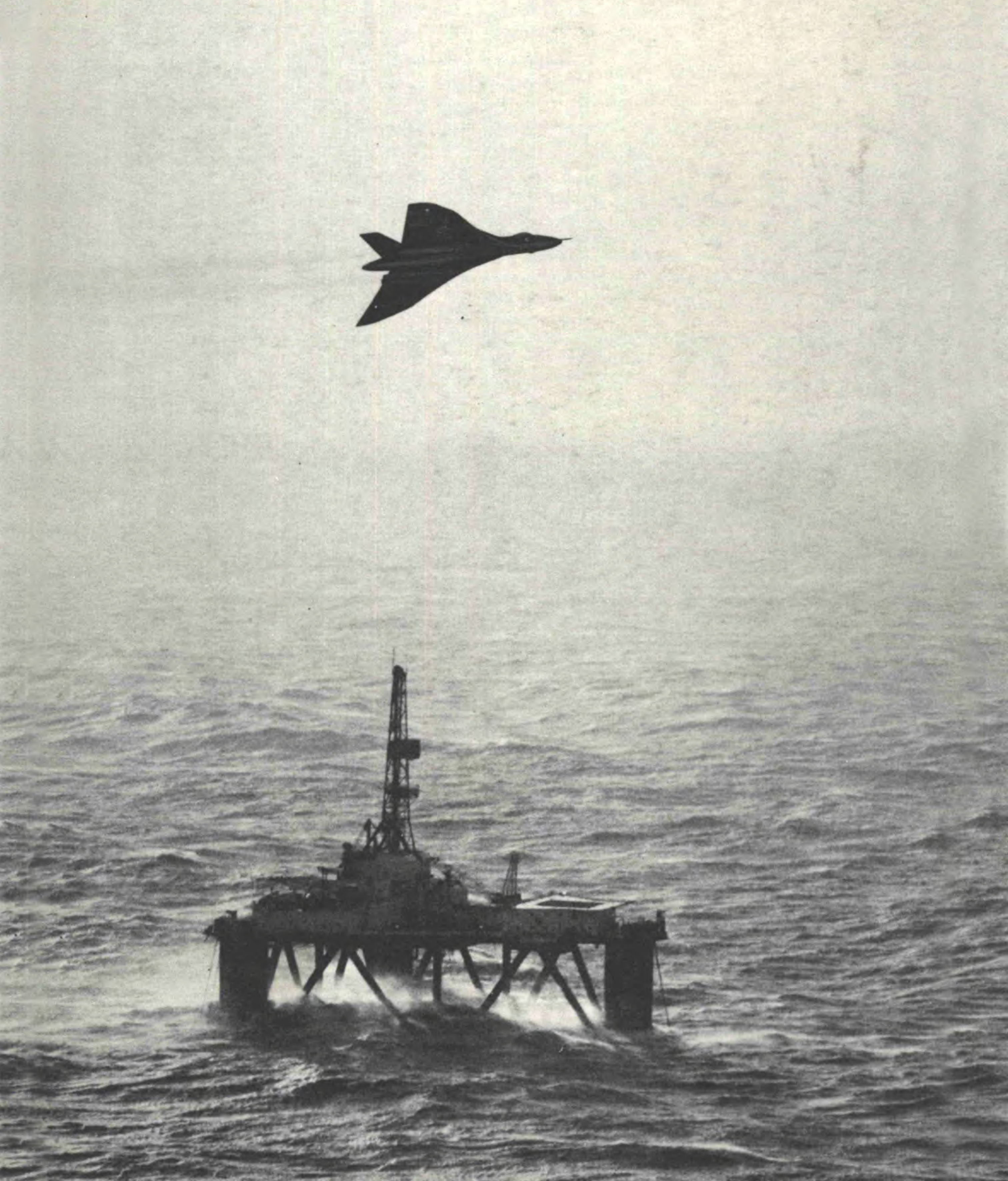
Meteorological Office

Annual Report 1976



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ANNUAL REPORT

ON THE

METEOROLOGICAL OFFICE

1976

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

LONDON
HER MAJESTY'S STATIONERY OFFICE

U.D.C.
551.5(058)

ISBN 0 11 400303 3

Cover photograph: A Vulcan of No. 27 Squadron, RAF Scampton, on a routine flight over the North Sea.

FOREWORD BY THE DIRECTOR-GENERAL

The year was dominated by the drought, the driest 16 month spell over England and Wales since 1727, followed by a very wet autumn during which the soil moisture and the water supply were replenished remarkably quickly. Such unusual events, which can be expected to occur on average only once in 500 years, cannot be predicted in advance but stimulate great public and scientific interest in the nature and causes of climatic fluctuations. The problems arising from the drought strengthened the already close collaboration between the Meteorological Office and the water industry and further demonstrated the value of our readily accessible data banks and of accurate forecasting for a few days ahead.

The drought, during which southern England received only 50 per cent and much of western Europe less than 75 per cent of the normal rainfall while western Russia and the Balkans had well above average amounts, was closely linked to changes in the atmospheric circulation over the northern hemisphere. During the drought the mean position of the Atlantic–European sector of the jet stream was displaced about 1500 kilometres north-westwards from the normal location to lie between Iceland and Scotland, and the centres of the major depressions moved well north of the British Isles. This was also accompanied by a marked recession of the Arctic ice.

Although these anomalies had dramatic consequences for the British Isles, they were much less impressive when viewed on the global scale and were probably the result of only rather minor fluctuations or readjustments in the large-scale atmospheric circulation which caused compensating changes elsewhere. Neither the European nor the Sahelian drought, both of which have since been followed by heavy rains, suggest major and permanent changes in the character of the climate, but both are expressions of its variability. Unfortunately there is no physical basis for predicting either the timing or the magnitude of such fluctuations because we do not as yet understand the underlying causes. The most promising approach lies in the development of complex computer models to simulate the global climate and its variations and is being very actively pursued in the Meteorological Office and in the United States. During the year our models have been used to study the likely local and widespread effects on the weather of sea-surface temperature anomalies in the tropical Pacific Ocean, the feedback mechanisms by which the dryness of the Sahara Desert is perpetuated, and the hypothesis that the major ice ages of the last million years were caused by variations in the intensity of the solar radiation as the result of long-term changes in the earth's orbit. Global models have also been used to help design the first global experiment of the Global Atmospheric Research Program due to take place in 1978–79. Techniques have been developed for inserting into the models observations from satellites, constant-level balloons, floating buoys and aircraft as well as those from the conventional global meteorological system, taking into account their different characteristics and accuracies, and for testing the effects of various configurations of observing platforms, especially of the proposed network of floating buoys in the Southern Oceans, on the quality of numerical simulations of global weather systems.

The computer models which form the basis of the daily weather forecasts have undergone further development and have been particularly successful in predicting the frequent and rapid weather changes of the last few months, including the heavy snowfalls in December. The introduction of new schemes for integration of the equations has reduced the computer time required by a further factor of three, so that the model is now running more than ten times faster than when it was introduced four years ago. Overall the computer forecasts for 48 hours ahead are now as good as the 24-hour predictions were a few years ago, while the 72-hour forecasts are now about as good as the earlier 48-hour predictions. Evaluation of computer forecasts made up to six days ahead shows that up to five days they are better than forecasts made on the basis of persistence and climatology but further progress will require improvements in the physics of the model and its extension to cover the tropics and perhaps the whole globe.

The demand for forecasts and for weather information and advice of all kinds continues to grow. The number of direct enquiries to forecasting offices reached a new record level of 1·87 million. In addition 2·15 million forecasts were made for civil and military aviation and 16·3 million calls were made on the Automatic Telephone Weather Service compared with 16·9 million in 1975. The dissemination of weather forecasts by television has been strengthened by additional live presentations on BBC–2 at 7 p.m. and on BBC–1 after the 9 p.m. news on Fridays only. The BBC Ceefax and IBA Oracle experimental data transmissions include weather information provided by the London Weather Centre and similar trials are being carried out on the Post Office Viewdata service. These services have considerable potential for bringing more local and detailed weather advice to special user-groups than is possible by the mass media. The introduction on Radio 3 of a comprehensive forecast, of about five minutes' duration, for land areas and inshore waters has proved of particular value for yachtsmen and others for whom the routine shipping forecast gives insufficient detail.

Specialized services for the offshore oil and gas industry continue to expand. The special team of forecasters at London Weather Centre has been further strengthened during the year and a new model for forecasting waves and swell is being developed. A tailor-made service for helicopters serving the rigs and platforms is provided from several forecasting offices; a new office for this purpose will be opened at Sumburgh in Shetland. The ship-routeing service continued to provide special forecasts and advice for the towing and erection of rigs including a supervised tow from Japan to the Persian Gulf lasting 67 days. Services for the offshore industry form the subject of the Special Topic on pages 1–7.

With the introduction of regular flights to Bahrain and Washington, the Office is co-operating closely with British Airways in developing forecast procedures that will allow Concorde to carry the maximum number of passengers. Forecasts are provided of winds and temperatures up to 55 000 ft and of the probabilities of encountering hail, clear-air-turbulence and convection cloud tops above 25 000 ft. At the request of the French authorities forecasts have also been provided for Concorde aircraft flying from Paris to the Middle and Far East.

The US weather ships having been lost from the western Atlantic, it was a relief when, after protracted negotiations, a new agreement was signed by enough nations to guarantee the operation of the four eastern Atlantic stations for at least the next five years. The Meteorological Office, instead of manning two stations with four ships, now operates one station with two ships, the other station being serviced by the USSR. The two best of our very old ships are now being refurbished and will be back in service early in 1977 under new names, *Admiral FitzRoy* and *Admiral Beaufort.*

The maintenance of an adequate network of observing stations on land and sea is likely to depend increasingly on automatic weather stations. Ten of these are now being installed to supplement or replace manned stations and additional units are being built by the Office for installation on oil rigs and platforms in the North Sea. A few stations have now operated very satisfactorily for more than a year.

To select only a few of the many research projects in physical meteorology, the following are worthy of special mention.

A continuing study of radiation fog using the tethered balloon facilities at Cardington has shown that the major factors which govern the life history of such fogs are the complex interactions between, on the one hand, radiative cooling which induces fog formation and, on the other hand, turbulent diffusion and the gravitational settling of fog droplets which inhibit it. Parallel development of numerical models and improved instrumentation to monitor the key parameters facilitates a more detailed study and the program is being extended to include the related problem of the formation of stratocumulus cloud in anticyclonic conditions.

Much work has been done in preparation for a major international Air–Sea Interaction Experiment in which the Netherlands, the Federal Republic of Germany, the USA, USSR and the UK will operate about 12 ships in an area of the North Atlantic near Rockall. The experiment is intended to study the detailed structures of the upper layers of the ocean and the lower layers of the atmosphere and the interaction of both with the larger-scale motions of air and sea. Our research group at Porton Down is co-ordinating the meteorological measurements to be made by all participants and is itself developing tethered balloon borne equipment to measure the vertical fluxes of heat, momentum and water vapour. The measurements will be extended upwards and over a wider area by research aircraft including one from our Meteorological Research Flight.

The vast quantity of data, amounting to one thousand million measurements, acquired during 40 sorties by the Hercules flying laboratory in the international Atlantic Tropical Experiment in 1974 has now been largely processed, checked and made available on magnetic tapes to the other countries participating in the experiment. The data are of high quality and will make a unique contribution to the experiment.

Good progress continues to be made in building radiometers to measure stratospheric temperatures from the next series of US meteorological satellites. The development model has passed rigorous testing in the UK and USA; the first flight model will be delivered very shortly and is scheduled for launch in 1978 in time to contribute to the global observing experiment. The Office has provided support and guidance to the European Space Agency in developing the geostationary weather satellite due to be launched in the autumn of 1977 and the associated data-processing facilities. Good progress has been made in building up the ground station at Lasham which will receive data from this and from United States satellites.

February 1977
Meteorological Office
Bracknell, Berks.

B. J. MASON

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FUNCTIONS OF
THE METEOROLOGICAL OFFICE

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

The general functions of the Meteorological Office are:

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

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

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

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

(e) The maintenance of the observatories at Kew and Lerwick.

(f) The provision of professional training in meteorology.

(g) Research in meteorology and geophysics.

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

Except for the common services provided by other government departments as part of their normal functions (e.g. accommodation by the Property Services Agency of the Department of the Environment, and stationery by Her Majesty's Stationery Office) the cost of the Meteorological Office is borne by Defence Votes.

The gross expenditure of the Meteorological Office for the financial year 1976/77 including that on the common services (Property Services Agency and HM Stationery Office) is estimated to be £28·3 million. Of the amount chargeable to Defence Votes, about £17·1 million represents expenditure associated with staff and £10·7 million expenditure on stores, communications and miscellaneous services. It is estimated that some £8·4 million will be recovered from other government departments and outside bodies for services rendered, sale of meteorological equipment etc.

COMMITTEES

METEOROLOGICAL COMMITTEE

Terms of reference:

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

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

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

Membership at 31 December 1976:

Chairman: The Earl of Halsbury, F.R.S.

Members: Professor A. H. Bunting, C.M.G.
Sir Frederic Harmer, C.M.G.
Professor J. T. Houghton, F.R.S. (Chairman, Meteorological Research Committee) (*ex officio*)
(and one vacancy)

Secretary: Mr A. C. Hughes (Secretary, Meteorological Office)

The Committee met once in 1976.

ADVISORY COMMITTEE ON METEOROLOGY FOR SCOTLAND

Terms of reference:

(a) To review the development of meteorological science and its application to Scotland.

(b) To submit to the Meteorological Committee any proposal in connection therewith.

Membership at 31 December 1976:

Chairman: Dr B. J. Mason, C.B., F.R.S. (Director-General, Meteorological Office)

Members: Mr R. J. H. Brush (University of Dundee)
Dr H. E. Butler, F.R.S.E. (Royal Society of Edinburgh)
Dr J. M. Caborn (University of Edinburgh)
Sir Samuel C. Curran, F.R.S.
Professor S. Desmond Smith, F.I.P., F.R.S.E. (Heriot-Watt University)
Mr J. Ferguson (Department of Agriculture and Fisheries for Scotland)
Professor G. M. Howe (University of Strathclyde)
Mr R. Lines (Forestry Commission)
Dr D. H. McIntosh, F.R.S.E. (Department of Meteorology, University of Edinburgh)
Councillor W. J. McKechin (Convention of Scottish Local Authorities)
Professor H. Meidner (University of Stirling)
Dr I. S. Robertson (University of Aberdeen)

Mr S. C. Agnew (Scottish Development Department)
Dr J. H. Steele (Department of Agriculture and Fisheries for Scotland)
Professor D. W. N. Stibbs, F.R.S.E. (University of St Andrews)
Professor P. A. Sweet (University of Glasgow)

Secretary: Mr W. G. Harper (Meteorological Office)

The Committee met once in 1976.

METEOROLOGICAL RESEARCH COMMITTEE

Terms of reference:

The Meteorological Research Committee will advise the Parliamentary Under-Secretary of State for Defence for the Royal Air Force on the general lines along which meteorological and geophysical research should be developed within the Meteorological Office and encouraged externally. It shall review progress and report annually.

It is empowered to appoint subcommittees, one of which shall be responsible for advising on the use of money allocated annually from Defence Votes for research projects conducted outside the Meteorological Office. The Committee will be responsible for co-ordinating the work of its subcommittees.

Membership at 31 December 1976:

Chairman: Professor J. T. Houghton, F.R.S.

Members: Instructor Captain R. K. Alcock, R.N. (Director of Naval Oceanography and Meteorology)
Professor R. L. F. Boyd, C.B.E., F.R.S.
Mr F. H. Bushby (Deputy Director, Dynamical Research, Meteorological Office)
Professor H. Charnock, F.R.S.
Mr G. A. Corby (Director of Services, Meteorological Office)
Professor D. R. Davies
Mr P. Goldsmith (Deputy Director, Physical Research, Meteorological Office)
Dr E. R. R. Holmberg (Army Department)
Professor J. Latham
Wing Commander D. M. Leslie (Air Force Department)
Dr B. J. Mason, C.B., F.R.S. (Director-General, Meteorological Office)
Mr F. O'Hara (Procurement Executive, Ministry of Defence)
Professor R. P. Pearce, F.R.S.E.
Mr J. S. Sawyer, F.R.S.
Professor P. A. Sheppard, C.B.E., F.R.S.
Dr K. H. Stewart (Director of Research, Meteorological Office)
Dr P. F. G. Twinn (Natural Environment Research Council)

Secretary: Mr R. A. Ebdon (Meteorological Office)

The Committee met twice in 1976 and its subcommittees seven times.

PRINCIPAL OFFICERS OF THE METEOROLOGICAL OFFICE

DIRECTOR-GENERAL

B. J. Mason, C.B., D.Sc., F.R.S.

DEPUTY TO THE DIRECTOR-GENERAL

G. A. Corby, B.Sc.

DIRECTORATE OF SERVICES

DIRECTOR	G. A. Corby, B.Sc.
INTERNATIONAL AND PLANNING	
Assistant Director	D. G. Harley, B.Sc.

FORECASTING SERVICES

DEPUTY DIRECTOR	N. Bradbury, B.Sc.
CENTRAL FORECASTING	
Assistant Director	D. E. Jones, M.Sc., D.I.C., A.R.C.S.
DEFENCE SERVICES	
Assistant Director	I. J. W. Pothecary, B.Sc., M.Inst.P.
Chief Meteorological Officer, H.Q. Strike Command	J. C. Gordon, M.A.
PUBLIC SERVICES	
Assistant Director	D. H. Johnson, M.Sc., D.I.C., A.R.C.S.
Chief Meteorological Officer, London/Heathrow Airport	A. Ward

COMMUNICATIONS AND COMPUTING

DEPUTY DIRECTOR	M. J. Blackwell, M.A.
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Assistant Director	D. McNaughton
DATA PROCESSING	
Assistant Director	G. A. Howkins, M.B.E., B.Sc.
SYSTEMS DEVELOPMENT	
Assistant Director	E. J. Sumner, B.A.

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OBSERVATIONAL REQUIREMENTS AND PRACTICES	
Assistant Director	G. J. Day, B.Sc.
Marine Superintendent	G. A. White, Captain, Extra Master
CLIMATOLOGICAL SERVICES	
Assistant Director	R. J. Ogden, B.Sc.
AGRICULTURE AND HYDROMETEOROLOGY	
Assistant Director	R. Murray, M.A.
OPERATIONAL INSTRUMENTATION	
Assistant Director	D. N. Axford, Ph.D.

DIRECTORATE OF RESEARCH

DIRECTOR	K. H. Stewart, Ph.D.

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DEPUTY DIRECTOR	P. Goldsmith, M.A.
GEOPHYSICAL FLUID DYNAMICS LABORATORY	
Head of Branch	R. Hide, Sc.D., F.R.S.
BOUNDARY LAYER RESEARCH	
Assistant Director	F. B. Smith, Ph.D.
METEOROLOGICAL RESEARCH FLIGHT	
Chief Meteorological Officer	D. G. James, Ph.D.
CLOUD PHYSICS	
Assistant Director	P. Ryder, Ph.D.
Chief Meteorological Officer, MRU, Malvern	K. A. Browning, Ph.D., D.I.C.
HIGH ATMOSPHERE	
Assistant Director	D. E. Miller, B.A.

DEPUTY DIRECTOR	F. H. Bushby, B.Sc., A.R.C.S.
SPECIAL INVESTIGATIONS	
Assistant Director	D. R. Grant, B.Sc.
FORECASTING RESEARCH	
Assistant Director	P. Graystone, B.A.
Special Post	R. Dixon, B.Sc.
SYNOPTIC CLIMATOLOGY	
Assistant Director	R. A. S. Ratcliffe, M.A.
PROFESSIONAL TRAINING	
Assistant Director and Principal, Meteorological Office College	S. G. Cornford, M.Sc.
DYNAMICAL CLIMATOLOGY	
Assistant Director	A. Gilchrist, M.A.
Special Post	R. J. Murgatroyd, O.B.E., Ph.D., C. Eng., M.I.E.E.

ADMINISTRATION, FINANCE AND SUPPLY

SECRETARY, METEOROLOGICAL OFFICE	A. C. Hughes, M.Sc., M.Phil.
PERSONNEL MANAGEMENT	
Assistant Director	W. D. S. McCaffery, B.Sc.

METEOROLOGICAL OFFICE HEADQUARTERS ORGANIZATION

(at 31 December 1976)

- Director-General
  - Director of Research
    - Deputy Director (Physical Research)
      - Met O 21 (Geophysical Fluid Dynamics)
      - Met O 19 (High Atmosphere)
      - Met O 15 (Cloud Physics)
      - Met O 14 (Boundary Layer Research)
      - Meteorological Research Flight
    - Deputy Director (Dynamical Research)
      - Met O 20 (Dynamical Climatology)
      - Met O 18 (Library, Publications, Archives and Cartographic Section)
      - Met O 13 (Synoptic Climatology)
      - Met O 11 (Forecasting Research)
      - Met O 9 (Special Investigations)
      - Met O College (Professional Training)
  - Secretary
    - Met O 10 (Personnel Management)
    - Met O 4 (Supply, Finance, Secretariat, Office Services)
  - Director of Services
    - Deputy Director (Forecasting Services)
      - Met O 7 (Public Services)
      - Met O 6 (Defence Services)
      - Met O 2 (Central Forecasting)
    - Deputy Director (Communications and Computing)
      - Met O 22 (Systems Development)
      - Met O 12 (Data Processing)
      - Met O 5 (Telecommunications)
    - Deputy Director (Observational Services)
      - Met O 16 (Operational Instrumentation)
      - Met O 8 (Agriculture and Hydrometeorology)
      - Met O 3 (Climatological Services)
      - Met O 1 (Observational Requirements and Practices)
    - Met O 17 (International and Planning)

DIRECTORATE OF SERVICES

Special Topic—Meteorological Services for the Offshore Industry

Introduction

In the early days of offshore exploration in the seas around the British Isles the operators tended to underestimate the severity of the weather and the size of the waves that they would encounter. It is now well recognized that the North Sea has provided some of the most difficult environmental conditions with which that industry has had to contend. Close co-operation between the operators and the meteorologist is essential in each phase of design, construction and operation if loss of life and costly damage are to be minimized. With an annual rate of British offshore investment running at upwards of 1000 million pounds and the cost of getting each new platform into production ranging between 100 and 200 million pounds, there is much to be protected in the North Sea from the hazards of wind and wave. The offshore industry therefore receives very substantial support from the Meteorological Office.

Services to the designers

Offshore installations must be designed to withstand all the stresses to which they are likely to be subjected during their working life by wind, wave and current. In calculating such stresses the engineer is guided by the meteorologist and the oceanographer who employ statistical techniques to deduce from past observations what adverse conditions of weather and sea will probably be met with, or exceeded, over a given period. The importance of not underestimating the worst which is likely to happen is obvious. On the other hand the operators, and all concerned with the profitability of the industry or with the cost of its products, are anxious to avoid the heavy financial penalties incurred in building a structure which is very much stronger than it need be. The probabilities calculated by the meteorologist and oceanographers must, therefore, be as accurate as possible and not biased towards optimism or pessimism. The operators, their customers, the official licensing authorities and the insurers all rely upon the quality of this professional advice.

As custodian of the national weather records, the Meteorological Office is the repository of the past weather data required for such statistical predictions. The records comprise observations from ships including light vessels and ocean weather ships together with anemograph data from coastal and island stations. When the statistical methods of extreme value analysis are applied to these data it is possible to derive the information required by the installation designers. However, the sets of past weather observations are neither as complete nor as representative as standard statistical techniques require and the professional meteorologist has been called upon to exercise much ingenuity and judgement in deriving the best possible estimates for design purposes. These aspects of the work are carried out by the Marine Climatologist working in the Climatological Services Branch of the Office.

Among the climatological information supplied to members of the Offshore Industry and to the various official and other bodies have been maps of the expected 50-year extreme values of wind speed, vertical wind profiles and data on air and sea temperatures and ice accretion. The Department of Energy is responsible for the production of the official 'Guidance on the Design and Construction of Offshore Installations'. The Meteorological Office has contributed data to this publication and is represented on the Department's Offshore Installations Technical Advisory Committee (OFINTAC) by the Marine Climatologist. Assistance has also been given to the British Standards Institution in preparing a draft standard for the development of offshore structures and information has been provided to a working group of the European States Safety and Pollution Conference, of which the Marine Climatologist is also a member.

With the continuing development of North Sea oil and gas production and the likely extension of exploration to other parts of the nearby continental shelf, there will be a continuing need for statistical estimates. Research is therefore being undertaken in the Climatological Services Branch into new methods of extreme value analysis. The standard techniques used hitherto have called for past records covering 20 years or more. Early results from a new method which can be applied to shorter-period records have been most promising. Work is also in hand to improve knowledge of low-level wind spectra and of the variation of wind with height over the sea, especially at high wind speeds.

Reliable past observations of wave heights and periods are much less readily available than those of wind and weather. Fortunately, since the waves arise through interaction between the wind and sea, surface wind data can be used in the estimation of the wave heights and periods likely to be encountered. The Climatological Services Branch has supplied wind data to the Institute of Oceanographic Sciences for this purpose. The Meteorological Office has also collaborated with the Institute of Oceanographic Sciences, the Hydrological Research Station and the offshore industry in the North Sea Wave Model (NORSWAM) project. The model is intended to be used in deriving, from accurate past synoptic weather analyses for storm situations, information on the heights and periods of the sea waves which were generated. This will supplement the extreme value data calculated by statistical methods. Scientists of the Central Forecasting Branch of the Office are members of the Technical Advisory Group for the NORSWAM project.

Forecasting services

The offshore industry needs weather forecasts for very many of its operations. The time scale of these varies from an hour or two, for a helicopter flight, to periods of a week or more when the movement of a drilling rig or the tow-out of a production platform to an oil field is involved. Most weather elements are important for one reason or another, wind and visibility being particularly so. The state of the sea surface is also crucial and it falls to the meteorologist to provide the necessary forecasts of the character of the sea waves and swell as well as of the weather.

The sensitivity of offshore work to conditions of wind and sea can best be appreciated from a few examples. With most rigs drilling has to stop when waves grow above a certain height, usually about eight metres. Otherwise the drill is liable to break in the hole so that the drilling work is wasted and the drill is lost. Recent northern North Sea experience has shown that waves of heights above 20 metres can be encountered there. Ideally, supply ships should leave harbour only when it is known that the weather at the offshore destination will allow the unloading of their cargo. For this, accurate weather forecasts are required for periods of one to four days. In strong winds or if wave heights exceed about three metres supply ships may have to stop using their cranes and stand off. Indeed for some of the more delicate unloading operations a steady wind in excess of 10 knots is too much. A sudden squall during the lifting of a module on to a platform may result in the loss of the load and even of the crane. Sufficient warning of the adverse weather must be given if the risk of accident is to be minimized. For tanker-loading from the oil wells at sea, wind speeds and wave heights must also be below specified limits if pipe breakage and oil spillage are to be avoided. For commercial reasons the operators have been reluctant to say what the limits are; they depend upon the equipments and techniques in use but are probably about 35 knots and 5 metres. Since it takes a period of, perhaps, eight hours to disconnect the pipes, advance warning of the development of unsuitable conditions is needed. When the oil is to be brought ashore directly from the well by pipe-line, the laying of a permanent pipe-line on the seabed is also weather-sensitive. Notifications may be required at least six hours ahead of the onset of a wind above 30 knots or of the arrival of a swell greater than two metres in height. Failure to give adequate warning of the development of these conditions may mean that a pipe-laying barge has to cut away its anchor or jettison some of its expensive pipe-laying gear. As a condition of certification Lloyd's have required that some production platforms be evacuated when waves are expected to reach prescribed heights. For certain southern North Sea gas platforms these are in the range from six to eight metres. Helicopters are not kept continuously at standby for evacuation, so several hours' notice of the expected event is needed.

Perhaps the largest single operation for which weather forecasts are decisive is the tow-out of a platform to an oil field after construction. This is a particularly complex and hazardous maritime operation. It requires quiet sea conditions to be sustained for several days during the tow and installation on site of the platform. Experts from the Meteorological Office participate as required throughout the planning stages, providing advice on routes and on the incidence, deduced from past records, of 'weather windows'. This term is used by the operators for the periods of settled weather for which they must wait before conducting the more sensitive operations. Once the platform is ready to move out the operator depends upon the forecaster to warn him in advance of the imminence of a weather window. A comprehensive and dedicated forecasting service is required, particular attention being given to the need to avoid waves of directions, heights and periods and winds of speeds and directions to which the structure is known to be most responsive. An opportunity to move is not to be missed, since a costly wait of several weeks might ensue before another occurs. On the other hand the platform and those engaged in the operation at sea must not be put at undue risk.

To deal with these requirements and others a specialized weather forecasting service is provided from the London Weather Centre. A team of senior forecasters, each with long experience in forecasting for the British Isles and the European continental shelf, is established there solely to meet the needs of the offshore industry. They have built up a considerable expertise. The requirements and particular weather sensitivities of each installation or operation are considered individually. A typical forecast for a rig or platform covers a period of 72 hours split into two 12 hour periods followed by two of 24 hours. It contains predictions of the 10 minute mean wind and of the maximum gusts to be expected, at the main deck level, some 30 to 50 metres above the sea surface, as well as at the meteorological standard height of 10 metres above sea level. The waves actually experienced at any location, and to be forecast, are the sum of those generated more or less locally, although these depend upon the fetch and the length of time for which the wind has been blowing, and of those arriving from long distances away as swell. The London Weather Centre forecasts normally include a prediction of the maximum wave height to be expected during a period of 10 minutes but the expected height and period of the 'significant wave' is also given. The significant wave is an oceanographical concept, its height being defined as the mean height of the highest one-third of the waves. The expected height, period and direction of the remotely generated swell waves, as well as the visibility, cloud and general weather are also forecast. Such detailed forecasts are usually dispatched twice a day through the appropriate company shore base to each installation manager of the companies subscribing to the service. In addition to the regular issues just described, and depending upon the character of the operation, warnings of specific weather or wave hazards can be given as required. They may relate to any threshold value of wind speed or wave height, period or direction as agreed with the customer. London Weather Centre provides round-the-clock forecasting services so that its subscribers have access at any time of the day or night to a forecaster. Members of the offshore forecasting team are frequently in direct communication by telephone with managers of installations and others aboard rigs, platforms and vessels in the North Sea or ashore. If necessary a forecaster can be detached to the site of the operation to give professional advice on the spot. In providing its services the London Weather Centre is backed by the resources of the Central Forecasting Office and of other specialist branches at the Meteorological Office Headquarters at Bracknell. The number of offshore installations and operations served from the Weather Centre varies with the season and with the general level of offshore activity; it reached 55 at times during 1976.

While the main forecasting services for the industry are provided by the London Weather Centre, certain other forecasting offices have roles to play. Unless appropriate precautions are taken the weather can cause serious damage to installations under construction. The platform and rig construction yards are normally served by the nearest forecasting office. In Scotland, for example, this may be the Glasgow Weather Centre. Helicopter traffic requires its own specialized service and the aviation forecasting offices at RAF Honington in Norfolk and at Prestwick Airport in Scotland are responsible for co-ordinating forecasting for flights over the southern and northern areas of the North Sea respectively. Helicopter crews can discuss the weather conditions personally with the forecasters at Aberdeen Airport and to provide a similar service for helicopters and general aviation in Shetland a meteorological office is due to be opened at Sumburgh Airport in 1977. The role of the Central Forecasting Office at Bracknell is primarily one of support for others which are in direct contact with the users. It does contain, however, a small team composed of qualified mariners which provides weather routeing services for the shipping industry. A number of companies have engaged the services of the weather routeing experts at Bracknell when wishing to move rigs and other floating installations over long distances across the world.

As described in later sections of the *Annual Report* the forecasting services provided by the Meteorological Office are supported by a vigorous research program. In meeting the specific requirements of the offshore industry care has been taken to identify problems capable of solution by further research and, especially, tasks for which a more accurate numerical treatment seems feasible. In particular, a substantial effort has been devoted to the problems of forecasting sea waves and swell. The co-operative work on the North Sea Wave Model (NORSWAM) has already been mentioned. NORSWAM will be capable of use in conjunction with meteorological models in prediction as well as for the diagnostic purposes previously described. In this connection improved methods of specifying the surface wind field as analysed and forecast have been under development in the Meteorological Office. For wave forecasting, as an interim measure, a technique has been in use in which winds at the sea surface are computed from parameters forecast for the free atmosphere by the Meteorological Office 10-level numerical prediction model. It is planned, however, to develop a computer-based scheme which will provide analysed surface winds at hourly intervals at points of a 50 km grid covering sea areas around the British Isles.

A substantial effort has been devoted to the problem of forecasting swell. Long period swells generated in Atlantic storms 1000 or more miles away may arrive days later in the northern North Sea in otherwise calm conditions with possible serious consequences for such operations as pipe-laying and the loading of tankers at single buoy moorings. Graphical methods of forecasting swell at specific locations introduced at the London Weather Centre late in 1975 have now been automated by scientists of the Central Forecasting Branch. The characteristics of swell expected to reach chosen locations on the continental shelf are calculated automatically from the most recent objectively derived wind fields. Forecast values of swell for selected points are now transmitted as routine twice daily from Bracknell to the London Weather Centre. There is a wider requirement to forecast swell waves at a network of points using automatic and objective techniques, taking into account the input of energy from the winds on a field basis. A parametrized model designed for this purpose has been under trial in the Central Forecasting Branch with encouraging first results.

Data collection

The many needs of the offshore industry for meteorological services can be met only if there is an adequate supply of meteorological and oceanographic data from the areas of interest. This is well understood by the industry. Many rigs and platforms are instrumented in some degree to make weather observations and in 1976 it became a statutory requirement for offshore installations equipped with helicopter landing pads to have certain meteorological instruments in the interests of safe helicopter operation. The services of one, and, more recently, two instruments inspectors from the Observational Requirements and Practices Branch of the Meteorological Office have been made freely available to the industry. They have made many visits to drilling rigs and permanent platforms to advise on the siting, calibration and operation of meteorological sensors. Partly as a result of their efforts observations are received fairly regularly from between 10 and 20 installations operating in the British sector of the North Sea. These data are subjected to quality control at the London Weather Centre and are then passed to the meteorological communications centre at Bracknell for inclusion in national and international meteorological broadcasts. The instruments inspectors are able to give advice on weather observing practices and problems during their visits offshore. At the request of the industry, however, more formal training is to be made available for company personnel responsible for making and dispatching weather observations from offshore installations. A series of one-week courses has been arranged to be held at the Meteorological Office College, near Reading.

The offshore industry is very alive to the need for meteorological and oceanographic data for planning purposes from areas to which regular operation might spread in the future. Accordingly it has sponsored the work under contract of two or three weather ships, commercially provided, which have been stationed at times in the Celtic Sea and in the seas around the Shetland Isles. The Office has participated in the training of those who make the weather observations aboard these vessels and for the ship in the Celtic Sea it has provided experienced supervisory observers, who serve on board in turn throughout the year. The Office has also provided advice to the industry on the use of instrumented buoys and automated observing systems in gathering environmental data.

National and international liaison

In providing climatological and forecasting services members of the Meteorological Office are in regular and frequent contact with members of the industry in its day-to-day operation. Often the relationship has a commercial basis since the individual companies pay at an economic rate for many of the services that they receive from the Office. There are national interests also to be served, however, and the Meteorological Office is a member of a number of national and international committees and groups of various kinds which have been set up to co-ordinate action in support of offshore activity.

The interests of operators working in British waters are furthered by the United Kingdom Offshore Operators Association (UKOOA). The meteorological and oceanographic requirements of the industry are the concern of the Oceanographic Committee of the UKOOA. The Meteorological Office is regularly represented in the Oceanographic Committee by the Principal Meteorological Officer of the London Weather Centre but experts from the specialist branches of the Office also attend its meetings as required. Through the Committee the Office has advised the industry on many questions. These have included, for example, the specification of an optimum network of meteorological observing stations in the North Sea, the establishment of a meteorological data bank and detailed requirements for the measurement and recording of meteorological data on offshore installations. The Principal

Meteorological Officer, London Weather Centre is also in frequent touch on future services and other matters with individual company officials based in London and elsewhere.

In co-operation with the Petroleum Industry Training Board training in the use of meteorological services has been provided for offshore installation managers by Meteorological Office staff. They have conducted in Aberdeen one-day courses which have been attended by representatives of all the major companies operating in the North Sea. While the main aim of these courses was to highlight the benefits and the limitations of weather forecasts provided for offshore work, they gave an opportunity for useful feedback from the operators with regard to the nature of the services which they require. A continuing liaison with the industry in Scotland and the Isles is effected through a member of the Office established during 1976 as a local meteorological consultant. He is located in the Offshore Supplies Office of the Department of Energy, in Aberdeen, and receives technical support from the London Weather Centre, the Climatological Services Branch and other specialist branches of the Office at Bracknell.

European co-ordination on environmental matters at government level is the concern of a working group of the European States Safety and Pollution Conference. Within the industry co-operation takes place through the International Exploration and Production Forum which meets quarterly in London. Members of the Meteorological Office attend these meetings and have been involved in discussions on such topics as the establishment of standards in the acquisition and reduction of wind and wave data. An exchange of views on a wider basis took place at a meeting in Oslo in October which was attended by representatives of several meteorological services of countries around or near the North Sea. Provision of meteorological advice for offshore operations in the North Sea was discussed. There was agreement on the need for standardization of practices in the provision of forecasting services and in the reporting and processing of meteorological data for the area. Following this a permanent working group, the North Sea Meteorological Panel, was set up, of which the Principal Meteorological Officer, London Weather Centre has been designated as United Kingdom member.

The future

The Meteorological Office has been closely involved with the offshore industry in many aspects of its work of exploration and production in the North Sea. It has membership of or association with the different bodies and groups within the industry and within government concerned with the industry's needs for environmental data and services, and with plans for satisfying these needs. It is thereby in a good position to anticipate the industry's requirements and develop its services to the extent required in support of expansion of the industry within the North Sea or into other areas of the continental shelf. With scientific expertise and operational skills of the highest calibre backed by the requisite computing power and instrumentation the Office is very well placed to respond to all the demands which the industry may make in the forthcoming years.

Forecasting Services

Central Forecasting Office

Bracknell is a Regional Meteorological Centre (RMC) within the framework of World Weather Watch. The latter is a concept ratified by the Congress of the World Meteorological Organization (WMO), whereby the meteorologically more advanced nations assist the less advanced. In the sphere of weather forecasting this assistance is achieved through the operations of the three World Meteorological Centres (WMCs) at Washington, Moscow and Melbourne and of a number of RMCs. The Central Forecasting Office (CFO) at Bracknell has undertaken, in fulfilment of its RMC role, to meet the stated needs of various National Meteorological Centres (NMCs) in Europe for regional forecasts and guidance. This it does by the preparation, for dissemination by, for example, wireless telegraphy and radio-facsimile transmissions, of analysed and forecast charts covering a large part of the North Atlantic, Europe and the Arctic; in some instances these products are transmitted in the form of data for agreed arrays of grid points used in the analysis and forecast programs. In addition to its role as an RMC in the World Weather Watch, CFO is also the chief forecasting centre of the State Meteorological Service.

The main tasks of CFO continued substantially unchanged from previous years. An important responsibility of the Senior Forecaster is the regular issue of guidance to outstation forecasters in the form of charts depicting actual and forecast conditions, augmented by advisory texts describing the expected weather. The routine forecasts are for the British Isles, the surrounding seas and the eastern North Atlantic; the charts cover a much wider area. CFO issues warnings of hazardous conditions such as gales or storms over sea and land, fog, snow, icy roads, frost, thaw and thunderstorms.

CFO makes major use of the forecasts produced from the 10-level numerical forecasting models, the basic procedure remaining similar to those described at length in previous *Annual Reports.*

Refinements to the operational numerical forecasting system are introduced as a result of continuing research work in which the numerical support team attached to the Central Forecasting Office and the Forecasting Research Branch play the major roles. During 1976 it was found possible to introduce in the numerical forecasting runs which are carried out several times a day a split explicit scheme for the forward time integrations in place of the semi-implicit scheme introduced towards the end of 1974. The split explicit scheme requires significantly less computer time (only one-third of the previous time) to produce comparable results and the resulting saved computer time is available for other purposes.

The present 'in-house' standby and backup procedure, involving forecast runs being produced on the IBM 370/158 computer on the rare occasions when the IBM 360/195 is unserviceable, has provided a better backup than the earlier procedure involving the use of the 360/195 computer system at Rutherford Laboratory, Harwell. The adoption of the more economical split explicit time integration scheme mentioned earlier was a further strengthening of the backup procedures since the time taken to produce a three-day forecast by this scheme is about the same as that required for a 24-hour forecast when the semi-implicit scheme was used.

The development, started in 1975, of a comprehensive orthogonal polynomial analysis scheme to cover both the pressure levels required for the 10-level numerical model (1000 mb to 100 mb) and stratospheric levels from 100 mb to 10 mb progressed sufficiently quickly to permit the use of this comprehensive scheme in the operational analysis runs from early 1976. Continued attention is being directed towards prediction at the pressure levels of most concern to Concorde operations (100 mb and 70 mb) to ensure an improved service for these flights.

Among the model modifications being tested in 1976 before adoption on the operational runs was the parametrization of topography, deep convection and long-wave radiation. In some respects the fine-mesh version of the 10-level model is still regarded as experimental, the forecasts arising therefrom being made available to the CFO forecasters but not disseminated outside Bracknell. However, this fine-mesh version does provide a very useful test-bed for examining modifications to the model prior to incorporation, after further testing, in the coarse-mesh version used to meet the main operational commitments.

In addition to examining ways of improving the 10-level model forecasts, the numerical support team is deeply involved in the generation of forecasts of meteorological parameters needed by the forecasters but not calculated directly in the numerical model. Of particular interest are the vertical temperature profiles and the location and strength of tropospheric jet streams in analysed and forecast fields from the model. Sea wave analyses and forecasts have been produced as routine in CFO since 1968 when the service for the weather routeing of ships was started; these wave analyses and forecasts were for the area of the North Atlantic Ocean. The problem of sea wave and swell forecasting for the North Sea and for other waters around the British Isles where offshore operations are being carried out is a rather more difficult problem, owing to the relatively shallow depth of these waters and the enclosed nature of the North Sea. The whole procedure of sea wave and swell forecasting is therefore being reviewed in an effort to produce better guidance and forecasts. This task involves liaison with oceanographers, especially those at the Institute of Oceanographic Sciences (IOS) at Wormley in Surrey. It is worth mentioning that the work of the numerical support team also involves liaison with civil aviation and other meteorological services, university departments, the European Centre for Medium-range Weather Forecasts currently situated in Bracknell, and other institutions which make use of the material generated by the operational numerical weather forecasts.

Greater use has been made of charts plotted automatically by use of the computer complex; these automatically plotted charts have now replaced the manually plotted hourly charts for facsimile transmission, as foreseen in the *Annual Report* for 1975. Automatically plotted charts are also becoming increasingly used internally in CFO since it is possible to provide a bigger range of plotted charts by this means than was possible with limited staff for manual plotting. Analysis over the North Atlantic and North Pacific areas is rendered easier and improved by the provision of additional larger-scale charts.

The numbers of visitors to CFO continued to be high and the visitors from other meteorological services and institutions overseas have shown great interest in the way in which the British Meteorological Service is attempting to widen and improve the forecasts and guidance. The methods whereby satellite and other less-conventional data are being incorporated into the numerical forecasting system through human intervention is one aspect of especial interest to visitors, involving as it does the use on-line of visual display units to manipulate data, background and analysed fields in the COSMOS computer system prior to running the operational forecast programs.

The following changes in land-line facsimile transmissions were made during 1976 in view of the importance to outstations of guidance for two to three days ahead: forecast charts produced from midnight data were disseminated in the early morning instead of the early afternoon, and additional forecasts based on midday data were issued in the evening. Reliable forecasts over extended periods of up to one week ahead are recognized as a firm requirement for agricultural, industrial and manufacturing interests and are also needed by the offshore operators engaged in weather-sensitive work such as pipe-laying, oil and gas rig installation and the maintenance of and supply services to such rigs and platforms.

Extended numerical forecasts up to six days ahead continued to be produced once daily from the full 12 GMT data bank in order to provide the medium-range forecasters with some assistance in attempting to meet demands for advice over these extended outlook periods. Further improvement of the 10-level model forecasts is needed in order to permit more detailed advice to be given; nevertheless the forecasts at the fifth and sixth day stage show some skill and other meteorological services have made requests that these extended forecasts be transmitted routinely from Bracknell RMC.

CFO continued to be responsible for the publication of the *Daily Weather Report* (*DWR*), with its *Overseas Supplement*, the *Monthly Summary* and the *Daily Aerological Record* (*DAR*). The upper-air charts were, however, omitted from the *DAR* with effect from 1 January 1976, as similar charts were incorporated in the *European Meteorological Bulletin* introduced on that date; duplication of such charts was avoided and some economies made. Another decision was to cease publication of the *Overseas Supplement*; this supplement was issued in arrears and the last issue, that for 31 December 1972, was dispatched to customers in April 1976.

In the international field the Assistant Director (Central Forecasting) continued to serve as a member of the Working Group on the Global Data Processing System (GDPS), one of the working groups of the WMO Commission for Basic Systems (CBS). The branch also provided the UK member on the Regional Association VI (Europe) Working Group on Requirements for GRID code (used for the dissemination of data in grid-point form).

Staff of the Central Forecasting Office and its numerical support team continued to be in demand for lecturing on various aspects of forecasting and numerical weather prediction. It is pertinent to note that the current forecasting staff includes members who have instructed on 'Weather and Sailing' and 'Weather and Mountaineering' courses, and active glider pilots who have assisted in providing meteorological guidance during competitions, including the World Gliding Championships in Finland in June when Britain won the open class; one other forecaster has carried out forecasting duties on the Trawler Support Ship in Icelandic waters for several seasons and one has also acted as meteorological adviser to the Embassy Daily Express Offshore Power Boat Race in the summer.

A member of the Office, Mr D. M. Houghton of the London Weather Centre, attended the Olympic Games in Kingston, Ontario as weather adviser to the successful British yachting team.

Services for industry, commerce and the general public

Forecasting services for industry, commerce and the general public are provided directly by the weather centres and by a number of other forecasting offices, or indirectly through radio, television, the Press and the Post Office's automatic telephone weather service. Most of the work is undertaken by 36 offices in various parts of the country, whose telephone numbers are published in the preface to area telephone directories, official leaflets and many trade journals. A further 50 unpublicized offices also handle requests for advice from industry and the general public.

The long dry and settled spell of weather in the spring and summer of 1976 resulted in a fall of 18 per cent compared to 1975 in the number of casual requests for advice from holidaymakers. However, the return of unsettled weather in September produced an upswing in the number of enquiries. The total number of enquiries in 1976 was 1 865 050 as against 1 840 820 in 1975. During the long dry period many meteorological records were broken and with the worsening drought conditions there were many requests for contributions from members of the Meteorological Office to television and radio programs. Staff at the Headquarters and at weather centres and other offices were called upon to handle an unusually large volume of Press enquiries. At the personal request of Lord Nugent, Chairman of the National Water Council, the Director-General arranged with the BBC for frequent reminders of the need to conserve water to be given by the radio and television weathermen in the course of their daily weather presentations.

The number of calls on the Post Office's automatic telephone weather service (ATWS) reached a total of 16 250 683 in 1976 compared with 16 935 351 in 1975 which was a record. For some years now ATWS forecasts for London and other areas in the south-east have been recorded by members of the London Weather Centre rather than by Post Office staff. This facilitates the updating and amendment of the recordings so that the public gets a better service. In preparation for the extension of this practice to other areas a trial was started at Manchester Weather Centre in May using less sophisticated sound-proofing equipment. The trial has been very successful and plans are now in hand to equip other forecasting offices with the recording equipment. At present the forecasts made available on the ATWS are for restricted areas. Plans are being made with the Post Office to extend the service geographically so that forecasts will be available through more telephone exchanges and most parts of the United Kingdom will be covered.

As in previous years, special forecasts were supplied to the Post Office in connection with a marine information service in the Swansea telephone area in the summer months and for a ski-report service in the Edinburgh telephone area during the winter. The Main Meteorological Office at Preston continued the supply of forecasts for the Lake District National Park Information Service. This forecast is recorded by staff of the Information Service and is available to the public on a Windermere telephone number. The service continues to prove very popular.

The dissemination by television and radio of routine forecasts and warnings of severe weather has continued. On BBC television the new symbols for the weatherman presentations achieved wide acceptance among the general viewing public. On the other hand a minority of viewers with a deeper knowledge of meteorology and its practices have found the symbols less satisfactory than those used internationally by professional meteorologists. Viewers with a specialist interest in the weather such as aviators, mariners and farmers have appreciated the introduction on BBC–2 television of a longer presentation following the News headlines at 7.00 p.m. on weekday evenings. This contains a more detailed discussion of the synoptic situation than is available at other times of the evening. Another welcome innovation from October was a live weatherman presentation on BBC–1 television at 9.25 p.m. on Friday evenings following the Nine o'clock News. It contains the prospects for the week-end. As in previous summers the Thursday evening BBC–1 presentation was extended to include an item on continental holiday weather. The outlook for the week given by the weatherman in the 1.00 p.m. Sunday BBC–1 program for farmers continues to be very well received by the farming community. A transcript of it has appeared in Monday issues of the *Daily Mail* newspaper. Services to Independent Television companies continued largely unchanged. The BBC Ceefax and IBA Oracle experimental data transmissions include weather information provided by the London Weather Centre. Arrangements were made for the Meteorological Office to participate in trials of the Post Office Viewdata service which is seen as having potential for communication of specialist weather information to smaller groups than are reached by the automatic telephone weather service.

Changes made in April to the early morning 'Today' program on BBC Radio 4 included the introduction of dialogues between the program presenter and the weatherman in which the national weather of the day is discussed with special reference to sporting and other events of current interest. These take place at a little before 7.30 a.m. and 8.30 a.m. on weekdays. For a short period the BBC dropped the more formal presentations containing detailed national forecasts by areas which preceded the 7.00 a.m. and 8.00 a.m. news bulletins on Radio 4. However, they were reinstated after complaints from listeners showed that there was still a strong demand for them. At about the same time a comprehensive forecast of five minutes' duration for United Kingdom land areas and inshore waters was introduced on Radio 3 at the commencement of programs each morning. This is of particular value for yachtsmen and others for whom the shipping forecast gives insufficient detail. Forecasting services were provided for all 20 BBC local radio stations and 6 commercial radio stations contracted for services. A large number of broadcasts and interviews were given by members of the staff, most of them on the subject of current weather.

Services to the Press followed patterns set in previous years. Many requests were received from the national and provincial Press for special interviews and comments on a wide variety of topics.

Services tailored to meet special requirements were provided for the British Gas Corporation, the Central Electricity Generating Board, British Rail, London Transport and very many other industrial, commercial and public concerns. Further publicity was given to the week-end temperature forecast service designed to assist those responsible for the heating of industrial and other premises during the winter both to protect vulnerable plant and to conserve energy. As a result the number of subscribers increased further in comparison with those of previous winters, the total reaching 65. Daily forecasts of temperature have also been used to conserve fuel used in heating. For example, they enabled the Royal Naval Aircraft Yard at Fleetlands, Gosport, Hampshire to save 150 000 gallons of fuel oil from October 1975 to March 1976. Other special services included warnings to highway authorities during the winter months of road dangers due to weather, forecasts for pigeon racing and notifications to farmers of dry spells during the summer. The latter service did not prove very popular in 1976, understandably perhaps in view of the prolonged spells during May to August of settled dry weather.

The weather centres at London, Glasgow, Manchester, Southampton and Newcastle and the public service office at Watnall, near Nottingham, continued to handle the bulk of the work in the public sector. Excluding weather maps provided for shipping at certain major ports, the total numbers of enquiries dealt with over the past three years were as follows:

	London	Glasgow	Manchester	Southampton	Newcastle	Watnall
1974	313 784	112 293	123 148	97 317	98 223	59 461
1975	311 354	114 974	121 225	102 298	108 147	61 501
1976	299 160	107 388	117 096	100 342	99 824	62 423

Grand totals: 1974, 894 226; 1975, 819 499; 1976, 786 233.

The marine aspects of the work of these offices are dealt with in a separate section of this report, whilst the increasingly important offshore work at the London Weather Centre is dealt with in the Directorate of Services Special Topic. There was much variety in the other services provided. To mention but a few, temperature forecasts have been supplied to ice cream makers to help them to predict the public demand and to confectionery manufacturers and frozen food companies to help in avoiding deterioration of their products when they are transported on hot days; daily weather summaries have been prepared for two organizations forecasting crop yields in England and north-west Europe as part of their economic commodities services; warnings of strong winds were given to one borough council especially concerned with the safety of houses affected by mining subsidence; and individual forecasts were supplied for a wide range of constructional activity embracing motorways, gas pipe-lines, offshore platforms, yachting marinas, factories and offices.

Public interest in the facilities of the Office and in the ways in which it works continued at a high level. Many parties of visitors were shown the operational work in progress at the Headquarters at Bracknell or visited out-stations. Members of the staff acting in a purely voluntary capacity and in their own time gave a large number of lectures and talks to non-professional outside bodies. Replies were sent to a steady stream of correspondence from members of the public of a very wide range of ages and technical understanding.

Services for the general public (overseas)

Meteorological offices serving the Royal Air Force stations in Cyprus, Malta and Gibraltar continued to provide forecasts for the general public by means of Press, radio and television. The needs of local government departments, oil-drilling operators and other engineering and commercial concerns for more detailed services were also catered for.

Services for marine activities

General services to shipping via BBC Radio 2 and the Post Office coastal radio stations continued on the lines of previous years. To meet the growing demand from local fishermen and yachtsmen a new service has been introduced on BBC Radio 3. This service provides a forecast for inshore waters every morning for the whole of the United Kingdom, and supplements the forecast given daily towards close-down on BBC Radio 4. The Office has also sponsored the printing of a new Weather Plotting Chart for Yachtsmen. This chart is now on sale at the Glasgow, London and Southampton Weather Centres and was first introduced to the public at the Southampton Boat Show where 2500 copies were sold.

London Weather Centre prepared forecasts for a wide range of marine activities, but their major work-load for marine interests has been for the offshore oil industry. Early in the year advice to offshore installations led to two platforms being evacuated in good time before the onset of severe gales. The importance of accurate and timely weather advice to the industry and the need for regular reliable observations on which to base the advice has been emphasized as oil operations extend northwards into more inhospitable waters. The forecasters at London Weather Centre are supported by the Central Forecasting Office and by the main computer complex at Bracknell. At present good progress is being made with the automation of the forecasting of swell in the North Sea. To help the Office to take a more active role in its relations with the industry a Meteorological Office Consultant commenced duty in July at the Offshore Supply Office in Aberdeen. The Principal Meteorological Officer at London Weather Centre has remained in personal contact with senior oil company officials and has continued to serve as a member of the Oceanographic Committee of the United Kingdom Offshire Operators Association. The Office is responsible for quality control of all relevant meteorological data received from offshore installations and the inspection of these installations is carried out, on request, by Meteorological Office staff who also advise on siting, operation and maintenance of the meteorological instruments.

Southampton Weather Centre's participation in the Southampton Boat Show helped considerably to widen the distribution of weather information to yachtsmen. During the season the Centre issued 8000 Weekend Sailing Charts. One-third of these were distributed to yachtsmen on the Hamble River and the remainder were sent to Cowes in the Isle of Wight. These special sailing charts, printed at the Weather Centre, were first introduced three years ago and have become popular with the sailing community in the Solent. Plans are currently in hand to provide the new Brighton Marina, when it becomes operational in June 1977, with a self-briefing weather service for yachtsmen. A direct communications system between the Marina and Southampton Weather Centre has been successfully tested at an official gala ceremony.

A ship routeing service is provided to advise on North Atlantic and North Pacific passages and to offer advice during the movement of tows. For vessels on passage the object of the service is to select the best course for a ship to steer in order to reach its destination in the shortest time with the least damage to hull and cargo, and with the most economical fuel consumption. The vessel's response to various wave fields is determined by extracting data from the deck log-books for the construction of a ship/wave performance curve. Wind and sea wave predictions at intervals of 12 hours for up to 72 hours ahead are supplied to the ship routeing officers by forecasters in the Central Forecasting Office and this information is applied to the performance curve to determine the most favourable course for the vessel to follow. Subjective consideration is given to the loading state of the ship, surface currents, navigational hazards such as shoals, ice and areas of fog. Later stages of the voyage are also borne in mind. Communication with the vessel is usually by telex before sailing and via predetermined coastal radio stations when the ship is on passage. The provision of routeing advice to tows which do not have too restrictive weather parameters is similar to that for conventional ships but allowance has to be made for the slower speed of the tow and for its reduced manœuvrability. When weather factors such as wave height or period, amount of heel or wind force are limiting, the routeing service advises when and where to seek shelter and when to resume the passage. About 300 routeings, including those for tows, were made during the year.

The Central Forecasting Office (CFO) supplied guidance forecasts and warnings to the forecasters on board the Trawler Support Ship stationed off the Icelandic coast during the winter months from late November until the end of April. The forecaster on the support ship maintained close liaison with the British fishing fleets in the area, issuing local forecasts and warnings of gales, storms and ice accretion. When time permitted the forecasters also made bathythermograph (deep sea temperature) soundings on behalf of the Navy Department.

The Main Meteorological Office at Pitreavie continued to provide a winter forecast service for the benefit of North Sea fishing vessels. Forecasts are issued daily from October to March, covering a 72-hour period.

Oil slicks and pollution at sea are emergencies in which CFO plays its part by issuing forecasts and advice on request. Warnings of tropical hurricanes, cyclones and typhoons are issued to Lloyd's. This office works closely with the officers of the Storm Tide Warning Service who are responsible for issuing alerts on occasions when unusually high tides caused by strong winds are liable to cause flooding on the east coast of England.

Forecasts for some Royal Navy ships were supplied by Pitreavie and Plymouth offices, and the Meteorological Office at Aberporth provided support to RN ships undertaking trials in Cardigan Bay. Royal Air Force marine craft at home and abroad were provided with forecasts by the nearest meteorological office.

Main Meteorological Office Gibraltar supplied forecasts for Gibraltar Bay during April and May in connection with barge loading operations. From early October the Main Meteorological Office at Luqa has supplied forecasts and warnings for the towing of two large concrete bases and two floating fuelling terminals from Malta Dockyards to near Tripoli. The project should be completed early in 1977.

Services for civil aviation

Meteorological services for civil aviation in the United Kingdom are provided by the Meteorological Office as agent of the Civil Aviation Authority. The Office has a dual role in relation to the Authority, first to give technical advice on meteorological matters and second to provide the staff and technical facilities to meet the Authority's requirements and standards.

Civil Aviation Forecasters within the Central Forecasting Office (CFO) at Bracknell are responsible for the forecasts of upper winds and temperatures required by civil aviation. They use data and forecasts processed by the Meteorological Office computer. These forecasts, together with forecasts of significant weather prepared at London/Heathrow Airport, form the basis of flight documentation distributed to major airports throughout the United Kingdom and Europe. Distribution within the United Kingdom is by the civil aviation facsimile network (CAMFAX), the hub of which is in the meteorological office at Heathrow. Charts of forecast upper winds and temperatures for levels from 5000 to 40 000 ft ($\approx$ 1500 to 12 000 m), significant weather and tropopause height are broadcast by CAMFAX every six hours to cover flights to destinations in Europe, the Mediterranean area, Canada, USA and the Caribbean region. Meteorologists at airports add information concerning take-off and landing conditions to complete the flight documents which are presented to aircraft captains at pre-flight briefings.

The Principal Forecasting Office at Heathrow is designated the European Area Forecast Centre for all flights to the USA, Canada and parts of the Caribbean from departure airfields in Europe. Flight documentation for these flights is passed by land-line facsimile to Dublin, Paris, Frankfurt, Rome, De Bilt and Copenhagen and by radio-facsimile to more distant recipients. Routine half-hourly observations of weather are made at all major airports in the United Kingdom as part of the network of airport weather reports continuously exchanged between airports throughout Europe and the Mediterranean area over discrete civil aviation teleprinter circuits.

Meteorological services for general aviation (private flying, air taxi services etc.) are provided on request by local civil and RAF meteorological offices. This type of service is specialized and calls for detailed assessments of cloud, visibility, low-level winds and weather hazardous to light aircraft. The general aviation visual flight service provides recorded forecasts of flight conditions in each of a number of defined subdivisions of England and Wales. Each subdivision is given a coding which indicates whether flight under visual flight rules is appropriate. The forecasts are available to the users by dialling published telephone numbers.

Helicopter operations in support of the offshore industry have increased markedly during the past few years. The operations require a specialized service in which particular attention is paid to low-level phenomena including visibility, low cloud, icing and the speed, direction and gustiness of the wind. The forecasting services for helicopters operating to North Sea rigs and platforms are centred upon the Main Meteorological Offices at Honington, which caters for the southern North Sea, and Prestwick which, together with its subsidiary offices, has borne the brunt of the work generated by the fast-growing northern oil and gas fields. To help in meeting the demands of helicopter operations based upon the Shetland Isles it is proposed to open a forecasting office at Sumburgh as soon as accommodation for it can be made available by the Civil Aviation Authority.

Early in the year British Airways introduced regular scheduled supersonic flights by Concorde aircraft, initially to Bahrain and later to Washington. The forecasts for these flights have been provided from CFO and Heathrow. They contain information on winds and temperatures expected at levels up to 55 000 ft ($\approx$ 17 000 m), together with forecast significant weather conditions, such as hail, clear-air turbulence and convection cloud tops, at levels above 25 000 ft ($\approx$ 8000 m). The latter are particularly hazardous for aircraft in supersonic or transonic flight. Concorde's operations are especially sensitive to the temperatures experienced on take-off and also during supersonic cruise. The Meteorological Office is co-operating closely with British Airways in developing forecasting procedures which enable the aircraft's capacity to be fully utilized. At the request of the French authorities forecasts have also been provided for Concorde aircraft bound from Paris for the Middle and Far East.

The supply of wind and temperature data to British Airways for flight-planning purposes is entirely automated. Such data, referring to about 35 000 ft ($\approx$ 11 000 m), are computed in the Meteorological Office computer system (COSMOS) in the course of the routine numerical forecasting runs. The data are then transmitted in grid-point format over a special link for direct input to the machine used by the airline for the computerized preparation of flight plans. Similar data are supplied to Shanwick Oceanic Control at Prestwick.

In April and May the 9th Air Navigation Conference of the International Civil Aviation Organization met jointly with the World Meteorological Organization Commission for Aeronautical Meteorology in Montreal. Members of the Meteorological Office represented the United Kingdom in the meetings which considered the future requirements of civil aviation. In October a member of the Office was included in the UK delegation to the International Civil Aviation Organization Caribbean/South American Regional Air Navigation Meeting, held in Lima, at which meteorological services in the Region were reviewed and recommendations for improvements were made. The Meteorological Office also provided support for the United Kingdom member of the International Civil Aviation Organization Special North Atlantic Panel. The task of the panel included review of the arrangements made in the interest of international civil aviation for joint funding by participating States of certain meteorological surface and upper-air observing stations in Iceland and Greenland together with the associated communication systems.

A more detailed account of the meteorological services for aviation was given as the Directorate of Services Special Topic in the Meteorological Office *Annual Report* for 1975.

Services for civil aviation (overseas)

Services for civil and general aviation continued to be provided from the offices at Royal Air Force stations in Cyprus, Malta and Gibraltar in the Mediterranean; at Wildenrath and Gütersloh in Germany; and at Masirah and Salalah in Oman.

In Cyprus, the Cyprus Meteorological Service opened an office at Larnaca Airport in April 1976 and that office gradually assumed responsibility for the provision of all meteorological services for that airport and for the Nicosia Flight Information Region, relieving our office at Royal Air Force Akrotiri of this task. The Akrotiri office continued to provide services for those civil aircraft, mainly UN charter flights, using Akrotiri.

Services for the Royal Air Force

A senior officer of the Meteorological Office is located at Headquarters Strike Command and another is located at Headquarters Royal Air Force Germany. These officers act as advisers on meteorological matters to their Air Officers Commanding-in-Chief and are responsible for the organization of meteorological services to meet the needs of Strike Command and the Royal Air Force in Germany.

Although most of the meteorological offices have multi-role functions, the forecasting services for the Royal Air Force at home continued to be provided by offices which are distributed largely in conformity with the RAF organization. There is a Principal Forecasting Office at Headquarters Strike Command, and Main Meteorological Offices, functioning throughout the 24 hours every day, are located at various centres to control and advise subsidiary offices at aerodromes and enable them to meet the requirements of aircraft of several types operating in different roles. At the subsidiary forecasting offices a forecaster is on duty at times which depend on the stated requirements of the Royal Air Force. There has been no major change in the organization during the year but there has been a decrease in the number of offices serving the Royal Air Force with the closure of stations resulting from the 1975 Defence Review. During the year RAF stations and associated meteorological offices at West Raynham, Little Rissington, Ternhill and Thorney Island were closed. Meteorological offices were withdrawn from RAF Abingdon, Cottesmore and Andover.

Maximum use is made of the technical support which is provided by the powerful computer system at Bracknell. At Headquarters Strike Command and Headquarters 38 Group a comprehensive six-hourly program of preparation, and issue by facsimile, of area and route forecasts in chart form is maintained as routine to meet most operational requirements. These routine issues include forecast charts of the surface pressure distribution and significant weather charts in addition to forecasts of winds and temperatures for standard upper levels. The routine issues are in a format suitable for self-briefing and are copied at subsidiary offices for issue as flight forecast documentation to aircrew. However, the personal briefing of RAF personnel continues to provide an important service to those concerned in planning and making decisions for military aviation.

Mobile meteorological units continued to support certain Royal Air Force and Army elements in the field and participated in exercises in the United Kingdom and overseas. Each unit has its own air-transportable sets of instrumental and communication equipment for use at locations away from permanent meteorological offices. The sets include radio-teleprinters, radio-facsimile recorders and satellite-cloud-picture receivers. Forecasters in the mobile units hold commissions in Class CC of the Royal Air Force Reserve of Officers.

Offices were opened temporarily for short periods at certain locations to provide a service during large-scale exercises and special operations. A forecaster was again detached to Barksdale, Louisiana, to provide support to the RAF team participating in the United States Air Force Bombing and Navigation Competition.

The provision of services for the Royal Air Force in Germany continued unchanged with a Command Office and a Main Meteorological Office at the Joint RAF/Army Headquarters at Rheindahlen supporting subsidiary offices at the four airfields of Royal Air Force Germany and at the Army Aviation airfield at Detmold.

In the Mediterranean, Main Meteorological Offices and radiosonde stations at Gibraltar and Malta also continued unchanged. In Cyprus, the Main Meteorological Office at Akrotiri, established in lieu of Episkopi late in 1975 as part of the rearrangement arising from the 1975 Defence Review, continued in being. During the first three months of the year the work and staff were progressively reduced to reach the planned Defence Review target on 1 April.

Also as part of the provisions of the Defence Review, the Main Meteorological Office at Gan in the Indian Ocean was closed at the end of March. A fully equipped observing office was left and a Maldivian Government observer took over the facilities. At a farewell ceremony on Hittadu, the Chief of Addu Atoll was presented with a suitably inscribed Kew-pattern mercury barometer.

In Oman, subsidiary offices continued to operate on the RAF station at Masirah and in support of the RAF detachment at Salalah. Following the announcement in midsummer that the Royal Air Force would withdraw from Masirah and Salalah on 31 March 1977, planning was started for the rundown and closure of our offices there and, to fit in with shipping availability, the Masirah radiosonde station closed on 1 November 1976.

A 'VOLMET' broadcast from West Drayton of plain-language weather reports for major RAF aerodromes was continued. This broadcast is provided mainly to meet the needs of transport aircraft returning from overseas to bases in the United Kingdom.

Although some meteorological offices are still required to give regular courses of instruction, the RAF-prepared training packages on meteorology are now in use at RAF schools and some meteorological staff have been released from the training task.

Services for the Army and Establishments of the Procurement Executive, Ministry of Defence

Increased meteorological support was provided to Army and MOD(PE) units for their planning, development and operational roles.

Forecasting offices for Army Aviation are maintained at Netheravon and Middle Wallop in England and at Detmold in Germany. Liaison was maintained with Headquarters of No 1 (BR) Corps through the Officer-in-Charge of the subsidiary office at Detmold and the Headquarters was supported by forecasting staff during exercises.

Further assistance was given in the development and testing of a mobile hydrogen generator. This will now be brought into service for use with the Army Meteorological System (AMETS) which measures and processes upper-air data for ballistic purposes.

An experiment is being carried out to investigate the effect of the natural variability of wind on tank gunfire.

Offices were maintained at the Royal School of Artillery, Larkhill, at the Royal Aircraft Establishment, Aberporth, and at the Proof and Experimental Establishments at Shoeburyness, Eskmeals and Pendine. The office at Shoeburyness also provides meteorological support to the Atomic Weapons Research Establishment at Foulness. Detailed planning for the modernization of the upper-air sensing equipment at most of these establishments was started.

Meteorological Office staff were attached to the Army practice camps at Sennybridge and Otterburn for several periods during the year to provide meteorological information for ballistic purposes.

The observing office at RAE West Freugh closed on 1 September.

Liaison with the Navy Department

Close co-operation was maintained with the Directorate of Naval Oceanography and Meteorology to ensure the co-ordination of plans to meet the requirements of military forces at home and overseas.

International defence services

The Meteorological Office participated actively in the work of NATO and CENTO committees concerned with the international co-ordination of meteorological support for military needs and contributed to studies associated with that support. At the invitation of the United Kingdom the spring 1976 meetings of the Working Groups on Weather Plans and Weather Communications of the NATO Military Committee Meteorological Group were held in London.

Services to the Home Office

The meteorological requirements of the Warning and Monitoring Branch of the Home Office have been kept under review in close working association with that Branch. Detailed plans for meeting these requirements as effectively as possible in an emergency continue to be maintained and tested in regular exercises. Lectures were given to groups of Home Office Sector Scientists, Chief Warning Officers and members of the Royal Observer Corps, who are equipped and trained to make simple meteorological observations in times of emergency.

Services for nuclear establishments

Arrangments for certain Main Meteorological Offices to supply information to nuclear establishments of the United Kingdom Atomic Energy Authority and the Electricity Generating Boards in the event of accidental release of radioactive or toxic material have been reviewed and exercised. A computer program for the rapid provision of forecast wind trajectories has been brought into use for this purpose.

Climatological Services

There are currently about 630 observing stations which make climatological returns to the Office (see Table IV on page 67), and at least four-fifths of these stations are maintained by voluntary observers or co-operating authorities. As observations are the necessary foundation for all climatological work, it would be difficult to overestimate the value and importance of this co-operation; it provides to the national archives a massive contribution for which the Office is extremely grateful. The difficulties and expense of making observations at 9 a.m. every day including week-ends are considerable, so it is not surprising that financial pressures during 1976 have led to the closure of more than 20 climatological stations. Long-period records are of especial value in climatological work, and the loss of stations such as Earls Colne and Dover (where observations had been made for 51 and 92 years respectively) is a serious matter, but on the credit side, there has been some welcome success this year in recruiting new stations, and it is hoped that measures now under discussion will make possible a greater degree of support for the network. In the longer term, however, automatic equipment will be needed to fill gaps in the network where human observations cannot be obtained, and this development will be particularly useful in parts of Scotland and Wales. Digital anemograph logging equipment (DALE) is now in production, and it is hoped to install it at 20 sites within the next two years. The design and construction of two prototype sets of automatic climatological recording equipment (ACRE) is now in hand in the Operational Instrumentation Branch at Bracknell.

Climatological returns from stations in England and Wales are collected at Bracknell, whilst those from Scotland and Northern Ireland are received by our offices in Edinburgh and Belfast respectively. All these data are transferred to magnetic tape by processor-controlled keying (PCK) in the Data Processing Branch at Bracknell. Using the computer, thorough checks for internal and serial consistency are then made, and at a later stage in the quality control process, observations are compared with those from neighbouring stations. During the year, the range of spatial checks was extended by developing a new program to compare wind directions; this has been so successful that on several occasions it has correctly indicated that the orientation of an anemograph was in error. When an observation fails to meet any of the tolerances set in the quality control programs, a query message is printed by the computer; these queries are then resolved by human scrutiny at Bracknell, Edinburgh or Belfast, and when necessary the point is referred back to the observer before amendments are made to the data set on magnetic tape. There is thus a need for quick and reliable transfer of data and quality control information between Bracknell and Edinburgh/Belfast; the introduction in June 1976 of a Data Post service which guarantees overnight transit of packets between Bracknell and Edinburgh has been a big step forward, and is working well. The processing of data from stations overseas for which the United Kingdom is responsible had to be stopped some years ago owing to staff shortages in the PCK section; during 1976 it has been possible to recommence this work and three years of backlog data from the Seychelles have been processed.

After the quality control process is complete, the clean data set is used in the computer to produce a film from which the *Monthly Weather Report* is printed. This process, which has the great merit of eliminating both manual type-setting and proof-reading, had run into a number of production difficulties and the issue for March 1975 was not published until January 1976. During the year, however, most of the problems were overcome and the issue for March 1976 was published in September; the target of publishing roughly four months in arrears should be attained during 1977. The magnetic tape archives were used in the same manner to produce the 1941–70 *Averages of Temperature* and *Averages of Bright Sunshine*; these were published by HMSO in June. Production of the annual *Snow Survey* had fallen several years into arrears, but this has now been brought up to date and the *Snow Survey* for 1975/76 was published late in the year. Several *Climatological Memoranda* were produced during the year and amongst these were some presenting maps of annual and monthly mean Pressure, Temperature, Humidity, Sunshine, Snow and Wind.

The total number of climatological enquiries handled at Bracknell, Edinburgh and Belfast is still increasing (see Table XIII on page 71). The very severe gale of 2 January, which caused structural damage in almost every county of England, Wales and Northern Ireland, gave rise to a large number of requests from civil and structural engineers and from solicitors and insurance assessors for advice about extreme wind speeds recorded during the gale and for comparisons with speeds reached in previous gales. The long hot summer also gave rise to a large number of enquiries, most of them from engineers concerned with the design and operation of cooling towers and air conditioning installations who needed information about dry-bulb and wet-bulb temperatures recorded during the hot spell in June and July; not surprisingly, however, there were very few enquiries during this period from building contractors, as delays due to adverse weather did not occur. Despite this, over the year as a whole, the largest proportion of enquiries came from the building and construction industries, with legal and insurance, water supply, agriculture and research also making substantial contributions to the total.

At the request of both the Department of Energy and the British Gas Corporation, data from 20 stations over 20 years have been analysed using computer methods to determine the number of degree days above given temperature thresholds. These analyses provide data bases with which figures to be supplied monthly in future will be compared; the aim of this exercise is to assist industry to achieve more effective conservation of energy. An interesting study to determine the maximum current which can safely be carried by exposed cables of the National Grid under extreme weather conditions has been commissioned by the Central Electricity Research Laboratory; basic relationships have been supplied to us, and actual meteorological data will be entered into these. The study of meteorological conditions along alternative routes for a possible new trans-Pennine motorway was completed during the year, and at the request of the Department of Transport, a similar study has been started in connection with the northward extension of the M1 motorway from Leeds; this contract project will involve the setting-up of several special observing sites and the analysis of records obtained over a period of two to three years.

The combination of wind and rain during three days in September caused an unprecedented amount of rain penetration into buildings in north-east England, and led to a number of enquiries from construction firms and planning authorities; investigation established that the return period of such an event in that area is about 50 years. Driving rain problems have received further attention during the year from the Building Climatology section which is funded by the Department of the Environment. The computer model developed to describe the water content of a wall has been used to identify the sequence of weather events which leads to rain penetration; the likely frequency of such weather sequences affecting walls facing in different directions and located in various parts of the country has been determined. Other activities of the section have included the preparation of a booklet to describe the climate of the Plymouth area; the style and content of this booklet have been designed specifically to meet the needs of the building and construction industries, and when approved for publication by the Building Research Establishment, will serve as a model for future issues that will eventually be produced to cover all major urban areas of the United Kingdom.

Almost 1500 of the enquiries received referred to the climate of other countries; this is a marked increase on the figures for 1975. Most of the requests were from consulting engineers and architects in the United Kingdom who are engaged in planning and design for new buildings and public works in Iran, Saudi Arabia and the Gulf States. The main requirements are for statistics of temperature and humidity in connection with the design of air conditioning systems, frequencies of intense falls of rain for design of storm sewers and culverts, and advice about extreme wind speeds for design and siting of new buildings and structures. It has been agreed that the necessary climatological input will be provided on a commercial basis for the British Urban Development Services Unit (BUDSU); this new section of the Department of the Environment has been set up to export British town planning expertise to developing countries in all parts of the world.

The land climatologist continues to serve as a member of several committees of the British Standards Institution. During the year, he also attended a meeting in Amsterdam set up by the International Organization for Standardization to discuss meteorological aspects of the draft European Code of Practice on Wind Loading. The Branch also provides members for two Working Groups of the World Meteorological Organization (WMO), one concerned with the *Guide to Climatological Practices* and the other with the issue of climatological data to users.

This has been the first full year of activity for the small research group which was set up in August 1975. Methods are being developed for the assessment of the accuracy of interpolation between observation points of stated separation. Results will enable an optimum spacing to be defined for different types of topography. Factor analysis is being used to define the characteristic patterns of spatial variation of the various climatic elements, and cluster analysis techniques are then used to group stations displaying maximum similarity. This work should lead to improvements in areal quality control. With the problems of week-end observing in mind, a study has been started into the feasibility and accuracy of interpolation in time and space from other data. The group also made a detailed study of the remarkable gale of 2 January, and possible repercussions on wind loading standards were discussed in a published paper. A similar study in depth of the notable hot spell of 23 June to 8 July is now in hand, and will be published in 1977.

Climatological services for Scotland are provided by an Edinburgh office which has now settled down following the move during 1975 to the Corstorphine Road. The main tenant of the building is the Forestry Commission, whose staff have been most helpful, for example by making available committee and lecture room facilities without charge. Apart from providing accommodation of a much higher standard, the move has enabled the Scottish meteorological archives to be housed alongside the offices, and this has been of great benefit when dealing with requests for past data. Despite the move out of the city centre, and the accidental omission from the Edinburgh Telephone Directory of an appropriate entry, enquiries have continued at a fairly high level, with substantial numbers coming from the building industry, from research interests, and from on-shore activities connected with North Sea oil and gas. Maintaining the climatological and rain-gauge networks in Scotland is always difficult, and the rapidly rising costs to co-operating authorities of providing observations at week-ends have brought new problems during 1976. A modest start has been made with automatic instrumentation, and with assistance from co-operating authorities, magnetic tape event recorders (MTER) have been installed at seven sites to measure rainfall.

The office in Belfast still provides full climatological services for Northern Ireland despite the continuing environment of terrorist activity. Indeed, during 1976 the number of enquiries dealt with has increased by almost 50 per cent, and the Senior Meteorological Officer and his staff are to be congratulated on this achievement. Whereas in England, Wales and Scotland most of the services for agriculture are provided by specialist units, the Belfast office combines this work with its other activities, and almost a fifth of the enquiries related to agriculture. The close relationship that has been established with the Water Data Unit of the Northern Ireland Department of the Environment continues to the mutual benefit of both parties, and MTER equipment is in process of installation at four sites.

The enquiry work of the Marine Climatology section has increased strikingly during 1976. For the second year running, the total number of enquiries handled has more than doubled. The enquiries themselves are now more complex, and many of them are urgent. Substantial numbers of marine observations from all parts of the world are now available at Bracknell on magnetic tape, but these data can only be accessed to provide processed information if appropriate programs are to hand, and it takes time to write these and test them. Early in the year it was decided to develop a suite of programs that would carry out for any sea area the types of analysis most commonly required. These include frequency distributions of any weather element or of spells of adverse weather such as gales or fog of specified duration, and extreme value analyses of, for example, wind or waves.

With the aid of these programs, it has been possible to meet the challenge posed by the changing pattern of enquiries and to provide very quickly detailed analyses for areas both near the United Kingdom and in more distant parts of the world. Information is needed in connection with the design of offshore installations, harbours or oil terminals, or to facilitate planning for tows of drilling rigs or other large structures. Some enquiries dealt with during the year were of particular interest and called for special investigations, for example of wind characteristics over the Wash in connection with design a study for a water storage scheme. As there were no long-period records of wind in this area, anemographs were installed locally for a period to enable relationships to be established with inland stations whose records were then used to produce representative frequencies. A study was made of winds off western Scotland and south-west England in connection with work being done to assess the potential of devices to extract energy from waves. The weather affecting the transport of oil by tanker from a production platform to a shore terminal was also investigated; interruptions to such operations have an important bearing on the storage capacities needed at both platform and terminal.

The increase in enquiry work and the need to develop the suite of computer programs have stretched the staff resources of the section to the limit. The operational commitments of the sea ice unit have been met in full, but it has only been possible to revise the ocean current, and, where applicable, sea ice sections of three volumes of *Admiralty Pilots*. Good progress has, however, been made with the computer programs needed to produce for WMO the *Marine Climatological Summaries for the Atlantic Ocean*; these programs are now virtually complete, but cannot be tested fully until the necessary marine data sets are available.

The marine climatologist has devoted a considerable amount of time to matters affecting the offshore industry. He has continued to participate in the activities of the Offshore Installations Technical Advisory Committee of the Department of Energy, the Environment Sub-Group of the European States Working Group on Safety and Pollution, and the British Standards Institution committee which is preparing a Draft Code for Development of Fixed Offshore Structures. He is also a member of the WMO Working Group on Marine Climatology, and attended the 7th Session of the Commission for Marine Meteorology in Geneva during December, when he gave a scientific lecture on sea surface currents. Despite these many activities, and work in connection with the more complex enquiries, time has been found to carry out some research into methods of extreme value analysis which can be applied to short-period wind records. The results so far are most encouraging, and it is hoped that the method developed will enable improved advice to be given to the offshore industry.

Services for Hydrometeorology

The collection, quality control and preservation of rainfall observations from about 6800 stations and evaporation data from about 60 stations in the United Kingdom continued throughout the year. The Edinburgh Office administers and inspects stations in Scotland and the Belfast office carries out these functions in Northern Ireland, although Bracknell has overall responsibility for the work.

The improved computer-based procedures for the quality control of rainfall observations, introduced in 1975, have had some teething problems but these have been mostly overcome. The computer programs indicate doubtful values and print out automatic corrections in many cases. For the remainder the human analyst scrutinizes the data and inserts corrections wherever necessary. It is now possible to present statistics of commonly occurring faults in rainfall observations, and the analysis of such statistics should aid the management of the rain-gauge network.

The computer-produced index of rainfall stations in the United Kingdom, known as RAINMASTER, has been revised and expanded during the year. Around 14 000 present and past rainfall stations are now listed. The contents are the subject of close liaison between the Office and the various water authorities. So far as automatic rain-recorders are concerned, there is also close liaison with the Institute of Hydrology. Copies of RAINMASTER or extracts from it are now available to customers.

Monthly and annual averages of rainfall for the period 1941–70 for some 8000 sites have been computed, quality-controlled and plotted. Maps of annual average rainfall on a scale of 1 : 250 000 have been completed and a simplified version has been prepared for publication on a scale of 1 : 625 000. Rainfall observations are prepared for publication in the *Monthly Weather Report* and *British Rainfall*. Progress in bringing the *British Rainfall* publication up to date is still delayed by a dispute in the printing industry.

The precision encoding and pattern recognition (PEPR) equipment at the Nuclear Physics Laboratory at Oxford University is being used to extract detailed information from about 1¼ million daily autographic rainfall charts. Some 350 000 charts have now been digitized and some of the information has already been used in statistical investigations. About 60 magnetic-tape event recorders (MTER) are now deployed to measure short-duration rainfall in remote areas where manual recording is difficult and in closely spaced networks of special interest to the research worker. A continuing investigation of the reliability of the rainfall information so acquired is proceeding and practical difficulties in the operation of the systems are being overcome. The retrieval rate of reliable rainfall data is currently over 90 per cent.

Hydrometeorological enquiries in the year increased by some 22 per cent on the 1975 total, which was itself about 47 per cent above the 1974 figure. As in previous years enquiries were most frequently concerned with building, drainage, legal and water matters although there was a marked decrease in enquiries from the building industry, no doubt partly due to the long spell of dry weather in the first eight months of the year. On the other hand there was a substantial increase in enquiries from the water industry, partly related to the extended drought.

The enquiry section utilizes suites of computer programs which enable tabulations to be made of rainfall amounts in specified durations (1 minute to 25 days) which will be equalled or exceeded for a wide range of return periods, e.g. from as often as twice a year to as seldom as once in 1000 years. Storm profiles can also readily be provided which, for any catchment area and return period, give intensities of rainfall at either side of the peak intensity. In the past year a suite of programs has also been introduced to compute the percentage of average rainfall corresponding to given return periods (from 2 to 1000 years) for any number of consecutive months (from 1 to 120) starting in any given month. The return period of any specified amount of rainfall in any given period of consecutive months can also be computed. Tabulations can be made for any point or area within Great Britain. These operational suites of programs are the outcome of investigations carried out within the Meteorological Office during the past few years.

The extended period of rainfall deficiency from May 1975 to August 1976 over England and Wales as a whole was unprecedented since records began in 1727. The total rainfall generally was 756 mm which is 63 per cent of the average for the 16 months (although Scotland and Northern Ireland were dry during the period, the deficiencies were much less marked, totals amounting to 83 and 73 per cent of the average respectively). Over England and Wales the second driest 16 months, May to August, was in 1749–50 (809 mm). From May 1975 to August 1976 the areas of most marked deficiency (less than 60 per cent of point rainfall) lay in southern England and South Wales, roughly from Carmarthen Bay to Flamborough Head, but excluding extreme south-west England and eastern England from the Wash to Dover. Less than 50 per cent of point average occurred along the south coast from Start Point to the Isle of Wight and locally in Midland England. The extended period of deficiency was brought to a decisive end by the rainfall of September and October 1976. It was the second wettest September over England and Wales generally since 1727 and the combined total for September and October was also the second highest on record.

An article on the prolonged rainfall deficiency for May 1975 to April 1976 was published in *The Times* in May 1976; a rather longer article on the same topic was published in the National Water Council's journal *Water* in July 1976. Many enquiries, particularly from the Press, radio, television and water authorities, on the marked deficiency in rainfall were answered. A considerable amount of information on the drought was supplied to the Central Water Planning Unit (CWPU) for incorporation in reports prepared by the Unit for the National Water Council and Regional Water Authorities. The information supplied to CWPU included maps showing percentages of average rainfall for specified durations within the 16 month period of rainfall deficiency, maps showing probabilities of occurrence of specified percentages of rainfall below average at points and over catchment areas, and maps showing percentages of average rainfall which occurred in notable earlier droughts (for example 1921, 1933/34). Tabular information was also supplied for England and Wales and for the former River Authority areas showing percentage of average rainfall corresponding to given return periods (up to once in 1000 years) for durations from 1 to 120 months.

Progress was made in the longer-term project for assessing monthly and daily rainfall over a large number of catchment areas for the Central Water Planning Unit. For some major areas the requirement is for information well back into the 19th century. The Water Data Unit has an expanding requirement for estimates of general rainfall for Surface Water Survey areas. A request was made for average rainfall and monthly rainfall in individual years for about 400 areas; this is additional to the estimates of monthly rainfall already prepared for about 500 areas, so that the future commitment is expected to be for areal rainfall for nearly 1000 catchments per year. Steady progress was made on the preparation of areal estimates for old and new areas. A considerable amount of material was provided for two Water Data Unit publications, the *Ground Water Yearbook 1971–73* and *Water Data 1975*. In the first publication an account was given of the weather in each of the three years in relation to groundwater levels and tables of rainfall, evaporation and soil moisture deficit were supplied for 17 groundwater regions. For *Water Data 1975*, maps of rainfall and potential evaporation, estimates of areal rainfall in 1975 over Regional Water Authority areas and a map of estimated residual rainfall 1975 (i.e. rainfall percolating to permanent groundwater) were supplied.

Requests for evaporation and soil moisture deficit data showed a marked increase during the year. Among the information supplied were estimates of daily rainfall and soil moisture deficit over six Northern Ireland catchment areas for the Department of Finance, Northern Ireland, potential evaporation for 20 years for five United Kingdom catchment areas for an International Commission on Irrigation and Drainage, study and estimates of rainfall, actual evaporation and soil moisture deficit 1950–75 over the Lincolnshire Wolds for the Anglian Water Authority. Additionally, progress was made on a major task for the Anglian Water Authority involving preparation of maps of annual rainfall and potential evaporation and estimates of monthly rainfall 1920–75 over the whole of the Authority's area and estimates of daily rainfall, evaporation and soil moisture deficit over the whole area and 24 smaller areas for 1961–75.

Work has also been carried out for various places overseas. Estimates of rainfall, evaporation and soil moisture deficit in Ghana were provided for the Commonwealth Development Corporation in connection with studies of the feasibility of oil palm development. Rainfall and other meteorological observations from western Nigeria have been analysed and estimates of Probable Maximum Precipitation have been made for various durations in support of reservoir design projects. Data on rainfall amount, duration and return period for other overseas locations, including Lagos and towns in Saudi Arabia have been prepared.

The bulletin on *Estimated Soil Moisture Deficit and Potential Evapotranspiration over Great Britain* was issued at frequent intervals during the year.

A reappraisal of the existing rain-gauge network, which has grown in a rather haphazard manner over the years since the first rain-gauge was installed in 1677 in Lancashire by Richard Townley, is overdue. The Meteorological Office is co-operating with the Institute of Hydrology in a project to assess the measures necessary to provide an adequate network for national and regional needs. A Principal Scientific Officer is a member of the Department of the Environment National Water Council Working Party concerned with the design of urban storm sewers which is preparing a revised code of practice for urban storm sewer design. A pilot study, commissioned by this Working Party, on storm movement was completed. The report submitted to the Working Party, which was only tentative, was not able to confirm that there were preferred directions of movement of rain-storms of relevance to storm sewer design. However, more work on this problem will probably be necessary.

Following the publication of the *Flood Studies Report* in 1975 further statistical investigations are proceeding, particularly on the probability of occurrence of short-duration rainfall. This type of work on short-duration rainfall exploits the detailed rainfall data in digital form which are being steadily accumulated from the PEPR project. Another investigation has confirmed the general soundness of assumptions made in the *Flood Studies Report* about the relationship between point and areal rainfall, and some useful additional information has been obtained.

Further analyses have led to the development of objective techniques for estimating the frequency of occurrence of falls of snow in terms of intensity, duration, accumulated depth on the ground and persistence of snow cover. Enquiries concerning snow and snowmelt in the United Kingdom can now be handled more objectively.

The study of the frequencies of accumulated rainfall deficiencies has been completed and an objective technique has been brought into use in the enquiry section to relate specified rainfall deficiencies with return period and also to relate specified return periods with rainfall deficiencies, at points and over defined areas. This facility has been employed in answering many enquiries about the 1976 drought and in contributing to studies of water resource planning. Analyses have been made of monthly rainfall and potential evaporation data for Kew and monthly hydrologically effective rainfall (the contribution of rainfall to water resource) have been derived for the period 1871 to 1976.

The main computer programming phase of the new model for computing soil moisture deficit has been completed and operational listing of procedures has started. Estimates of incoming radiation, radiation balance and potential evaporation obtained from Penman's formula have been compared with direct measurements. A computerized archive of British evaporation data has been set up.

The Dee Weather Radar Project, involving co-operation between the Meteorological Office, the Water Research Centre, the Central Water Planning Unit, the Water Data Unit, the Dee and Clwyd River Division of the Welsh National Water Development Authority and Plessey Radar Ltd, continued throughout the year, but at the end of September the radar data collection ceased as planned. The real-time processing system using a PDP 11/40 computer at the Llandegla site, which came into operation at the beginning of 1975, was extended to include real-time calibration using data obtained from three rain-gauge sites situated within the Dee catchment.

Data were supplied via telephone lines in real time to a computer situated at the River Control Centre at Bala, for use as one input to a hydrological flow model of the River Dee. Assessment of the usefulness of the radar data in this model is continuing at the Institute of Hydrology and the Water Research Centre in consultation with the Meteorological Office.

Confirmation was obtained that the radar measurements of rain falling on subcatchments (about 100 km^2) in the real-time mode differ on average from rain-gauge estimates by about the same amount (15–20 per cent) as was found in the previous year.

In order to provide an assessment of the usefulness of the radar data to operational hydrologists and meteorologists, the radar data were transmitted in real time over telephone lines on an experimental basis to the Main Meteorological Offices at Preston and Gloucester, and to the offices of the Severn–Trent Water Authority at Malvern.

Further work was carried out on the development of a numerical model, employing a grid length of 1 km, for use in estimating rainfall, taking account of the orography of North Wales. A method of allowing for inefficiencies in the orographic rainfall process in certain synoptic situations, using radar data and numerical techniques has been suggested. A series of experimental forecasts were carried out after the event, and an assessment made of possible forecast accuracy given real-time data from a network of radars.

A Principal Scientific Officer continued to be attached to the Institute of Hydrology and a team led by him made a further series of micrometeorological measurements over Thetford Forest. The evaporation was measured over 60 days at the central experimental site (four kilometres from the south-west edge of the forest) and also on about 30 days at the second experimental site (one kilometre from the edge of the forest) when the wind was blowing from the south-west quarter. It is intended to use the data to develop a model describing the biological control (through closing of the stomata) of the evaporation from the forest and to investigate any changes in evaporation across the forest.

The routine collection of climatic data and the rainfall, throughfall and stemflow measurements have been continued at Thetford Forest. Similar data for 1975 were used in a model to estimate interception of water developed by Professor Rutter and his co-workers at Imperial College and results of the calculations of the annual interception agreed to within five per cent with the measured interception. Using the measurements of interception and estimates of the transpiration based on the Monteith–Penman equation with a simple model of the diurnal variation of the surface resistance of the forest showed that in 1975 the total evaporation from the forest agreed within experimental error with the Penman estimate of potential evaporation from short grass in the same area.

Co-operation on hydrological matters continued at international and national levels, through the World Meteorological Organization, Unesco, the UK International Committee for International Hydrology and in other less formal ways. Mr R. Murray (Principal Delegate), Mr O. Gibb and Mr H. J. Richards (Central Water Planning Unit) attended the WMO Commission for Hydrology Session V at Ottawa, Canada, from 5 to 16 July 1976. A symposium on the hydrometeorological work of the Office was held at the Meteorological Office College on 24 March and was opened by the Director-General; another was held in Edinburgh on 13 May. In each case an invited audience of hydrologists and engineers from the water industry was present.

Services for Agriculture

Services for agriculture have continued to develop, although the number of staff at Headquarters and the four regional offices at Bristol, Cambridge, Edinburgh and Harrogate has remained virtually constant at about 20. Experienced staff members moved from the Bristol and Edinburgh Offices and Mr L. P. Smith, Special Merit Senior Principal Scientific Officer, retired from the headquarters unit in May after nearly 30 years of distinguished service to agricultural meteorology. He was president of the WMO Commission for Agricultural Meteorology for 10 years from 1962.

The effort of staff at headquarters has been devoted mainly to advancing the science of agricultural meteorology but at the same time certain routine services have been maintained and developed and work at the outstations has been supported by the extraction and computer processing of data for their use. As well as maintaining their advisory roles with other disciplines within the Agricultural Development and Advisory Service (ADAS) of the Ministry of Agriculture, Fisheries and Food (MAFF), staff at the regional offices have continued their own lines of investigation. These are usually closely related to the problems on which they are asked to give meteorological advice.

Co-operative work and discussions have continued with many institutes involved in agricultural research and development, such as the Central Veterinary Laboratory, Plant Pathology Laboratory, Weed Research Organization and Grassland Research Institute, as well as Experimental Husbandry Farms and Experimental Horticultural Stations. A member of the headquarters staff is associated with the Joint ADAS/ARC Committee on Grassland Manuring and outstation staff sit on a variety of committees and advisory boards.

Now firmly established is the supply of routine agrometeorological data to the regional offices, including indices relevant to barley-mildew, apple scab and potato blight. Daily meteorological data are extracted by COSMOS from the synoptic data bank and transmitted to ADAS offices. Other cereal disease indices, for septoria in wheat and rhynchosporium in barley, have been transmitted experimentally to plant pathologists for use in conjunction with disease criteria trials. As in previous years, staff have been on 'stand-by' for possible deployment to an epidemiological control centre in the event of the confirmation of foot-and-mouth disease.

A wide variety of investigations into relations between climate and agriculture and horticulture have been carried out. Examples are: climatological comparison between UK and European viticulture sites, wilting of grass crops, late frosts in south-east Scotland, vernalization of sugar beet seed, the ventilation requirements for grain storage, and meteorological constraints on crop spraying. Following the oil crisis there has been an effort to assess heat losses from glasshouses and plastic structures. Work has continued on the search for relationships between certain animal diseases and the weather and for weather influences on insect populations. Good progress was made on work relating to agroclimatic areas in Scotland. In addition, the summer drought prompted many enquiries to headquarters and outstations for information on soil moisture deficits, evaporation and irrigation need.

Field experiments included studies of various designs of pig houses, a demonstration of the effect of planted straw as a windbreak and a survey, in conjunction with ADAS (South-eastern Region), into mortality in lambs prior to weaning. Several frost surveys have been carried out. The Bristol Office continues to be closely involved in a project organized by the Permanent Pasture Group of the Grassland Research Institute.

There have been consultations with MAFF on the development of automated agricultural weather stations and the inception of a trial of forecasts of the probability of rainfall of 1 mm or more which may form the basis of a new service to farmers. Other contributions by staff include: radio interviews on 'Weather influences on crop spraying' and on the hay fever season; presentation of display material on 'Focus on grass' and 'Aircraft in agriculture' at agricultural shows and open days.

Over 40 internal memoranda were issued and several papers were published. HMSO undertook the publication of two MAFF *Technical Bulletins* on 'Drainage and Climate' (No. 34) and 'The Agricultural Climate of England and Wales' (No. 35).

Observational Requirements and Practices

The Branch, of which the Marine Division under the Marine Superintendent is a part, has overall responsibility for arranging that regular meteorological observations of suitable quality are made on land, at sea and in the upper atmosphere in sufficient numbers and with an appropriate distribution in time and space to meet national and international requirements. It specifies how meteorological sensors and observing systems shall be exposed and details the observing techniques to be employed. It arranges for observing stations to be inspected regularly to ensure that approved standards of site, instrumentation and observational procedures are maintained. The Branch establishes, on behalf of the forecasting, climatological and hydrometeorological branches, requirements for new or improved sensors, observational systems or practices, and organizes field trials to determine suitability for operational work, optimum procedures for their routine use and the effect of their introduction on the accuracy and comparability of the basic observational data. It works closely with the Operational Instrumentation Branch on the specification of new sensors or observational systems and on the design of trials to establish the performance of prototypes.

The Branch provides the Chairman and Secretary of an internal working group concerned with reviewing the UK Observational Networks. In the international field the Assistant Director (Observational Practices) serves on the WMO Working Group on the Global Observing System (GOS), whilst senior branch members serve on working groups concerned with radiation measurements and with the requirements, accuracy and quality assurance of observational data.

The Assistant Director (Observational Practices) is chairman of a European Co-operation in Science and Technology (COST 72) Sub-group on Automatic Weather Stations. The Meteorological Office has had a contract from the 19 COST countries to produce a report on Automatic Weather Stations in Europe and to organize a Technical Conference on the subject. The Technical Conference, which was opened by the Director-General, was held at the University of Reading between 22 and 24 September and attracted 153 participants and 23 exhibitors representing 13 countries. The Assistant Director (Observational Practices) acted as Conference Director. The Final Report was presented to the Technical Committee for COST 72 in November thus completing three years' work on the contract.

Observatories

The Observatories at Kew and Lerwick and the Meteorological Office section at Eskdalemuir (a NERC Geomagnetic and Seismological Observatory) are important stations in the observing network, providing data of the highest quality.

The program of internal renovation of the historic building at Kew is approaching an end and the opportunity has been taken to deposit many of the historic documents and instruments no longer required with appropriate authorities.

The program of work at Lerwick is the most extensive of all and includes observations of ozone, noctilucent clouds and aurora and certain chemical constituents of air and rain. Lerwick is a designated WMO 'base-line' station for atmospheric pollution studies. The program of solar radiation observations and upper-air soundings continues and a full program of thunderstorm location as part of the UK network is now undertaken.

Observations of atmospheric potential gradient are undertaken at all three Observatories. The continuing need for these observations has been discussed with all interested authorities during the year and a program of modernization of equipment and techniques is now under way. The entry into force of the Health and Safety at Work Act has led to the Department of the Government Chemist to discontinue the preparation of polonium coated collectors used in this work after many years of co-operation with the Meteorological Office. New arrangements have been made with the Radiochemical Centre at Amersham which has the necessary facilities.

The program of evaluation of new or improved instruments and observing techniques continues at all three Observatories. In most cases these are necessarily lengthy in order that most atmospheric conditions likely to be encountered in operational service are explored. The availability of staff free from the need to provide an operational service and able to give full attention to trials makes the Observatories especially valuable in the program of evaluations.

Surface observations

Several different kinds of surface observations are made to meet particular requirements. For weather analysis and forecasting purposes a network is maintained consisting of observing stations making weather reports at fixed times agreed internationally. It is essential that such reports, known as 'synoptic' reports, should be received without delay for use in weather analysis and forecasting. The United Kingdom synoptic reporting network consists of 260 stations, of which 75 make hourly reports, and 47 make 3-hourly reports, throughout the 24 hours of every day of the year. The remaining 138 stations report less frequently, some closing at night or at weekends. Meteorological Office staff man 80 synoptic reporting stations, most of which are located at civil and military airfields. An important addition to these Meteorological Office staffed stations during the year has been one reporting hourly throughout the 24 hours and located at the Royal Greenwich Observatory, Herstmonceux. This represents a significant improvement in the observing network in south-east England which has been deficient for some years. The remaining 180 stations are manned by staff of various other authorities and organizations, such as coastguards and lighthouse keepers, or by private individuals; these stations are known as auxiliary reporting stations. Special courses for training auxiliary observers in the making and reporting of weather observations are held at the Meteorological Office College. If it is not possible for an auxiliary observer to attend one of these courses arrangements are made for instruction to be given at a nearby meteorological office, or for a member of the staff of that office to visit the auxiliary reporting station to give instruction on the spot.

There is also a requirement for records of meteorological variables to be maintained over long periods at sites representative of the various types of terrain and urban environment. These 'climatological data' provide information for the long-term averages, extreme values and frequency distribution of meteorological variables and are used in a variety of planning activities notably in agriculture, town planning and industry. It is, of course, important that the exposure of climatological stations should remain substantially unchanged for long periods and this is becoming increasingly difficult to ensure.

Many stations making synoptic reports submit climatological returns as well, usually for several observing hours each day. In the case of a number of key climatological stations manned by Meteorological Office staff these returns cover the whole 24 hour period. About 500 other stations make climatological returns only, usually of data read at 09 GMT though some make returns for additional hours. Most climatological stations are operated by local authorities or similar organizations but a number are still operated by private individuals on a voluntary basis at their own expense. Courses for climatological observers are held at the Meteorological Office College.

In the particular case of rainfall a more extensive network is required to provide the data needed to determine the distribution. This information is of great value for water use, control and planning. Data are received from about

6800 stations most of which measure rainfall only, though a few also measure evaporation. The majority of rainfall stations are maintained by co-operating authorities, usually Regional Water Authorities; the remainder are operated by a variety of other authorities and by private individuals. Though the Meteorological Office operates a relatively small proportion of the total number of rain-gauges it gathers data from all those meeting suitable standards of exposure and equipment and carries out an inspection program to ensure that suitable standards are maintained. In recent years the rate of inspection has fallen well below that shown to be necessary by the incidence of faults revealed by frequent inspections in a small network. The inspecting staff has therefore been increased and a rearrangement of the inspection program is being studied.

In order to assist the forecasting of weather conditions along major roads a network of 81 stations has been set up providing plain-language reports (PLAINOB). Of these, 51 are at road maintenance depots alongside motorways, 16 are at Automobile Association and Royal Automobile Club offices and 14 are at other locations. Reports are made at approximately three-hourly intervals during daylight hours throughout the year and are also made during the night in the winter months. The program of inspections of 'PLAINOB' stations begun in 1975 was completed during the year and the continuing need for these observing points was confirmed by the branches using the data for operational purposes. Arrangements are being made for a regular program of inspections and more frequent liaison visits to these stations.

Radiation observations

There is a long history of solar and terrestrial surface radiation measurement in the Office, notably at Kew Observatory, but it was not until the 1950s that systematic observations were undertaken at a number of stations. The Meteorological Office network now comprises eight stations in the United Kingdom and one overseas. In addition, observations are made at the North Atlantic Ocean Station 'L' (57°N 20°W). Global and diffuse solar radiation on a horizontal surface are recorded continuously at eight of these stations and daylight illumination at six. At two stations the intensity of the direct solar beam is also recorded and at one the radiation incident on vertical surfaces having various orientations. At four stations the net flux of solar and terrestrial surface radiation is also measured.

There are also 21 co-operating stations, operated mainly by organizations having an agricultural or hydrological interest, and these provide data, mainly in the form of daily totals, for which the Meteorological Office operates quality-control procedures. During the year enquiries addressed to a variety of authorities revealed the existence of several other stations at which solar radiation data are recorded. Attempts are being made to secure the co-operation of these stations and arrangements have been made for the entry of some past data from these stations into the data bank.

Radiation data from Meteorological Office and co-operating stations are stored on magnetic tape and computer programs have been written for the processing and printing of these data for a variety of purposes. The demand for solar radiation data continues at about the 1975 level.

The study of all data of assured quality continues both in certain universities and in the Observational Requirements and Practices Branch. A comprehensive report summarizing quality control procedures and the available data in convenient form is progressing well.

Reliable radiation measurements of suitable accuracy can only be achieved by painstaking daily attention to instruments, by frequent calibration of recording circuits and by frequent comparison of sensors with travelling sub-standards. The travelling sub-standards themselves require frequent comparison with the national standard presently embodied in a family of Ångström pyrheliometers which are compared regularly with other national standards in a program of international intercomparisons. Arrangements have been made to add a new, conical-cavity radiometer, absolute instrument to the national standards.

Increasing national and international interest in possible applications of solar energy has led to the establishment of several new co-ordinating groups. Amongst these the Meteorological Office has been represented on the Inter-Departmental Steering Group on Solar Energy Research and Development and on the EEC Solar Radiation Data Acquisition Group.

Arrangements have been made during the year for an enhancement of the Meteorological Office solar radiation observing network and equipment is on order for eight new stations. Figure 1 shows the existing network, including co-operating stations currently operating, and the stations planned to open during 1977.

Runway visual range

At many airfields, both civil and military, observers assess the 'runway visual range' in conditions of poor visibility with the aid of lights at known distances. Although these observations do not form part of the set of data required by meteorologists the Office provides a service of inspection and calibration of the installations for the Civil Aviation Authority and the Royal Air Force. Visits are made twice yearly to 32 civil airports in the United Kingdom and to 36 RAF stations at home and abroad.

At a few major airports automatic systems are installed for the estimation of runway visual range but these are not inspected by the Meteorological Office.

Upper-air observations

The normal program of upper-air observations comprises pressure, temperature and humidity soundings by radiosonde at 00 and 12 GMT and upper-wind measurements by radar at 00, 06, 12 and 18 GMT. At the beginning of the year the network consisted of eight stations in the United Kingdom, the North Atlantic Ocean Station 'L' (at 57°N 20°W) and four stations overseas. Of the latter the station at Masirah closed on 31 October.

During the year trials of upper-wind finding methods based on the use of the LORAN-C navigational system ('NAVAID') were undertaken on OWS *Weather Surveyor*. This method was used on the British ships during the

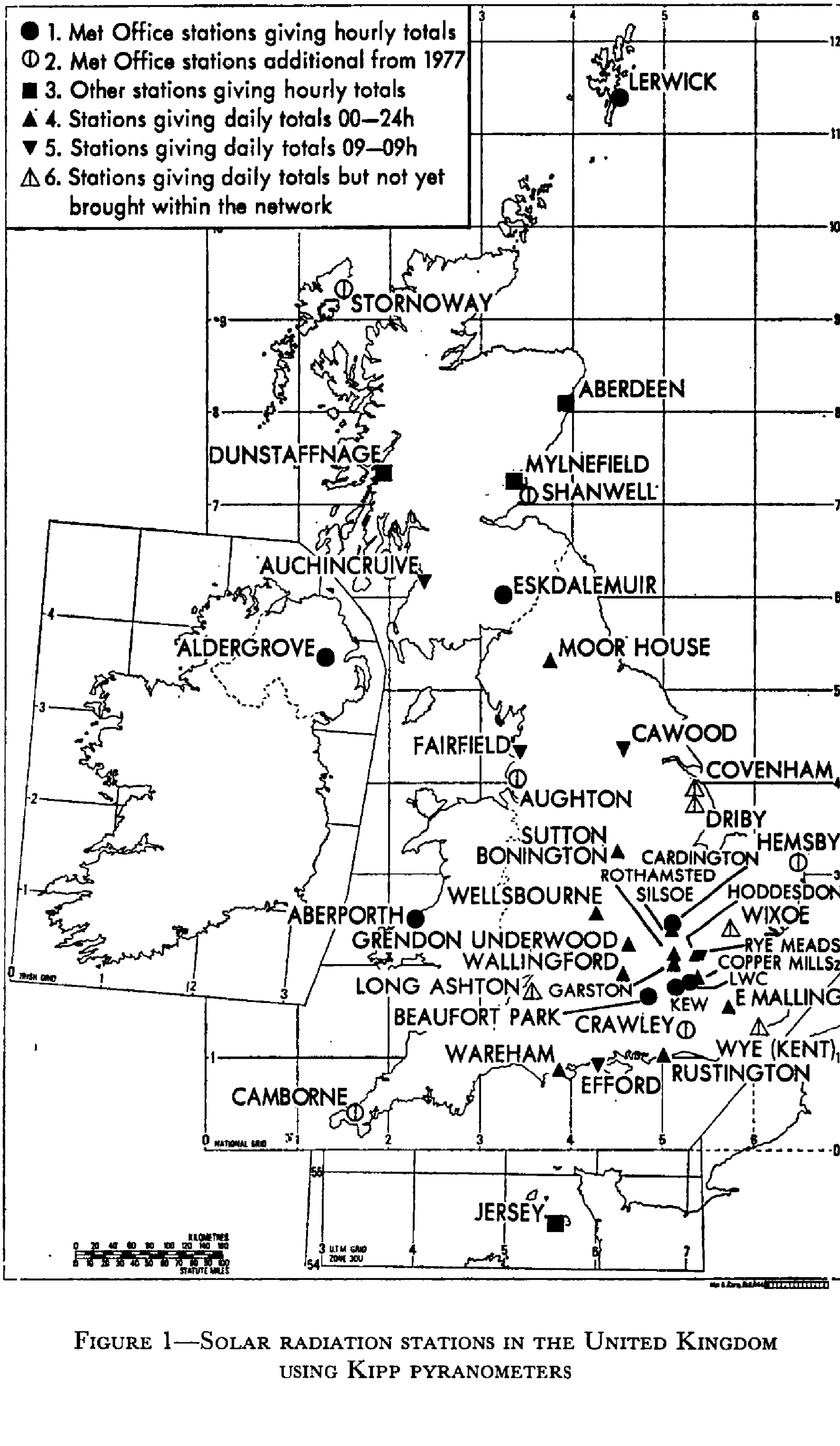


Figure 1—Solar radiation stations in the United Kingdom using Kipp pyranometers

Atlantic Tropical Experiment of the Global Atmospheric Research Program. As a result of the trial a modified upper-air system is to be adopted for use at station 'L' in which wind-finding will be by NAVAID methods and radiosonde data will be processed by a programmable desk calculator in a similar manner to that developed for use with the Mk 3 radiosonde. The calculator programs have been written and proved in the Observational Requirements and Practices Branch during the year.

Close liaison continued with the International and Planning Branch in the support of stations established overseas as part of the UK support for the World Weather Watch program. The station at Mahé in the Seychelles has become operational during the year and a visit of inspection has been made to the joint Anglo–French station in the New Hebrides. A new station has been established at St Helena and staff are in position and under training.

The performance of high-altitude balloons continued to be satisfactory but there was little change in their use. The performance of standard neoprene balloons showed an unusually marked seasonal variation, that in the summer months being well above average. The improvement in the performance of the standard rubber balloon noted in the second half of 1975 continues. Rubber balloons are used in nearly all the 06 and 18 GMT soundings.

Thunderstorm location and surveillance

A full program of observations was maintained throughout the year by means of a network of cathode-ray direction-finding (CRDF) stations comprising Lerwick, Shanwell, Camborne, Hemsby, Gibraltar and Malta. The addition of the station at Lerwick in place of that at Long Kesh has improved the coverage to the north-east and north-west of the United Kingdom. The closure of the station in Cyprus early in the year has degraded performance particularly in the Eastern Mediterranean.

Theoretical studies of the CRDF system continue, using ten years of data now available in machinable form. An extensive theoretical study of a possible method of automatic thunderstorm location has been completed. Such studies are an important preparation for the replacement of the existing CRDF system which is obsolescent.

Marine Division

As the oceans occupy three-quarters of the world's surface, the value of regular weather observations from oceanic areas is obvious, both for forecasting in this country and for climatological purposes. With the exception of HM ships, ocean weather ships and research vessels, surface observations from the oceans are provided entirely voluntarily by the masters and officers of merchant ships and the organization for obtaining them has been, since 1855, the responsibility of the Marine Division. Vessels from which these observations are made form what is termed the British Voluntary Observing Fleet and the ships vary from passenger liners and general cargo ships to coastal vessels and distant water trawlers. The numerical strength of the UK voluntary observing fleet is about 550 ships and has remained almost static during the year with new recruitments to the scheme roughly balancing withdrawals. Seven Port Meteorological Officers are stationed at major ports in the United Kingdom. These officers, all master mariners with considerable experience of voluntary observing at sea, are responsible for the recruitment of ships and for the supply and replenishment of meteorological instruments which are supplied on loan to the vessels. Port Meteorological Officers maintain personal contact with the shipmasters, deck and radio officers and advise and instruct officers in the techniques of observing at sea. There can be little doubt that the personal touch, bringing goodwill on both sides, has been a major factor in maintaining the high quality of the observations received from these voluntary observers at sea. Throughout their voyages the officers aboard voluntary observing ships record their observations in logbooks, in addition to transmitting them by radio, and at the end of the voyage these logbooks are returned to the Marine Division for scrutiny and extraction of the data. During the year 1250 logbooks containing about 250 000 observations were received from regular ships of the Voluntary Observing Fleet. In addition, 60 000 observations were received from light vessels, fishery protection vessels and other marine craft.

Acknowledgement should once again be made of the valuable service rendered by many Commonwealth and foreign Port Meteorological Officers for their services in the replacement of defective instruments in UK Selected Ships on protracted voyages, and the withdrawal of instruments from British vessels which have been sold abroad to foreign interests. The timely intervention of the foreign Port Meteorological Officers has been of immense assistance to us as the number of vessels ending their British sea-going career in ports abroad has been increasing considerably.

The building program of the Merchant Navy is directed mostly toward larger and faster ships and the whole tendency of seaborne trade is towards the container type vessel, bulk carrier and super-tanker. As these vessels spend less time in port than their predecessors the number of observations received has increased steadily over the years. Awards of books were, as customary, made to the shipmasters, principal observing officers and radio officers who have been responsible for submitting the 100 best meteorological logbooks during the year. Barographs were presented to four shipmasters whose long record and consistently good service were considered as deserving of special recognition. Awards were also made to masters and officers of vessels on the short sea trades for their contribution in making sea surface temperature observations. Trawler skippers and radio officers who had the best records in making and sending non-instrumental observations from the fishing regions also received awards.

The policy of installing distant-reading meteorological equipment in merchant ships under construction, in order to ease the work-load of the observing officers, continues to receive the whole-hearted support and co-operaton of shipowners. A further development in the automation of ship's observations has been undertaken during the year when, in conjunction with colleagues in the Operational Instrumentation and Communications branches, staff of the Marine Division have been actively engaged in the planning of a project whereby observations from ships at sea could be automatically transmitted to a coastal radio station. It is hoped that this will avoid the transmission of observations being delayed until the radio officer returns to watchkeeping after a spell of off-duty time.

During the year the Marine Division conducted a survey within the shipping industry to obtain opinions regarding the meteorological services available to the industry. Response to the questionnaire issued was most encouraging and ranged from brief comment to very full treatment of the subject. The full results of the survey have still to be analysed and the relevant authorities consulted but it is pleasing to record that no major changes or improvements appear to have been requested.

The WMO Agreement for Joint Financing of North Atlantic Ocean Stations formally came into force on 1 December prior to which date the United Kingdom continued to implement an interim agreement whereby the British weather ships *Weather Surveyor* and *Weather Reporter* manned Station 'L' (57°N 20°W) continuously. The vessels thus completed 17 years' service as weather ships and altogether 32 years' service since they were first commissioned as Castle class frigates in the Royal Navy. To allow UK participation in NAOS to be extended to the early 1980s, the *Weather Adviser* and *Weather Monitor* were moved to Manchester in early July for an extensive refit. It is anticipated that they will return to service early in 1977 and will take over station duties from their UK sister weather ships. The refurbishment will include improvements to accommodation and crew recreation spaces, automation of the boiler controls, installation of the new upper-wind finding equipment (NAVAID) and the complete modernization of the communications equipment.

The Weather Ships make hourly surface and six-hourly upper air observations (the heights reached in upper-air ascents are given in Table V) as well as observations of solar radiation and sea temperature and salinity to considerable depths. In addition rain water samples are collected for analyses by the International Atomic Energy Agency, plankton net hauls are made for the Institute of Oceanographic Sciences, sea water samples are taken at monthly intervals for an International Atomic Energy Commission WMO tritium survey as well as on passage to and from station for monitoring radioactive content. The ships also report the presence of any floating pollutants to the Intergovernmental Oceanographic Commission and operate a Tucker sea and swell recorder when on station.

The number of marine enquiries received has continued to rise and amounted to 520 during the year. These enquiries were mainly from official organizations, solicitors, insurance companies, shipping interests, universities and industrial firms in the British Isles. Subjects of the enquiries were extremely varied; they included a request for the weather conditions at the time of the sinking of HMS *Victory* on 3 October 1744, the sea conditions at the probable abandonment of the *Marie Celeste* between 7 and 25 November 1872 and the weather conditions in the Bay of Biscay on 12 March 1976 when the British container vessel *Frendo Star* developed a heavy list due to the cargo shifting and the crew had to abandon ship.

The *Marine Observer* was published every quarter and continues to have a very wide circulation.

Operational Instrumentation

The Operational Instrumentation Branch is responsible for meeting the changing needs of the user branches for instruments and data-acquisition systems. The requirements of the forecasting, climatological and hydrometeorological branches are examined in close co-operation with the Observational Requirements and Practices Branch, and either the most suitable combination of existing sensors, data acquisition system and observational techniques for the particular application is chosen or an Operational Requirement defining the need for a new development in an area of measurement or system technology is raised.

The Branch then carries out the necessary design, development and/or adaptation of equipment required to meet the application. When prototypes and pre-production equipments have successfully passed their trials, or suitable equipment is already commercially available, manufacturing contracts are placed for a production quantity of equipment. The Branch is then responsible for the technical progressing of the contract, for acceptance testing and the calibration of the delivered equipment, for planning and installation in the field, and finally for maintaining and servicing the equipment on the outstations and for making any subsequent modification of the equipment throughout its life.

Much of the work in recent years has been directed towards equipment requiring less attention from the human observer, which can supplement his efforts by the use of semi-automatic or automatic measurements where this is possible. This equipment needs to be capable of operating with high reliability at remote or relatively inaccessible places at (sometimes) inconvenient times. It also needs to be able either to record the data digitally on magnetic tape for easy analysis, or to transmit it in real time and in a convenient form to the local observer and to the Meteorological Office computer system, and to provide the necessary display and interface with the human operator so that the quality of the data can readily be assessed.

This work is well illustrated by the two items which receive special mention this year: the successful conclusion of the trials of the Meteorological Office

Weather Observing System (MOWOS) which heralds the procurement and installation of a number of automatic weather stations (AWS), and the Branch participation in the UK Data Buoy Project.

The MOWOS automatic weather stations have now been on trial at manned weather observing stations for two years. Over 80 station-months of data have been analysed. This analysis has shown that the electronic equipment can operate unattended for several months and the accuracy of the wind, pressure and temperature data received by the user (for example a forecasting office) is comparable to that obtained from conventional stations which use human observers. With the successful completion of these trials the next step will be to move five of the eight MOWOS equipments to new, more remote locations for operational use.

An alternative type of data processor for an automatic weather station has been developed during the year within the Branch. In this system the data processing and organization is carried out by software programs instead of with hardware circuitry, giving much greater flexibility in meeting user requirements. The first such system, using a mini-computer, will be installed at Theddlethorpe in Lincolnshire. A micro-processor version is also well advanced in its development. The operating prototype was displayed in September at a Technical Conference on Automatic Weather Stations held in Reading.

The Branch is also participating in the UK Data Buoy Project, in which the Department of Industry takes the leading role. The buoy (DB-1) has been deployed 8 km off Lowestoft throughout the year. The meteorological instrumentation, which includes sensors to measure wind speed and direction, air and sea temperature, pressure, visibility and rainfall, has survived satisfactorily in the harsh marine environment. Quantitative evaluation of the first five variables has shown that the accuracy is comparable to that from automatic weather stations on land, but there have been some problems with the sea-to-shore telemetry link. It has not proved possible to assess the accuracy of the visibility or rainfall sensors in the marine environment because of the lack of independent measurements.

Co-operative projects: national and international

Participation by the Branch in international projects during the year continued with two projects by the European Economic Community scheme for Co-operation in Science and Technology (COST).

In Project 72, which is concerned with the development and standardization of meteorological instruments within Europe, senior officers were involved in all three active sub-groups. In particular, much time and effort was put in by members of the Branch in collaboration with the Observational Requirements and Practices Branch, in preparing for and organizing the Technical Conference and Exhibition of the COST 72 sub-group on Automatic Weather Stations which was held at the University of Reading in September. (See also p. 115.) The United Kingdom was also involved in the COST 72 sub-groups on Balloons and Radiosondes, both of which prepared final reports on their work during 1976.

One of the senior officers of the Branch was also actively concerned on the Technical Committee of COST Project 43 which is concerned with the development of meteorological/oceanographic data acquisition systems on buoys, and with the progressive harmonization of the separate European national data-buoy programs into a common network. The project has taken a large step forward during the year following the appointment of a Program Co-ordinator, and much activity has been concerned with the preparation of an Agreement defining a 4-year experimental pilot project. It is hoped that this Agreement will be signed by the EEC and participating non-Member States early in 1977.

A senior officer of the Branch chaired a number of meetings of the Standing Committee on Ocean Data Stations (SCODS) Working Group. This Working Group was tasked with assessing the current projects being undertaken in the United Kingdom on Ocean Data Acquisition Systems (ODAS), and ascertaining the probable future plans of the various Departments involved. Representatives of MOD(N), MAFF, DAFS, IOS, DoE and DoI were involved as well as the Meteorological Office. A similar SCODS Working Group was also set up to review the long-term UK needs for data-buoy networks and to decide whether there is a requirement for a further design study on instrumented deep-water buoys.

Mention should also be made of the considerable liaison activity which has occurred between members of the Branch and the United Kingdom Offshore Operators Association (UKOOA) following the decision to instrument a number of the North Sea oil platforms, some with conventional meteorological instruments and three with automatic weather stations. Plans are now well advanced, but there are still technical and administrative problems to be overcome.

Discussions with Trinity House have led to an agreement to install an automatic weather station on a Light Beacon in the Thames area. This station will now meet the operational requirement for data from that area. Also, a small toroidal buoy (OBOE 1) has been instrumented for deployment by MOD(N) in Lyme Bay in the English Channel where the data will be used as an aid to forecasting with particular reference to oil tanker operations in that area.

The co-operative trials of visibility sensors which might be used to monitor fog on motorways were concluded in the autumn. These two-year trials were run jointly with the Home Office Police Scientific Development Branch and the Transport and Road Research Laboratory. A report has been prepared, and a member of the Branch presented a joint paper on the results to the Royal Meteorological Society in December.

A one-day Discussion Meeting on the use of Acoustic Sounding Equipment was organized by the Branch at Shinfield Park in April. This meeting served a useful role in acquainting UK representatives of Government, universities and Industry with the current programs of research in acoustic sounding in the United Kingdom, and in looking at the future potentials and limitations of these techniques.

Finally, the Branch is also co-operating with Heriot-Watt University and the Institute of Hydrology in a three-year project to develop an automatic weather station suitable for the severe environment on the summit of Cairn Gorm. The Meteorological Office has supplied a VHF telecommunication link, and has undertaken to evaluate the station when completed.

Development, production and evaluation of new instruments and systems

The first Mk 3 radiosonde ground station (at Beaufort Park) was installed early in the year and extensive flight testing completed. Final quality assurance procedures both on hardware and software remain to be carried out before the station can be accepted. Equipment for the other stations in the UK network is now in full production with installation at Aughton expected to begin in the spring of 1977.

The successful completion of the full ground station software suite proved to be a task of greater complexity than was originally envisaged. This has resulted in substantial delay in bringing the system into operational service. However, the problems have now largely been overcome and the Office will soon be fully equipped with one of the finest operational radiosonde systems available in the world.

The central calibration plant for the Mk 3 radiosonde system was dogged by problems of a different kind. The discovery of a serious problem connected with asbestos roofing in the calibration hall forced the evacuation of the entire premises. New accommodation had to be equipped with the necessary services at very short notice and the entire plant moved. This resulted in a delay of nearly four months, but the work has now been completed and the plant is expected to be operational in mid 1977.

The program for refurbishing NAVAID wind-finding equipment and installing it on the ocean weather ships has gone ahead smoothly. The two existing sets have been fully overhauled and brought to a common standard. Sea trials of the equipment were continued as opportunity permitted, and, in general, the results were satisfactory. Close consultation with Marine Division and other sections of Met O 1 resulted in an agreed specification for both the hardware and the software against which the procurement of a third NAVAID set is proceeding. The software specification takes account of both the UK and WMO requirements for upper-air data, and will be fully implemented for the existing NAVAID sets once the third set has been accepted and commissioned. This will entail modifications to the hardware build of the two existing sets, and these will be carried out by the manufacturer in mid 1977.

In response to a requirement of the user branches for the retention of a viable thunderstorm location system a feasibility study has been carried out of the available methods of tackling the problem. Both of the alternative methods that have been considered in detail have the desirable feature that they can be automated with a consequent saving in staff. Two further MOWOS automatic weather stations were brought into routine operation, one at the BBC transmitting station at Holme Moss and the other at the CEGB station at Bradford West. A further MOWOS was installed on the IBA mast at Lichfield where it is being used in an experiment to determine the possible use to forecasters of data from a number of different heights. There are now eight MOWOS stations in use.

Following the re-engineering of the digital anemograph logging equipment (DALE) to take account of a new magnetic-tape deck, three of these equipments have been in operation at Stornoway, Valley and Boscombe Down. Approval has been given for the purchase of a further 20 of these systems. A contract has been placed to obtain replacement data logging equipments (MODLE) for all radiation recording stations in the network, and a sunshine sensor, developed in the Branch, is to be included at these stations as an aid to quality control.

Looking forward to new systems, financial approval has been given for the development of two prototype automatic climatological recording equipments (ACRE), and for an initial network of 10 ACRE stations in data-sparse areas when the development is complete. A specification has been agreed with the user branches, and the proposed system will as far as possible use the same modules as those used for the software-based data processor developed for synoptic automatic weather stations. A feasibility study is also being undertaken for an automatic weather station to be used on UK registered merchant ships in the North Atlantic. It is hoped that data can be communicated automatically to the shore, but there are serious technical and administrative problems to be overcome before this can be practicable.

In the field of sensor development, two laser cloud base recorders (LCBR) have been purchased in order to evaluate whether the physical principle used in this type of cloud base recorder (CBR) is suitable for the measurement of cloud base to the required accuracy in operational conditions. The performance of these two instruments is being compared with the standard 'nodding beam' Mk 3 CBR which, though still in service, is coming to the end of its design life. After an initial comparison at Beaufort Park one of the LCBRs will be moved first to Birmingham Airport to investigate performance in an industrial atmosphere and then to Dyce. Further work has continued on the improved 'nodding beam' Mk 5 CBR in case the laser principle is not found to be satisfactory.

The Meteorological Office 200-metre base line transmissometer has been approved by the user branches for airfield and automatic weather station locations. This instrument is inconvenient in some locations because of its long base line, and is rather expensive, so the performance of three commercially available alternatives, using different principles and sampling a much shorter base line, is being evaluated. This trial will take at least a year.

Technical management and services

A considerable part of the effort of the Branch is concerned with the services required to support the Branch development sections and also the other user branches. This effort includes the technical aspects of procurement, documentation, testing and calibration, installation, maintenance and post-design services.

The development of systems rather than instruments has shown the need for competent project management. This has been extended to cover all projects, large and small, but it is particularly important when other Branches or Departments are involved. Proper use of planning aids, such as Program Evaluation and Review Techniques (PERTs) and Bar Charts, ensures more realistic target dates and allows optimum use of both manpower and materials.

It is now standard practice, where 'in-house' design is concerned, for at least one pre-production model to be manufactured in the workshops in order to 'prove' the drawings, to enable the quality of the final design to be judged and to provide data for a test specification. Although this delays the placing of the production contract, it ensures that the manufacturer can then proceed without fear of expensive delays while drawing or design errors are resolved.

Works services have been completed at Theddlethorpe and Wainfleet (Lincolnshire) for the installation of two automatic weather stations. The equipment is expected to be available early in the New Year.

The requirements for Mk 5 Wind Systems are being processed. The flexibility of these Meteorological Office designed systems allows for the large number of outputs that are needed at major airfields and permits telemetry over longer distances than previous versions of wind measuring systems. Thus anemometers may be sited at the ends of runways rather than in a central, unrepresentative area or, in another context, at an appropriate site in a city. The data are then routed to a central office. The present requirement is for 14 systems mainly for airfields in the United Kingdom and Germany.

With the successful completion of the data-gathering phase of the Dee Weather Radar Project, the Llandegla Research Station ceased operation on 30 September. The equipment was subsequently dismantled and the radar and peripheral equipment were transferred to the Meteorological Research Unit, Malvern.

Planning of the Camborne weather radar installation continued, works services were completed and the Plessey 43S radar (ex-Singapore) was on site at the end of the year.

Other work carried out by the installation section has included the removal of four large S-band radars from overseas stations which have closed down. Two X-band wind-finding radars have been installed in the Seychelles and at St Helena.

A member of the Branch took part in an EEC trial, carried out by a number of European nations, in South Yorkshire to obtain information on the dispersion of tall stack plumes from power stations. An X-band radar was supplied, maintained and operated as part of the radiosonde/wind-finding system. A large number of ascents was made in the 13-day exercise.

Acceptance flights of UK-manufactured upper-air balloons have given poor results this year, and do not augur well for future operational performance.

The activities of the test and calibration section continue at a high level. Calibration of radiation sensors has now been taken on by the Branch and ways are being sought of modernizing the equipment and methods used. This is essential in view of the anticipated increase in radiation work. Initial calibrations appear as a new entry in Table XV.

Additions have been made to the Electrical Standards Room, as a result of which a wider range of parameters can be checked, and the accuracy and stability of the measurement instruments can now be referred to the UK National Standards.

Technical enquiries, mostly concerning conventional instruments, are dealt with by a Branch Information Officer. There has been a large number of these, emanating from a variety of sources at home and overseas, many of them not meteorological.

The rapidly increasing use of digital computation techniques in all aspects of meteorological instrumentation has generated the need for a specialist software services cell within the Branch. This cell has now been set up and among its principal activities are programming tasks on the Mk 3 radiosonde system, automatic weather stations (both marine and land), automatic climatological stations and on a management service project to automate the records of the Regional Servicing Organization.

Servicing and technical training

The Regional Servicing Organization has provided increasing support at home and at the remaining overseas stations. Some 700 electrical/electronic equipments, comprising 27 different types, are installed at over 330 locations, and each of these requires regular maintenance. One major activity this year has been the introduction of the new facsimile recorder Type TR4 which has a 240 rev/min capability. So far, 110 of these have been installed in the United Kingdom, mostly on the MOLFAX circuit, and a further 7 in Germany. The exercise has called for close liaison with the Telecommunications Branch. Similar liaison has been undertaken with the Hydrometeorology Branch in respect of the network of tipping-bucket rain-gauges and their associated magnetic-tape event recorders. Support for the MOWOS field trials has continued and the reliability aspects of the equipment have been closely monitored. Field calibration of the associated sensors has been carried out regularly in order to validate the trials data.

The scope of activities continued to expand. Meteorological equipment aboard the Data Buoy (DB-1) moored 8 km off Lowestoft, has been maintained, occasionally under difficult sea state conditions. Visits have also been made to service equipment aboard the gas platform 'ARPET A' in the Hewitt Field and on the Royal Sovereign light tower off Beachy Head. Other 'marine' activities included a wide measure of support for Port Meteorological Officers, often at short notice, to accommodate ships docking for a few hours only.

The maintenance of the 'Myriad' computer-based message-switching system, previously carried out by the manufacturer, is to be undertaken next year by the Servicing Organization on behalf of the Telecommunications Branch. The headquarters team is being expanded and trained accordingly.

The present design for meteorological electronic instruments is based on the concept of system engineering. Such design permits the adoption of modular construction, incorporating integrated circuits mounted on printed circuit boards. This philosophy allows a maintenance policy of 'repair by replacement' with consequent improvements in equipment availability and reduction in support costs resulting from central repair facilities.

Implementation of this policy requires servicing staff to be less concerned with the details of electronic circuitry; therefore their training now concentrates on an understanding of system engineering. This approach still demands a high degree of skill from the technician but it enables him to maintain effectively an increasing number of different systems.

A number of courses have been held in 1976, mainly on equipment recently introduced or undergoing trials. In order to familiarize them with the techniques which are an integral feature of new systems, some staff have attended a basic course on computing and logic principles at RAF Sealand.

Computing and Data Processing

The Data Processing Branch is responsible for operating the main computer system of the Office, known as COSMOS, and for the supporting software needed for its operation. It provides general-purpose programs to store, control the quality of and retrieve observational data received in real time from the telecommunication system, and to produce plotted and line-drawn charts and graphical displays required for operational tasks and some research work. An advisory service is available for COSMOS users and there is a limited service of data extraction from machinable archives. The Branch is also responsible for operating the processor-controlled key-to-disc data entry system (PCK) and the punched card unit.

During the year the Branch made a concentrated effort in three areas; operational introduction of automated plotting services for the Central Forecasting Office (CFO) and outstations, transcription of the punched-card archives to magnetic tape and continued optimization of the main computer system including equipment, procedures and programming techniques.

The COSMOS Computing Laboratory

The COSMOS computing system is based on the very fast IBM 360/195 computer, coupled to the smaller IBM 370/158 computer. The 370/158 computer, although having only about one-fifth of the power of the 360/195, releases the main processor for the more demanding work such as computing for numerical models of the atmosphere but, when the main 360/195 processor is unserviceable, the 370/158 has sufficient power to provide a back-up service for essential operational work. In normal operation the smaller processor provides line-drawing, plotting and remote-terminals services, undertakes the computation for most of the smaller tasks and handles all input and output requirements. The two processors share most of the 20 disc drives, the fixed-heads disc and six of the magnetic-tape drives. Although, normally, all input and output devices are connected to the smaller processor, they may be switched to the 360/195 if the 370/158 fails.

Three operating systems are required to operate the coupled twin-processor system; the Asymmetric Multiprocessing System (ASP) to control the flow of work to and from the two processors, the Virtual Storage System (VS2) to control the work done in the 370/158 and the Multiprogramming System with a Variable Number of Tasks (MVT) to supervise the work done in the 360/195. About 30 000 jobs are submitted each month, either from terminals, from the card reader in the Receipt/Despatch area or as scheduled operational tasks.

Both the 360/195 and the 370/158 computers and peripheral equipment continued to give generally reliable service throughout the year. Three disc head crashes occurred during the year but prompt action by operations staff confined damage to one disc drive and one disc in all cases, although there were delays in processing until the discs involved had been inspected by the suppliers. Most of the remaining incidents arose from faults in the 360/195 central processing unit (CPU) or channels, or from problems with power supplies and air conditioning during the very hot summer. Engineering changes also contributed to loss of computing time, but the lower level of maintenance cover on the 360/195, arranged last year as an economy measure, has had no noticeable effect on availability.

Very little spare capacity was available on COSMOS but revenue of £65 000 was earned by performing several large computing tasks for the European Centre for Medium-range Weather Forecasts (ECMWF).

Remote Terminals

Four more VDU terminals were installed during the year; at the Meteorological Research Flight Farnborough, Strike Command Headquarters High Wycombe, Eastern Road Bracknell and Beaufort Park Easthampstead. The typewriter terminal previously at Farnborough was installed at the Meteorological Research Unit Cardington, and a similar device at the offices of Marex Ltd at Cowes, Isle of Wight was linked to COSMOS to enable the Company to process North Sea data on behalf of the UK Offshore Operators Association (UKOOA). Also during the year a link was established between COSMOS and the PDP 11/40 mini-computer in the Systems Development Branch. The Time Sharing Option (TSO) operating system provides support for most of the terminals. TSO services are largely confined to normal working hours, but some operational services are now provided throughout the 24 hours at the terminals in CFO and the Meteorological Telecommunication Centre (Met TC). The number of user sessions at terminals rose during the summer from an average of 2000 per month to a peak of 3000 in July. Terminals are now used by programmers for program development and also by non-programming staff for extraction of data to answer enquiries and for the monitoring and control of real-time data, including its operational use during the objective analysis computations which precede the operational forecast runs.

Interest continued in the software written by the Branch to support visual display terminals under IBM Conversational Remote Job Entry (CRJE) and three more organizations bought the package, making a total of nine since the software was written in 1974.

Data Handling and Monitoring

The data flow from the automated telecommunications complex (AUTOCOM) to COSMOS through the IBM System 7 high-speed electronic interface was steadily improved during the year by careful selection and scheduling of the data to suit operational requirements. In the latter part of the year the Telecommunications Branch completed the necessary development work to enable the data link to be used in the reverse direction to pass processed data (for example computed chart information in grid-point format) from COSMOS to AUTOCOM for transmission to other countries.

The data supplied to COSMOS through the System 7 interface are captured by the Synoptic Data Bank (SDB) programs which store and control the quality of real-time observational data in preparation for their use, operationally, in analysis and forecasting programs and for their presentation to forecasters in various ways. The most time-critical operation is the automatic plotting of hourly charts of British Isles surface observations, particularly for facsimile transmission. To meet this requirement the SDB suite of programs was restructured so that data could be processed in an almost continuous stream from AUTOCOM, these data then being handled by the chart-plotting programs with the minimum of delay. As a result, it was possible to introduce a full service of machine-plotted hourly charts for use in CFO, and also for transmission by facsimile to forecasting offices throughout the British Isles. This meets the basic requirement for a timely product with a satisfactory cover of reports but a continuous program of development is needed to produce a fully effective service. The increasing demands for time-critical operations have necessitated the monitoring of the flow of data at critical points in the overall (telecommunications and computing) system. For instance, CFO continues to develop ways for the forecaster to intervene in the production of automated analyses, and to do this the forecaster needs to know exactly what observations were used in the analysis programs. During the year programs to monitor from VDU terminals the flow of data were developed in collaboration with the Central Forecasting Branch. These are now in regular operational use in the Met TC as well as CFO.

Line Drawing and Plotting

The scheme for replacing the very expensive pre-printed continuous stationery used on the Calcomp 1136 drum plotters by cheaper individual charts printed by Her Majesty's Stationery Office was fully proved in readiness for introduction into operational use in 1977.

Successful tests were made of the production of line-printer type of output directly on to 16 mm film, using a modified camera in conjunction with the Calcomp 1670 Computer Output on Microfilm (COM) equipment. The tests will be followed by the transfer of some large volume output to microfilm when a suitable viewer is available.

Applications for COM equipment continue to grow. One important new function is the generation of high-quality satellite pictures from data received from Scanning Radiometer (SR) equipment on weather satellites. The pictures are generated by filling in different areas with dots of varying separation and brightness to produce differing optical density and create the effect of a continuous-tone photograph. Initially, the plotting instructions required considerable involvement of the main computer and the stream of instructions to the Calcomp controller took up to one hour to create a single picture. A new technique has been developed, in collaboration with the University of London Computer Centre, whereby the instructions are now generated within the Calcomp controller which drives the plotter, with a considerable saving of time and main computer capacity.

Optimization of the System

The term 'optimization' covers many interrelated aspects; the balance of hardware components in the system, the efficiency of the operating system software, operating procedures, programming techniques and the matching of these to the system. The Branch collects, mostly by use of hardware and software monitors, management information about the performance of the various components of the COSMOS system and its associated off-line equipment, and applies the information to improve the overall efficiency of both the equipment and the controlling software (operating systems). Measurements of activity at several points in the COSMOS system, made by means of a hardware monitor, indicated that better use could be made of the overall system by upgrading the capacity of two of the magnetic disc drives and the addition of two further magnetic tape units. These additions are due to take place early in 1977. Software monitors also revealed some inefficiencies in data set and program design, correction of which significantly improved some operational procedures. In a further effort to improve efficiency a programming techniques group has been set up, with representatives from all parts of the Office, to provide guidelines and standards for good programming design suited to the COSMOS configuration. It is sometimes found that a particular program has been optimized to the detriment of other users' work. Thus the impact of changes in the configuration on programming, and vice versa, needs to be kept under continual review.

Considerable effort also continued on the production of management information on the use of computing facilities by user branches. Each year computing branches are asked to provide forward estimates of their proposed use of computing facilities on approved projects. This gives early warning of changing requirements and some indication of possible overloading of the system. In spite of the addition of the 370/158 last year, bids for computing time greatly exceeded the available capacity. The Data Processing Branch provides users with information to enable them to monitor their own computer usage and to help branches to remain within their overall budgets for computing.

Data Management for Experiments within the Global Atmospheric Research Program (GARP)

Processing of the 100 days of data, collected in 1974 during the GARP Atlantic Tropical Experiment (GATE), was completed during the first half of the year. Planning was started for the collection and reduction of coded surface and upper-air observational data during the First GARP Global Experiment (FGGE) observing period in 1978–79, preceded by operational test phases during 1977–78. The UK Meteorological Office has accepted responsibility for the management of data provided by much of Africa and Europe for international exchange on telecommunication channels, but during the FGGE special efforts will be made to collect missing data by postal exchanges and to merge such data with that received by telecommunications. The objective is to produce as complete a coverage of data as possible to enable research meteorologists to carry out special studies.

Storage and Preparation of Data

An intensive effort was made to complete the transcription of the entire library of punched-card data to magnetic tape. The work started on a routine basis in November 1975, using a card reader specially rented for the purpose, and continued almost without interruption until its completion in September. The project involved the transcription of about 45 million punched cards to 600 magnetic tapes (including duplicates). The project has rendered the data much more accessible to the user, and has released 400 cubic metres of partially air-conditioned storage space.

The holding of over 4000 ¾″ magnetic tapes, written on the KDF9 computer which was disposed of in 1970, was reviewed and most of the essential data were transferred to ½″ magnetic tapes which have about four times the storage capacity of the older tapes. Transference of these data to ½″ tapes will make it possible to dispense with the KDF9 tape units early in 1977, providing space for installation of the additional ½″ tape units referred to earlier.

A serial printer and an additional disc unit were added to the Redifon Seecheck processor-controlled keying (PCK) installation during the second quarter of the year and two additional key stations were installed in December to meet increased demand for data preparation, mainly from the marine and climatological branches. Considerable effort was also applied to the improvement of individual performances in the keying of data and, with the full co-operation of the staff, an average increase of 20 per cent in the output per operator has been achieved. This gain was offset for part of the year by undermanning and an exceptionally high incidence of sickness, and it was necessary to withdraw the four operators from the punched-card section and employ them in the PCK installation to avoid serious delays in the preparation of data for routine publications such as the *Monthly Weather Report.*

Systems Development

The activities of the Systems Development Branch are broadly twofold: those devoted to the build-up and usage of the main archives of meteorological data in (digital) machinable forms and those concerned with the application of new, usually computer-based, systems. Both require constant study of relevant automatic data processing (ADP) principles, techniques and new equipment. The emphasis, however, is on practical implementation.

Machinable archives

Very large quantities of meteorological records exist from the past and the contemporary inflow is ever-increasing as the opportunities for observing the earth's atmosphere expand. The records comprise a great diversity of types (surface, upper-air, satellite, marine, hydrological, etc.) and sources (logbooks, forms and autographic traces, magnetic tape cassettes from field loggers, data collected via computers from remote sensors and through the WMO Global Telecommunication System, etc.).

Over the years an increasing proportion of the data arriving in the traditional (paper) media has been transposed to machinable form, which is a rather laborious manual process. Nowadays almost all are so transposed but there is a considerable backlog of historical data still to be converted. For several decades after 1921 the only machine processing and storage medium was punched cards but in recent years the preferred medium has been ½" magnetic tape, to which by the end of the year all the older forms (including ¾" tape from our previous computer) had been converted. The management of these records, whether they require hand conversion or arrive more directly in machinable forms, requires a large, sustained effort in systems design and computer programming to classify, index, update, check, file in prescribed order and retrieve them for all conceivable purposes, both now and in the future.

Marine data are especially fraught with difficulties because of the many changes of code, units, etc., since the record began in the mid-nineteenth century. For some years there has been a co-operative international effort under WMO auspices to assemble and make available in prescribed order selected elements (air and sea temperatures, surface wind and atmospheric pressure, etc.) of all the existing ships' observations, originally held on punched cards, for all the oceans of the world. By the end of the year all the available British data, amounting to some 6½ million cards for the epoch 1854–1960, had been transcribed to magnetic tape and sent to the meteorological services responsible for particular oceanic areas (the Federal Republic of Germany, the Netherlands and the USA). The whole will then be sent to the US National Weather Records Center in Asheville, North Carolina, for final checking, filing on tape and production of published summaries. The remaining elements (weather, clouds, visibility, etc.) present special problems and the task remains of absorbing these and forming one coherent record, also suitable for the more plentiful data since 1960 when an internationally agreed format for marine observations was introduced.

To facilitate the maintenance and use of the archives in general, a special suite of programs has been written to enable programmers on COSMOS to handle, quickly and efficiently, the data transfers between magnetic disc or tape and computer memory, and to display and edit them via visual display unit (VDU) terminals. This suite is now in constant use throughout the Office. All the data sets contain their own indexes whereby the required data can be selected, arranged and transferred to specified memory locations.

A catalogue of the data is prepared and published annually: it contains a concise description of each family of data sets, including the periods covered and the place (geographical region or country of origin, station number or names). Much more information, e.g. the site locations and exposures, instrumentation, range of elements observed and units of measurement, are available if required but such information is not always readily accessible. Master directories on magnetic disc are already being created for all the British stations, about 800 climatological and 11 000 rainfall, and a selection of some 10 000 world synoptic stations. There is a constant turnover of stations, so that these directories have to be frequently revised. Moreover they only contain, at present, the more easily encoded information and it will be some time before such entities as site exposure and instrumentation can be included. However, what is already available, together with the sort of information contained in the annual catalogue (which is also being entered on magnetic disc), will be used to develop a more automatic information retrieval system via user terminals.

Headquarters mini-computer laboratory

The mini-computer (a DEC PDP 11/40) installed in the Branch in the spring of 1974 is now equipped with a wide range of devices operable on a real-time multi-programming basis, and is also linked directly to COSMOS. The total configuration comprises 160 kilobytes of memory, two magnetic disc and two standard magnetic tape units, card and paper tape readers, an electrostatic printer/plotter, a graphics terminal (itself incorporating a smaller mini-computer), VDU and typewriter terminals, three non-standard tape drives to take Epsylon, 3M and Philips cassettes and an automatic calling unit to provide interrogation of remote devices through the Post Office (PO) telephone system. There are also devices to convert satellite and other analogue signals to digital form and vice versa. A colour semi-graphics display is to be added early in 1977.

The system is a central facility for use by branches as a test-bed for experimental projects or to develop new systems or to carry out routine work requiring more specialized peripherals than are available to COSMOS.

Routine work

About a quarter of the time of the PDP 11 is taken up with work of a routine nature at present. This includes the conversion of cassettes from field loggers to standard (IBM-compatible) tape and the checking and reformatting of the data before absorption into the main archives. The volume of such work is expected to grow over the next few years as more loggers are installed, particularly when upper-air data on 3M cassettes from the new computer-controlled Mk 3 radiosonde system begin to flow in. There is also the conversion of a growing amount of paper tape received from a variety of sources. Another regular task is the automatic monitoring of the developing network of unmanned MOWOS (Meteorological Office Weather Observing System) stations through the PO telephone system. There are six of these in the field, each supplying readings of pressure, dry-bulb, wet-bulb and dew-point temperature, visibility, wind and cumulative rainfall. Normally a selection of stations is interrogated at one- or three-hourly intervals throughout the day and night, on an experimental basis. The data are checked and stored for presentation, immediately or later, in a variety of ways, in text or graphical form. A paper on our experience with the network so far was presented at the COST 72 Conference on Automatic Weather Stations at Reading University in the autumn.

Library automation

The project to automate the editing and cataloguing of the bibliographic information relevant to the 1200 or so publications received by the National Meteorological Library each month is nearing implementation. The necessary equipment (a PDP 11 computer, 2 magnetic discs and 2 VDUs) is due for delivery early in 1977 and the software has been developed within our mini-computer laboratory. The system will replace the present one based on paper-tape editing machines and will be directly connected to COSMOS where archives will be maintained and most of the printed output will be produced. Library records from more than five years were available on paper tapes from the old system and these have been converted to magnetic tape. The data are now being systematically checked and corrected and will form the beginning of a growing machinable bibliography which it is hoped will ultimately be placed on disc, to provide users of the library with an on-line information retrieval system.

Satellite data processing

At present satellite pictures, both visible and infra-red, are directly recorded by facsimile receivers. The digitization of the received signals via a computer opens the way to many sorts of refinements so as to bring out the meteorologically significant information. For example the contrast in radiation intensity may be better balanced over the field of view or selectively enhanced to improve the visual resolution. Also, the pictures can be transposed to practically any map scale and projection, with coastal outlines and latitude–longitude grids superimposed. Pictures from successive orbits of the same satellite, or from different satellites, may be combined into one composite display.

By the end of the year the PDP 11 and associated devices were being used to produce good-quality satellite pictures on a polar-stereographic map projection (1:20 million), as required by the forecasters in the Central Forecasting Office, either via the attached facsimile receiver or via the microfilm plotter on COSMOS*. Some special hardware had to be constructed to reduce the computer time required for sampling and digitizing the incoming satellite signals.

Miscellaneous studies and experiments

A wide range of data-processing functions (data collection and editing, chart plotting, contour drawing, etc.) go on at main meteorological offices and their outstations, most of them requiring considerable manual effort. The application of ADP techniques to these tasks has been under consideration for some time and a specific study of the possibilities of automating some of the work at the Principal Forecasting Office, Strike Command, was completed in July. It was concluded that there could be appreciable benefits for this and other major offices, including earlier reception of basic data and numerical forecasting products from Bracknell. A configuration of plotters, printers, VDUs, etc., based on a dual mini-computer system seems to offer the required performance and facilities. The PDP 11 has been used to test many of the ideas involved in the distributed computer system that would result from installing small computers at major outstations. For instance, the synoptic data bank and forecast data sets in COSMOS have been interrogated through the direct link and the results plotted or prepared as line-drawn charts as appropriate.

Experimental work was started in the autumn to automate certain aspects of the ship-routeing service provided by the Office. A computer program was developed to determine the optimum routeing of ships, allowing for the forecast

*An example of the latter, namely a three-orbit infra-red composite, is reproduced in Plate III together with a synoptic chart for the same occasion (Plate II).

surface winds and resultant wave action, and it is hoped to incorporate this into operational practice.

A final report on the problems and advantages of microfilming the ten million old records (logbooks, manuscript returns, synoptic charts, etc.) earmarked for permanent retention by the Office was completed in August. A trial filming of samples of the various types of record was started in 1974 at HMSO, Basildon as part of this exercise, and is still continuing. The extent to which the Office may go over to a microfilm system is still under consideration but, in any event, the preservation of the information contained in the records and their accessibility to users including the public will be paramount.

Some effort was devoted to the study of mass storage devices and to computer systems of advanced design. The former is relevant to the growing problem of accessing the main data archives, which already take up several thousand reels of magnetic tape. The latter is largely in the context of numerical modelling in dynamical meteorology where computer speeds of at least 50 million arithmetic operations per second are likely to be required by the end of the present decade when COSMOS is due for enhancement.

Meteorological Telecommunications

Telecommunications are indispensable to the provision of meteorological services. Observational information has to be collected and exchanged, and processed information (such as analyses and forecasts) has to be disseminated. These information transfers must be effected speedily, and exclusively meteorological circuits are essential. The demand for speed is now even more insistent, with the rapid increase of numerical forecasting using large computers, and so too is the demand for more complete hemispherical and even global geographical coverage.

The main Meteorological Office Telecommunication Centre (Met TC) is located at the Bracknell Headquarters. It forms the hub of an extensive meteorological land-line network for teleprinter and facsimile traffic in the United Kingdom. Operated from the Centre are two radio-facsimile broadcasts and a radio-teleprinter broadcast, each being designed to provide reliable reception by other meteorological services and by ships within a radius of over 3000 km. Bracknell is the radio Shore Collecting Centre for observations from the North Atlantic Ocean Station (NAOS) network. Linked to the Centre is the Lasham station which receives pictorial and digital data from meteorological satellites.

Bracknell is a Regional Telecommunication Hub (RTH) of the WMO Global Telecommunication System (GTS), responsible for receiving and retransmitting all scheduled observational and processed data, and information in pictorial form, on the Main Trunk Circuit (MTC) between North America and Europe. The circuit operates at high speed (2400 bits/second), and is fully automated. The functions of the Bracknell RTH also include the collection of observational data from the United Kingdom, Gibraltar, Greenland, Iceland, the Republic of Ireland, The Netherlands, merchant ships and aircraft and the transmission of these data on the MTC and its branches. Another function is the selective distribution of meteorological information to the National

Meteorological Centres (NMCs) at Brussels, Copenhagen, De Bilt, Dublin, Oslo and Reykjavik. The RTH is responsible for ensuring that standard telecommunication procedures are maintained, and for checking the validity of national observational data before onward transmission.

The Telecommunications Branch operates the Met TC in accordance with the responsibilities of an RTH, namely data collection and exchange, and distribution of processed information on global, regional and national levels. It is responsible also for making the necessary arrangements for the provision of land-lines and radio facilities for teleprinter and facsimile services, for the telecommunication aspects of the NAOS scheme, and for the local reception and dissemination of satellite data. Many of the functions of the Met TC are now automated, but require skilled support from the telecommunication staff, development engineers and meteorologists who together constitute the Telecommunications Branch.

Three items are worthy of special mention this year: the steady growth in the services provided by the Bracknell Automated Telecommunication System; the equipment being installed in two UK ocean weather ships which are being extensively refurbished; and further enhancement of the receiving equipment at the Lasham satellite facility which is operated in collaboration with the Royal Aircraft Establishment (RAE), Farnborough.

Bracknell Automated Telecommunication System

Based on a twin system of Marconi Myriad II message-switching computers, the automated complex (AUTOCOM) is an important hub on the GTS Main Trunk Circuit between North America and Europe. It controls high-speed (2400 bits per second) links with Washington, Paris and Offenbach; medium-speed (1200 bits per second) links with Oslo and De Bilt; low-speed (50 baud) teleprinter links with Dublin, Brussels, Reykjavik, Rheindahlen, Cyprus, Malta, Gibraltar, 11 data-collecting centres and many outstations in the United Kingdom; and a radio-teleprinter broadcast.

During the year further national and international services were developed; they included:

(a) An automatically compiled teleprinter broadcast to serve RAF stations in Germany which had hitherto received a locally compiled broadcast from Rheindahlen. Apart from providing a better product, the service requires fewer RAF teleprinter operators, and has a Preferred Queue List facility whereby more urgent material automatically receives priority over the less urgent.

(b) The supply of information to the Royal Netherlands Air Force at Hilversum, using four teleprinter lines.

(c) A special teleprinter link to Pitreavie in Scotland, carrying a supply of data chosen by the user.

An important feature of the AUTOCOM system is the ability to compile bulletins automatically, in accordance with a strict time schedule, by selecting information from other bulletins which have previously been received by the system. During the year, the number of bulletins of surface and upper-air observations compiled in this way was increased, and the use of this facility extended to cover other applications such as the preparation of messages containing a selection of aerodrome weather forecasts (TAFs); a similar process is now being used to supply a list of up-to-date reports of weather conditions at selected stations to the Central Electricity Generating Board, a service previously supplied by manual methods.

Increasingly, AUTOCOM and the main data processing complex COSMOS are becoming interdependent as specialized sub-centres within an overall system. They were linked last year by a dedicated mini-computer (an IBM System 7) which eliminated the use of punched paper tape for the transfer of data to COSMOS. During the year, full duplex operation of the link has been achieved, enabling processed information to be transferred from COSMOS to AUTOCOM for distribution. An increasing amount of this traffic is of forecasts in grid-point form.

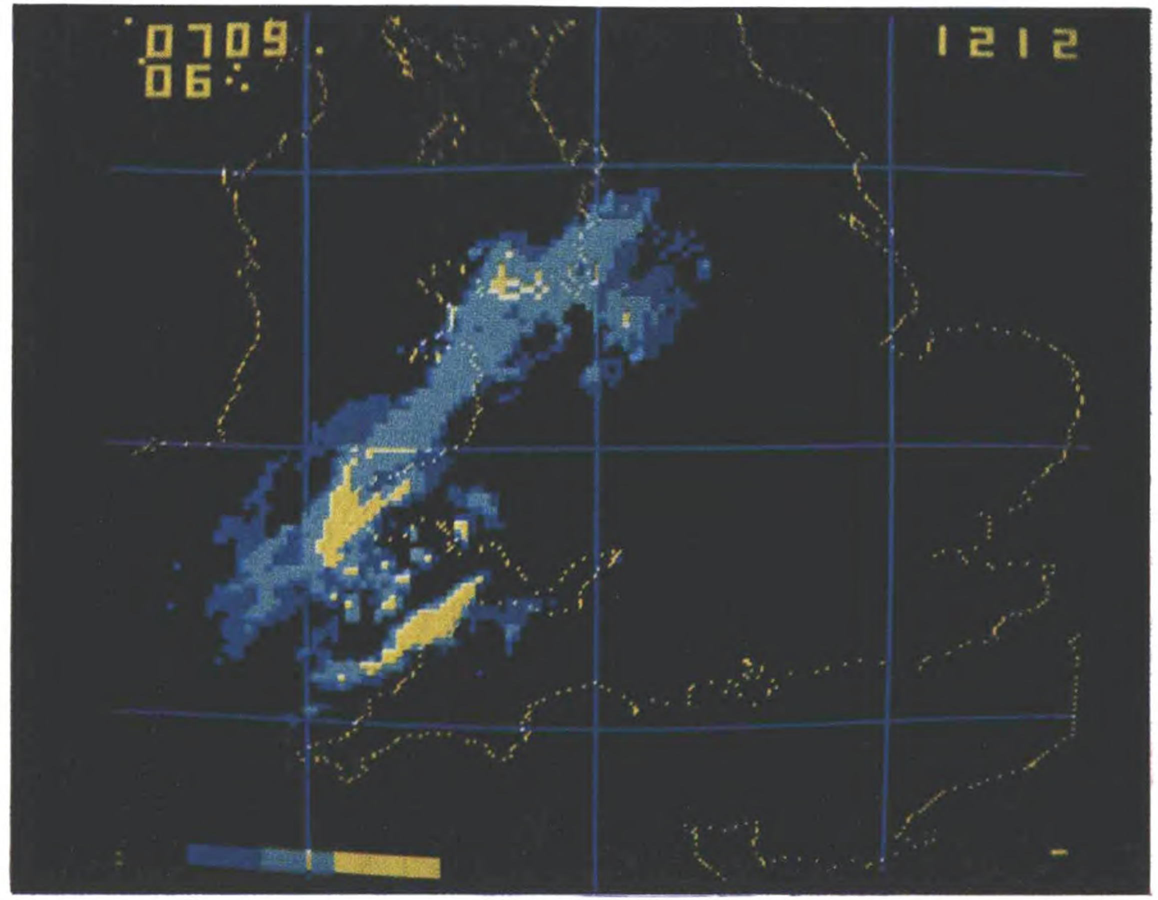
With the increasing use of automatic methods for the handling of meteorological data any shortcomings in the flow, coverage and quality of the data tend to be concealed until the end-products become available. In consequence, it is now recognized that specific steps need to be taken to monitor the traffic on the GTS so that scanty coverage, unsatisfactory reception, etc. can be detected quickly and remedial action taken. With this in mind, an important step has been the installation in the monitoring section of the Met TC of a visual display unit providing direct access to the synoptic data bank in COSMOS. This not only provides a valuable check on the completeness of the data received, but (because the data have been subjected to quality control and suspected errors have been marked) enables quick remedial action to be requested from the originating stations. This subject has also been receiving attention within WMO and has been discussed during the year at a number of international meetings. The Branch has participated in several co-operative monitoring exercises including a major review of the reception of ship observations.

During the year the contract for the additional twin system of Ferranti Argus 700S message-switching computers made rather disappointing progress, and the probable delivery date is likely to be in the second half of 1977, with full operational availability delayed into 1978. This means that the benefits of this major enhancement will barely come in time to enable AUTOCOM to handle the increased data flow for the First GARP Global Experiment (FGGE).

Facsimile developments

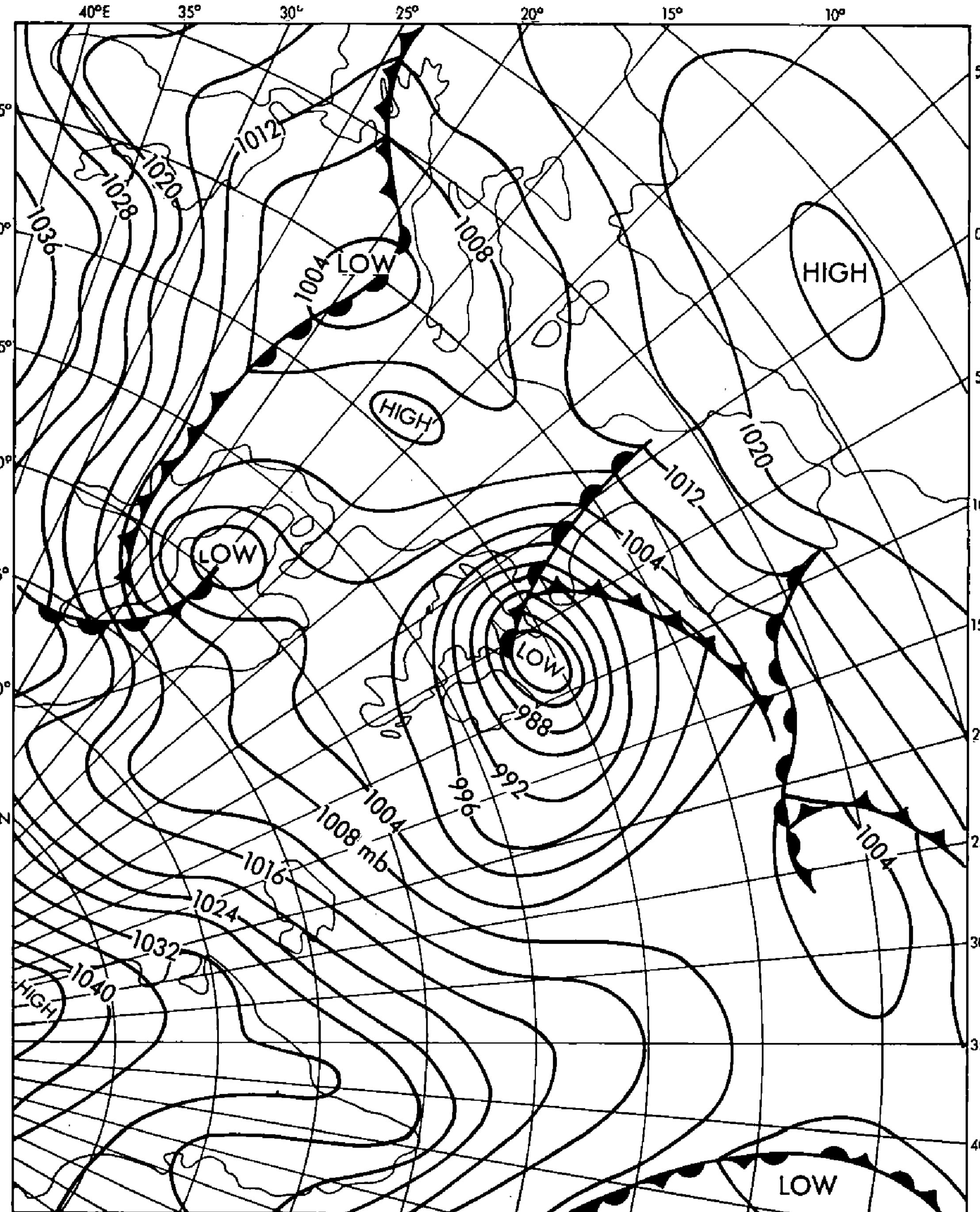
The recorder replacement program continues. By November most stations connected to the UK national land-line facsimile network (MOLFAX) had been equipped with new recorders capable of receiving 240 rev/min transmissions, and three charts per day were being scheduled at this speed in order to assess picture quality. All other MOLFAX transmissions are still made at 120 rev/min.

A series of test charts was received from Washington during the year, using Coded Digital Facsimile (CDF), and forwarded through the automated system to Paris and Offenbach. At the same time, Bracknell tested a system (which had



REMOTE DISPLAY OF RAINFALL DATA AS OBTAINED IN REAL TIME FROM A NETWORK OF RADARS

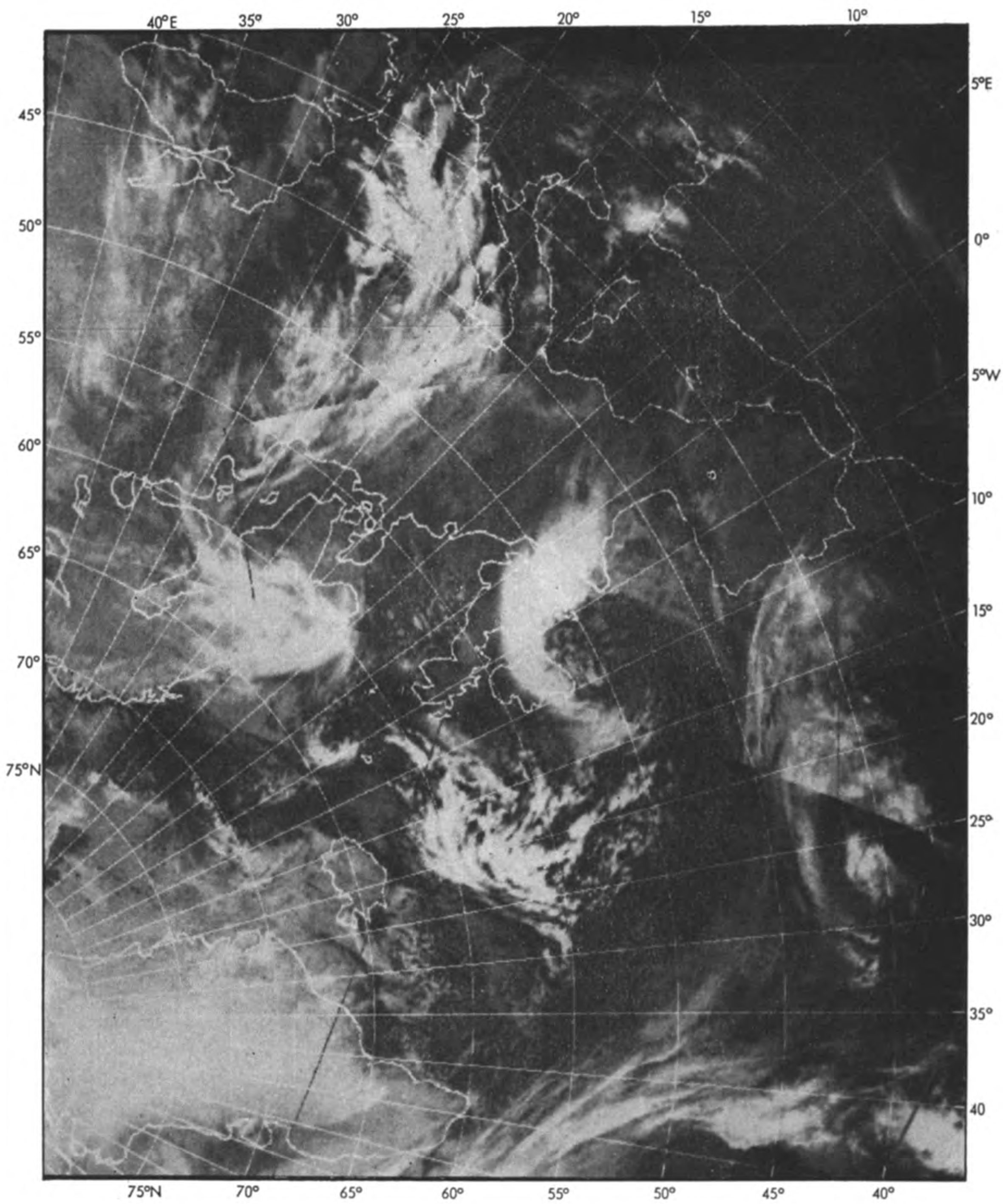
This example shows bands of rain at 0709 GMT on 12 December 1975 as detected by radars at Llandegla (North Wales) and Castlemartin (South Wales) and displayed on a colour television receiver at Malvern. The different rainfall intensities on the television screen stand out vividly, dark and light blue corresponding to light and moderate rain and yellow to heavy rain. Other colours can be reserved for thunderstorms and hailstorms which produce characteristically intense radar echoes. A specially designed receiver terminal enables several such pictures to be replayed in time-lapse. It also enables a grid (200 km in this case), adjustable cross wires (not shown) and any desired map (in this case the coastline of the British Isles) to be superimposed with accurate registration. (See page 87.)



Synoptic chart for 1200 gmt, 13 January 1977

This chart shows the mean-sea-level pressure and frontal analyses on a polar-stereographic map projection for the same area as for the satellite picture on the facing page.

The weather situation over the British Isles was one with snow already lying over the northern half of the country and with snow (which later turned to rain) beginning to fall further south. The cloud structures of the depression that was producing this precipitation and of the one further west on the Atlantic are particularly well delineated on the satellite picture. (See page 55.)

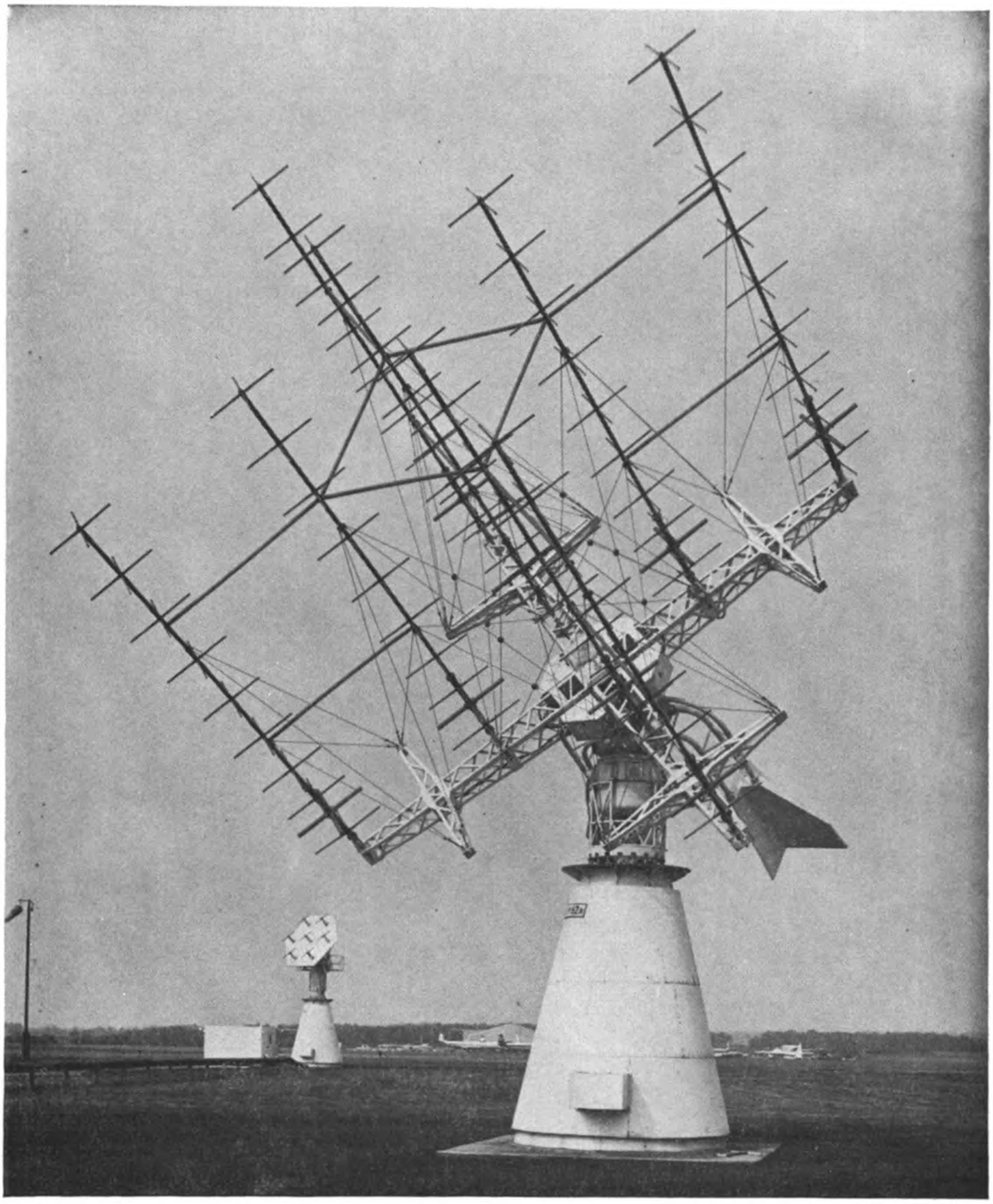


NOAA-5 SATELLITE INFRA-RED COMPOSITE PICTURE FOR 13 JANUARY 1977

Adjacent sectors of pictures from successive orbits of the satellite (nearly two hours apart, hence the discontinuities in cloud structure) are presented on a map with the same scale and projection as for the chart on Plate II. Each pass takes about 20 minutes, the start times appropriate to the most northerly edges of each of the three sectors from east to west being 0806, 1000 and 1153 GMT respectively.

Infra-red pictures in effect reveal the temperature distribution of the radiating surfaces below the satellite, the coldest regions (e.g. the tops of the highest clouds, the Greenland ice-cap) being the whitest; the less cold (e.g. the tops of lower clouds, the snow-clad areas of the British Isles and Scandinavia) are greyer and the warmest areas (e.g. sea and unfrozen land areas, particularly in the south) are the blackest. (See page 55.)

PLATE IV



SATELLITE GROUND STATION AT LASHAM SHOWING IN THE FOREGROUND THE MAIN AERIAL FOR THE RECEPTION OF SATELLITE IMAGERY IN THE 136 MHz BAND

(See page 59.)

been developed locally) for storing, decoding and recording these charts for use in the United Kingdom or for onward transmission to associated NMCs. Decoding was carried out by means of special programs in System 7, and the charts were recorded on a modified facsimile recorder. Both aspects of the tests were successful. The use of CDF in preference to analogue facsimile could increase the throughput of pictorial information along the GTS, and prevent loss of quality due to magnetic-tape relay operations at RTHs. The benefits of CDF will arise partly from the fact that any increase in signalling speeds (say to 4800 bits per second) will reduce transmission times and partly because digital data are more readily handled by the computers which are increasingly used to handle meteorological data on the GTS.

Recognizing, however, that analogue facsimile will still have a part to play for some time to come, further effort was also applied to the development of a microprocessor-based system to reduce the serious cumulative delays which occur in relaying pictorial information over several segments of the GTS. The device (which eliminates the use of magnetic tape) restores the amplitude and dynamic range of the incoming signal, digitizes and stores the information content, and reconverts to analogue form when required for transmission.

VAP Project for Iceland

Contracts for an automated telecommunications system for Reykjavik were awarded at the beginning of the year by WMO. The contractors are IBM and LOGICA, and a telecommunications engineer in the Branch is acting as technical consultant and liaison officer with WMO. Tests of line traffic to LOGICA in London began in the autumn.

Satellite Data Reception and Dissemination

The RAE satellite ground station facility at Lasham has received Scanning Radiometer (SR) cloud pictures and Vertical Temperature Profile Radiometer (VTPR) data from the US National Oceanic and Atmospheric Administration (NOAA) series of satellites throughout the year. The superior technical performance of the Lasham equipment has enabled the reception of low-elevation passes which would have been too low for satisfactory reception by the Beaufort Park equipment used in previous years, and has also extended the coverage of high-elevation passes. On suitable passes, the coverage now extends from the Arctic to near the southern tip of Africa.

Late in the year contracts were placed for, and work commenced on, the upgrading of the Lasham facility to receive the Very High Resolution Radiometer (VHRR) transmissions from the NOAA satellites. Selected areas of the VHRR field of view will be extracted in analogue form for transmission to outstations equipped with suitable recorders. The full VHRR data will be stored in digital form on magnetic tape for subsequent use by research workers. Other preparations are being put in hand to receive data from the European geostationary satellite METEOSAT (from late 1977) and from the US satellite TIROS-N (1978).

Deliveries of Mufax TR4 facsimile recorders, modified by Hawker Siddeley Dynamics Ltd, have been received and the first machines introduced into service for SR reception in the Central Forecasting Office (in August) and at outstations (from November). Since there is a requirement to receive VHRR data from Lasham on these new recorders in 1977, steps are being taken to provide modifications at the appropriate time.

Satellite prediction bulletins are received daily on the GTS from Washington. To assist other interested organizations, such as universities, the bulletins have been included on the Bracknell radio-teleprinter (RTT) broadcast GFL.

Ocean Weather Service

The operation of the North Atlantic ocean stations continued throughout the year, with Bracknell acting as the telecommunication shore control centre for the whole scheme. The method of communication continued to be by morse code, though the introduction of RTT working is under consideration by the NAOS countries. New radio communication equipment, now being installed as part of the refurbishing of two UK ocean weather ships, will ease the task of the operators, permit the future use of RTT operation if this is eventually agreed, and generally lead to more reliable communications.

Table III

The section of Table III on page 66 which analyses the source areas for ship reports has been slightly simplified because automated methods of message handling do not distinguish between 'reception via European countries' and 'reception via USA and Canada'. The analysis itself is now carried out by computer, enabling the figures to be based on more representative five-day means rather than on individual days.

International and Planning

Almost all international co-operation in meteorology is carried on either through the World Meteorological Organization (WMO) or in relation to WMO procedures and arrangements, and most of it takes place between governmental services. The requirements for networks of fixed or mobile observing stations, the systems of telecommunications, and the detailed standards and formats used, are all agreed through WMO. The International Civil Aviation Organization (ICAO) and the North Atlantic Treaty Organization (NATO) naturally deal with the meteorological aspects of their work on this basis. The Global Atmospheric Research Program (GARP) is the joint concern of WMO and the International Council of Scientific Unions (ICSU), the organizational work being carried out through or by WMO. Such enterprises as the European Centre for Medium-range Weather Forecasts (ECMWF) and the development of meteorological satellites by the European Space Agency (ESA) are carried out in close relationship to WMO plans.

As it is very much in the interests of the United Kingdom that such international arrangements should be soundly developed both scientifically and in terms of needs and resources available, and as we are also in global terms a major source of meteorological expertise, we are widely involved in WMO work. Besides its six Regional Associations, of which the United Kingdom belongs to two, and the eight Technical Commissions, in all of which the United Kingdom is represented, there are a number of special purpose, less permanent, panels. It is in these various bodies that the scientific and technical work of WMO is carried forward. Correspondence between WMO and the United Kingdom on most questions is handled by the International and Planning Branch, which is also involved in varying degrees with most of the other modes of international co-operation mentioned above. ICAO and NATO meteorological questions are handled elsewhere in the Office. Participation in ICSU is by scientists as individuals rather than by official organizations such as the Meteorological Office.

In previous years preparation for and participation in the annual session of WMO's Executive Committee took up much time in the spring. The absence of that requirement in 1976 was balanced in the latter part of the year by an unusual concentration of important meetings for which the Branch co-ordinated the preparation of the brief. The increasing recognition of the potential value of meteorology in many human activities is also necessitating better co-ordination with other government departments, universities, and other organizations in developing agreed national views for presentation in these international bodies.

The World Weather Watch Program of the WMO comprises the basic systems for observation, collection, distribution, storage and retrieval of data for all general service purposes. The United Kingdom contribution to the establishment of new meteorological stations in the global network, mostly for upper-air observations, is now almost complete. The last of these stations, at St Helena, is expected to become operational in the early weeks of 1977. The Office continues to support such WWW stations after they have become operational (and in most cases integrated with national meteorological services) by the secondment of staff, technical and other advice if needed, and by inspection services as well as grants in aid. Two projects are worthy of particular note. One is on Aldabra, a tiny coral island off the East Africa coast where the Royal Society has a long-term ecological study program. The Meteorological Office supplies a volunteer observer to work with the Royal Society, which in turn provides assistance and facilities for an observing program. The post is unique, calling for particular qualities of resourcefulness and a taste for pioneering. The other is in the New Hebrides in the Pacific, where an upper-air station has been established and is financed on an equal shares basis with the French, with whom we enjoy an amicable and effective co-operation. Other WWW stations are at Tarawa in the Gilbert Islands where the technician post is on the strength of the Meteorological Office, though the station is administered and otherwise manned by the New Zealand Meteorological Service; at Funafuti (Tuvalu, formerly Ellice Islands), Mahé in the Seychelles and St Helena in the South Atlantic. The last-named station will continue to be directly controlled by the Meteorological Office as there is no local meteorological service.

The WMO Voluntary Assistance Program (VAP) has had the continued support of the Office throughout the year with the aim of helping less developed countries to make their contribution to WWW. During 1976 projects have been completed and brought into operation in Sierra Leone (RTT point-to-point link and facsimile) and the Maldives (surface observation equipment). The latter was carried out under bilateral arrangements as the Republic of the Maldives is not a member of WMO. Installation of radio-facsimile equipment in Belize was almost complete by the end of the year and completion of radar wind-finding equipment in Mauritius is expected early in 1977. A number of other projects have made progress during the year, most of them in Africa. It is interesting to note as an example of the difficulties encountered in implementing many projects that in Botswana, where the United Kingdom has supplied a telecommunication system (single side-band radio) and power generators the Director of the Botswana Meteorological Service personally travelled 3000 km in delivering aerial masts to about half the stations. The Director expected the remainder to be delivered and the whole network installed (by himself and a WMO expert) by the beginning of 1977. Agreement has been reached and plans are going ahead for the supply and installation of wind-finding radars in Malawi and Zambia.

The selection of projects for implementation is made primarily on scientific and technical grounds in keeping with the traditional role of meteorologists. An informal meeting of representatives of major and potential donor countries was held in Geneva at the end of January to consider how to make their contributions most effective, including the question of co-ordinated or joint action in suitable cases. With the changing economic pattern of recent years the possibilities of getting wider financial support for VAP were also discussed.

In selecting VAP projects for implementation particular regard has been paid to the potential contribution to the First GARP Global Experiment (FGGE), and in this the Office has been helped by WMO assessments of FGGE priorities. A meeting was held at Bracknell Headquarters in August with Mr B. Zavos, Chief of the VAP branch of the United States National Oceanic and Atmospheric Administration (NOAA), during which amongst other topics the possibility of joint use of technical personnel was discussed, for the more efficient and economical use of resources.

As a contribution to FGGE the Meteorological Office has undertaken to supply the consumable items (radiosondes, balloons and targets) to enable the British Antarctic Survey to continue upper-air observations at its bases in the Antarctic during the Special Observing Periods. In the important data handling section of the FGGE Plan the United Kingdom has undertaken to carry out some special data processing functions and, with other countries, will provide some help to Sweden to handle another essential data preparation task. The jointly financed European Centre for Medium-range Weather Forecasts will prepare basic analyses of the data, a task closely related to its own needs.

The WMO Agreement on North Atlantic Ocean Stations (NAOS) came into operation on 1 December when enough signatories had ratified it to guarantee 80 per cent of the requisite finance. Meanwhile, in the expectation that it would enter into force, the United Kingdom and the other ship-operating signatory States had continued under provisional arrangements to operate the intended system. With the first meeting of the NAOS Board in December the scheme got firmly under way. The observations both surface and upper-air are of particular importance to European meteorological services which are partners to the agreement, but they are also important elements of WWW on the global scale.

In the first full year of existence of the European Centre for Medium-range Weather Forecasts (ECMWF) its governing body, the Council, and its Scientific Advisory Committee each met twice, and the Finance Committee four times. After the initial burst of necessary policy decisions the volume of work for these bodies is likely to decrease somewhat. As the Centre is at present located in Bracknell and uses the Meteorological Office computing system (COSMOS) for part of its research work, working relations are close and cordial. Several members of the Office staff are now on the staff of the Centre on limited term contracts. When the Centre reaches its operational stage in its permanent buildings near Reading it will receive the real-time observational data needed for its work over a direct link with our Bracknell Headquarters. As Bracknell is a Regional Telecommunication Hub on the Main Trunk Circuit of WMO's Global Telecommunication System, the Centre will thereby have access to the world's observational data flowing on that circuit. As with WMO the International and Planning Branch acts as contact point between the Centre and the United Kingdom.

The two projects of meteorological interest being developed within European Co-operation in Science and Technology (COST) cover the areas of observations at sea of both oceanographic and meteorological interest, and meteorological instruments. Both are being developed separately from, but in co-ordination with, related work in WMO. Developments in WMO usually originate in the action of single Members or groups of Members, and the success of the experimental networks of data buoys envisaged by COST will also be of great interest elsewhere in the world.

A part of the project on meteorological instruments is concerned with the development of automatic weather stations, of use in many different situations. Under COST auspices the United Kingdom organized a conference and exhibition on the subject which, with the co-operation of the University of Reading, was held there in September. Meteorologists and manufacturers of equipment from several European countries took part in a four-day program of lectures, discussions and demonstrations of equipment. The organization and running of the conference and exhibition were carried out by staff of the Operational Instrumentation and International and Planning Branches.

A study was made jointly by administrative planning and accountant staff of the kind of financial and management accounting system the Office ought now to have. From the planning point of view particular concern was that those responsible for deciding the Office's programs and projects should have readily available appropriate information on the current and projected use of all kinds of available resources. This would be essential for a comprehensive, efficient and flexible system for planning and review of all activities.

An officer of the Japan Meteorological Agency, Mr Toshiyuki Ono, made a five-months' study visit to the Office. Mr Ono is a scientist engaged in planning for extension of meteorological services in his country, and in the course of a crowded program he visited most Headquarters branches, London Weather Centre and a number of other outstations of the Office. He also attended the Senior Meteorologists' Course at the Meteorological Office College as an observer and visited some outside organizations related to meteorology. As usual a number of meteorologists from other countries also paid brief visits to the Headquarters in Bracknell during the year. A number of them took the opportunity to call at Bracknell while *en route* to or from meetings at WMO Headquarters in Geneva. Such informal visits are generally welcome and beneficial to both sides.

G. A. CORBY
Director of Services

STATISTICS OF THE SERVICES DIRECTORATE

The quantitative analyses in this section are intended to provide an indication of the distribution of work within the Directorate of Services and of the extent of the services provided.

TABLE I—NUMBERS OF OFFICES OF VARIOUS TYPES STAFFED BY THE METEOROLOGICAL OFFICE AND OPERATING ON 31 DECEMBER 1976

	Within UK	Overseas
Principal Forecasting Offices associated with the RAF ...	1	—
Main Meteorological Offices associated with the RAF ...	6	4
Subsidiary offices associated with the RAF	27	5
Observing offices associated with the RAF	5	3
Principal Forecasting Offices associated with civil aviation ...	1	—
Main Meteorological Offices associated with civil aviation ...	3	—
Subsidiary offices associated with civil aviation	11	—
Observing offices associated with civil aviation	7	—
Upper-air observing offices	8	2
Public service offices	6	—
CRDF offices	5	2
Port Meteorological Offices	6	—
Offices associated with the Agricultural Development and Advisory Service (MAFF)	3	—
Other offices	24*	3

*Four of these stations are administered by DR Met O

Notes

A Principal Forecasting Office meets the needs of aircraft flying over long distances and operates throughout the 24 hours.

A Main Meteorological Office operates throughout the 24 hours for the benefit of aviation and normally supervises the work of subsidiary offices.

A subsidiary office is open for that part of the day necessary to meet aviation requirements.

At an observing office no forecaster is available.

An upper-air observing office may be located with an office of another type if this is convenient.

Public service offices are located in certain large cities.

CRDF offices form the network for thunderstorm location.

Port Meteorological Offices are maintained at the bigger ports.

TABLE II—OCEAN WEATHER SHIPS

Between 1 July 1975 and the entry into force of the new NAOS/WMO Agreement for the Joint Financing of the North Atlantic Ocean Station (NAOS) on 1 December 1976, the operating states, of which the UK is one, agreed to provide ships to man the four stations of the network in the central and eastern North Atlantic in accordance with an interim arrangement. The UK operated two ships to man ocean station 'L' both during the interim period and subsequently. Two ships from France, one ship from the Netherlands, two ships operated jointly by Norway and Sweden and five ships from the USSR provided coverage at the other three stations of the network. In particular, the French ships manned ocean station 'R', the Netherlands and joint Norwegian/Swedish ships manned ocean station 'M' and the USSR ships manned ocean station 'C'. During 1976 the British ocean weather ships spent a total of 358·5 days on station and 66·3 days on passage.

TABLE III—MERCHANT NAVY SHIPS

A total of about 7500 ships of the merchant navies of the world make and transmit meteorological reports to the appropriate meteorological centres ashore under arrangements co-ordinated by the World Meteorological Organization. Most of them, including British ships, do this on a voluntary basis. Ships which report in full at four specified times daily are known as 'selected ships'; those which report at the same times daily, but in a less complete form, are known as 'supplementary ships'. A number of coasting vessels, lightships, distant-water trawlers and 'auxiliary ships' also make and transmit meteorological observations.

On 31 December 1976 the numbers of British ships reporting were:

Selected ships	522
Supplementary ships	41
	Including 10 trawlers
Coasting vessels	56
Lightships	13
Trawlers	14
Auxiliary ships	9
Total	655

The British Voluntary Observing Fleet includes ships of many shipping companies, and the numbers on the various routes are as follows:

UK to Australasia	49
UK to Far East	98
UK to Persian Gulf	30
UK to South Africa	42
UK to West Indies	25
UK to Atlantic coast of North America	72
UK to Pacific coast of North America	8
UK to South America	17
UK to European ports	69
UK to Falkland Island and Antarctica	2
UK to distant-water fishing grounds	20
World-wide tramping	151

During two typical five-day periods, one in June, the other in November, the average daily numbers of reports from ships received at Bracknell were as follows:

	Reports	
	June	*November*
Direct reception from:		
British ships in eastern North Atlantic	122	130
Foreign ships in eastern North Atlantic	115	91
British ships in North Sea	19	28
Foreign ships in North Sea	4	2
Ships in other waters	6	4
Total	266	255
Reception via other countries:*		
Ships in eastern North Atlantic	409	376
Ships in western North Atlantic	299	288
Ships in Mediterranean	58	63
Ships in North Sea	79	96
Ships in Arctic Ocean	42	47
Ships in North Pacific	603	809
Ships in other waters	363	239
Total	1853	1918

*Via the Global Telecommunication System

TABLE IV—CLASSIFICATION OF STATIONS RENDERING CLIMATOLOGICAL RETURNS

A large amount of data is obtained for climatological purposes from stations which are not part of the Meteorological Office organization. The following table shows how sources of climatological information in the United Kingdom (including Meteorological Office stations) were distributed on 31 December 1976. The areas and titles of the districts are those used in the *Monthly Weather Report*.

	Stations Supplying Returns					Stations Supplying Autographic Records		
	Observatories	*Synoptic*	*Agrometeorological*	*Climatological*	*Rainfall**	*Sunshine*	*Rainfall*	*Wind*
Scotland, north	1	9	2	32	311	28	12	15
Scotland, east	0	11	9	61	569	45	24	11
Scotland, west	1	12	1	50	517	28	21	20
England, east and north-east ...	0	9	9	28	532	30	19	15
East Anglia	0	11	14	21	494	28	10	13
Midland Counties	0	11	14	42	1371	48	21	17
England, south-east and central southern (including Greater London)	1	15	18	42	830	61	25	23
England, south-west	0	16	8	31	661	37	6	11
England, north-west	0	6	3	22	540	20	20	13
Isle of Man	0	2	0	1	22	3	1	3
Wales, North	0	3	3	17	285	12	3	4
Wales, South	0	10	9	17	380	22	5	6
Channel Islands	0	2	0	4	21	6	0	2
Northern Ireland	0	5	7	44	288	28	46	9
Total	3	122	97	412	6821	396	213	162

*Includes stations in earlier columns.

TABLE V—HEIGHTS REACHED IN UPPER-AIR ASCENTS

The following table shows the number of upper-air ascents giving observations of (a) temperature, pressure and humidity and (b) wind, which have reached specified heights, and the height performance of the largest balloons.

(a) Observations of temperature, pressure and humidity.

	Number of observations	Percentage of all balloons reaching				Percentage of largest balloon reaching
		100 mb 16 000 m (approx.)	*50 mb 20 000 m (approx.)*	*30 mb 24 000 m (approx.)*	*10 mb 30 000 m (approx.)*	*10 mb 30 000 m (approx.)*
Eight stations in the UK ...	... 5840	95·9	82·5	56·1	22·4	61·0
Three stations overseas ...	... 2011	97·6	91·5	67·0	44·0	62·4
Two Ocean Weather Ships	... 711	95·4	75·4	28·6	1·1	—

(b) Observations of wind

	Number of observations	Percentage of all balloons reaching				Percentage of largest balloon reaching
		100 mb 16 000 m (approx.)	*50 mb 20 000 m (approx.)*	*30 mb 24 000 m (approx.)*	*10 mb 30 000 m (approx.)*	*10 mb 30 000 m (approx.)*
Eight stations in the UK ...	... 11 607	91·6	72·2	36·3	11·2	59·2
Three stations overseas ...	... 3 747	95·9	84·3	50·3	25·0	62·7
Two Ocean Weather Ships	... 1 381	90·4	64·6	23·5	0·9	—

TABLE VI—THUNDERSTORM LOCATION

Number of thunderstorm positions reported by CRDF Network:

In 1976 ... ... 56 962

TABLE VII—METEOROLOGICAL COMMUNICATION TRAFFIC

Almost all the national and international exchanges of meteorological data which are used in the construction of synoptic charts and the production of forecasts are effected by coded messages. The coded messages are composed of groups of five figures and there may be from 5 to around 300 such groups in one message. The messages are exchanged by radio and land-line facilities. In addition there is an exchange, both nationally and internationally, of meteorological information in pictorial format. This information is largely analyses and forecasts derived from processing observational data. The transmission method is analogue facsimile by either radio or land-line.

The following figures give an analysis of the traffic (mainly coded messages and information in pictorial format) through the Meteorological Office Telecommunication Centre, Bracknell, for one typical day (24 hours) taken in November 1976 and, for comparison, some corresponding figures are given for one day near the end of 1975.

	In	Out	Total	Total in 1975
	(number of groups in one day)			
Coded messages				
Land-line teleprinter and data transmission	691 209	1 988 212	2 679 421	1 859 945
Radio transmission	54 120	160 060	214 180	411 758
Facsimile charts (pictorial format)				
	(number of charts in one day)			
Land-line transmission ...	97	1 066	1 163	953
Radio transmission	31	116	147	161

The large increase in transmissions by land-line compared with the previous year reflects the provision of extra outputs to UK and European recipients.

TABLE VIII—SPECIAL SEASONAL FORECASTS

There is a need for forecasts of a special type at certain seasons. These are described in *Met O Leaflet* No. 1 (1975). The numbers receiving such specialized services were as follows:

	Year	No. of customers	Year	No. of customers
Dry-spell notifications (a summer service primarily for farmers) ...	1975	154	1976	135
Week-end temperature forecasts (a winter service primarily for industrialists)	1975–76	55	1976–77	65
Winter road danger warnings (primarily for local authorities) ...	1975–76	296	1976–77	300

TABLE IX—FORECASTS FOR AVIATION

Forecasting for aviation constitutes the primary function of many of the offices. The Central Forecasting Office, acting as a Regional Meteorological Centre of the World Weather Watch, is mainly concerned with the analysis of the weather situation and with the issue of forecast charts for the guidance of other offices, including the two Principal Forecasting Offices which serve civil aviation from London/Heathrow Airport and military aviation from the Headquarters of RAF Strike Command. The Central Forecasting Office also has a commitment to civil aviation in the provision of wind and temperature charts for use with the significant weather charts produced by the Principal Forecasting Office at Heathrow and for the transmission of grid-point data direct to the British Airways BOADICEA and APOLLO computers at Heathrow and Prestwick respectively and to the Dutch and Belgian Meteorological Services.

The following figures indicate the numbers of forecasts issued for aviation and the numbers of meteorological briefings that took place during 1975 and 1976. These do not include warnings and routine general forecasts.

	1975	1976
Number of meteorological briefings for		
aviation in the UK	359 670	363 467
aviation at overseas stations	41 115	37 766
Number of aviation forecasts issued for		
aviation in the UK	1 797 406	1 852 416
aviation at overseas stations	386 529	304 223

TABLE X—NON-AVIATION INQUIRIES

In addition to the five Weather Centres in London, Manchester, Glasgow, Southampton and Newcastle, and the office in Nottingham (Watnall) whose function is to meet the needs of the general public for forecasts for special purposes many other forecast offices, established primarily to meet the needs of aviation, also answer requests for forecasts and other weather information from the general public, Press, public corporations, commercial firms, etc. These inquiries, most of which refer to current or future weather, are listed below according to the purpose of the inquiry.

	1975	1976
Total number of non-aviation inquiries	1 840 820	1 865 050
Percentage relating to:		
agriculture	10·4	10·7
building	5·2	4·7
commerce, industry	5·3	5·1
holidays	21·1	18·8
marine matters	14·6	14·7
Press	10·7	10·8
public utilities	9·2	9·4
road transport	8·2	9·5
other known purposes	5·9	6·3
unknown purposes	9·4	10·0

TABLE XI—FLASH WEATHER MESSAGES

FLASH weather messages are passed to the BBC and to most Independent Broadcasting Companies for inclusion in their programs at a convenient break. They are, effectively, warnings of the actual occurrence of weather conditions which might cause considerable inconvenience to a large number of people. The following table shows the kind of weather and areas of the country for which FLASH messages are broadcast and the number issued in 1976.

Area	Dense fog	Moderate or heavy snow	Heavy rain	Glazed frost and icy roads	Severe inland gales
Edinburgh and south-east Scotland	—	—	—	1	1
Glasgow and south-west Scotland	1	1	2	1	2
Belfast and Northern Ireland	1	—	1	—	1
Industrial north-east England	1	1	1	1	1
Industrial Lancashire and Merseyside	3	—	2	2	3
Industrial Midlands	—	—	1	1	1
Bristol and Bath	—	—	—	1	1
South Wales	1	1	3	1	2
London and south-east England	2	—	1	3	3
Plymouth and south-west England	—	—	2	6	4
Yorkshire	—	—	—	1	4
Southampton and Portsmouth	—	—	—	1	1
Total	9	3	13	19	24

TABLE XII—AUTOMATIC TELEPHONE WEATHER SERVICE FORECASTS

Information Service Centre	Forecast area	Number of calls 1975	Number of calls 1976
Bedford	40 miles radius of Bedford	250 441	238 481
Belfast	Belfast	275 869	260 533
Birmingham	Birmingham	775 888	821 772
Bishop's Stortford	40 miles radius of Bedford	79 735	77 234
Blackburn	Lancashire, Cheshire, Greater Manchester and Merseyside	314 493	220 601
Blackpool	Lancashire, Cheshire, Greater Manchester and Merseyside	159 737	153 492
Bournemouth	South Hampshire	290 144	271 982
Bradford	Leeds, Bradford, Huddersfield	109 758	104 732
Brighton and Hove	Sussex coast	574 982	461 872
Bristol	Bristol	525 484	542 056
Cardiff	Cardiff	483 203	520 489
Canterbury	Kent coast	259 436	251 064
Chelmsford	Essex coast	128 451	114 032
Cheltenham	South-west Midlands	102 360	102 748
Chester	Chester and North Wales coast	141 324	150 282
Colchester	Essex coast	207 368	184 937
Colwyn Bay	Chester and North Wales coast	78 616	78 156
Coventry	Birmingham	196 027	193 377
Derby	Nottinghamshire, Derbyshire, Leicester	149 266	133 436
Doncaster	Sheffield, Chesterfield, Doncaster, Barnsley	43 164	43 384
Edinburgh	Edinburgh	349 051	387 826
Exeter	Devon and Cornwall	167 817	181 672
Glasgow	Glasgow	580 622	555 830
Gloucester	South-west Midlands	164 836	165 836
Grimsby	North Lincolnshire and Retford area	50 063	53 847

Information Service Centre	Forecast area	Number of calls 1975	1976
Guildford	London	121 766	118 019
Hastings	Sussex coast	—	23 012
Hereford	South-west Midlands	82 801	79 912
High Wycombe	Thames Valley	98 408	87 147
Huddersfield	Leeds, Bradford, Huddersfield	67 057	38 599
Ipswich	Norfolk and Suffolk	175 717	171 320
Leeds	Leeds, Bradford, Huddersfield	352 277	351 055
Leicester	Nottinghamshire, Derbyshire, Leicestershire	251 836	191 415
Lincoln	North Lincolnshire and Retford Area	107 281	118 369
Liverpool	Lancashire, Cheshire, Greater Manchester and Merseyside	286 040	324 976
Liverpool	Chester and North Wales coast	46 763	39 151
London	London	3 400 531	2 934 872
London	Essex coast	142 401	123 888
London	Kent coast	169 187	141 765
London	Sussex coast	343 564	277 298
London	Thames Valley	166 656	164 097
London	40 miles radius of Bedford	96 623	93 430
Luton	40 miles radius of Bedford	154 744	163 517
Manchester	Lancashire, Cheshire, Greater Manchester and Merseyside	533 886	551 068
Manchester	Chester and North Wales coast	82 671	68 916
Medway	Kent coast	178 322	154 797
Middlesbrough	North-east England	163 410	168 793
Newcastle	North-east England	348 781	478 984
Northampton	40 miles radius of Bedford	—	13 743
Norwich	Norfolk and Suffolk	242 250	248 917
Nottingham	Nottinghamshire, Derbyshire, Leicestershire	481 678	428 925
Oxford	Thames Valley	215 205	225 081
Peterborough	40 miles radius of Bedford	85 088	89 332
Plymouth	Devon and Cornwall	173 963	320 936
Portsmouth	South Hampshire	391 770	363 578
Reading	Thames Valley	242 399	277 256
Sheffield	Sheffield, Chesterfield, Doncaster, Barnsley	300 629	286 870
Southampton	South Hampshire	450 353	397 526
Southend	Essex Coast	227 943	197 768
Southport	Lancashire, Cheshire, Greater Manchester and Merseyside	47 569	48 182
Swindon	Bristol	39 048	38 934
Torquay	Devon and Cornwall	137 130	111 381
Tunbridge Wells	London	71 469	68 183
Total		16 935 351	16 250 683

TABLE XIII—CLIMATOLOGICAL INQUIRIES

Met O 3, Met O 8, Edinburgh and Belfast receive a number of inquiries relating to past weather, to climatology and to the application of meteorological data to agriculture. The following figures give the total number of inquiries and the percentages of this number in various categories.

	1975	1976
Total number of climatological inquiries	23 077	26 126
Percentages relating to		
agriculture (farming, forestry, market gardening)		9·4
building and design (including siting)		18·7
commerce (sales, marketing, advertising)		3·2
drainage		3·0
education and literature		5·3
flooding		0·1
heating and ventilation		4·4
industrial and manufacturing activities		4·5
law (damage, accident, insurance)		11·7
medical and health		0·9
press and information centres		3·1
research		7·4
sport, hobbies, holidays		1·3
transport and communications		3·5
water supplies		9·8
miscellaneous (purpose known)		5·4
miscellaneous (purpose unknown)		8·3

TABLE XIV—DATA PROCESSING

(a) Punched-card installation

Number of cards punched by the Meteorological Office installation	480 732
Number of cards punched elsewhere on behalf of the Meteorological Office	139 625

(b) Processor-controlled keying system
The processor-controlled keying (PCK) system was used for data preparation during 1705 hours.

(c) Computer installations
(1) The 360/195 computer was used for computing during 8534 hours.
(2) The 370/158 computer was used for computing during 8639 hours.

TABLE XV—INSTRUMENT TESTING, CALIBRATION AND ACCEPTANCE

General meteorological instruments:	
Wind measuring	982
Pressure measuring	994
Humidity measuring	36
Precipitation measuring	1 252
Radiation measuring	226
Sunshine recording	96
Temperature measuring	4 562
Miscellaneous	4 537
Electrical/electronic instruments and systems	892
Electrical/electronic components	868
Balloons	61 187
Radiosonde batteries:	
for Mk 2B radiosonde	5 987
for Mk 3 radiosonde	4 591
Radar reflectors	25 560
Radiosonde parachutes	27 500
Radiosonde unwinders	3 110
Mk 2B radiosondes calibrated	15 114
Mk 2B radiosonde recoveries received	1 992
Mk 3 radiosonde component parts	145 556
Total	305 042

DIRECTORATE OF RESEARCH

Special Topic—Climatic Variability and Interannual Variability

Introduction

In recent years there has been a considerable upsurge of interest in the subject of climate and climatic change, caused mainly by increasing awareness that quite small unfavourable changes in climate would have disastrous effects on world food supplies. It has also become apparent that there are a number of ways in which man's activities might, in the foreseeable future, bring about significant changes in weather and climate. The whole future of man on earth may well depend on how fully we can understand the changes that have occurred in the past and prepare for those that may occur in the future.

Before discussing recent work in the Meteorological Office on the subject, this report attempts to set matters in perspective by briefly reviewing our knowledge of past fluctuations on different time-scales and of possible causes of these fluctuations.

Scales of variation

Analyses of the cores taken from the ocean bed indicate that the climate of the earth has undergone repeated changes in the past. Figure 2 (after Shackleton and Opdyke (1973)*) displays the course of the amount of water held as ice during the last million years based on such core analysis. During the epochs with a large quantity of ice, the so-called glacial periods, the global temperature is estimated to have been 5–10 °C lower than in the intervening warmer interglacial periods. Towards the end of the last glacial period an ice sheet is known to have extended down to near 50°N over Britain and much of Europe and somewhat further south over America. Much of the water of the Atlantic is estimated to have been 5–10 °C colder than it is today.

Even after the recession of the ice sheet about 10 000 years ago the climate has not been constant though the variations have not been so large.

During the last millenium the climate has displayed quite marked variability. Colder periods in Europe around A.D. 800 and A.D. 1600 alternated with warmer periods around A.D. 1100 and the twentieth century.

Decades or groups of decades also show differences. In recent times the last two decades of the nineteenth century were cooler than the first four of the twentieth century and the 1950s and 1960s reverted some way towards the earlier regime.

The variations of temperature on each of these time-scales increases with the length of the period studied. It may be as large as 10 °C between the glacial and interglacial periods, about 1 °C for variations of a few hundred years and about 0·5 °C for those lasting a few decades.

*SHACKLETON, N. J. and OPDYKE, N. D.; *Quaternary Research*, **3**, 1973, p. 39.

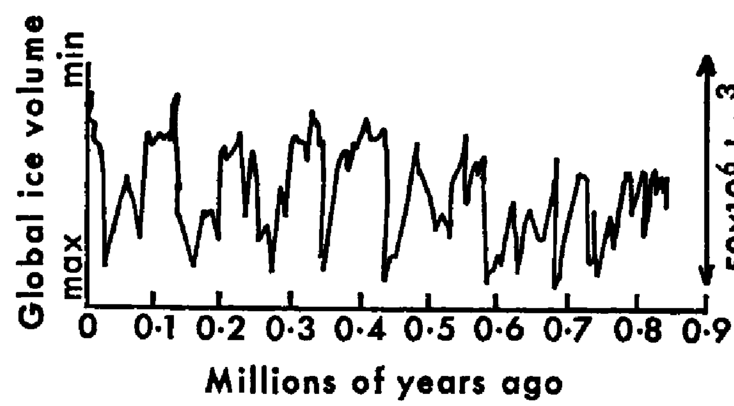


FIGURE 2—GLOBAL ICE VOLUME INFERRED FROM A DEEP SEA CORE
After Shackleton and Opdyke (1973).

Instrumental temperature measurements go back about 300 years but only in the last 150 years have they been well standardized. Measurements from different places can be combined to give estimates of the average temperature for each year over the whole globe or the northern hemisphere; results for the northern hemisphere, expressed as 5-year means, are shown in Figure 3. The typical year-to-year variation (standard deviation) of global mean temperature is about 0·4 °C and differences of as much as 1 °C between one year and the next are not uncommon. For a limited area or a single place the variability is, of course, much greater. These random variations set a limit to the size of trend or systematic change in climate that can be detected.

Changes in rainfall have also occurred in the past. Present-day deserts such as the Sahara and the Thar desert in north-west India are known to have had enough rainfall at one time to allow extensive settlement. The longest rainfall records in Great Britain, though not completely homogeneous, indicate that much of the eighteenth century was drier than the nineteenth and twentieth centuries.

There have also been changes in the atmospheric circulation. The middle latitude westerlies are thought to have been displaced southwards during the last glacial period so that their most usual location was over France and Spain rather than over Great Britain. Over the last 100 years there have been marked changes in the strength of the surface westerlies over the Atlantic. These have broadly paralleled the changes in the westerlies for the whole northern hemisphere, which are illustrated in Figure 3 by the variations in a zonal index for the latitude band 35–55°N. This indicates that over the 20-year period from 1910 to 1929 the westerly circulation was about 40 per cent stronger than during the preceding and following periods. This is probably quite intimately related to the temperature variation (shown in the same figure) even though the two peak periods are displaced from each other by some 20–25 years.

The extent to which these different kinds of variations are periodic is controversial. The palaeoclimatic data appear to have a strong periodicity near 100 000 years and at the other extreme most climatic elements show periodicity at about 2·2 years—the so-called quasi-biennial oscillation. The literature contains claims for the existence of almost every period in between; the most diligently sought after are those which correspond to the periodicity of sunspot activity. Many of these cycles change their phase from time to time and generally they do not account for much of the total variability.

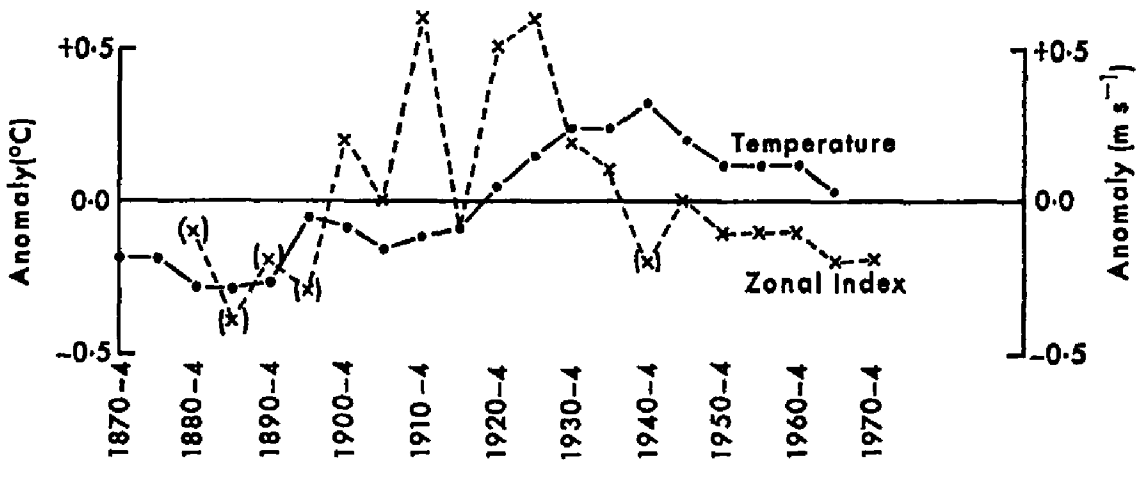


FIGURE 3—ANOMALIES OF NORTHERN HEMISPHERE TEMPERATURE AND ZONAL INDEX (35°–55°N) FROM THEIR OWN LONG-PERIOD AVERAGES

Possible causes of variations

We have seen that individual years may differ considerably in their mean temperature and it is possible that the changes over the last 100 years may arise from random grouping of these anomalies. However, the chance that a 25-year period as warm as 1925–49 will arise by such a random process in a series with this variability is less than one in a thousand. This makes it a reasonable task to look for specific causes for the observed variability.

Changes in solar radiation. The equilibrium temperature for the atmosphere is that at which it radiates to space as much heat as it absorbs from the sun. If the earth behaved as an ideal 'black-body' this equilibrium temperature would be about 240 °C and would change by about 0·6 °C if the incident solar radiation (whose magnitude is usually referred to as the 'solar constant') changed by 1 per cent. The fact that the average temperature at the earth's surface is some 45 °C higher is largely due to the presence of gases (principally water vapour and carbon dioxide) which absorb and reradiate the infra-red radiation from the earth's surface. Water vapour content usually increases with a rise in temperature and so will magnify a change produced originally by, say, a variation in the solar constant. Calculations with the assumption that cloudiness remains constant indicate that the initial rise is approximately doubled by the change in water vapour concentration; this represents a permanent positive feedback effect for all but the most rapid changes of temperature.

If these were the only considerations it would appear that changes of the solar constant by some 5 per cent were required to effect the transition from an interglacial to a glacial period. There is, however, a further important positive feedback effect that makes the earth more sensitive to changes of incident radiation. A fall of surface temperature increases the area of snow and ice in high latitudes and because these surfaces have a higher reflecting power (or albedo) than the average for the earth there will be less of the incident solar radiation absorbed and a further fall in temperature results. Early work with simple models indicated that this feedback was so strong that an ice-age might be produced by a reduction of only 2 per cent in the solar constant.

Determinations of the solar constant from terrestrial observations have an uncertainty of nearly $\pm$ 1 per cent, so that the changes of a small fraction of 1 per cent required to produce the changes of the last few hundred years cannot be established from such measurements. This has naturally led to a great interest in other possible indicators of solar radiation such as the number of sunspots, the frequency and intensity of solar flares and related changes in the solar and terrestrial magnetic fields. Large changes in the intensity of the far ultra-violet part of the solar spectrum occur during the sunspot cycle but they represent much less than 0·1 per cent of the total energy from the sun. Measurements from balloons flown at 30 km, published in 1970, were claimed to demonstrate a relation between the solar constant and the Wolf number—a standardized count of the number of sunspots. However, even at this altitude the corrections for atmospheric turbidity were of the same order of magnitude as the real differences and the relationship cannot be regarded as having been conclusively established.

There is some statistical evidence that global temperature, circulation intensity and rainfall are related to the Wolf number, or the strength of the geomagnetic field, but the amount of the variance explained is usually small and there are epochs and areas of the globe in which the connection is absent.

The only undisputed changes in solar radiation are those that must occur, on very long time-scales, through changes in the orbit of the earth and the tilt of its axis. These changes have a negligible effect on the total radiation reaching the earth in the course of a year but they do have quite big effects on the distribution of this total between summer and winter and between different latitudes. Recent work has shown that these changes in distribution of radiation must be taken seriously as a possible cause of the fluctuations from glacial to interglacial climate, but since the most rapid orbital change has a period of about 20 000 years, this mechanism will have no detectable effects on a time-scale of decades or even centuries.

Changes in atmospheric composition. Variations in any of the constituents of the atmosphere which absorb and radiate in the wavelengths of the solar or the terrestrial surface radiation will alter the surface equilibrium temperature. Ozone absorbs strongly in the ultra-violet but the temperature effects are mainly in the stratosphere where the ozone is largely concentrated. Carbon dioxide, however, also absorbs in the infra-red and calculations with a radiative model indicate that a doubling of the present concentration would lead to a rise of surface temperature of 2–3 °C. It has been claimed that natural variations of carbon dioxide during the Quaternary Era were large enough to explain the transitions from glacial to interglacial.

Anything which changes the albedo of the earth–atmosphere system is likely to lead to temperature changes. Clouds have a mean albedo above that of all the other reflecting surfaces except ice and snow so an increase in total cloudiness will cause an additional loss of solar input. This will probably lead to a lower temperature despite the fact that clouds also absorb and reradiate long-wave radiation. Knowledge of variations in cloudiness is insufficient to enable us to assess the role of clouds in climatic variability.

Variations in dust content can also change the intensity of the direct solar radiation measured at the earth's surface. For many months after a violent volcanic eruption there is often a depletion of the direct solar beam of order 10 per cent produced by fine particles in the stratosphere. They may remain there for several years and so affect the earth's temperature over a substantial time. Recent work has indicated that volcanic dust is also a strong absorber of solar radiation and so its role is not simply one of increasing the planetary albedo. It may very well be that the effects on surface temperature will vary from one eruption to another, depending on the optical properties of the dust. Measurements in recent years have revealed the presence in the stratosphere of aerosols (mainly sulphates) which are the products of man's industrial activity. These absorb both in the visible and the infra-red; their presence increases the effective albedo only when they occur over surfaces of low reflectivity such as the tropical oceans.

Changes in air–sea interaction. A large part of the incident solar radiation is absorbed by the tropical oceans and handed over to the atmosphere either in the tropics themselves or in middle latitudes. The depth to which this absorbed heat is spread and the equilibrium sea surface temperature depend on the strength of the winds. Both of these factors could alter the temperature of the atmosphere. The oceanic circulation is also affected by the strength of low-level winds. These interactions provide a mechanism whereby temperature variability on a variety of time-scales could be brought about. This variability may be regarded as internal to the ocean–atmosphere system; it does not necessarily depend on changes in the other factors discussed above for its occurrence.

Knowledge of time variations

A satisfactory explanation of past climatic variability requires besides fairly precise knowledge of the effects likely to follow from the various causative factors, quantitative information about the variations in these factors in the past. For example the validation of the hypothesis that volcanic dust has been responsible for some of the temperature and circulation changes requires comparable values of the dust concentration associated with volcanic eruptions of the past. Lamb attempted to meet this need when he made estimates of a dust veil index (DVI) based on recorded estimates of the amount of material ejected by each eruption, the areal and temporal extent of the dust and, when available, data on the reduction in the recorded direct radiation in the months following the eruption. There have been criticisms of this index as being an inappropriate measure of the effects of the dust on the radiation balance, but it has been widely used and moreover decadal values show a high correlation with temperature data. The existence of this index has taken the volcanic hypothesis out of the realm of untestable speculation. If the hypothesis has not yet reached general acceptance this is probably as much due to other considerations as to deficiencies in the index. Among such considerations are the difficulties in separating the effects of individual eruptions from the inherent interannual variability, and from effects due to other factors, as well as a possibility, revealed by recent research, that the optical properties of the dust may vary from one eruption to another.

An alternative approach to the dust problem has been made in the USSR, where a time-series of the intensity of direct solar radiation based on pyranometer (solarimeter) measurements since the late nineteenth century has been produced. There is a good deal of doubt about the accuracy of this series on the grounds that the calibrations of the instruments may not be comparable at different epochs, that the accuracy of radiation measurements was not until recent years good enough to determine anomalies of the order of 2–3 per cent, and that the data refer to a rather limited part of the globe. However, Budyko has concluded that these variations of direct radiation amounting to about $\pm$ 2 per cent are mainly or indeed entirely due to variations in the dust content of the atmosphere. From his estimate that a 1 per cent change in direct radiation implies a 0·15 per cent change in direct plus scattered radiation he concludes that there was almost a 0·5 per cent increase in the latter between the end of the nineteenth century and the culmination of the warming in 1940 owing to the absence of volcanic eruptions after 1912 until the 1950s. His series shows an almost equal reduction in the global radiation by the 1960s which he attributes largely to increased man-made pollution.

The value of this time-series depends on how good and representative the pyranometer records are and how reliable the relation between changes in direct and global radiation is. Other attempts to determine trends of atmospheric turbidity over varying time periods have not provided much confirmation of its value.

The changes in the carbon dioxide concentration, though based on only a limited number of observations, appear to follow the fossil fuel consumption curve so that the general shape and the imputed increase of 10 per cent this century are not much in doubt. The calculated effect of this on hemispheric temperature, that is to say a rise of 0·2 to 0·3 °C, is just about the net rise of temperature since the 1880s, which may of course be a coincidence but shows that this calculated effect is probably of the right magnitude.

The time variations of the intensity of the low-level circulation are known fairly well back to 1900, but the values for even the latter part of the nineteenth century are not sufficiently accurate for comparison purposes. Earlier they become increasingly uncertain and research which can provide reliable indirect estimates for this period is extremely valuable and necessary.

Homogeneous time-series of sea temperatures for the principal water masses of the world are not at present available and this represents a very severe handicap indeed, in view of the potentially dominant role of the oceans in climatic variability.

Various regional indices of ice extent have been published but they are not all for the same period of years Trends for the various regions are not always similar and so no one of the regional indices can be regarded as a reliable measure of changes in the planetary albedo. This has been a handicap in attempting to assess the size of the ice-albedo feedback contribution to the global temperature changes. Qualitatively there must have been a reduction in the albedo of the northern hemisphere after the well-known warming of the Arctic in the first three decades of this century but we cannot say what effect this has had on the associated global warming. Satellite photographs have provided fairly homogeneous data since 1967 but the hemispheric temperature data with which to make more precise determinations of the associated variations of the feedback effects are not yet available.

The records of direct solar radiation which go back to the end of the nineteenth century have already been mentioned. They are not sufficiently accurate to enable us to say whether there have been variations of the solar constant within $\pm$ 1 per cent. Satellite-borne instruments to give the greater accuracy required are not yet in service. Homogeneous data about the variations in solar activity are of varying length. For the variations in energy associated with short ultra-violet and centimetric radiation they extend back a few decades, for the changes in solar flare activity back to the end of the nineteenth century and for sunspot numbers back to 1750 or perhaps even to 1650. The Russian attempts to relate these to the solar constant have been mentioned; there have been others and Baur has tried to establish a relation of Abbott's determinations of solar constant to the phases of the 11-year sunspot cycle. Again, the errors in the determination appear to be of about the same size as the putative real changes, making it difficult to prove the relation conclusively.

The nature of the research problem

At this stage it is possible to say something about the nature of the research problem presented by the variability of climate. The likely causative factors are fairly well known. Some estimate of the size of their effects can in most cases be made. These effects over the last few hundred years have been about the same size as the inherent variability of the ocean–atmosphere system so that in individual cases they cannot be isolated. Sometimes two or more effects may be capable of producing the observed variations and then the lack of precision in the estimates invalidates efforts to determine whether one alone has been effective or what the relative contributions may have been. An inadequate climatic theory for the earth particularly in the matter of the relation of the general circulation to the thermal variables of the system is a further barrier to progress.

Some of the aspects which needed attention in the early 1970s may in the light of the foregoing discussion be summarized under the following seven headings:

1. Effects due to changes in atmospheric composition, for example dust (volcanic and man-made), carbon dioxide and changes in albedo.
2. Variation of cloudiness and its effects.
3. Variations in solar activity.
4. Significance of circulation changes in climatic variability.
5. Role of ocean–atmosphere interaction in climatic variability.
6. The reality of periodicities and their contribution to observed variability.
7. The establishment of homogeneous time-series of causative factors.

It has become clear that to make progress with the first five items an integrated numerical approach is necessary. Only a numerical treatment that successfully explains the past variations will put us in a position to give reliable advice about future variations. This means a numerical modelling of the ocean and the atmosphere in which the three-dimensional motion field and the heat balance are described by the equations of motion and the thermodynamic equations. The future motions and changes of temperature may then be obtained by repeated solution of a suitable combination of these equations at a grid of points covering the globe or a large part of it. Such numerical models have come to be known as General Circulation Models (GCMs) and can only be run on very fast computers with very large storage capacity. Even so, to obtain a solution for one month requires several hours unshared use of such a computer. The averages of temperature, rainfall and so on for a simulated period of a month or two are interpreted as the 'climate' of the model and the object of the work is to see how this climate changes when conditions in the model—for example the solar radiation, the amount of carbon dioxide in the atmosphere or the distribution of land and sea—are changed. Unfortunately the 'climate' of the model is not defined precisely by any one run of the model; the exact average values obtained will depend on accidental factors such as the length of the run and the particular starting conditions of wind and temperature. Unless the change produced by a change in external conditions exceeds the range of variation inherent in the model, we cannot be certain it is genuine, and consequently a good deal of effort has to go into estimating the inherent variability of the model.

Only a few researchers are in a position to use GCMs in this way and consequently much climatic research has been performed with simpler models often in two dimensions (a meridional and a height axis) with the important transport properties of cyclones being represented or 'parametrized' by zonally meaned quantities held in the model. The meridional transport of heat and water vapour is a crucial item in studying climatic variability. It is a well-established fact that inter-epochal temperature changes in high latitudes are several times greater than those in the tropics: this may be as much due to the relatively greater contribution of heat transported from lower latitudes to the heat budget of these higher latitudes as to the magnifying effect of ice-albedo feedback. It is therefore important to get this transport accurately represented in numerical models if they are to give reliable guidance about changes in different climatic zones. At present GCMs have been mainly used to carry out 'sensitivity studies'. Runs with different ice boundaries and different sea temperatures are compared to find the equilibrium response of temperature and circulation. Such a procedure gives us no information about how the transition from the one state to the other takes place. With GCMs this would take an impossibly long time to simulate and is another reason why simpler models are likely to be needed for many years to come.

Recent research activity

The research effort in the Meteorological Office has been mainly devoted to understanding changes over the last 100 years in order to improve the basis for giving advice on likely future climatic trends in the British Isles. Circulation changes play a large part in determining this so a major part of the effort in the Synoptic Climatology Branch has been under item 4 above. There has been some attention paid to most of the other items. In the Dynamical Climatology Branch the main effort has been under item 5 with subsidiary effort under item 2.

The work under item 4 has been carried on by the development of indices of the surface zonal and meridional circulation of middle and subpolar latitudes. The zonal index displays very large differences from year to year and, as can be seen from Figure 3, from epoch to epoch. The reason for these changes is not known, but studies have been made of the relationships between the zonal index and other quantities such as meridional temperature gradient, meridional circulation indices and estimates of the poleward flux of heat. In particular the relation between zonal index and the poleward flux of sensible heat was examined. The provisional conclusion for a zonal index for latitudes 35–55°N and the flux at 45°N is that there is very little relation between them. This has prompted the question 'how is the mean monthly zonal index for an area related to the number and intensity of cyclonic systems in that area during the month?' Some preliminary studies for the North Atlantic in winter indicate that there is very little correlation between the two but that if the count of cyclones is for an area displaced by 10° of latitude to the north of that for which the zonal index is computed there is a significant positive correlation. The first result goes some way to explain the weak relation between flux and westerly. The second result is interesting in the light of a recent study in the United States which compares the winter flux of sensible heat for the periods 1900–41 and 1942–72. This showed that while the flux at 45°N was nearly the same, that at 60°N was substantially greater in the earlier epoch of stronger circulation. This result is consistent with a complementary finding from our work that the changes in flux appear to be quite closely related to a meridional index. This has been computed for two latitude bands 35–55°N and 55–75°N and while that for the southern band changed little between the two epochs that for the northern band was about 20 per cent higher in the earlier epoch. The implied difference in the flux divergence for the zone 45–65°N between these two epochs suggests a substantial change in the heat transfer between ocean and air in this zone which is probably due to the change in the surface westerlies; efforts are being made to incorporate this idea into a simple numerical model.

The work under items 1 and 3 has been approached by computing the coefficients of a statistical equation (multiple linear regression equation) relating five-year mean values of hemispheric temperature to five-year means of carbon dioxide concentration, Lamb's dust veil index, the Wolf number, the zonal index and an ice index. The first three time-series were derived from data already published, the latter two were built up during the course of recent research. Various combinations of the variables were used and the result which emerged was that changes in carbon dioxide, volcanic dust and ice feedback together could account for about 80 per cent of the variance of hemispheric temperature over the last 100 years and produced effects of the same order of magnitude. The Wolf number and zonal index variations were not capable of explaining any appreciable amount of the variance compared with these three factors.

Further work carried out under item 3 has comprised a global study of surface pressure changes during the 11-year sunspot cycle. Monthly mean values of pressure for the months of January and July back to 1750 for a network of points covering the entire globe were used. For January several areas were found where the pressure difference between three years round the sunspot maximum and three years round the sunspot minimum was more than twice the standard deviation of pressure. The largest areas were mostly near 60°N, but the total area with these big pressure differences was not greater than would be expected by chance. So, although there are some correlations meriting further study, results so far do not support the hypothesis that the sunspot cycle affects surface pressure. For July results were similar, but the 'significant' areas were more widely scattered.

Some preliminary studies had suggested an interesting relation between geomagnetic activity and the circulation pattern over the north-east Atlantic and Norwegian Sea in winter. As a measure of the geomagnetic activity the daily index A_p was used. This is the daily mean of the 3-hourly range of disturbances of the earth's magnetic field made up from data from 10 to 20 observatories. For winter months with a mean $A_p \geqslant 17$ there is a markedly intensified gradient of surface pressure between the Azores and the Norwegian Sea; in view of this result and the lively interest in the possible effect of geomagnetic changes on the tropospheric circulation it was decided to carry out a systematic examination for all months of the year. The pressure difference between months with a high A_p index and those with a low A_p index was obtained for each grid point over the northern hemisphere. Results so far are inconclusive.

Considerable effort has also been devoted to obtaining long time-series of temperature and rainfall records and subjecting them to the modern types of power spectrum analysis in order to reveal periodicities in their amplitude and any variations from epoch to epoch. For annual means from Manley's central England series there are significant peaks in the spectrum at periods of just over 2 years, near 5 years, 7½ years, 12 years, 15 years, 23 years and between 80 and 100 years. These spectral peaks explain in all well over a third of the total variance but even so they are not of great assistance in understanding the temperature variability because their amplitude and phase do not remain constant. For example the 23-year period may perhaps be associated with the 'double sunspot cycle' because it has been mostly in phase with it, but it was nearly out of phase between 1700 and 1750 and its amplitude has been less than 0.05°C since 1930, when the amplitude of the sunspot cycle was becoming large and the length was near to 10 years. Spectral analysis of the Kew winter rainfall data shows significant power in the range 10–13 years since 1910. Filter analysis then reveals that the interval between peaks has decreased from about 12 years just after 1910 to 8–9 years latterly and there has been a small decrease in the amplitude.

A major program for extracting sea temperatures from a variety of sources, entering them on magnetic tape and applying quality controls was embarked on about three years ago. Some monthly means of these data for the tropical North Atlantic have recently been subjected to a mathematical analysis to separate the various time-scales. Besides the annual variation there is a long-term upward trend present in all months of the year. It is also apparent that there is a long-term relationship between the sea temperature trend and the surface pressure field in middle latitudes over the Atlantic such that the low sea temperatures are associated with the enhanced mid-latitude westerlies and the higher sea temperatures since about 1940 with weaker westerlies. It may be naïve perhaps to ask which is cause and which is effect but correlations for one area with the sea temperatures lagging behind the westerlies are larger than with the sea temperatures leading.

Extensive studies of the ocean–atmosphere interaction have also been carried out using a 5-layer GCM. One of the most rewarding areas for study has been that of the effects of sea-surface temperature anomalies on the pressure field. The most interesting result in the context of climatic variability is that which indicates a fall of surface pressure centred at latitudes 45–50°N when the model is run with an area of anomalously warm sea in the tropics. The magnitude of the fall is about 4 mb for a + 1 °C anomaly of tropical sea temperature. A fall of pressure at this latitude usually means a reduced westerly index so we have the same kind of relation as mentioned above, but now we can say that the sea temperature change is the cause, at least in the model atmosphere.

The same GCM has been used to examine the effect on the monsoon rainfall over West Africa of changes in the temperature of the tropical Atlantic. The results showed that a cooling of the sea led to a reduction of the rainfall over the western part of the critical Sahelian belt and an increase further east. The interpretation of this single experiment is difficult and further integrations with restrictions on the availability of soil moisture for evaporation are needed before any firm conclusions relevant to Sahelian droughts can be drawn. There were marked changes in the surface pressure pattern over the North Atlantic accompanying one cold sea occurrence. These had some similarity to those actually observed to be dominant during dry years in the Sahel. Another study revealed significantly different pressure patterns in the eastern North Atlantic and western Europe in the months of April and May preceding the dry and wet summers in the Sahel. Despite a number of studies in the United Kingdom and elsewhere it still remains uncertain to what extent the severity of the recent drought in the Sahelian zone is due to a change in the general circulation. It cannot simply be ascribed to a southward shift of the climatic zones because the shift in the subtropical high pressure belt and the westerlies appears to have been northwards over the last few decades.

In speculations about the mechanism whereby radiation changes associated with changes in the number of sunspots may cause climatic changes the role of stratospheric ozone is often mentioned. Its concentration could be altered by the variations in ultra-violet radiation and this might produce temperature or circulation changes in the troposphere. Work was carried out in the Meteorological Office to assess the effects on the ozone concentration of the additional gases injected into the stratosphere by fleets of supersonic aircraft flying in the stratosphere. During this study a 13-level 3-dimensional numerical model was developed in the Meteorological Office in connection with a special research program to investigate the consequences of man-made pollution on the environment. In one series of experiments the effects of a 50 per cent reduction in the concentration of ozone in the stratosphere were studied. This produced cooling of over 10 °C over large areas in the stratosphere but no significant temperature changes were produced in the lower troposphere.

The same model was used to examine the effect of a stratospheric dust layer capable of absorbing solar radiation but not scattering it. Considerable warming was obtained in the stratosphere but there were no discernible changes of temperature at ground level. These changes resemble the effects observed in the months following the eruption of Mt Agung in Bali in 1963.

The Meteorological Office 5-layer model has been used to study the effects of changes in the amount of cirrus cloud. An increase of this by 20 per cent did not show any effects on the model's climatology beyond its natural variability and no firm conclusions are possible about the cloud feedback.

The model has also been used to simulate the effects of changes in solar radiation produced by changes in the earth's orbit and axial inclination. Conditions appropriate to 8000 BC were found to give a northern hemisphere summer some 5 °C warmer than at present, but because the simulation extended over only two months and did not represent interaction with the oceans at all realistically, this result must be interpreted with great caution.

Conclusions

Recent research work has not given final answers to any of the outstanding problems of climatic variation, but it has produced a more precise appreciation of the position and perhaps set some generally agreed limits to speculation.

As far as variability over the last 100 years is concerned it is clear that changes in dust and carbon dioxide amplified by the two main positive feedback effects (the effects of ice and water vapour on radiation) could have produced the main temperature changes without the need for any extraterrestrial effects. However, this has not yet been demonstrated conclusively, and the reservation needs to be made that changes in the heat transfer between oceans and atmosphere due to circulation changes could have produced comparable temperature changes. Some of this variability could be periodic and yet not forced by the various periodicities shown by sunspot activity, so statistical studies may continue to be required.

However, it seems that definitive answers to the main questions will have to be obtained from comprehensive numerical models which include interactions beween atmosphere and oceans and simulate some of the oceanic motion and heat changes as well. At present the changes on a time-scale of decades lie within the inherent variability of GCMs. Moreover while these models can compare the equilibrium temperatures, say, for two sets of conditions they cannot be run over several decades of model time to show what happens during the transition period. Statistical–dynamical models in which the transport properties of the cyclones and long waves are parametrized will enable simulation over such times to be performed and may have an important role to play in future research. Much detailed work involving comparison of results from GCMs with observational data will be required to achieve a satisfactory parametrization. Improved time-series of relevant factors such as atmospheric turbidity, sea temperature and ice extent may be vital for checking the realism of the various numerical models which may be developed in the future.

Measurements of the solar constant from satellites to an accuracy of 0·1 per cent will help considerably towards an answer to the question to what extent variations of solar output occur and affect the earth/atmosphere/ocean system.

Physical Research

Cloud physics

The major effort of cloud physics research continues to be directed at improving our knowledge of the physical processes responsible for clouds and precipitation. Such processes are important on scales which vary from that of individual dust particles (less than 1 μm) to that of the organization of clouds and precipitation into bands and clusters of convective elements (10 to 100 km) within synoptic weather systems. Weather is often dominated by phenomena on this latter, so-called mesoscale, and adequate observations are important, both as a precursor to an improved understanding and to allow application of that understanding, in the production of better forecasts. Naturally many different techniques are necessary in a study of phenomena on such a large range of scales and often the required measurements are both costly and difficult to make or interpret. Nevertheless, there is no doubt that future progress depends upon an adequate quantitative description of atmospheric behaviour.

It is against this background that a very significant investment in the development of observational techniques has been made. This investment is now beginning to pay dividends. Thus the ability to measure and record the distribution of cloud droplet sizes, liquid water content, atmospheric temperature and humidity and the three components of air motion, from the Meteorological Research Flight C-130 aircraft, has been achieved. A package developed to measure similar quantities, together with net radiation and its divergence is being used, suspended from the cable of a large balloon, in the study of low stratiform cloud and fog. Co-operative research between the Chemical Defence Establishment, Porton Down and the Meteorological Office has led to the development of a tractable method of automatically analysing holograms of droplets and ice crystals. The installation of the hologram-forming pulsed laser and camera on the C-130 aircraft has begun and the automatic analyser is in use. The unique potential of this instrument in allowing observation of the position and size of droplets and crystals within a relatively large, almost cubic, volume of cloud offers one of the most exciting advances in the study of cloud microphysics in recent years.

Development of instruments and techniques to determine the atmospheric concentration of droplet and ice forming nuclei is continuing, and an increasing involvement in the related study of air pollution has demonstrated the need for high-quality observations of chemical composition. The capabilities of measuring the number concentration of sub-micrometre particles, the distribution of trace species and the absorption of the solar beam by aerosols are all either being developed or are beginning to be used.

For studies of the larger scale of cloud dynamics and structure, equipment capable of tracking up to five dropsondes at a time, through the use of the radio navigation aid, LORAN-C, is being installed on the C-130 aircraft. Transducers on each sonde provide data on temperature, humidity and pressure while the tracking data permit specification of the wind field beneath the aircraft. Within the large area, encompassing much of the United Kingdom and the North Atlantic, within which LORAN-C reception is adequate, the aircraft can undertake a sampling program independently of ground support. Thus experiments may be carried out in the frame of reference of weather systems rather than as dictated by fixed ground-based installations. The first 150 dropsondes are being produced for the study of active frontal systems in the North Atlantic during 1977.

Ground-based radar has become established as the primary tool for observing the mesoscale structure of precipitation and has been in use for many years by the Meteorological Research Unit at Malvern for basic research. A recently completed study in the Dee Weather Radar Project has confirmed the ability of radar to measure surface rainfall with a high degree of accuracy, even in the hilly parts of North Wales where the study was carried out. However, a factor that has limited the extent to which radar has been exploited operationally is the problem of processing and displaying the vast amount of information and of transmitting it in timely fashion and at reasonable cost to users remote from the radar site. Modern developments in digital components and techniques, particularly for data processing and transmission, have enabled the Royal Signals and Radar Establishment (RSRE) team working with Meteorological Office personnel at Malvern to design a system that overcomes these difficulties. The essence of this system is the use of a mini-computer at the radar site to 'clean' the data and to convert the pattern of radar echo intensity into rainfall intensity in a matrix of 2 or 5 km squares. The on-site data processing involves, among other things, signal integration, removal of echoes from ground targets (so-called ground clutter), corrections for partial screening of the radar beam by hills, corrections for attenuation, and calibration using telemetered rain-gauge data. The resulting matrix of rainfall intensity data is then transmitted by standard telephone lines to remote offices equipped with a special receiver which can store up to nine pictures for display on an ordinary colour television set.

The accuracy of measurement of surface rainfall decreases with distance from the radar and quantitative measurements are restricted to within about 100 km even for a well-sited radar. Thus, for operational and research purposes alike, it is necessary to use a network of radars. An advantage of the new rainfall display scheme is that the data from radars at several remote sites can be combined on the same display in virtually real time to give a clear unified presentation. An example of one such composite display is shown in Plate I, which shows a band of rain behind a cold front coming into Wales from the Irish Sea on 12 December 1975. Although work is still under way to improve the accuracy of the composited data, this figure nevertheless gives a good impression of the potential of this form of display, especially when it is realized that a sequence of such pictures can be replayed in time-lapse to give an indication of the movement and evolution of the rainfall pattern. The next step, to be embarked upon shortly, is the setting up of a small network of continuously operating radars. Over a period of years this will provide not only practical experience of how to optimize the accuracy and reliability of the overall system, but also a computer-archived body of data for research into the basic meteorology and climatology of mesoscale rain systems. This in turn will enable the data from a radar network to be interpreted more intelligently in an operational context.

Another part of the research program at Malvern involves the use of a high-power S-Band Doppler radar at the RSRE site at Defford. Because of its ability to detect echoes from the optically clear air (due to back-scatter from small scale inhomogenities in temperature and humidity), this radar has been used in the past for studies of clear-air turbulence and boundary layer mixing. Although the angular resolution of this radar is very good as a result of the large size of its aerial (25 m diameter), the 200 m range resolution employed until recently has been too low to enable more than the coarsest features of atmospheric turbulence to be resolved. Accordingly, during 1976 the Defford radar has been equipped with a pulse compression subsystem capable of improving the range resolution to 30 m.

Projects to determine the detailed spatial and time varying structure of convective elements, ranging from thermals within the atmospheric boundary layer to cumulonimbus clouds, are in progress, using the various techniques described above. The orographic enhancement of precipitation over the Welsh mountains is the subject of a current field study. It appears that major enhancement is closely associated with moist low level jets in or near the warm sector of depressions.

The other major field project being carried out is the continuing study of radiation fog using the tethered balloon facilities at Cardington. The complex interactions between, on the one hand, radiative cooling which induces fog formation and, on the other hand, turbulent diffusion and the gravitational settling of fog droplets, which inhibit it, have been shown in recent publications to be the major factors governing the life history of this type of fog. Parallel development of numerical models and improved instrumentation to monitor key variables is allowing more detailed study and expansion of the program to include the related problem of the physics of stratocumulus under anticyclonic conditions.

Laboratory studies of the ice multiplication process which occurs during riming at approximately —5 °C and of the electrification of simulated hail pellets during collison with other hydrometeors are in progress and nearing completion.

The atmospheric boundary layer

The boundary layer—roughly speaking, the lowest kilometre of the atmosphere—is important not only because it provides the immediate environment for many human activities but also because it determines the transfers of heat, momentum and moisture from the earth's surface to the atmosphere above.

In the past, observations have been made mainly by instruments carried on towers or balloons. Some development work on such instruments, in particular on fast-response anemometers, has continued, but the newer techniques of radar and acoustic sounding are also now being exploited and developed. All three techniques were combined during an experiment near Malvern in June and July, intended to study the evolution of convective circulations in the boundary layer and the nature of the entrainment process at the top of the layer. In another experiment, at Cardington, measurements were made of the solar radiation absorbed by the air; it was confirmed that this direct heating is quite important in comparison with heating by eddy diffusion.

A good deal of work has been done in preparation for a major international experiment known as JASIN (Joint Air–Sea Interaction experiment), to be undertaken in 1978 in an area of the North Atlantic near Rockall. JASIN is intended to study the details of the upper layers of the ocean as well as the lower layers of the atmosphere and the interactions of both with the larger-scale motions of air and sea. The Meteorological Office unit at Porton has been co-ordinating the meteorological measurements to be made by all participants and is itself developing balloon-borne equipment to measure the vertical fluxes of heat, momentum and water vapour. These measurements will be extended upwards and over a wider area by aircraft, including one from the Meteorological Research Flight.

Work has continued on the analysis of the co-operative boundary layer experiments reported in previous years. Results from the 1973 experiments in America have been published. They show that by use of appropriate scaling factors many of the features of boundary layer behaviour can be represented by 'universal' curves. These results, together with developments in the theory of turbulence elsewhere, encourage the hope that useful numerical models of the boundary layer can now be constructed, and work on these lines has started. As a first stage a very much idealized model of airflow over a small hill has been made. The most surprising result so far is that the hill has no net effect on momentum transfer; the increased pressure force is balanced by a reduced viscous drag. Future work will replace some of the idealized assumptions of the model by more realistic representations of the atmosphere.

Work has continued on the United Kingdom co-ordinated effort on long-range transport of air pollution. This is associated with the Organization for Economic Co-operation and Development (OECD) major investigation into European sulphate pollution mentioned in previous reports. Significant sections of our work are being incorporated into the report of the OECD experiment. Further work is currently in progress on the character of both sulphate depositions and rainfall over Europe. Evidence suggests that in many areas a few days can contribute 30 per cent or more of the total annual sulphate deposition. This behaviour casts doubts on some of the statistical models used in other countries in the analysis of the relative importance of various sources of sulphate deposition.

High atmosphere

The role of satellites in extending the coverage of temperature and wind observations available to meteorologists, and the Office's participation in two international satellite projects (TIROS-N and METEOSAT) was described in a special article in last year's report. It will be recalled that the Office is developing an infra-red radiometer which will form part of a group of temperature-sounding instruments to be carried on the forthcoming TIROS-N series of polar-orbiting meteorological satellites, the first of which is due to be launched early in 1978. The Office's instrument, known as the Stratospheric Sounding Unit (SSU), will measure temperatures within the layer from 25 to 45 km using the pressure-modulation technique of selective chopping developed at Oxford University. The construction of instruments is now well advanced and good progress has been made during the year.

Tests on the development model SSU showed that it generally met the radiometric and spectroscopic performance requirements. The instrument was subjected to rigorous environmental tests in order to provide confidence that it will survive launching and operate correctly under the pressure and temperature conditions in orbit. The only really significant problems occurred during vibration testing; excessive resonances within the radiometer caused damage to two of the pressure modulator cells. However, following modifications, the test was successfully completed. Results from this test program were presented to the US authorities in Washington in July and it was agreed that the design of the SSU had been proved to be satisfactory. During October and November the development model was used to conduct preliminary compatibility tests with the spacecraft in the USA. These tests were principally intended to check the effect of sunlight on the SSU's operating temperature and to search for spurious interactions induced by rotating and oscillating mechanisms within the various instruments. The results showed that the SSU was effectively immune to interference from these sources. Assembly of the first flight unit has proceeded without major problems and it is due to be delivered to the USA in February 1977. Work on the second, third and fourth flight instruments is well under way and steps are being taken to procure SSUs for the remaining four TIROS-N spacecraft to be launched over the period up to about 1984.

Further and more detailed investigations of the radiometric performance of the SSU have revealed the causes of most of the minor deviations from expected behaviour noted during the initial testing. Stray response outside the nominal field-of-view proved a particularly difficult problem, both with respect to obtaining precise measurements and in achieving the desired performance. A better understanding of the spectroscopic performance has been obtained through further laboratory measurements of the transmission of a path of CO_2 and by extensions to our theoretical transmission calculations to take account of Doppler broadening. Dr Rodgers, of Oxford University (working as a vacation consultant) made a major contribution to this study. In order to obtain direct measurements of atmospheric transmission, a pressure modulator cell of the type used in the SSU was flown in March on a large balloon from Holloman Air Force Base, New Mexico. The flight was successful and the instrument apparently functioned correctly. However, because of an intermittent fault in the telemetry system, we had great difficulty in recovering useful data. Interpretation of these data has only just begun and is being conducted in conjunction with Oxford University who were responsible for much of the experiment.

Considerable effort has been put into planning the routine processing of TIROS-N data at Bracknell and to estimating the necessary resources, in terms of telecommunication lines, interface equipment and computing power.

The TIROS-N data, when available, will be used to prepare daily global charts of the stratosphere up to levels of 1 mb. In preparation for this, daily charts for the northern hemisphere at 50, 20 and 10 mb are already being produced, based on the limited number of radiosonde and rocketsonde observations now available. This requires critical examination of each observation and careful attention to the continuity between one chart and the next. In the last year some experience with satellite data has been gained by incorporating data from experiments on the NIMBUS series of satellites. The stratospheric charts have been used to study the dynamics and energetics of the stratosphere and also to look for possible interactions between stratosphere and troposphere.

Satellite-borne instruments such as the SSU do not directly measure quantities of meteorological interest, such as temperature; they measure the infra-red radiation ('radiance') from the atmosphere at selected wavelengths and fairly elaborate calculations are needed to estimate temperatures from sets of radiance observations. Radiance observations from existing satellite instruments are received at the ground station at Lasham (Hants) and have been used to study and improve various methods of calculating temperatures; in particular, new methods of allowing for the effects of cloud on the radiances have been developed. Temperatures derived from satellite observations are routinely distributed from the USA and these have been monitored by comparison with conventional (radiosonde) observations and with the stratospheric charts mentioned above. In earlier years the satellite data sometimes had rather large systematic errors, but there has been a considerable improvement recently. It has been shown that the satellite data, which are essentially uniform over the whole world, can be used to estimate the systematic differences which exist between the different types of radiosonde used in various parts of the world.

Fourteen SKUA rockets, measuring wind and temperature, were fired from the Hebrides range during January and February, mostly timed to coincide with over-passes by the NIMBUS-5 and NIMBUS-6 satellites. These satellites carry infra-red radiometers developed by Oxford University for temperature-sounding in the stratosphere and mesosphere. Direct comparisons of the radiances observed by these radiometers and the detailed temperature structure obtained from the rocketsonde are extremely valuable in checking the performance and long-term stability of the satellite instrumentation. Similar comparisons are planned for the Stratospheric Sounding Units from 1978 onwards. The campaign was technically very successful, proving the value of the modifications to SKUA introduced since the previous winter; wind profiles were obtained from all 14 firings and temperature profiles from 13. During a campaign in August when six SKUAS were fired, experiments were conducted with a less densely packed parachute to get the parachute to deploy more effectively above 75 km. Two twin payloads (i.e. sonde plus radar-reflective chaff for wind measurement at around 80 km) were flown and two further over-pass coincidences were obtained with NIMBUS-6. A flight test of a SKUA incorporating various modifications to increase the fall-speed of the spent motor case was made from Aberporth in November and proved completely successful.

Analysis of data from past SKYLARK rocket experiments to determine ozone and oxygen densities between 40 and 100 km from measurements of atmospheric attenuation of ultra-violet sunlight was completed. The ozone measurements show that, between 50 and 70 km, the concentration at sunset in April at 30°S was higher, by about 75 per cent, than at sunset in February at 66°N. The latter values were in turn higher than measurements made at the following sunrise, by about 50 per cent. At 50 km the three measurements were in close agreement. By careful analysis uncertainties in the deduced concentrations were reduced to $\pm$ 10 per cent below 70 km and to $\pm$ 20 per cent at the secondary ozone maximum at 85 km. Acceptable oxygen densities were also obtained. Work has begun on a new experiment to study the diurnal variation of ozone in the height range 40 to 80 km. This will culminate in four flights from the Hebrides using PETREL rockets, within a period of 18 hours, probably in 1978. Initially a pay-load for measurement of the night-time ozone profile, using the moon as a source of ultra-violet radiation, is being prepared.

The high-power dye laser installation at Bracknell has continued to be used for studies of stratospheric aerosol. Most of the measurements have been confined to 10–30 km, the back-scattering being observed successively at wavelengths of 605 and 465 nm during the course of a night by changing the dye solution. The stratosphere was remarkably clean; the aerosol scattering at 605 nm was generally less than 15 per cent of the Rayleigh scattering by air molecules. Various relatively minor technical modifications were introduced, aimed at improving the stability and accuracy of measurement of output energy. In analysing the data in terms of number density various assumptions have to be made about the microphysical properties (e.g. size distribution of particles and refractive index) of the stratospheric aerosol. Studies have been performed to assess the effects of these assumptions when the laser data are used to estimate the effects of the aerosol on heat transfer by radiation. Experiments have begun in using the laser to study back-scatter from clouds, especially cirrus, and it has proved possible to obtain acceptable echoes in daylight with the present system. The potential of such measurements for studying the radiative properties of clouds is being investigated.

The joint project with the National Physical Laboratory to develop a small broad-band balloon-borne radiometer to measure the concentration of water vapour or ozone in the stratosphere has made steady progress. No flights of the radiometer have yet taken place. Ground testing revealed that temperature control of the detector was inadequate, leading to unacceptably high noise levels. Various methods of overcoming this problem within the stringent weight limitations for the pay-load are being explored.

Routine Dobson ozone spectrophotometer work has been maintained. Following an initial problem, the instrument installed at Mahé (Seychelles) in November 1975 has functioned satisfactorily. Observations at Gan ceased when the station was closed in March. The instrument will be set up at St Helena, where its observations will help fill an important gap in the global ozone monitoring network.

There has been much discussion recently of the possible effects of halogen-containing compounds, particularly man-made ones, on the atmospheric ozone. A prototype instrument, a gas chromatograph with an electron-capture detector, has been constructed for the measurement of the concentration of the most important compounds, the halomethanes, and it is beginning to be used.

Meteosat

The joint European project to provide a geostationary meteorological satellite was described in some detail in last year's report. The satellite, to be launched in the autumn of 1977, will provide pictures of Africa, Europe and much of the Atlantic at visible and infra-red wavelengths every half hour. The Office has continued to provide support and guidance to the European Space Agency in the development of the satellite and, in particular, of the associated data-processing facilities. A Protocol governing the operation of these facilities during the lifetime of the satellite was signed by the Director-General on behalf of the United Kingdom in July. Arrangements are being made to use the station at Lasham for reception of some of the data from the satellite.

Meteorological Research Flight

The Meteorological Research Flight is based at Farnborough. It comprises two aircraft, a Hercules (C-130) and a Canberra and flying crews are provided by the Royal Air Force. The function of the Flight is to carry out meteorological observations for the purpose of atmospheric research. A large part of the program is aimed to provide the observations required by other research branches of the Office in the course of their studies of cloud physics, atmospheric turbulence etc. However, studies of some atmospheric phenomena are also carried out by scientists based at Farnborough as part of the establishment of the Flight. The Flight also carries out observations for other government departments and organizations from time to time.

The Hercules has been used extensively for the investigation of the turbulent transfer of heat momentum and water vapour in the boundary layer over the sea in a variety of meteorological conditions, priority being given to occasions of very strong wind.

During March and April the Hercules participated in a statistical investigation of the meteorological conditions producing clear-air turbulence. Although the survey was mainly conducted by civil airliners on routine flights, the Hercules was used to investigate areas near the United Kingdom away from regular flight tracks where turbulence was forecast to occur.

The Canberra continued the regular program of humidity measurements in the lower stratosphere until July, when the aircraft was grounded for its regular 'major' servicing. A survey of the measurements made fairly regularly over the last five years and comparison with measurements made by MRF some 20 years ago suggests that there have been some fairly large long-term fluctuations in water vapour in the stratosphere.

The Canberra also made three successful flights with a sub-millimetric interferometer designed by the National Physical Laboratory (NPL) to measure the long-wave infra-red radiation emitted by trace gases such as water vapour, ozone and oxides of nitrogen. The installation of this instrument has taken almost three years' effort by MRF and NPL. Good low-resolution spectra were obtained on the three flights at levels up to 14 km ($\approx$ 46 000 ft) and the data are now being analysed.

A good deal of effort has gone into maintaining and improving the instrumentation of both aircraft. Improvements have been made to the data recording system of the Hercules, and upward- and downward-looking radiometers have been installed for the study of radiation in the atmosphere. As noted in the cloud physics section, a holographic device for recording cloud droplets is being installed, and preparations are in hand for operating a dropsonde system from the aircraft. This has involved several ground and air tests of the ejection of sondes from the aircraft. Some modifications to the mechanism were needed to ensure that the sondes cleared the aircraft tail-plane with a satisfactory margin.

In 1974 the MRF Hercules took part in the major international experiment known as GATE (the Atlantic Tropical Experiment of the Global Atmospheric Research Program). The Hercules flew 40 sorties, totalling 360 flying hours, to gather data on the boundary layer over the tropical ocean. Altogether about a thousand million measurements were recorded, and for the past two years the MRF has acted as a National Processing Centre for these data. After processing, validated basic and derived data are recorded on magnetic tape and dispatched to five GATE Sub-program Data Centres and two World Data Centres; for each flight three data sets are prepared—a high frequency set, in which the three components of wind, temperature and specific humidity are included at 20 samples per second, and 1-second mean and 1-minute mean sets. About 85 per cent of the processing is now complete.

All National Processing Centres were required to 'validate' their data, namely to check for, and correct if possible, poor data as assessed from either an instrumental or meteorological standpoint. A good method of detecting instrumental faults in MRF data was essential since at the start of the project the C-130 aircraft and its instruments had only been available for flight testing for six weeks. To perform the validation 35 mm film plots were obtained of time-series of 34 basic and derived parameters at frequencies of 2 and 20 samples/second, and the 1000 plots so obtained for each flight were examined by eye. Results of the validation were included in a 40-page booklet dispatched with each flight.

The full processing procedure also had to allow for corrections to be made to data for periods where flight records or validation checks showed poor data. The full procedure was thus as follows. Firstly the MRF PDP8/I computer was used to transcribe the airborne tape into a format suitable for processing on the ICL 1904A computer at RAE; the PDP8/I was also used to compute various correction factors and instrumental drifts, and analogue output obtained at this stage also enabled gross instrumental faults to be detected. The second stage of the processing, on the 1904A, included quality control and calibration of the data, application of drifts and corrections derived on the PDP8/I, and production of 'plotting tapes' of data at 2 samples/second from which the 35 mm film was obtained. This stage of the processing—performed primarily for validation purposes—took 8 hours of computer time per flight. The next stage of processing, also performed on the 1904A, was the production of the main data set at 20 samples/second. All the numerical operations performed on the '2 samples/second pass' were repeated, but with revised and additional corrections where the validation had shown these to be necessary; 35 mm film plots of data at 20 samples/second were obtained for the five key parameters to assess (amongst other things) if any noise at frequencies greater than 0·5 Hz was present. This stage of processing took 36 hours (elapsed time) for each flight. The fourth and final stage of the processing was carried out on the IBM 360/195 at Bracknell. Here the data were taken from the ICL tapes and put into the special GATE format and the three data sets were produced with added tape headers describing various features of the sets including, for example, instrument performance and validation results. Multiple copies of all the sets were then produced for dispatch to the seven Data Centres.

Details of the task undertaken by the National Processing Centre at MRF, and maps of the wind, temperature and humidity fields for every flight (superimposed on radar data) are being presented in a Meteorological Office *Geophysical Memoir.*

Geophysical fluid dynamics

The high degree of complexity of the atmosphere. tends to obscure the fundamental factors which control large-scale atmospheric motions. The main work of the Geophysical Fluid Dynamics Laboratory is intended to explore basic dynamical processes in rapidly rotating fluids, of which the atmosphere is but one example. Other natural fluid systems in which rotation plays a dominant role are to be found in the atmospheres of the planets, in the oceans, and in the liquid core of the earth, where the earth's magnetism originates.

The studies are carried out using a variety of methods, including the detailed examination of motions in rotating fluids in the laboratory, theoretical mathematical investigations and numerical work using high-speed electronic computers. The laboratory systems provide valuable and stringent tests of mathematical theory and suggest new lines of theoretical research. In the laboratory the experimental conditions can be varied over a wide range and theories thereby tested in a manner which is not possible if they are applied only to the atmosphere. We cannot change the rate of rotation of the earth to see if a theory continues to apply, but we can change the rate of rotation of the fluid container in the laboratory.

Many features of the large-scale atmospheric circulation can be reproduced in liquid filling a rotating annulus, the inner and outer walls of which are maintained at different temperatures. The transfer of heat by the fluid between these walls simulates the transport of heat from the equatorial regions towards the poles by the wind systems. The laboratory studies show that several different regimes are possible. The flow may be axisymmetric, it may contain a 'jet stream' with wave-like perturbations or it may be highly irregular. Experimental and theoretical studies have established the conditions under which such regimes are to be expected. One phenomenon of special interest is known as 'vacillation'. In it a system of wave-like disturbances in the flow undergo a very regular cycle of changes in which their amplitude increases and decreases and their form changes. There are certain similarities with some much less regular cycles which take place in the atmospheric circulation. The changes which take place in the laboratory fluid during vacillation have been examined by temperature probes placed in the fluid and interpreted in terms of basic theoretical ideas concerning non-linear interactions between various wave-modes.

Other investigations carried out during 1976 include studies of (a) various topographic effects, including the combined influence of rotation and density stratification on topographic drag, (b) the effect of the (simulated) variation of Coriolis parameter with latitude on the scale and other properties of baroclinic waves, (c) the structure and stability of Kelvin waves in a deep rotating fluid, (d) the conditions under which flow fields in rotating fluids possess the important property of helicity, and (e) the structure and stability of the thermocline in a rotating fluid subject to heating and cooling at the same level.

Dynamical and Synoptic Research

Research related to short-period weather forecasting

The present operational numerical forecasts are computed on the basis of representations of the wind, temperature, humidity and pressure at 10 levels in the atmosphere. Although the atmosphere is a continuous fluid, it is represented in these computations by values at regular arrays of points. Two such arrays are used; one with the points 300 km apart covers the northern hemisphere down to 15°N and the other, with the points 100 km apart, covers a more limited area centred on the British Isles in greater detail. Though a considerable degree of success has been achieved, errors can arise from many causes. Research has continued with a view both to improving the current operational system and to introducing more accurate methods in the future.

Many experiments have now been made in which the horizontal grid length of the larger area was halved—hence calculations were needed at four times the number of grid points. The effect on ensuing forecasts proved smaller than had been expected; on only about one occasion in four were results noticeably better. Similar experiments were carried out in which the number and vertical spacing of levels were varied. It was found that forecast errors near the tropopause could be reduced by adding more levels in that region, but improved resolution in the lower atmosphere did not appear to be helpful. However, the initial data on which these forecasts were based were interpolated from the coarser operational values, and these results may need to be reassessed when more detailed initial values can be obtained.

Another modification has been to extend the area of the computations down to the equator, and comparative integrations suggest that there are some benefits to be gained by so doing, particularly in the handling of systems which move north from low latitudes.

The causes of different types of error are being examined using integrations derived from a version of the 10-level model in which it is possible to suppress particular physical processes. Integrations have been made using both real and artificial initial data. This work includes a co-operative experiment with the Department of Geophysics of the University of Reading, the purpose of which is to compare the treatment of simple flows by different types of numerical model.

Methods of representing the atmosphere's physical processes in the current operational forecast system have continued to be developed. A procedure to incorporate atmospheric radiation more fully, particularly as affected by predicted cloud amounts, has been devised. It is found that errors in forecast upper-air temperatures are greatly reduced by this procedure, though as a drawback, the mean level of predicted surface pressure tends to be too high. Attempts are also being made to improve forecasts of rainfall amounts by allowing for the vertical motions induced by local orographic features, and by changes in the formulation of the cloud and rain-producing processes.

There is reason to believe that errors in initial data constitute one of the most frequent sources of forecast error. Two techniques are being explored in an attempt to improve the accuracy and consistency of the initial fields. The first involves the absorption of additional observations made at times between the standard 0000 and 1200 GMT reports used at present for analysis purposes. These additional reports are assimilated directly into the numerical forecast. A fair measure of success has been achieved in incorporating observations of pressure and geopotential, but wind observations present problems since the resulting imbalance between the wind and mass fields generates unrealistic wave motions in the ensuing forecast. Ways of circumventing this are being sought.

The second technique, which may later be used in conjunction with the first, is dynamic initialization, whereby the mass and wind fields are made to adjust each other in accordance with the formulation of the forecast model before the integration commences. A procedure applicable to the 10-level model is now working, though as it involves stepping both forward and backward in time, the irreversible physical processes have to be omitted altogether. Results as compared with the operational diagnostic initialization procedure are not so far very different except near mountain areas, but further experiments are being made.

Although the computed forecasts do not directly predict all weather elements, they do contain material which can provide forecasters with useful information in addition to the standard surface and upper-air charts. A broad program of work is under way which will aim at giving an interpretation of numerical output in terms of weather. The production of worded forecasts direct from the computer has been continued and copies have been distributed internally for a trial period to assess their potential usefulness. A serious limitation at present is the difficulty of predicting certain phenomena such as fog by current numerical techniques. Further studies in the interpretation of computed forecasts are being made with a view to predicting occasions of heavy rain.

Development work has continued on a numerical model formulated with a view to studying atmospheric features whose scale is not large enough for them to be handled successfully by general predictive models. One version which omits processes involving water vapour has been used to attempt to reproduce the diurnal variation of weather elements during a typical anticyclonic summer situation over the United Kingdom. Following experimental adjustment of the surface exchange processes and of lateral boundary assumptions, a 24-hour integration has been carried out which simulates quite realistically the development of sea-breezes. In parallel, experiments with a more complete version of the model incorporating the condensation and evaporation processes have continued. Preliminary integrations intended to reproduce the development of a cumulus cloud have led to some problems which are being explored. Further experiments are in hand to study the small-scale effects of orography, and it is intended later to use the model in studies of frontal structure.

Research work during the year has brought to light new mathematical and computational problems. The partial differential equations occurring in numerical prediction can be converted into a set of simultaneous equations by the application of finite differences, and solutions have hitherto been found by iterative procedures yielding successively closer values to the true solutions. There are frequently uncertainties in the rapidity with which such solutions converge, and recent developments in mathematical techniques have shown that direct methods of solving these equations, as well as producing more exact solutions, may be quicker. Experimental work in this field is proceeding.

The first steps have also been taken to investigate the impact which the next generation of computers will have on computational techniques. Such computers are expected to process groups of numbers rather than individual numbers and an assessment is being made of methods of realizing their full potential in numerical prediction. It is likely that the methods of incorporating physical processes in the integration procedures will need much further thought and experimentation.

General circulation of the atmosphere

The term 'general circulation' is usually taken to refer to the complete three-dimensional flow of the global atmosphere, and more particularly those aspects that are its essential response to external factors such as the latitudinal distribution of solar heating or the distribution of land, sea and mountains over the earth's surface. The fundamental physical and dynamical laws governing the behaviour of the atmosphere are, for the most part, well known. They can be expressed mathematically and the resulting equations can be solved in a computer. In this way it is possible to attempt to simulate the atmosphere numerically. General circulation models for this purpose have been developed over a number of years and are now one of the most powerful tools available for investigating a large variety of important problems which may be of concern not only scientifically, but in the wider context of the human environment. For example they have applications in examining atmospheric predictability on both a theoretical and practical basis, and in increasing the range to which useful forecasts can be made; in investigating the interaction of the atmosphere with the oceans and other features of the earth's surface which may help to explain prolonged abnormalities of the general circulation; in exploring causes for changes in climate known to have occurred in the past; in assessing the impact of natural or man-made pollution on climate; in determining what observations are needed to delineate the motions and structure of the global atmosphere adequately and most economically and so on. The Meteorological Office general circulation models have already been used in all these fields of enquiry. At the same time substantial efforts have been made to improve the quality of the models' simulations so that greater reliance can be placed on their results, and the formulations have been altered to extend the range of problems to which they can be applied.

One of the most important practical fields in which the models have been used is in trying to assess the possibility of predicting atmospheric developments on time-scales of a month or more. The problems involved are of great difficulty and it would be foolhardy to expect practical solutions to emerge quickly. On the one hand we have the knowledge gained by examining the evolution of the model from two initial states differing by no more than the uncertainty of the observations of wind, pressure and temperature, that it is impossible ever to forecast moving cyclones and anticyclones beyond a period of, at most, two to three weeks. On the other hand we have the observed fact that many of the unusual atmospheric states, such as that which gave rise to the drought in the United Kingdom during 1975 and 1976, are relatively very persistent and able to survive the effects of individual depressions or series of depressions. To simulate effects of this kind numerically will undoubtedly involve very complex models taking into account all the variables in the most realistic way possible. Nevertheless existing models are capable of reproducing some features which give cause for hoping that they may eventually prove capable of dealing with such persistent effects. For example, predictions over periods of 30–50 days appear to indicate that, at least on occasions, general circulation models have a measure of predictive skill in positioning the long wave features of the upper circulation when the average is taken over periods of 5 to 10 days. That is, although the individual cyclones and anticyclones cannot be predicted beyond a few days, larger-scale features may be correctly indicated. This is a topic that is evidently of the most pressing practical importance. It is, however, a difficult one to pursue since obtaining a sample of forecasts large enough to reach statistically significant results requires a major effort and a large amount of computer time. The problem is being pursued with vigour, however, and indeed it is the intention to expand efforts in this direction during the coming year.

The problem of predictability over extended periods is linked to that of determining how the atmosphere is affected by persistent anomalous conditions at the earth's surface. The Meteorological Office models have already been used in a series of experiments to determine the effect on the atmosphere of sea-surface temperature anomalies, and it has been demonstrated for example that anomalies in the tropical oceans have effects not only within the tropics themselves but at much higher latitudes. More recent experiments continuing this line of investigation have included an attempt to assess the importance of unusually warm water in the tropical Pacific Ocean which produced significant local weather anomalies during the summer of 1972 and may have been responsible for more widespread effects. The model simulations successfully reproduced the effects in the tropics, and also suggested significant changes in middle latitudes of both the northern and southern hemispheres. A comparison of these results with what was observed in the atmosphere is still being carried out.

The models which have been used up to the present have assumed that the sea surface temperatures were known and that they did not vary during a simulation. This is clearly a severe restriction since the oceans react to the atmosphere motions, albeit on a relatively long time-scale. For attempts to look at the atmospheric circulation over periods beyond a month or so, it is essential to bring in the interaction with the oceans more realistically. Models which treat the ocean and the atmosphere jointly have been created at one or two research centres, but the problems associated with them are much greater than with an atmosphere-only model and many unsolved problems remain. Within the Meteorological Office the problem has been approached by using a very simple ocean model which represents the top of the ocean only and assumes that all the meteorological interaction affects this rather shallow layer. This should enable experiments to be run over a longer time-scale than is at present possible, but it leaves aside for the moment the interaction of the atmosphere with the deeper ocean which is one of the major factors in the general problem of climatic change. At the present time the simple ocean mixed layer model is being inserted into the general circulation model and experiments with it are expected to begin in the near future.

The specification of the optimum observing system for the global atmosphere, is a problem of great practical importance particularly in view of the coming global experiment (the First GARP Global Experiment) due to take place in 1978–79 with a run-up period beginning in 1977. The objective of the experiment is to define the atmosphere on a global scale with sufficient provision to allow the development and testing of improved forecasting models. The resources that will be available are becoming increasingly well defined, and the problem of how best to deploy them is therefore increasingly urgent. The Meteorological Office general circulation models have been used to help towards a solution. The method is to use one model (with 11 layers and a horizontal grid-length of 220 km) to create 'observations' which are then used as input to a second model (with 5 layers and a horizontal grid-length of 330 km) which uses them in a manner similar to a forecasting model using real observations. Making allowance for the known errors of different kinds of observations it has been possible to make estimates of the likely errors in the analyses to be expected from various possible observing systems. During the current year there was particular interest in selecting the best distribution of floating buoys which are intended to be deployed in the oceans of the southern hemisphere. Results of experiments carried out in the Meteorological Office were given to the relevant international committees which are charged with setting up the experiment. In carrying out the investigation new techniques were developed for dealing with a variety of observational platforms; these included satellites, constant level balloons, floating buoys as well as the more usual types of meteorological observing system. The method of analysis has been designed to cope with observations of varying characteristics and accuracies. In this sense it is likely to be the forerunner of similar systems that will be necessary on a routine basis as these newer observational platforms become more generally used.

Following significant results obtained with the general circulation model on the effect of inserting large amounts of waste from power stations into the atmosphere, discussions were held with scientists at the International Institute for Applied Systems Analysis at Laxenburg, Vienna on further experiments which could be carried out to explore the impact of such man-made pollution on the global atmosphere. As a result, a version of one of the Meteorological Office models is being used in a further three experiments being run on a computer at the Kernforschungszentrum in the German Federal Republic. Results from the first have already been examined and appear to show that predictions made from the first two experiments have been, in general, borne out.

The practice of testing general circulation models in forecasting experiments involving integrations of up to 15 days from real atmospheric situations has continued. Integrations were made, in particular, from a series of initial states agreed internationally so that the performance of models from a number of countries could be compared. The results of the forecasts by the Meteorological Office general circulation models were on the whole well up to the standard that is generally achieved by models developed specifically for routine forecasting, and this has led to a program to evaluate the potential of the models for routine forecasting in direct comparison with models regularly used for this purpose. The comparisons using internationally agreed initial situations included testing models based on the 'finite element' rather than on the more usual 'finite difference' approach to representing the basic equations in numerical form. The results indicated that the overall standard achieved was about the same as that of the more conventional method though, because a lower resolution was used, small-scale features of the atmospheric field were less well forecast.

There has also been a continuing effort to improve the methods of including the effects of small-scale convection and of the surface exchange of heat, water vapour and momentum. These processes are effected in the real atmosphere by turbulence whose scale is too small to be represented explicitly in models attempting to simulate the large-scale features of the global atmosphere. They have therefore to be accounted for by 'parametrization'—that is, by expressing them statistically in terms of the variables that are actually available. This part of the research is heavily dependent on observational experiments which attempt to find out how the quantities are related to the large-scale atmospheric motion in practice. During the last few years, a large amount of new material has accumulated from important new experiments, notably from the GARP Atlantic Tropical Experiment, which can form the basis of improved parametrizations. Extensive studies have been carried out on how these can be incorporated into the existing structure of the general circulation models.

Estimates of the heat transferred to and from the 1000–500 mb layer have been derived daily from the operational 10-level analyses, by subtracting from the observed temperature changes those due to horizontal and vertical air motion. The aims of the study are to identify the geographical regions of major heat exchange and the associated effects upon the thermal gradients and also to observe their evolution with time. Two four-month periods have been studied covering the winter 1975–76 and summer 1976. The analysis confirms that most of the heat exchanges are serving to destroy the horizontal thermal gradients.

A study of 'blocking' in the northern hemisphere has been started. Blocking is the name given to the occasional interruption of the normal eastward motion of depressions and ridges by a persistent anticyclone. The first aim of the study is to obtain consistent and reliable descriptive statistics of the phenomenon, which can be used to look for possible long-term changes, relationships with the sunspot cycle etc. The second aim is to study the dynamics of the onset, maintenance and decay of blocking. This has been begun by looking at the 500 mb flow associated with blocking near the British Isles; the blocks seem to be associated with changes of flow over much of the hemisphere and generally to evolve in a westward direction over a period of about 30 days.

Stratospheric modelling

Following the completion of the report of the studies conducted from 1972–75 by the Committee on Meteorological Effects of Stratospheric Aircraft (COMESA) relating to the possible perturbations that might be caused by the operation of large numbers of aircraft, particularly supersonic transports, a more limited stratospheric research program has continued. Apart from the requirement to improve basic understanding, this is necessary for studies of the effects of other possible pollutants such as chlorofluorocarbons and nitrous oxide which are released into the lower atmosphere by human activities and drift upwards into the stratosphere. Problems of this type are being examined in conjunction with a national research program co-ordinated by the Central Unit on Environmental Pollution and also a Tripartite Agreement on co-operation in stratospheric studies and monitoring made with the USA and France in May 1976.

The principal lines of research at present in progress comprise the further development of a comprehensive two-dimensional model of stratospheric composition as determined by its photochemical and transport mechanisms and detailed studies of the previous outputs of integrations with the large COMESA three-dimensional model. These later studies include the investigation of the nature of troposphere–stratosphere interactions and the processes leading to stratospheric 'sudden warmings' and also the derivation of parametrized atmospheric transports for use in the two-dimensional model studies. In addition to its potential for basic investigations of the natural stratosphere it is expected that the two-dimensional model will ultimately be developed into a useful means of studying problems in the stratospheric pollution field.

Tropical meteorology

An understanding of the tropical atmosphere is fundamental to an understanding of the atmospheric circulation as a whole, since it is in the tropics that the bulk of the solar radiation which drives the air motions is received. Recognizing this, and recognizing also that many aspects of tropical meteorology are still imperfectly understood, the GARP Tropical Atlantic Experiment was organized internationally and carried out off the coast of West Africa in the late summer of 1974. A vast amount of data was obtained, and since the experiment it has been being gathered together at special collection centres so that it can be distributed to interested scientists in an acceptable form. The centre for the larger-scale synoptic observations has been located within the Meteorological Office and during 1976 the processes of collecting data from many countries and of carrying out checks for compatibility and accuracy have been proceeding. The aim is to provide, on an international basis, data sets which can be used to achieve the objectives of the experiment—primarily an understanding of the tropical motions and their interaction with middle latitudes—without the need for individual monitoring of the observations. The task of the Synoptic Scale Data Centre is now well advanced and despite some lag in the schedules due to late arrival of data from some countries and unexpected problems in the processing of wind observations made using a navigational aid system, the data sets from the centre should be completed in the next year and available in the World Data Centres at Washington and Moscow more or less on time.

The data collected during GATE have already been extensively used, particularly in developing parametrization of convective transfers of heat and moisture vertically through the atmosphere and in studying how cloud amount and type (which determine to a large extent the interaction of radiation with the atmosphere) are related to relative humidity, vertical motion and the intensity of convective activity. It is of particular value in pursuing these investigations to be able to use a tropical weather forecasting model which was originally developed for running during GATE in near-real time. In combination with the observations made during the experiment it provides a method of assessing the adequacy of parametrizations. For example, the model predicts rainfall, which in the tropics is primarily of convective origin. Since the rainfall represents an amount of latent heat that is released into the atmosphere, it is important that any parametrization of convection should achieve approximately the correct value, and this can be tested in a simulated forecast integration.

In order to provide data sets which present the atmospheric situations as values on a regular grid of points rather than at the places where observations were made, it is intended to rerun the forecast made during GATE for a number of selected days, using the best possible parametrizations and analysis methods. Improvement of the analysis method which incorporates statistical information on the probable structure of the tropical atmosphere has also been continuing and has been making use of the observations available from GATE.

Research related to long-range forecasting

The issue of 30-day forecasts covering each calendar month and each mid month–mid month period has continued throughout the year. The forecasts are made available to the Press, radio and television and interest in them has been maintained at a high level: indeed staff from the long-range forecasting branch have taken part in some 17 radio or television programs either live or recorded during the year. A more detailed document giving not only the 30-day forecast, but also climatological statistics which help in its interpretation, is posted regularly to a large number of customers who pay a very small fee for this service. Despite unusual weather, success rate of the forecasts remains about the same as in previous years, some 75 per cent having at least moderate agreement with events as assessed *ex post facto* by an independent panel of experts. There were a few failures in 1976 but also some notable successes. Two forecasts predicted the correct category of temperature (out of 5) in all 10 districts of the British Isles and in another case the rainfall category was correctly forecast in 9 of the 10 districts and was only marginally awry in the tenth. During the drought advice on expected future rainfall was regularly given to the National Water Council and also to the regular meetings of the Regional Water Co-ordinators convened by the Department of the Environment.

Thirty-day forecasts do not attempt to forecast the day-to-day weather but try to indicate the overall monthly mean temperature as one of 5 equally probable categories and the total rainfall as one of 3 similar categories. In addition techniques have been developed which enable the broad sequence of weather events to be deduced on some occasions. In winter, forecasts indicate the probable frequency of frost, fog, snow and gales in relation to 1941–70 averages: in summer, information on probable sunshine totals and the frequency of thunderstorms is included. Although it is planned to set up early in 1977 a small research group to study the possibility of using dynamical methods to forecast on a monthly time-scale, almost all long-range forecasting research in 1976 was of a statistical nature. The techniques of principal component (eigenvector) analysis whereby a particular chart can be closely represented by seven independent patterns each multiplied by a coefficient and a summation carried out over the seven patterns, has been greatly exploited in 1976. The prediction of half-month 500 mb anomalies over about a third of the northern hemisphere using this technique and multiple linear regression methods has become a routine contribution to the twice-monthly long-range forecast discussions. The technique makes use of relationships between the principal components of the 500 mb anomaly field in a particular half-month and the principal components in earlier half-months up to a year back. Most of the predictive information (75 per cent) is available at least two months before the predicted half-month. Verification on independent data comprising some 40 forecasts in 1975/76 indicates some success but, less gratifyingly, there is a region of minimum success centred over Biscay and embracing the United Kingdom. Work has started on extending the area to cover most of the northern hemisphere to see if the East Asia–Pacific sector, currently omitted, has a significant effect upon anomalies in the Atlantic–European sector.

Progress has been made in an attempt to predict the sequence of pentad (5 day) 500 mb anomalies (usually 6–9 pentads) over a limited domain of the northern hemisphere. This technique is based on a timewise principal component analysis (time unit one pentad) of the spatial principal components of the 500 mb anomaly field. The analysis revealed that only seven timewise components are generally required to account for 90 per cent of the variance in the anomaly field on a pentad scale during a two-month period. The technique aims to identify the most significant timewise components during the first 3–5 pentads of a two-month period. Tests on the method during 1975–76 reveal substantial areas of success.

Principal component analysis is also being used for the objective selection of analogues at 500 mb. The coefficients of the top ten components for each of the four most recent half-months are matched with historical data and a ranking list is prepared from the sum of the squares of the differences of the matching process. The aim is to see if analogue matching over the most recent period can produce superior predictions of 500 mb anomalies to the regression technique for two successive half-month periods. Preliminary results suggest that predictions are marginally better than regression for the first half-month but markedly inferior for the second half-month. Regression relationships have also been derived between the 500 mb principal components and monthly temperature and rainfall anomalies over the United Kingdom. Synchronous as well as lag relationships have been derived which appear to be highly significant at various times of the year.

Another area in which some progress has been made in 1976 is in the study of the effects of sea surface temperature (SST) anomalies in the tropical Atlantic on atmospheric circulation. Using Meteorological Office data for 1949–69 and earlier data for 1906–38 published by Bullig, the suggestion from earlier numerical experiments that a warm tropical Atlantic was related to negative anomalies of pressure around 45°N to the north of the SST anomaly has been tested. It has been found that synchronous and lead correlations exist between some of the principal components of the monthly mean sea level pressure anomalies, and SST anomalies in the tropical Atlantic near the Cape Verde islands. Warmer than usual seas in this area appear to be associated with lower than usual pressures near 45°N 30°W, especially in winter. These relationships are being optimized for use as an additional tool for monthly forecasting. As a corollary it has been noted that there has been a long-term rising trend in sea temperature in the tropical Atlantic. Since warmer ocean appears to be related to more blocked atmospheric circulation in the Atlantic sector, this relationship is consistent with the more blocked mean-sea-level pressure patterns noted in 1951–66 compared to the period 1900–39.

The method of monthly forecasting which operates by finding areas in the northern hemisphere where pressure (or 500 mb height) is significantly different in the month preceding a warm month compared to a month preceding a cold month, has been refined. The new methods eliminate some of the spurious significant points by selecting only those which are meteorologically meaningful. Once the significant areas have been defined it is a simple matter to evaluate anomalies in the current month and test objectively whether they are similar to those which precede warm or cold months.

Study of the evolution in time of 15- and 30-day mean flow patterns at 500 mb has been made and shows that the usual dynamical principles apply to time-meaned long waves. There are in general slow variations in the position of the long waves, with increase of wavelength when the flow is stronger, but there are rapid readjustments of wavelengths and repositioning of trough and ridges when the flow becomes weak. The time evolution of the surface and 500 mb fields has been modelled in terms of normalized indices of westerly and southerly flow and vorticity, and these have then been represented in terms of a few fundamental dynamical patterns which are effective in all seasons of the year. The evolution in a given year can be matched objectively with that in all previous years, and the best analogues chosen. A useful degree of success in seasonal forecasting can be achieved by using the best analogues for the evolution of the westerly flow during the previous season to predict temperature, and the best analogues for the evolution of the cyclonicity to predict rainfall.

A study is being made of the teleconnections between the Atlantic–Europe area and other regions, with special relation to events like the Southern Oscillation, the Nile Flood and the Indian Monsoon which link the hemispheres or distinguish between Pacific and Atlantic sectors.

Statistical methods of research into long-range forecasting problems require enormous amounts of past data to enable possible relationships to be explored. The marine data set containing some 32 million observations which was received from US sources last year is now being processed systematically. Parts of these data have been used for research purposes already and much sorting and quality control is under way in preparation for a major attempt to produce monthly mean sea temperature anomaly maps back to the middle of last century for as much of the world's oceans as possible. Data for the 500 mb level for 1968–76 for the southern hemisphere south of 15°S were purchased from Australia and have been successfully incorporated into our data bank.

Another advance has been the computation of 500 mb, and 1000–500 mb thickness charts for the period 1891–1944 when no upper-air data were available. These 'deduced' charts have been prepared from the grid-point monthly mean surface temperature data purchased last year from the USSR and our own pressure data. The method was to take each grid point for 1947–72 and compute the regression of thickness in terms of surface temperature, pressure and southerly and westerly flow indices for each month of the year. Suitable smoothing between grid points and between monthly means was then carried out. The smoothed regression coefficients were then used to compute thickness at each grid point and thus thickness charts (and hence 500 mb charts) for each month of the year for the period 1891–1944. It is hoped to modify this technique to produce half-monthly deduced charts and hence mid month–mid month charts. Because of the unique nature of our data bank and its relative ease of access, parts of it are in constant demand. This year sales have been made to the USA, Australia, Poland, Switzerland, India, and Germany as well as to various universities in Britain and elsewhere and to other bodies such as the Fisheries Laboratory, Lowestoft and the Department of the Environment.

Climatic change

After several very mild winters and two very good summers including the most severe drought since rainfall records began 250 years ago, it is not surprising that there has been great interest in the possibility that our climate may be changing. Pressure anomalies at the point 50°N 10°W over the drought period were as high as 3·3 standard deviations above the mean but checks on all previous such periods indicated that, on average, there was one point as unusual as this somewhere in the northern hemisphere every year. The deduction was that locally the period was a very rare occurrence but that it did not imply anything unusual in the general meteorological patterns over the northern hemisphere. As a result of the apparently anomalous weather events in Britain over the last few years, a preliminary study was carried out with the object of seeing if our climate had become more variable. Results showed that the frequency of extreme months (either of temperature or of rainfall) was no greater in the 1970s than in other decades over the last 100 years. There is a possibility that events on other than the monthly time-scale may indicate more variability in recent climate but this has not been demonstrated.

The subject of climatic change, including research done by the Office in this field, is described in some detail in the Directorate of Research's Special Topic article on pages 73–85.

Special investigations

The Special Investigations Branch deals with enquiries from the aviation industry and others requiring investigations in applied meteorology, including such fields as air pollution, storm tide surges and radio propagation. Some of these require considerable investigational effort and the use of scientific judgement in appraising scanty data. For example during 1976, in the aviation field, advice has been given on possible meteorological causes of abnormally high rates of descent on approaches to airfields, the severity of convective activity near the site of an aircraft accident and the probability that pilots in controlled air space will have to take action to avoid cumulonimbus clouds. In addition over 200 other enquiries of a wide range of difficulty and complexity have been answered. A non-aviation enquiry on which a considerable amount of time was spent was a detailed theoretical study of the dispersion of a buoyant jet of gas for which estimates were required of the probability of high concentration of the gas for short periods of time at places down-wind of the source.

During 1976 the main emphasis has been on the occurrence of wind shears below about 600 m, which can cause difficulties to aircraft during take-off and landing. Measurements of winds above 10 m are not made at airports, and the meteorologist can only infer from indirect evidence that potentially dangerous shears might be present. Studies are being made of the small amount of data available and plans are being prepared in collaboration with British Airways and the Royal Air Force for a trial next year of methods of assessing the probability of shear being present and warning pilots to be prepared for it.

During the spring of 1976 reports of clear-air turbulence (CAT) were received from over 5000 flights over Europe and the North Atlantic. Most of the main airlines and meteorological offices in the area co-operated in the project. All the information collected is being quality controlled and stored on magnetic tape in preparation for a continuation of the study to find the best predictors of CAT which can be derived from the 10-level model forecasts. A comparison is also being made of predictors of convective activity with a view to selecting one to use with the 10-level model forecasts to predict the severity of convection.

Other activities include the preparation of descriptions and statistics of weather at airfields under British control, reports on climate in all parts of the world and statistics on weather in sea areas around the British Isles.

A small team helps and encourages investigations carried out at outstations mainly in relation to problems involving local weather. Computer services for the provision of data and various forms of analysis as well as guidance and constructive criticism have been supplied to the investigators. This team also provides a computer service for students' projects at the Meteorological Office College and helps in the assessment of the projects.

General Activities of the Research Directorate

The Meteorological Office continued to work closely with a number of national and international bodies which are concerned with meteorological research. The Office provides representatives on a number of research-oriented committees of the Royal Society, the Natural Environment Research Council and the Science Research Council. In the international field, scientists from the Office serve on several working groups of the World Meteorological Organization and of the International Association of Meteorology and Atmospheric Physics.

The scientific research of the Office was reviewed by the Meteorological Research Committee and its subcommittees during the course of nine meetings. The Committee also advises on a number of small university research projects which are directly supported by the Meteorological Office; these number four in addition to seven placed through the Gassiot Committee of the Royal Society.

During the year four members of university staffs worked in the Office as consultants for short periods. Also one research scientist from overseas carried out research in the Meteorological Office for an extended period during which he was supported by his home institution.

Library, Publications, Archives and Cartographic Section

The National Meteorological Library forms part of the Meteorological Office Headquarters at Bracknell. It is used mainly by staff of the Office, but also meets a large demand for its services from universities, schools, commercial and industrial firms, and the general public.

The number of items classified and catalogued (which includes all relevant journal articles) continues to run at a high level. The number of loans showed little change from recent years, but the reader/printer for microfiche and microfilm is in increasing demand. Some figures representative of the work of the Library are given in Table XVI on page 112.

Staff of the Office have continued to participate in the facilities offered by the Association of Special Libraries and Information Bureaux (ASLIB) and the Circle of State Librarians.

A comprehensive survey of books and journals purchased was carried out to determine which purchases could be cut with least damage to the work of the Office.

The Editing Section remained responsible for the preparation for printing of most official publications of the Office, and co-operated closely with Her Majesty's Stationery Office in the maintenance of publishing standards. Some difficulties have been caused by the refusal of a print union to handle computer-produced 'copy', and camera-ready 'copy' not prepared by its members. In particular the production of *British Rainfall* for 1969 and subsequent years is at a standstill.

Works published during the year are listed in Appendix III; these include the *Meteorological Magazine*, a monthly journal containing short scientific articles, reviews and items of interest to meteorologists everywhere.

The distribution to the many outstations of the Office of publications, both official and commercial (scientific journals, textbooks, works of reference, etc.), is under the control of the Publications Section, which is also responsible for the half-yearly issue of some 350 000 forms of all kinds to over 6000 reporting stations.

Meteorological observations in manuscript and other original documents and records are kept, in accordance with the Public Records Act 1958 and the Public Records (Scotland) Act 1937, in special repositories (archives) in Bracknell, Edinburgh and Belfast. The material in these archives is consulted by a large number of people, both inside and outside the Office; during the year, for instance, over 2000 loans were made from the archives at Bracknell.

The Cartographic Section prepares diagrams for Meteorological Office publications, for internal memoranda and for papers contributed to scientific journals by members of the staff. It also prepares for various areas of the world the many charts and diagrams which are used as background maps on which meteorological observations are plotted. The preparation of data-entry forms, exhibition displays, lecture and training viewfoils and slides is undertaken, together with the reprographic action necessary for printing these and other miscellaneous items.

Some statistics showing the extent of the work carried out by the Cartographic Section are given in Table XVI.

Professional Training

The Meteorological Office Training Board, under the chairmanship of the Director-General, determines policy on professional and managerial training of Meteorological Office staff. Most of the professional training is provided within the Meteorological Office itself, either at the Meteorological Office College or at the Meteorological Office Technical Training School, although a number of staff are sent on specialist courses outside the Office, usually for non-meteorological subjects.

The Meteorological Office College is a residential college designed to accommodate just over 100 students and has been at Shinfield Park, south of Reading, since October 1971. The College caters for all the requirements for training in basic meteorology at all levels in the Office as well as in forecasting (basic and refresher courses), observing and related topics. The College is well equipped both for normal teaching and for practical work. It has a large cinema for an audience of 94, two lecture theatres, seven very large classrooms for practical work with charts, five classrooms for more general use and a specialized instrument classroom. An important part of many courses is the simulation of operational working conditions, and equipment installed in two communication rooms allows the timely reception of current operational meteorological data from many parts of the world, both by teleprinter and by facsimile channels; this includes the reception of satellite pictures. The College has recently acquired closed circuit television apparatus to assist with briefing training for forecasting staff. The extensive grounds at the College provide plenty of room for field work and for the siting of meteorological instruments, and there are excellent social facilities including squash court, tennis courts, bar, table tennis and television rooms.

The number of students completing courses at the College this year was almost as large as the record number in 1975: 634 compared with 640. An increase in the number of Extension Courses and the introduction of extra courses for Co-operating and Auxiliary Observers offset the fall in the number of initial training courses caused by reduced recruitment into the Office, particularly into the Assistant Scientific Officer grade. A breakdown of the number of trainees according to type of course and to whether Meteorological Office staff or not is shown in Table XVII. There have been few changes to College courses this year. The Scientific Officer Course, for graduates with high honours, has been shortened by omitting the three weeks devoted to computer programming, because most scientists attending the course these days have had experience with large computers. On the Scientific Officer Course which finished at the beginning of the year there were 21 students including one each from Malaysia and Cyprus. The course which started in the latter part of the year has 10 full-time students all from within the Meteorological Office. The Applied Meteorology Course for new entrants with graduate qualifications or with Higher National Certificate is designed both for support-scientists and for staff going into forecasting. This year the duration of the support-scientist section, which is less than that of the forecaster section was increased by one week by extending the treatment of boundary layer meteorology and climatology. The course which finished at the beginning of the year was full, with

36 students including four from overseas. On the course commencing at the end of the year there are 14 students including two from overseas (Switzerland and Jordan).

The other course concerned with basic forecaster training is the Initial Forecasting Course and this was fairly well attended with 26 students including 11 from overseas. The latter included eight members of the Saudi-Arabian Meteorological Service who had been selected by their Service for forecaster training. The Initial Forecasting Course is not only a complete course in its own right but also forms an integral part of the University of Reading Sandwich Course leading to an honours degree in meteorology.

The Sandwich Course is entered with GCE 'A' levels in mathematics and physics; it lasts for three and a half to four years and consists of alternating periods of academic and practical work, the latter usually being done at a forecast office in the Meteorological Office. In this way students are able to obtain in a single course both a good graduate qualification and training in the practical aspects of weather forecasting. Two Meteorological Office staff and four overseas students successfully completed the course this year. Several candidates for the MSc course at the Geophysics Department of the University of Reading took a Meteorological Office College course as part of their preparatory studies.

In keeping with the Training Board's policy to provide refresher courses at intervals of 5–10 years there was an increase in the number of Extension Courses from three last year to seven this year. The Extension Course is for Higher Scientific Officers and besides revising basic synoptic meteorology it includes basic statistics, which helps a forecaster to conduct minor research investigations into the weather at his own station or in his local area.

The training of Assistant Scientific Officers working in forecast offices normally consists of a four-week Initial Assistant Course during which they are taught the rudiments of plotting, coding and the making of observations, followed after about two years by the six-week Advanced Assistant Course which gives training in elementary meteorology, more advanced coding, pilot balloon work and elementary instrument maintenance. As with many courses in the Office, practical training is not finished when the student leaves the College; on-the-job training at outstations is an essential part of the overall scheme. The Scientific Officer (Supervisors) Course still fills a valuable role for Scientific Officers newly appointed to fill supervisory posts on promotion from Assistant Scientific Officer. The number of new entrants into the Office dropped considerably this year, but at the College the reduction in Meteorological Office staff trained was partly offset by the number of students on courses for observers who are not members of the Meteorological Office but man the Auxiliary Reporting and Climatological Stations. Their numbers increased from 106 to 153. Courses were also run for Air Traffic Control Officers who are required to make weather observations at aerodromes, and a new course in general meteorological background was arranged for ground control staff of the British Airports Authority.

The College has continued to be used by a number of outside organizations for meetings and conferences; any enquiries concerning this facility or any of the courses at the College should be addressed to The Principal, Meteorological Office College, Shinfield Park, Reading RG2 9AU.

The small radiosonde/radiowind training school was maintained at Beaufort Park, near Bracknell, and 11 members of staff received training in upper-air observational techniques. This number included two members of staff who are to open the upper-air station at St Helena and a further two who were engaged in a European Remote Sensing Experiment at Drax, Humberside. There was no requirement for an initial course for Radio (Met) Technicians this year, and further training of RMTs in the Office is described in the section on the Operational Instrumentation Branch.

Those joining the Meteorological Office as Assistant Scientific Officers are expected to take advantage of the part-time courses offered by technical colleges and colleges of further education to improve their academic qualifications in scientific subjects. The number of staff given release for such part-time study this year was 247 and in addition 30 members of staff are taking Open University courses with assistance under the Civil Service Further Education Scheme. In addition to the above, the Office has 27 staff who have taken advantage of arrangements made with the Reading College of Technology for a Block Release HNC course in mathematics, statistics and computing which was started in 1974 for staff who do not live within easy reach of suitable colleges. The course consists of four six-week periods of full-time study spread over two years and the staff live at Shinfield Park during these periods. Out of 18 staff taking their final examinations this year 13 successfully obtained their HNC and four were referred in one subject. Eleven members of staff have been given full-time release with pay for university studies or to attend Sandwich Courses, and six have taken advantage of a scheme under which scientists can continue to work in the Office while studying for a PhD under the joint supervision of the Office and a co-operating university.

The overseas students shown in Table XVII as having attended courses at the Meteorological Office College were sponsored by their governments, by WMO or by Overseas Development Aid. In addition to these, special arrangements were made for a number of sponsored students to undergo on-the-job training in various branches of the Office; subjects included meteorological applications of computer processing and archiving of data, and aeronautical climatology. Arrangements were also made for training of several foreign technicians in the maintenance of mechanical, electrical and electronic instruments; these programs are arranged with the Technical Training School at Beaufort Park, and use is made of the Training Services Agency Skillcentre in Cardiff for training in some basic skills.

The Office continues to support a number of fellowships under the Voluntary Assistance Program of the World Meteorological Organization, and there are at present 11 students being assisted in this way. Students from Jordan, East Africa, Mauritius, Netherlands Antilles and Ecuador are taking first degrees in meteorology at Reading University; MSc courses are being taken by students from Sri Lanka, Bangladesh, East Africa and Ghana; one student from Egypt is taking a PhD at Reading University. This year two VAP students successfully completed the Reading University Sandwich Course in meteorology.

K. H. Stewart
Director of Research

STATISTICS OF THE RESEARCH DIRECTORATE

TABLE XVI—LIBRARY, ARCHIVES AND CARTOGRAPHIC SECTION

Library	
Publications received:	
Daily weather reports	11 645
Books and journals etc.	7 630
Slides and photographs	774
Individual books, pamphlets, articles etc. classified and catalogued	7 786
Publications lent (excluding internal 48 hour loans):	
Daily weather reports	4 614
Books, journals, etc.	17 789
Slides and photographs	6 687
Number of exchange agreements	1 118
Number of pages translated by library translator	560
Russian 456, German 85, Bulgarian 12, Serbo-Croat 5, French 2	
Number of pages translated by freelance translators	542
French 218, German 147, Russian 73, Dutch 72, Japanese 15, Italian 8, Icelandic 4, Spanish 3, Portuguese 2	
Archives	
Number of loans	2 246
Cartographic Section	
Number of diagrams, maps and charts completed during year	2 962
Number of reprographic jobs during year	417

TABLE XVII—TRAINING

The following figures give details of courses completed during 1976 at the Meteorological Office training establishments at Shinfield Park and Beaufort Park.

	Number of courses	Length of course in weeks	Met. Office Staff	Others	Total
Scientific Officers	1	23	19	2	21
Applied Meteorology	1	19	32	4	36
Initial Forecasting	1	19	15	11	26
Advanced Forecasting	3	7	11	7	18
Extension Course	7	4	75	8	83
Senior Meteorologists	2	3	41	1	42
Meteorological Statistics	2	4	16	4	20
Tropical Meteorology	2	3	3	5	8
Mediterranean Meteorology	2	3	2	11	13
SO (Supervisors)	4	4	34	0	34
Auxiliary and Co-operating Observers	10	1	0	153	153
Basic Meteorology (Assistant Level)	1	4	5	0	5
Initial Assistant	3	4	18	9	27
Advanced Assistant	5	6	55	4	59
Air Traffic Control Officers	2	1	0	12	12
Meteorology for Technicians	2	2	22	0	22
British Airports Authority	1	1	0	4	4
Radiosonde (Initial)	1	6	3	0	3
Radiosonde (Initial)	1	4	3	0	3
Radiosonde (Refresher)	1	1	1	0	1
Radiosonde (Refresher)	1	2	1	0	1
Radiosonde (Refresher)	1	3	1	0	1
Radiosonde (Special)	1	1	2	0	2
Technical Updating	4	3	17	2	19
Technical Updating	3	2	21	0	21
Totals			397	237	634

Students from the following territories attended courses which terminated during 1976.

	Number of students
Antigua	1
Bahrain	3
Bangladesh	1
Cyprus	2
Ghana	2
Hong Kong	4
Iraq	1
Jamaica	2
Japan	1
Jersey	2
Kenya	4
Maldives	1
Malaysia	1
Netherlands Antilles	1
Saudi Arabia	8
Sri Lanka	1
Switzerland	1
Syria	2
Tanzania	1
Turkey	1
Uganda	1
Yemen	1
Total	42

INTERNATIONAL CO-OPERATION

The United Kingdom sent delegations to the sessions of one Regional Association and four Technical Commissions of WMO* during the year. Regional Association VI (Europe) met in Budapest in October to consider the European aspects of many WMO activities. The delegation was led by Mr G. A. Corby, Director of Services, with Mr D. G. Harley, Assistant Director (International and Planning) and Mr D. McNaughton, Assistant Director (Telecommunications). In May the RA VI Working Group on Meteorological Telecommunications had met in Geneva, when the United Kingdom was represented by Mr McNaughton.

The Commission for Aeronautical Meteorology met jointly with the ICAO 9th Air Navigation Conference and subsequently in separate session in Montreal in April and May. Mr D. H. Johnson, Assistant Director (Public Services) and Mr C. H. Hinkel, Met O 7, took part.

The Commission for Hydrology met in Ottawa in June. Mr R. Murray, Assistant Director (Agriculture and Hydrometeorology) led the delegation which also included Mr O. Gibb, Director, and Mr H. J. Richards, both of the Central Water Planning Unit, Reading. The Commission for Basic Systems, which has large responsibilities in respect of World Weather Watch, met in Geneva in November, when Mr N. Bradbury, Deputy Director (Forecasting) led the delegation. Other members were Mr G. J. Day, Assistant Director (Observational Requirements and Practices), Mr D. McNaughton, Assistant Director (Telecommunications) and Lt.-Cdr D. J. Malone, RN. The Commission for Marine Meteorology met, also in Geneva, from 29 November to 10 December. Dr N. E. Rider, Deputy Director (Observations) led the delegation which included Captain G. A. White, Marine Superintendent, Captain R. K. Alcock, RN, and Mr D. J. Painting, Met O 3. This session was immediately preceded by a WMO Technical Conference on 'The applications of Marine Meteorology to high seas and coastal zone development', which was attended by the same group apart from Mr Painting, and by representatives of several marine interests in the United Kingdom.

In the Global Atmospheric Research Program preparations for the First GARP Global Experiment (FGGE) increased in pace. At the end of January an Intergovernmental Planning Conference was held in Geneva at which the Director-General, Dr B. J. Mason, was accompanied by Mr G. A. Corby, at the time Deputy Director (Communications and Computing). Mr Corby also took part in the immediately following session of the Executive Committee Intergovernmental Panel of Experts on FGGE, and in the Panel's session in July. Several informal planning meetings on special observing systems and on data management are listed in the following pages. The last of these was held at the Meteorological Office College near Reading. Other GARP meetings included the 8th Session of the Tropical Experiment Board of GATE when Dr B. J. Mason was again in the Chair and Mr F. H. Bushby, Deputy Director (Dynamical Research) took part; two sessions of the JOC Working Group on

*The abbreviations used in this section, and their meanings, are included in Appendix IV.

Numerical Experimentation in Exeter and Montreal, attended by Mr F. H. Bushby, and the GARP Study Group Conference on 'Airflow over and around mountains' in Yugoslavia. Dr R. Hide, Head of Met O 21, Dr P. W. White, Met O 11, and Mr J. M. Nicholls, Meteorological Research Flight, attended this last.

The Council of the European Centre for Medium-range Weather Forecasts (ECMWF) met in London in May and November. Dr B. J. Mason attended both meetings, as a member, assisted by Mr D. G. Harley. The Finance Committee met four times to prepare for Council sessions, but meteorological participation was necessary only in the April session when Mr Harley took part. An Advisory Group on Communications with members including Dr R. L. Wiley, Met O 22, for the United Kingdom met in Helsinki in October, and the permanent Scientific Advisory Committee met in March and September in Bracknell. Mr J. S. Sawyer, Director of Research until his retirement in June, is Chairman of this committee. A number of members of staff attended lectures at an international seminar organized by ECMWF in September at the Meteorological Office College, on the treatment of the boundary layer in numerical weather prediction.

United Kingdom participation in meteorological satellite programs continued. For the European Space Agency's METEOSAT, the Program Board met in Paris in January and June, and Dr B. J. Mason took part. Dr K. H. Stewart, Director of Research after Mr Sawyer's retirement, took part in four meetings of the Scientific and Technical Advisory Group, the June and October sessions of the Program Board, and three sessions of the ESA Working Group on Space Meteorology. Our contribution to the USA TIROS-N satellite involved five short meetings in Washington, USA, in which various staff of the High Atmosphere and Telecommunications Branches took part. Dr Stewart also attended meetings in Oxford in May and September of the NIMBUS-G Stratospheric and Mesospheric Sounder Experiment Team.

The Western European Directors of Meteorological Services continued their series of annual informal discussions at their 6th Meeting in Norrköping, Sweden, in June. Dr B. J. Mason took part. Earlier that month, accompanied by Mr D. G. Harley, he had a brief meeting in Grenoble, France, with the Heads of the Meteorological Services of USA, France, the Federal Republic of Germany and Sweden.

European Co-operation in Science and Technology (COST) includes work on ocean data buoys under Project 43 and on the standardization of meteorological instruments under Project 72. Meetings of the Project 43 Technical Committee were held in Brussels in March, June and October; Dr D. N. Axford, Assistant Director (Operational Instrumentation) participated. COST 72 Technical Committees met in May and November, also in Brussels, and were attended by Mr G. A. Clift; the May meeting was also attended by Mr K. J. T. Sands. Sub-groups set up under Project 72 to study the standardization problems of radiosonde and automatic weather stations met four times, in Paris, in Brussels and twice in Reading. Dr Axford attended the Paris meeting, Mr Sands the others. The Technical Conference on Automatic Weather Stations planned last year was held in September at the University of

Reading. This was organized by members of the International & Planning and Operational Instrumentation branches and opened by Dr B. J. Mason and Mr C. Silver, Chairman of the COST Senior Officials. Mr G. J. Day, Assistant Director (Observational Requirements and Practices) chaired the conference. Several members of the Directorate and other scientific staff attended parts of the conference.

The Agreement on North Atlantic Ocean Stations (NAOS) came into force on 1 December 1976 and the first session of the NAOS Board followed in Geneva from 13 to 16 December, when Mr N. Bradbury, Deputy Director (Forecasting) led the UK delegation. In November Mr D. McNaughton attended an informal meeting, also in Geneva, on the NAOS ship-to-shore telecommunication system, which is centred on Bracknell.

Other WMO Meetings, or joint WMO Meetings with other international bodies, in which Meteorological Office staff took part, were as follows:

Subject	*Place and date*	*Attended by*
Informal Planning Meeting of VAP Donors	Geneva January	Mr D. G. Harley, Assistant Director (International and Planning)
Advisory Group on Boundary Layer Sub-Program for GATE	Hamburg February	Dr N. Thompson (Porton Down)
CAeM *ad hoc* Working Group	Brussels February	Mr C. H. Hinkel (Met O 7)
CBS Working Group on GDPS	Geneva March/April	Mr G. R. R. Benwell, Assistant Director (Central Forecasting)
IOC/WMO IPLAN and UNEP Group of Governmental Experts, and 3rd session of Joint Planning Group	Geneva March	Mr N. Bradbury, Deputy Director (Forecasting Services)
WMO Informal Meetings to consider NAVAID windfinding methods on tropical ships in the FGGE	Geneva March, July	Dr P. Ryder, Assistant Director (Cloud Physics)
4th session of CBS Working Group on Codes	Geneva March	Mr P. Menmuir (Met O 6)
CBS Working Group on the GTS. Study Group on Data Transmission Techniques	Geneva April	Mr E. J. Bell, Assistant Director (Telecommunications)
CMM Working Group on Marine Meteorological Services	Geneva April	Capt. G. A. White, Marine Superintendent
Meetings on Level 11b Data Production and Data Management for FGGE	Geneva May	Mr E. A. Spackman (Met O 20)
CBS Working Group on the Guide for the GOS	Geneva May	Mr G. J. Day, Assistant Director (Observational Requirements and Practices)
EC Panel Meeting on Weather Modification	Geneva May	Mr P. Goldsmith, as Assistant Director (Cloud Physics)
19th Meeting of COSPAR, and Symposium on Satellite Meteorology	Philadelphia June	Dr N. E. Rider, Deputy Director (Observational Services) Mr B. R. May (Met O 19)
WWW Informal Planning Meeting on the Improvement in Observational Data Coverage over the Oceans	Geneva June	Mr D. McNaughton, Assistant Director (Telecommunications)
International Conference on Cloud Physics	Boulder, Colorado July	Dr B. J. Mason, Director-General Dr P. Ryder, Assistant Director (Cloud Physics) Dr D. A. Bennetts (Met O 15)

Subject	*Place and date*	*Attended by*
Conference on Weather Modification	Boulder, Colorado August	Dr B. J. Mason, Director-General Dr P. Ryder, Assistant Director (Cloud Physics)
Symposium on Atmospheric Ozone	Dresden August	Mr P. Goldsmith, Deputy Director (Physical Research) Dr A. F. Tuck (Met O 15)
CBS Working Group on Monitoring the Global Observing System	Geneva August	Mr G. J. Day, Assistant Director (Observational Requirements and Practices)
UNESCO/WMO Symposium on Solar Energy	Geneva August	Mr C. V. Smith (Met O 1)
IAMAP/WMO Symposium on Radiation in the Atmosphere	Garmisch-Partenkirchen August	Dr W. T. Roach (Met O 15)
Initial Planning Meeting on Satellite Applications in Marine Activities including Oceanography	Geneva September	Capt G. A. White, Marine Superintendent
Joint Oceanographic Assembly	Edinburgh September	Mr R. A. S. Ratcliffe, Assistant Director (Synoptic Climatology) Mr R. J. Ogden, Assistant Director (Climatological Services)
CBS Working Group on the GTS	Geneva September	Mr D. McNaughton, Assistant Director (Telecommunications)
Symposium on Interpretation of Broad-scale Numerical Weather Prediction tion Products for Local Forecasting Purposes	Warsaw October	Mr A. Woodroffe (Met O 2) Mr P. G. Wickham (Met O 11)
FGGE Informal Planning Meeting on Formats for International Data Exchange	Geneva October	Dr R. Love (Met O 12)
CIMO Advisory Working Group	Geneva October	Mr A. Hooper (Met O 1)
Conference on Meteorological Services for Platforms in the North Sea Area	Oslo October	Mr N. Bradbury, Deputy Director (Forecasting Services) Mr D. M. Houghton (London Weather Centre)
Precipitation Enhancement Project Meeting	Geneva November	Mr P. Goldsmith, Deputy Director (Physical Research)
CAeM Advisory Working Group	Geneva November	Mr C. H. Hinkel (Met O 7)
NAOS RTT Trials, Informal Planning Meeting	Geneva November	Mr D. McNaughton, Assistant Director (Telecommunications) Mr B. W. Anderson (Met O 5)
CIMO Working Group on Upper-air Systems	Geneva December	Mr E. A. Spackman (Met O 20)

Attendances not already listed, at international conferences sponsored wholly or primarily by bodies other than WMO, and other visits abroad were as follows:

Subject	*Place and date*	*Attended by*
Workshop on US NAVAID (Navigation Aid) Processing Program for Measuring Winds	Washington January	Mr E. A. Spackman (Met O 20)
NATO MCMG Working Group Subgroup II	Brussels January	Mr C. E. Goodison (Met O 5)
Meteorological Institute of East African Weather Service, and University of Nairobi, Lectures and Commissioning of Fluid Dynamics Teaching Apparatus	Nairobi January	Dr R. Hide (Head of Met O 21)
Technical Advisory Group of NORSWAM (North Sea Wave Model Study)	Wormley, UK February Wallingford, UK October	Dr A. J. Gadd (Met O 2) Mr B. W. Golding (Met O 2)
Mariner, Jupiter, Saturn (1977) Science Steering Group	Tucson, Ariz. February	Dr G. E. Hunt (Met O 20)
Meeting of the Advisory Group for the Co-ordination in Europe on the Reception and Evaluation of Information from Satellites	Rome February	Dr J. L. Brownscombe (Met O 19)
Visits to NOAA, Denver University and Holloman AFB to Prepare and Launch joint Oxford University/ Meteorological Office Balloon-borne Radiometer	USA February March	Dr D. R. Pick (Met O 19)
NATO MCMG Working Group on Weather Communications	London March/April	Mr C. E. Goodison (Met O 5) Mr G. A. Cowling (Met O 6)
COSPAR Committee on the International Solar System Program	Paris March	Dr R. Hide (Head of Met O 21)
Visits to Computer Manufacturers	USA March	Mr G. A. Corby, Deputy Director (Communications & Computing) Mr F. H. Bushby, Deputy Director (Dynamical Research) Dr R. L. Wiley (Met O 22)
CNRS Scientific Committee. Discussion of Program of Research into the Radiative and Thermal Balance of the Atmosphere	Paris March and September	Dr P. R. Jonas (Met O 21)
Meeting of Group concerned with Meteorological Parameters and Stochastic Phenomena, ISO Committee on Wind Loading	Amsterdam March	Mr R. H. Collingbourne (Met O 3)
Meetings of ESA Solar System Working Group	Paris April, July October	Dr G. E. Hunt (Met O 19)

Subject	*Place and date*	*Attended by*
Anglo–French–American Meeting to Formulate a Tripartite Agreement on Stratospheric Research and Monitoring	Paris April	Dr R. J. Murgatroyd (Met O 20)
Symposium on Rainfall Measurement	Delft, The Netherlands April	Dr T. W. Harrold (Met O 16)
AFCENT Meteorological Committee	Traben-Trarbach April	Mr W. G. Durbin (Met O 6) Mr E. Cayhill (Met O 6)
Meeting of IBM Equipment Users	Montpellier April Berlin September	Mr E. J. English (Met O 12)
ESRIN/ESA Spacelab Symposium	Frascati, Italy May	Dr R. J. Murgatroyd (Met O 20) Dr G. E. Hunt (Met O 19)
Co-ordination Meeting for NATO International Exercise	London May	Mr P. G. Rackliff (Met O 6)
ICAO Special North Atlantic Panel	Montreal May	Mr C. H. Hinkel (Met O 7)
21st Tactical Weather Network Conference	Traben-Trarbach May	Mr E. Cayhill (Met O 6) Mr C. Alderson (Met O 6) Mr N. Holdsworth (Met O 6)
Meetings of Mariner, Jupiter, Saturn Imaging Team	Washington and Los Angeles June Chicago and Los Angeles September	Dr G. E. Hunt (Met O 19)
International Symposium on Solar–Terrestrial Physics	Boulder, Colorado June	Mr C. K. Folland (Met O 13)
EEC Environmental Research Program Meeting of the Expert Group on Halocarbons in the Atmosphere	Brussels June, December	Dr R. J. Murgatroyd (Met O 20)
NATO MCMG Working Group	Brussels June	Mr I. J. W. Pothecary, Assistant Director (Defence Services) Mr G. A. Cowling (Met O 6)
Conference on 'Finite Elements in Water Research'	Princeton, N.J. July	Dr M. J. P. Cullen (Met O 20)
NATO MCMG Working Group Subgroup VIII	Bracknell July	Mr C. E. Goodison (Met O 5)
Meetings at NOAA and NESS and AMS Conference on Tropical Meteorology	Washington, D.C. Virginia July	Dr B. J. Mason, Director-General
Conference on 'Simulation of Large-scale Atmospheric Processes'	Hamburg August/September	Mr A. Gilchrist, Assistant Director (Dynamical Climatology) Dr D. J. Carson (Met O 20) Dr H. Cattle (Met O 11)
11th Symposium on Mathematical Geophysics	Frankfurt August	Dr R. Hide (Head of Met O 21)

Subject	*Place and date*	*Attended by*
Meso-meteorological Advisory Panel Meeting	El Paso, Texas September/ October	Mr F. H. Bushby, Deputy Director (Dynamical Research)
International Organization for Standardization Sub-committee on Standard Atmospheres	London September	Mr J. Crabtree (Met O 9)
Discussion with Dynamical Meteorology Laboratory	Palaiseau, France September	Dr P. R. Jonas (Met O 21)
NATO Army Armaments Group AC/225 Panel XII	Brussels September	Mr G. F. W. Clapp (Met O 6)
CENTO Meteorological Co-ordination Conference	Ankara September	Mr D. W. Tann (Met O 6)
ESA Space Meteorology Working Group	Shinfield Park September	Dr B. J. Mason, Director-General
Meeting in connection with Minimetsat Project	Munich September	Mr D. E. Miller, Assistant Director (High Atmosphere)
Two Lectures to a EURATOM Course	Ispra, Italy October	Dr F. B. Smith, Assistant Director (Boundary Layer)
NATO MCMG Working Group Subgroup I	Brussels December	Mr C. E. Goodison (Met O 5)
Instructional Courses and Subsequent Development Work on the use of Vector Processing Computers	Minneapolis October November December	Dr P. W. White (Met O 11) Miss J. Perfect (Met O 11) Mr J. Turner (Met O 11)
NATO MCMG Working Group	Traben-Trarbach October	Mr I. J. W. Pothecary, Assistant Director (Defence Services) Mr C. E. Goodison (Met O 5)
Lecture to the Working Group of the ECE Task Force on Air Pollution	Lillestrøm, Norway October	Dr F. B. Smith, Assistant Director (Boundary Layer)
Symposium on Large Scale Weather Research and Long-range Forecasting	Bad Homburg October	Mr M. K. Miles (Met O 13)
ICAO Caribbean/South American Regional Air Navigation Meeting	Lima October	Mr J. E. Skilling (Met O 7)
Boundary Layer and Air Pollution Lectures at University of Stockholm	Stockholm November	Dr F. B. Smith, Assistant Director (Boundary Layer)
EEC Solar Radiation Advisory Group	Brussels November	Mr C. V. Smith (Met O 1)
NATO Working Party on International Exercise	Brussels December	Mr P. G. Rackliff (Met O 6)
Allied Command Europe C Met O's Sub-committee	Brussels December	Mr J. C. Gordon (Met O 6)
Meeting on Research into Climatic Problems within the EEC	Brussels December	Mr A. Gilchrist, Assistant Director (Dynamical Climatology)

The following staff were released by the Office during 1976 for service with international and other organizations:

Mr J. K. Gibson	Senior Scientific Officer	ECMWF, Bracknell
Mr C. T. Little	Higher Scientific Officer	ECMWF, Bracknell
Mr A. C. Lorenc	Senior Scientific Officer	ECMWF, Bracknell
Mr C. Temperton	Senior Scientific Officer	ECMWF, Bracknell
Mr B. J. Moffit	Senior Scientific Officer	Malawi
Dr R. A. Plumb	Senior Scientific Officer	CSIRO (Australia)
Mr D. E. Pritchard	Higher Scientific Officer	International Aeradio
Mr W. P. Wakelin	Higher Scientific Officer	International Aeradio
Mr P. L. Stewart	Higher Scientific Officer	International Aeradio
Mr A. Stemmler	Higher Scientific Officer	Brunei
Mr R. W. Mason	Scientific Officer	United Kingdom Offshore Operators Association
Mr B. A. Halls	Assistant Scientific Officer	WMO, Geneva
Mr G. C. M. Taylor	Assistant Scientific Officer	The Royal Society, Aldabra Research Station

Staff returning from international and other secondment appointments were:

Mr P. F. Emery	Senior Scientific Officer	Fiji
Mr W. K. Young	Scientific Officer	WMO, Geneva
Mr R. C. Wilderspin	Assistant Scientific Officer	The Royal Society, Aldabra Research Station

STAFF

GENERAL

The names of the Principal Officers of the Meteorological Office are listed on pages xi–xiii and the organization of the Office is shown in the diagram on page xiv. At the end of 1976 the total number of posts of all grades was 3395, a decrease of 109 over the year. The actual strength at the end of the year was made up as follows:

Deputy Secretary	1
Under Secretary	2
Science Group	
Chief Scientific Officer	1
Deputy Chief Scientific Officer	6
Senior Principal Scientific Officer	25
Principal Scientific Officer	113
Senior Scientific Officer	280
Higher Scientific Officer	516
Scientific Officer	518
Assistant Scientific Officer	963
Administration Group	
Assistant Secretary	1
Principal	1
Executive Grades	35
Clerical Grades	141
Marine Staff	
Marine Superintendent	1
Nautical Officer Grades	12
Ocean Weather Ships and Base	
Officers and non-industrial grades	54
Crew and industrial grades	55
Professional Engineer Staff	
Principal Professional and Technology Officer	1
Professional and Technology Officer Grade I	3
Professional and Technology Officer Grade II	5
Professional and Technology Officer Grade III	4
Professional and Technology Officer Grade IV	5
Technical and Signals Grades	303
Typing and miscellaneous non-industrial grades	136
Industrial employees	106
Locally entered staff and employees overseas	104

Staff turnover remained at a low level throughout the year, owing in part to the high level of unemployment generally. No competitions were held for Assistant Scientific Officer recruitment and the one competition for graduates was successful in filling the five Scientific Officer vacancies.

One Cartographic Draughtswoman and two Nautical Officers were recruited and two members of the Professional and Technology grades transferred in from other MOD Sections. There was also some recruitment into the clerical and ancillary grades.

Casually employed staff included five college-based Sandwich Course Students who came to the Office to receive industrial training, seven vacation students and one Nautical Officer. Four vacation consultants spent short periods in some of the research branches during the summer.

HONOURS AND DISTINCTIONS

Mr I. A. Nixon was awarded the M.B.E. in the Queen's Birthday Honours List.

The Director-General was elected senior Vice-President and Treasurer of the Royal Society for a five-year term, and President of the Institute of Physics for a two-year term.

The L. G. Groves Memorial Prize for Meteorology was awarded to Mr C. L. Hawson and Mr D. J. George received the Meteorological Observer's Award.

Mr A. F. Jenkinson, I.S.O., received the Hugh Robert Mill Award of the Royal Meteorological Society for 1976.

APPENDIX I

BOOKS OR PAPERS BY MEMBERS OF THE STAFF

ADAMS, R. J., Ph.D.; Agriculture in the Eastern Region—Climate. Ministry of Agriculture, Fisheries and Food, Cambridge. 1976.

ADAMS, R. J., Ph.D.; French beans—effect of artificial shelter on yield. Ministry of Agriculture, Fisheries and Food. ADAS experiments in Eastern Region 1975. Cambridge, 1976.

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BLACKBURN, M. R., *see* WILEY, R. L. and BLACKBURN, M. R.

BRADBURY, T. A. M.; Spring weather and record breaking gliding flights. *Sailpl Gliding, London,* **27,** 1976, pp. 150–153.

BROWN, R., B.Sc., and ROACH, W. T., Ph.D., D.I.C.; The physics of radiation fog: II—a numerical study. *Q J R Met Soc, London,* **102,** 1976, pp. 335–354.

BROWN, R., *see* ROACH, W. T., BROWN, R., CAUGHEY, S. J., GARLAND, J. A. and READINGS, C. J.

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CATTLE, H., Ph.D., D.I.C.; Data assimilation experiments with the Meteorological Office 10-level model. International Council of Scientific Unions/World Meteorological Organization, Global Atmospheric Research Programme, Working Group on Numerical Experimentation (Proceedings of the JOC Study Group Conference on the Four-dimensional Data Assimilation, Paris, November 1975), Report No. 11, Geneva, 1976, pp. 397–409.

CAUGHEY, S. J., Ph.D.; Observational studies of the planetary boundary layer over land. Bracknell, European Centre for Medium-range Weather Forecasts. Seminars on the Treatment of Boundary Layer in Numerical Weather Prediction, Reading, September 1976, Bracknell, 1976, pp. 108–137.

Caughey, S. J., Ph.D., Crease, B. A., M.Sc., Asimakopoulos, D. N. and Cole, R. S.; A comparison of acoustic Doppler vertical velocities with direct measurements in the atmospheric boundary layer. *Nature, London,* **262,** 1976, pp. 274–276.

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Caughey, S. J., Ph.D. and Crease, B.A., M.Sc. *in* Asimakopoulos, D. N., Cole, R. S. Caughey, S. J. and Crease, B. A.; A quantitative comparison between acoustic sounder returns and the direct measurement of atmospheric temperature fluctuations. *Boundary Layer Met, Dordrecht,* **10,** 1976, pp. 137–147.

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WESCOTT, P., *see* KEERS, J. F. and WESCOTT, P.

APPENDIX II

A SELECTION OF LECTURES AND BROADCASTS GIVEN BY MEMBERS OF STAFF

ADAMS, R. J., Ph.D.
Meteorology and agriculture. *Hertfordshire Grassland Society, Hatfield.* 19 January.
The implications of impending high soil moisture deficits in summer 1976. *Potato Processors' Association, Peterborough.* 3 June.
The work of the agrometeorologist in ADAS. *Divisional Agricultural Officers' Meeting, Norwich.* 6 September.

ALLEN, J.
Yachtmasters (Meteorological) Courses at the Royal Guildford Grammar School (8 lectures) and *the Manor School, Aldershot (7 lectures) (both Adult Further Education Centres).* January–March.

ARMOUR, D. G.
Irrigation needs. *East of Scotland College of Agriculture (Advisory Service), Cupar, Fife.* 29 January.

BADER, M. J., M.Sc. (with DOUGLAS, H. A., B.Sc.)
An assessment of the meteorological sensors in the UK Data Buoy DB-1. *DB-1 Symposium, Institute of Oceanographic Sciences, Wormley.* 23 November.

BENWELL, G. R. R., M.A.
Numerical weather prediction. *Seminar on 'Forecasting', Civil Service College, Sunningdale.* 6–10 December.

BEST, K. E.
Understanding your weather forecast. *Lecture to Petroleum Industry Training Board Course, Aberdeen.* 16 March.
History of the Meteorological Office. *Week-end course on Meteorology, Denman College, Abingdon.* 6–8 August.

BLACKALL, R. M., B.Sc.
Anomalous propagation of radio transmissions.
UK Frequency Modulation Group, London. 13 January.
Radio Society, Harrow. 27 February.
Work of the Meteorological Office. *Thames Valley Association for Mental Health, Reading.* 10 May.

BLACKHAM, A.
Economic aspects of ship routeing. *International Marine and Shipping Conference, London.* 28 April.

BRADBURY, T. A. M.
On a record gliding day. *Royal Meteorological Society Meeting on Short-period Weather Forecasting, London.* 25 September.

BROWNING, K. A., Ph.D., D.I.C.
The measurement and forecasting of rainfall using radar. *Institution of Civil Engineers, South Wales Branch, Cardiff.* 8 April.
Hail, hailstorms and hail suppression. *Imperial College Environmental and Meteorological Society, London.* 13 May.
The use of radar in short-period weather forecasting. *Royal Meteorological Society Meeting on Short-period Weather Forecasting, London.* 25 September.
Our current understanding of cumulonimbus convection: observational aspects. *Royal Meteorological Society, London.* 17 November.
Radar—versatile tool for the meteorologist. 1976 *Winter Conference of the Controller, Research and Development Establishments and Research, MOD(PE), London.* 3 December.

BROWNING, K. A., Ph.D., D.I.C. and COLLIER, C. G., B.Sc., A.R.C.S.
Demonstration of a radar rainfall processing, transmission and display system. *Institution of Civil Engineers Conversazione, London.* 16 June.
BROWNING, K. A., Ph.D., D.I.C., and TAYLOR, B. C., Ph.D.
Demonstration of a radar rainfall processing, transmission and display system before the Queen and the Duke of Edinburgh during their visit to the Royal Signals and Radar Establishment (RSRE), Malvern. 26 March.
BROWNSCOMBE, J. L., Ph.D.
Satellites as part of the Global Meteorological Observing System—present status and future plans. *Colston Symposium on Remote Sensing of the Terrestrial Environment, Bristol.* 8 April.
BUSHBY, F. H., B.Sc., A.R.C.S.
Current research in mesoscale meteorology in the United Kingdom Meteorological Office. *Conference on Army Mesometeorological Research, New Mexico State University, Las Cruces, New Mexico, USA* 28 September.

CARSON, D. J., Ph.D.
Numerical forecasts produced from the GARP Basic Data Sets by the Meteorological Office Dynamical Climatology Branch (Met O 20). *Royal Meteorological Society Specialist Group on Dynamical Problems, University of Reading.* 25 March.
Intercomparison of short-range numerical forecasts using finite difference and finite element models from the UK Meteorological Office. *Joint DMG/AMS International Conference on Simulation of Large-scale Atmospheric Processes, Hamburg.* 30 August.
CATTLE, H., Ph.D., D.I.C.
Experiments in data assimilation. *Joint DMG/AMS International Conference on Simulation of Large-scale Atmospheric Processes, Hamburg.* 1 September.
CAUGHEY, S. J., Ph.D.
Acoustic sounding at Cardington. *One-day discussion meeting on acoustic sounding, Meteorological Office College, Shinfield Park.* 6 April.
Observational studies of the planetary boundary layer over land. *ECMWF Seminar on Treatment of the Boundary Layer in Numerical Weather Prediction, Meteorological Office College, Shinfield Park.* 8 September.
Acoustic sounders studies of the stable boundary layer including fog conditions. *Royal Meteorological Society Discussion Meeting on Fog, Imperial College of Science and Technology, London.* 15 December.
CHILDS, J. H. F.
The work of the Meteorological Office. *Week-end course on Meteorology, Denman College, Abingdon, visit to Bracknell.* 7 August.
The Meteorological Office and forecasting the weather. *University of Surrey, Guildford.* 24 November.
CLAPP, G. F. W.
The production and use of prediction downwind messages. *UK Warning and Monitoring Organization, Metropolitan Sector Conference, Worthing.* 29 February.
COWLEY, J. P., M.Sc.
Changes in solar radiation at Kew. *University of Sheffield.* 30 April.
CULLEN, M. J. P., Ph.D.
Comparison of integrations with the GARP basic data set using general circulation models. *Royal Meteorological Society Specialist Group on Dynamical Problems, University of Reading.* 25 March.
The application of finite element methods to the primitive equations of fluid motion. *International Symposium on Finite Elements in Water Resources, Princeton University, USA* 16 July.
A finite element forecast model. *Geophysical Fluid Dynamics Laboratory, Princeton University, USA* 22 July.

DAY, G. J., B.Sc.
Keynote lecture. *COST 72 Technical Conference on Automatic Weather Systems, University of Reading.* 22 September.

DEEKS, P. H. G.
Forecasting services for inshore waters. *Lecture to Royal Meteorological Society course on Meteorology for Civil Engineering and Building, University of Reading.* 26 March.

DOUGLAS, H. A., B.Sc.
Measurement of humidity in operational meteorology. *SIRA Seminar on sensors for humidity measurement and their applications, the City University, London.* 10 November.
The measurement of fog on motorways. *Royal Meteorological Society Discussion Meeting on Fog, London.* 15 December.

DOUGLAS, H. A., B.Sc. and EINSTEIN, P., Ph.D.
Sodar—a potential operational meteorological instrument. One-day Discussion Meeting on Acoustic Sounding. Meteorological Office College, Shinfield Park. 6 April.

FISH, M. J.
The dry weather in the United Kingdom. *A filmed interview for the Canadian Broadcasting Company.* 14 April.

FLOOD, C. R., B.A.
Application of quantitative satellite data in CFO. *Royal Meteorological Society Discussion Meeting on Use of Satellite Data in Meteorology, London.* 19 May.

FOLLAND, C. K., B.Sc.
Solar–terrestrial relationships. *Royal Meteorological Society, London.* 21 January.
Climatic fluctuations past and present. *Croydon Geographical Society.* 26 February.

FORSDYKE, D., B.Sc.
The significance of annual rainfall. *ADAS South-west Region Drainage Conference, Babbacombe.* 22 January.
Interpretation of potential transpiration. *ADAS Inter-regional Horticultural Staff Conference, Babbacombe.* 11 February.

FRANCIS, P. E., Ph.D.
Mathematics and meteorology. *Glasgow University Maclaurin Society, Glasgow.* 18 February.

GADD, A. J., Ph.D.
Computer weather forecasting. *Ministry of Defence, Procurement Executive, London.* 25 March.

GEORGE, D. J.
On a Trawler Support Vessel. *Royal Meteorological Society Meeting on Short-period Weather Forecasting, London.* 25 September.

GILCHRIST, A., M.A.
The tropical circulation from a version of the Meteorological Office 5-level general circulation model. *JOC (GARP) Study Group Conference, Exeter.* 5 April.
Some general considerations about some general circulation models of the atmosphere. *Royal Meteorological Society Summer Meeting, Norwich.* 16 July.
The United Kingdom Meteorological Office general circulation model and some results from experiments with sea-surface temperature anomalies. *Joint DMG/AMS International Conference on Simulation of Large-scale Atmospheric Processes, Hamburg.* 30 August.

GOLDING, B. W., B.Sc.
Use of computers in weather prediction.
British Computer Society, Oxford. 24 February.
British Computer Society, Bournemouth. 4 November.

GOLDSMITH, P., M.A.
Weather modification—intentional. *University of Reading.* 5 February.
Weather modification—unintentional. *University of Reading.* 12 February.
Calculations of the quantity of nitrogen oxides injected into the stratosphere by past nuclear explosions and its effect on total ozone. *Symposium on Atmospheric Ozone and Related Topics, Dresden, German Democratic Republic.* 12 August.

GRANT, D. R., B.Sc.
Low level wind shear. *Flight Safety Committee, London.* 28 April.

GRAYSTONE, P., B.A.
The use of computers in weather forecasting. *British Computer Society, Dundee College of Technology.* 18 May.

HARROLD, T. W., Ph.D., D.I.C.
Measurement of meteorological elements of interest to water management. *Meteorological Office Symposium for Water Management, Reading.* 24 March.
Measurement of rainfall by radar in the United Kingdom. *Committee for Hydrological Research, National Centre of Applied Research (TNO), Delft, The Netherlands.* 9 April.
An evaluation of the performance of the Meteorological Office Weather Observing System. *COST 72 Technical Conference on Automatic Weather Stations, University of Reading.* 22 September.

HAWORTH, C., B.Sc.
Participation in Harlech Television program 'Report Extra'. 24 September.

HIDE, R., Sc.D., F.R.S.
Dynamics, magnetohydrodynamics and structure of the earth's deep interior.
Department of Physics, University of Nairobi. 7 January.
Discussion meeting, The Royal Society, London. 28 February.
International Symposium on Mathematical Geophysics, Seeheim, Federal Republic of Germany. 26 August.
Department of Geophysics, University of Cambridge. 10 November.
Motions in planetary atmospheres.
Department of Meteorology, University of Nairobi. 8 January.
Natural Science Club, University College, London. 26 January.
Hampstead Scientific Society, London. 14 October.
Department of Applied Physics, University of Hull. 28 October.
Physical Society, University of Leeds. 29 October.
Royal Meteorological Society, Scottish Branch, Edinburgh. 19 November.
Department of Aeronautics, Imperial College of Science and Technology, London. 15 December.
Helicity. *Department of Mathematics, University College, London.* 6 February.
Rotating fluids in geophysics and astrophysics. *Department of Astronomy, University of Oxford.* 2 March.
Experiments with rotating fluids. *Presidential Address to the Royal Meteorological Society, London.* 21 April.
Boundary layers in rotating fluids. *European Centre for Medium-range Weather Forecasts, Shinfield Park, Reading.* 6 September.

HOPKINS, J. S., B.Sc., A.R.C.S.
Lectures on temperature, humidity, and planning studies. *Royal Meteorological Society course on Meteorology for Civil Engineering and Building, University of Reading.* 25–26 March.

HOUGHTON, D. M., M.Sc., D.I.C.
Predicting wind and waves for offshore operations. *Society of Petroleum Engineers, London.* 27 January.
The weather. *One-hour phone-in program, London Broadcasting Company.* 4 February.
Weather for engineers and yachtsmen. *Institute of Heating and Ventilation Engineers, Southampton.* 5 February.
Understanding your weather forecast. *Lecture to Petroleum Industry Training Board Course, Aberdeen.* 16 March.
The lack of rainfall in parts of Britain. *A radio interview for New York Radio Station WOR.* 5 May.
The weather prospects—'Observer' single-handed transatlantic yacht race. *A radio interview for the BBC Radio* 4 *'Today' program.* 5 June.

HUNT, G. E., Ph.D., F.I.M.A.
Contribution to BBC TV program 'The sky at night' concerning Mars. 18 January.
The role of radiation and clouds in the general circulation of the atmosphere. *Department of Atmospheric Physics, University of Oxford.* 6 May.
Sun Earth Observatory and Climatology Satellite Project. *Presentation of Mission Definition Study to the European Space Agency, Paris.* 28 June.
Contribution to BBC TV program 'The sky at night' concerning VIKING mission to Mars. 14 July.
*Contribution to BBC TV program 'The sky at night' concerning first results from VIKING-*1. 11 August.
The lower atmosphere of Jupiter. *International Astronomical Union General Assembly, Commission* 16 *on the Planets, Grenoble.* 1 September.
*Contribution to BBC TV program 'The sky at night' concerning Mars from VIKING-*1 *and* 2. 29 September.
Titan. *Joint meeting of the Royal Meteorological Society and the Royal Astronomical Society, London.* 8 October.

HUNT, G. S. F.
Meteorology. *Course of six lectures to private pilots, Coventry Technical College.* January–February.

JAMES, I. N., Ph.D.
Some numerical simulation of Taylor Column flows. *Department of Mathematics, University College, London.* 15 October.
Numerical simulation of baroclinic waves. *Department of Mathematics, University of Leeds.* 29 October.

JENKINS, G. J., Ph.D.
Laser studies of the high atmosphere. *University of Sussex, Falmer.* 11 Mar.
Laser probing of the atmosphere. *University of Lancaster.* 16 November.

JENKINS, I., B.Sc.
A course of lectures to the Royal Meteorological Society Field Study Course on Weather Science and Forecasting. *Nettlecombe Court.* 25 August–1 September.

JENKINSON, A. F., I.S.O., M.A.
Analysis of rainfall extremes. *Association of British Climatologists, University of Strathclyde, Glasgow.* 13 September.
Spectral analysis—a new approach. *Climatic Research Unit, University of East Anglia, Norwich.* 12 November.

KEERS, J. F., B.Sc.
Rainfall analysis and snow studies for drainage design. *Meteorological Office Symposia for Water Management.* 24 March (Reading) and 13 May (Edinburgh).
Handling meteorological data. *Meteorological Office Symposium for Water Management, Edinburgh.* 13 May.

MACEY, C. J.
Uses of satellite pictures in CFO. *Royal Meteorological Society Discussion Meeting on 'Use of Satellite Data in Meteorology', London.* 19 May.

MACFADYEN, M. R., B.Sc. and MASON, P. J., Ph.D.
The radial structure of baroclinic waves in an annulus. *Department of Mathematics, University College, London.* 15 October.

McILVEEN, W. A., Ph.D.
Operational numerical weather prediction. *Nuclear Physics Department, Harwell.* 29 January.

McKELLAR, H. A.
Scottish Highland weather. *A broadcast on BBC Radio 4 (Scotland).* 28 September.

MARSHALL, G. A.
The work of the Manchester Weather Centre. *A program on BBC Radio Manchester.* 6 October.

MASON, B. J., C.B., D.Sc., F.R.S.
The understanding and prediction of climatic change. *Rothamsted Experimental Station, Harpenden, Herts.* 8 March.
Towards the understanding and prediction of climatic change. *Symons Memorial Lecture of the Royal Meteorological Society, London.* 17 March.
Climatic catastrophe round the corner? *Ladies' Talk Dinner at the Athenaeum, London.* 12 April.
Tropical convection. *American Meteorological Society Conference on Tropical Meteorology, University of Virginia, U.S.A.* 7 July.
Two Public Lectures (1) The understanding and prediction of climatic change, and (2) The impact of climatic change, and three Departmental Lectures (1) The initiation of the ice phase in supercooled clouds, (2) The physics of fog formation, and (3) Charge generation in thunderclouds. *The University of Washington, Seattle, U.S.A.* July.
The nature and prediction of climatic change. *Culham College, Abingdon, Oxon.* 17 September.
Man's influence on weather and climate. *The Royal Society of Arts, London.* 1 December.

MASON, P. J., Ph.D.
Forces on spheres moving horizontally through a rotating stratified fluid. *Department of Mathematics, University College, London.* 24 May.

MAY, B. R., B.Sc.
Experiences in the use of VTPR direct read-out radiances. *COSPAR Symposium C on meteorological observations from space: their contribution to FGGE, Philadelphia, USA* 9 June.
Some results of comparisons of thickness and temperature from radiosonde and SIRS soundings (text by B. R. MAY and J. S. CAMPBELL, B.Sc.). *COSPAR Symposium C on meteorological observations from space: their contribution to FGGE, Philadelphia, USA.* 9 June.

MILES, M. K., M.Sc., A.R.C.S., D.I.C.
Likely causes of climatic change. *Meeting of the Quaternary Research Association, Manchester.* 3 January.
Participation in ITV's 'Weekend World' (with A. F. JENKINSON, I.S.O., M. A. and C. K. FOLLAND, B.Sc.). 23 April.
The application of indices of the hemispheric circulation to large-scale weather research. *Professor Baur's Symposium, Bad Homburg, Federal Republic of Germany.* 10 October.

MOORE, J. G., B.Sc.
Numerical forecast models. *Royal Meteorological Society Meeting on Short-period Weather Forecasting, London.* 25 September.

MORRIS, R. M., B.Sc.
Principal component analysis. *Climatic Research Unit, University of East Anglia, Norwich.* 11 November.

MURGATROYD, R. J., O.B.E., Ph.D., C.Eng., M.I.E.E.
Stratospheric models (text by R. J. MURGATROYD, A. O'NEILL, B.A. and S. A. CLOUGH, Ph.D.). *ESA/ESRIN Symposium, Frascati, Italy.* 12 May.
Stratospheric pollution. *Atmospheric Environment Committee of the Aeronautical Research Council, London.* 20 October.

MURRAY, R., M.A.
Hydrometeorological services and development work in the Meteorological Office. *Association of British Climatologists, University of Strathclyde, Glasgow.* 13 September.

NICHOLLS, J. M., B.Sc.
Short talk on the activities of the Meteorological Research Flight in the measurement of wind, temperature, humidity and flux from aircraft. *GARP Study Group Conference on airflow over and around mountains, Sveti Stefan, Yugoslavia.* 6 May.

OGDEN, R. J., B.Sc.
Computers and meteorology. *Department of Systems and Computing, North-east London Polytechnic, Dagenham.* 17 March.
Lectures on weather and climate and on wind. *Royal Meteorological Society courses on Meteorology for Civil Engineering and Building, University of Reading.* 25–26 March.
The modern approach to weather forecasting. *Scientific Society, University of Oxford.* 21 May.
Meteorology and some applications to agriculture. *The Grassland Research Institute, Hurley.* 11 November.

PAINTING, D. J., B.Sc.
Recent climatic change. *Atmospheric Physics Group, Department of Physics, Imperial College of Science and Technology, London.* 29 January.
The collection and use of sea surface current data in the United Kingdom. *WMO Commission for Marine Meteorology, Geneva.* 8 December.

PARKER, B. N.
An investigation of the planetary mean geomagnetic index and surface pressure anomalies on a monthly time scale over the northern hemisphere. *Royal Meteorological Society, London.* 21 January.

PARREY, G. E., B.Sc.
The current water shortage. *A broadcast on BBC Radio Nottingham.* 1 June.

PARTINGTON, S. J. G.
Meteorological reports and their bearing on the water industry. *Northern Ireland Association of Water Officers, Kilkeel, Co. Down.* 5 March.

PERFECT, JOAN C., M.Sc.
Sensitivity and predictability experiments with a simple numerical model. *Department of Mathematics (Applied Mathematics Seminar), University of Exeter.* 30 April.

PETTIFER, R. E. W., Ph.D.
The use of laster techniques in meteorology. *University of Hull.* 19 January.

PLANT, J. A.
Climatological services for land sites. *Royal Meteorological Society course on Meteorology for Civil Engineering and Building.* University of Reading. 26 March.

POTHECARY, I. J. W., B.Sc., M.Inst.P.
Meteorology and the military environment. *Royal Military College of Science, Shrivenham.* 30 June.

RATCLIFFE, R. A. S., M.A.
BBC Radio 2. *Interview with Jimmy Young.* 3 May.
BBC World Service. *Recorded interview.* 4 May.
Participation in BBC TV 'Horizon' program. 17 May.
Radio Solent. *Interview.* 24 June.
ITN News. *Participation in program.* 28 June.
BBC Radio 4 'World at 1'. *10-minute interview.* 2 July.
Radio Cleveland. *10-minute interview.* 8 July.
Participation in BBC Radio 4 'Today' program. 3 August.
BBC World Service 'Talkabout'. *Participation in program.* 10 August.
BBC Radio News. *Participation in program.* 11 August.
BBC TV News. *Participation in program.* 16 August.
Participation in London Broadcasting Company 'Talkback' program. 27 August.
Radio London half-hour line program 'Matter of Fact'. 31 August.
The relationship between tropical Atlantic sea temperatures and Atlantic circulation. *Joint Oceanographic Assembly, Edinburgh.* 17 September.
London Broadcasting Company. *10-minute interview.* 30 September.
Participation in BBC TV 'Nationwide' program. 12 October.

ROWNTREE, P. R., Ph.D.
Development of convective parameterization using GATE data.
JOC (GARP) Study Group Conference, Exeter. 6 April.
Royal Meteorological Society Dynamical Sub-group meeting, Imperial College of Science and Technology, London. 17 June.
A cloud parameterization scheme for use with the radiation scheme in a general circulation model (text by JULIA M. WALKER, B.Sc.). *JOC (GARP) Study Group Conference, Exeter.* 6 April.
A survey of experiments with numerical models concerning the atmospheric effects of ocean temperature anomalies. *Royal Meteorological Society Summer Meeting, Norwich.* 16 July.
The effects of mountains on large-scale flow in the five-layer model. *Royal Meteorological Society Specialist Dynamical Group Meeting, Bracknell.* 12 October.

SCOTT, J.
Forecasting services for land sites. *Lecture to Royal Meteorological Society course on Meteorology for Civil Engineering and Building, University of Reading.* 26 March.
How the weather forecast is prepared—services to Press, radio and television. *Week-end course on Meteorology, Denman College, Abingdon.* 6–8 August.
Weather forecasting. *Contribution to 'Multi-coloured Swap Shop', BBC TV.* 2 and 23 October.

SHAW, D. B., B.Sc.
The relative usefulness of height, wind and humidity analysis in short-range tropical prediction. *JOC (GARP) Study Group Conference, Exeter.* 5 April.

SHEARMAN, R. J., B.Sc.
Handling meteorological data. *Meteorological Office Symposium for Water Management, Reading.* 24 March.
Rain and snow. *Royal Meteorological Society course on Meteorology for Civil Engineering and Building, University of Reading.* 25–26 March.

SIMS, F. P.
The meteorologist and the farmer. *District Agricultural Discussion Group, Cullompton, Devon.* 3 February.
The meteorological service for agriculture. *Frome Agricultural Discussion Group.* 10 February.

SINGLETON, F., B.Sc., D.I.C.
Meteorology for yachtsmen.
Course of five lectures to the Cruising Association, London. January–February.
Course of six lectures to the Little Ship Club, London. February.

SLINGO, A., Ph.D.
Satellite meteorology. *West Surrey and North-east Hants Astronomical Society, Yateley.* 8 December.

SMITH, F. B., Ph.D.
Boundary-layer meteorology and dispersion. *Six lectures to the M.Sc. course, University of Surrey, Guildford.* 5, 12 and 19 February.
The long-range transport of air pollutants. *A post-experience course, Imperial College of Science and Technology, London.* 22 March.
Forecasting sulphur dioxide concentrations in cities. *Royal Meteorological Society Colloquium, Manchester.* 24 April.
Urban air pollution meteorology. Statistical modelling of air pollution. *Two lectures to EURATOM course, Ispra, Italy.* 6–8 October.
The results of the Meteorological Office's LRTAP model. *Working Group of the EEC Task Force on Air Pollution, Lillestrøm, Norway.* 18–19 October.
Development in boundary-layer research. Various forms of the diffusion equation. Urban air pollution modelling. The long-range transport of air pollution problem—(1) Sector analysis. The long-range transport of air pollution problem—(2) Analysis of episodes. *Five lectures at the University of Stockholm, Sweden.* 1–19 November.
Air pollution modelling. *University of Southampton.* 7 December.

SMITH, K. C.
British weather patterns and their implications for agriculture. *National Society of Dairy Technology, Exeter.* 16 January.

SPACKMAN, E. A., M.Sc.
The SSDC data sets and their data coverage. *JOC (GARP) Study Group Conference, Exeter.* 8 April.

SPALDING, T. R., B.Sc.
Mountain weather. *Course of lectures to the Royal Meteorological Society Field.Study Course, Betws-y-coed, Gwynedd,* 4–11 August.

STANSFIELD, R.
Meteorology applied to the nuclear threat. *UK Warning and Monitoring Organization, Southern Sector Conference, RAF Hereford.* 5 December.

STARR, J. R., Ph.D.
Clouds, rain and rainmaking.
Physics Society, University of Cambridge. 30 January.
Physical Society, University of Nottingham. 16 November.
Flukes, frost, calves and crops. *Newbury Beef Discussion Group.* 28 March.
Head in the clouds, feet on the ground. *The Agriminders Farmers Group, Hungerford, Berks.* 9 November.

TEMPERTON, C., B.Sc.
Cyclic tridiagonal systems—some algorithms and applications. *Loughborough University of Technology.* 23 April.

THOMPSON, N., Ph.D.
Turbulence measurements during GATE. *Joint Meeting of the Royal Meteorological Society and Challenger Society on GATE and JASIN, London.* 3 March.
Observations of the planetary boundary layer in numerical weather prediction. *European Centre for Medium-range Weather Forecasts Seminar, Meteorological Office College, Shinfield Park, Reading.* 7 September.

TUCK, A. F., Ph.D.
Numerical studies of nitrogen oxide injections into the stratosphere. *Chemical Society, Gas Kinetics Group, University of Birmingham.* 4 January.
Atmospheric chemical kinetics. *Chemical Department, University of Edinburgh.* 26 May.

TYLDESLEY, J. B., B.A.
Winter weather. *Houghside High School, Leeds.* 7 January.
Weather forecasting. *National Association for Gifted Children, Leeds Branch.* 10 January.
The degree-day with particular reference to the eyespot fungus (ercosporella Lerpotrichoides). *Plant Pathology Colloquium, University of Leeds.* 14 January.
Weather and amenity grassland. *Greenkeepers' Association, Yorkshire Branch, Moor Allerton.* 29 February.
Weather for crop spraying. *Interview on 'Farming Today', BBC Radio* 4. 20 March.
A new method of forecasting Septoria of wheat. *Septoria Working Group, MAFF, London.* 16 September.

WHITE, P. W., Ph.D.
10-level model integrations with the GARP basic data set. *Royal Meteorological Society Specialist Group on Dynamical Problems, University of Reading.* 25 March.
Meso-scale modelling. *Royal Meteorological Society, London.* 20 October.
WICKHAM, P. G., M.A.
Weather systems. *Royal Meteorological Society Meeting on Short-period Weather Forecasting, London.* 25 September.
The interpretation and presentation of numerical forecast data. *WMO Symposium on Interpretation of Broad-scale Numerical Weather Prediction Products in terms of Weather for Local Forecasting Purposes, Warsaw, Poland.* 15 October.
WALES-SMITH, B. G.
Answering enquiries on rainfall, evaporation and soil moisture deficit. *Meteorological Office symposia for Water Management.* 24 March (Reading) and 13 May (Edinburgh).
WILEY, R. L., Ph.D. and BLACKBURN, M. R.
An experiment in the automatic interrogation of automatic weather stations. *COST 72 Technical Conference on Automatic Weather Systems, University of Reading.* 23 September.

APPENDIX III

PUBLICATIONS

The publications prepared by the Meteorological Office are generally issued by Her Majesty's Stationery Office as official publications. Catalogues listing all the publications which may be purchased through the sales offices or usual agents of Her Majesty's Stationery Office, or direct from the Meteorological Office at Bracknell, are sent free to any applicant.

The following publications have been issued:

PERIODICALS

Annual Report on the Meteorological Office 1975.

Daily Aerological Record containing information in respect of meteorological conditions in the upper air for the British Isles.

Daily Weather Report containing weather maps for the northern hemisphere, British Isles etc., and data.

Monthly Summary of the Daily Weather Report.

Monthly Weather Survey and Prospects, a monthly publication containing climatological data for the United Kingdom, the weather of the past month, a general survey and inference, and weather prospects for the coming month in the United Kingdom; a supplementary document, containing survey, inference and prospects only, is published in mid month.

Estimated Soil Moisture Deficit and Potential Evapotranspiration over Great Britain, a seasonal fortnightly publication providing estimates of soil moisture deficit in map form and as a tabular statement for river authority areas.

Sea Ice Charts (daily).

Monthly (coloured) *Ice Maps* (to October 1976).

Meteorological Magazine (monthly).

Monthly Weather Report (to November 1976).

Marine Observer (quarterly).

SERIAL

Scientific Paper:

35. A study of some aspects of the climate of the northern hemisphere in recent years, by D. J. Painting, B.Sc.

OCCASIONAL

Averages of bright sunshine for the United Kingdom 1941–70.

Averages of temperature for the United Kingdom 1941–70.

ACRONYMS AND ABBREVIATIONS

ACRE	Automatic Climatological Recording Equipment
ADAS	Agricultural Development and Advisory Service
ADP	Automatic Data Processing
AFB	Air Force Base
AFCENT	Allied Forces Central Europe
AMETS	Army Meteorological System
AMS	American Meteorological Society
ASP	Asymmetric Multiprocessing System
ATWS	Automatic Telephone Weather Service
AUTOCOM	Automated Telecommunications Complex
BBC	British Broadcasting Corporation
BUDSU	British Urban Development Services Unit
CAeM	Commission for Aeronautical Meteorology
CAMFAX	Civil Aviation Meteorological Facsimile Network
CAT	Clear Air Turbulence
CBR	Cloud Base Recorder
CBS	Commission for Basic Systems
CDF	Coded Digital Facsimile
CEGB	Central Electricity Generating Board
CENTO	Central Treaty Organization
CFO	Central Forecasting Office
CMM	Commission for Marine Meteorology
CNRS	Centre National de Recherche Scientifique
COM	Computer Output on Microfilm
COMESA	Committee on Meteorological Effects of Stratospheric Aircraft
COSMOS	Meteorological Office Computing System
COSPAR	Committee for Space Research
CRDF	Cathode Ray Direction Finding
CRJE	Conversational Remote Job Entry
CSIRO	Commonwealth Scientific and Industrial Research Organization
CWPU	Central Water Planning Unit
DAFS	Department of Agriculture and Fisheries for Scotland
DALE	Digital Anemograph Logging Equipment
DAR	Daily Aerological Record
DB	Data Buoy
DEC	Digital Equipment Corporation
DMG	Deutsche Meteorologische Gesellschaft
DoE	Department of the Environment
DoI	Department of Industry
DR Met O	Director of Research, Meteorological Office
DWR	Daily Weather Report
EC	Executive Committee
ECE	Economic Commission for Europe (UN)
ECMWF	European Centre for Medium-range Weather Forecasts
EEC	European Economic Community
ESA	European Space Agency
ESRIN	European Space Research Institute

FGGE	First GARP Global Experiment
GARP	Global Atmospheric Research Program
GATE	GARP Atlantic Tropical Experiment
GCM	General Circulation Model
GDPS	Global Data Processing System
GMT	Greenwich Mean Time
GOS	Global Observing System
GTS	Global Telecommunications System
HMSO	Her Majesty's Stationery Office
HNC	Higher National Certificate
IAMAP	International Association of Meteorology and Atmospheric Physics
IBA	Independent Broadcasting Authority
IBM	International Business Machines
ICAO	International Civil Aviation Organization
ICL	International Computers Limited
ICSU	International Council of Scientific Unions
IGOSS	Integrated Global Ocean Station System
IOC	Inter-governmental Oceanographic Commission
IOS	Institute of Oceanographic Sciences
IPLAN	Joint IOC/WMO Planning Group for IGOSS
ISO	International Organization for Standardization
JASIN	Joint Air–Sea Interaction Experiment
LORAN	Long Range Navigation System
LCBR	Laser Cloud Base Recorder
MAFF	Ministry of Agriculture, Fisheries and Food
MCMG	Military Committee Meteorological Group
MODLE	Meteorological Office Data Logging Equipment
MOLFAX	Meteorological Office Land-line Facsimile Network
MOWOS	Meteorological Office Weather Observing System
MRF	Meteorological Research Flight
MRU	Meteorological Research Unit
MSL	Mean Sea Level
MTC	Main Trunk Circuit
MTER	Magnetic Tape Event Recorder
MVT	Multiprogramming System with Variable number of Tasks
NAOS	North Atlantic Ocean Station
NATO	North Atlantic Treaty Organization
NAVAID	LORAN-C navigational system
NERC	Natural Environmental Research Council
NESS	National Environmental Satellite Service
NMC	National Meteorological Centre
NOAA	National Oceanic and Atmospheric Administration
NORSWAM	North Sea Wave Model
NPL	National Physical Laboratory

ODAS	Ocean Data Acquisition System
OECD	Organization for Economic Co-operation and Development
OFINTAC	Offshore Installations Technical Advisory Committee
OWS	Ocean Weather Ship, Ocean Weather Station
PCK	Processor-controlled keying
PE	Procurement Executive
PEPR	Precision Encoding and Pattern Recognition
PERT	Program Evaluation and Review Technique
PLAINOB	Plain-language report
PO	Post Office
RAE	Royal Aircraft Establishment
RAF	Royal Air Force
RMC	Regional Meteorological Centre
RMT	Radio (Meteorological) Technician
RN	Royal Navy
RSO	Regional Servicing Organization
RTH	Regional Telecommunications Hub
RTT	Radio tele-type
SCODS	Standing Committee on Ocean Data Systems
SDB	Synoptic Data Bank
SR	Scanning Radiometer
SRC	Science Research Council
SSU	Stratospheric Sounding Unit
TAF	Terminal aerodrome weather forecast
UK	United Kingdom
UKOOA	United Kingdom Offshore Operators Association
UNEP	United Nations Environment Program
Unesco	United Nations Educational, Scientific and Cultural Organization
USA	United States of America
USSR	Union of Soviet Socialist Republics
VAP	Voluntary Assistance Program
VDU	Visual Display Unit
VS2	Virtual Storage System
WMC	World Meteorological Centre
WMO	World Meteorological Organization
WWW	World Weather Watch

Printed in England for Her Majesty's Stationery Office by McCorquodale Printers Ltd.
HM 9105 Dd. 585894 K11 8/77

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ISBN 0 11 400303 3